Vision-21

Interdisciplinary Science and Engineering in the Era of Cyberspace

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Interdisciplinary Science and Engineering in the Era of Cyberspace

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Space Administration

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**Scientific and Technical
Information Program**

1993

Into the Era of Cyberspace

Our robots precede us
with infinite diversity
exploring the universe
delighting in complexity

A matrix of neurons,
we create our own reality
of carbon and of silicon,
we evolve toward what we chose to be.

GL 1993

FOREWORD

The symposium "Vision 21: Interdisciplinary Science and Engineering in the Era of Cyberspace" was held at the Holiday Inn in Westlake, Ohio on March 30-31, 1993, sponsored by the NASA Lewis Research Center's Aerospace Technology Directorate under the auspices of the NASA Office of Aeronautics, Exploration and Technology. In the NASA space program there is always a major focus on near-term development of technologies and hardware; however, there is also a continuing need to consider the more visionary far-term concepts and ideas that might lead to radical breakthroughs in the next century. This symposium was conducted to gather people who have an interest in speculative far-term concepts and advanced ideas to permit discussions and information exchange.

In keeping with the intent to stimulate interdisciplinary thinking, we chose to invite as keynote speakers, four individuals who have made major contributions in two different fields. Hans Moravec, of the Robotics Laboratory at Carnegie Mellon University, is both a leading-edge roboticist and also was one of the first to propose several concepts for the use of tethers for orbital transportation. Vernor Vinge of San Diego State University is both a mathematician, a computer scientist, and a well-known science-fiction writer. Carol Stoker, of the Telepresence for Planetary Exploration Project at NASA Ames Research Center, is a leading researcher in both telerobotics and Mars. Myron Krueger of Artificial Reality Corporation is one of the founders of the emerging field of virtual reality, and is involved with both the arts and sciences of virtual reality.

Papers for all the invited speakers are included as a separate section in these proceedings. The banquet speaker John Dalton, Project Manager of the EOS Ground System and Operations Projects at the NASA Goddard Space Flight Center, gave an address on "Information Systems to Support Research in Global Change", but did not submit a written paper. In addition to the invited speakers, contributed papers in the form of a poster session at the symposium presented concepts by a number of attendees; the papers that expand on the posters are included in a separate section of this conference publication. This approach maximized the interaction of participants with presenters and allowed presenters to answer questions and discuss concepts in a much detail as was needed.

A series of workshops was also held during the symposium to explore topics of interest. The purpose of these workshops was to gather ideas and allow informal interaction among participants that explored and promoted synergies among various concepts and ideas. Summaries from these sessions are included as a section in this publication.

The Vision-21 Committee would like to thank all participants for their parts in making the Vision 21 symposium a success. Our personal thanks also go to the OAI staff for supporting mailings for this symposium, and to Mecklar, Inc., for mailings to their virtual reality interest list.

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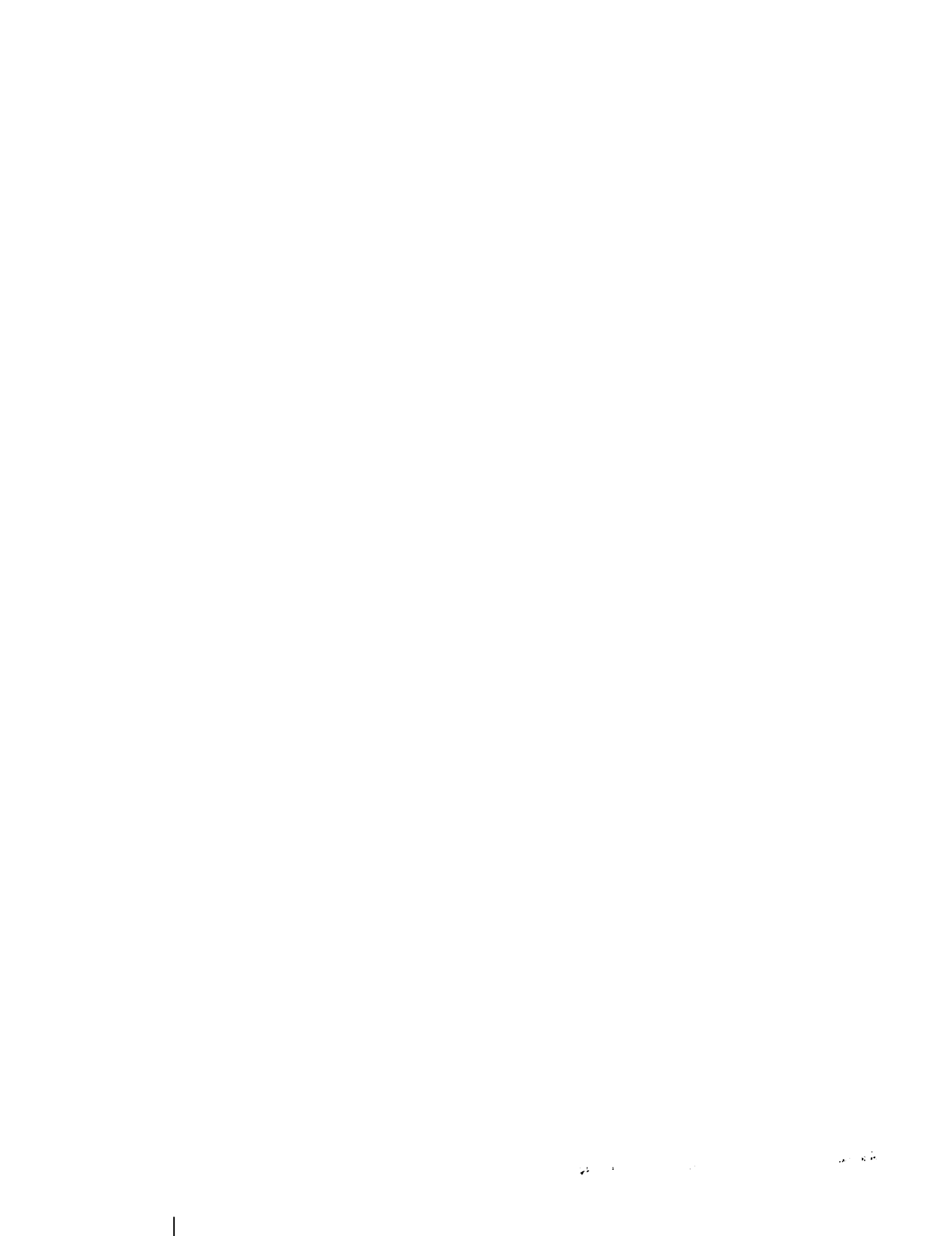   22800 Cedar Point Road
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WHAT IS VISION-21?

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Technologies that exist today were once just visions in the minds of their creators, and these same technologies will become obsolete, supplanted by technologies that are today just visions.

To sustain a leading role in this evolutionary process requires more than just sustaining a mastery over the existing technologies. To genuinely be on the cutting edge requires the ability to create new technologies that surpass the physical limitations of their predecessors. Steam ships were not created by mastering the technologies of sails and riggings. Jet aircraft did not result from mastering piston-propeller aircraft. Transistors were not invented by mastering vacuum tubes. Photocopiers did not result from mastering carbon paper.

The main emphasis of day-to-day engineering is to be a master of your chosen technology. Creating new and superior technologies, however, is a wholly different type of work.

Realizing that technological preeminence cannot be sustained by merely being a master of existing technologies, and realizing the difficulties of being a pioneer amidst the emphasis toward mastery, a small group of scientists and engineers at NASA's Lewis Research Center formed "Vision-21-- Visions Toward the Twenty-First Century and Beyond." Vision-21 is a volunteer group that encourages explorations of technologies yet to come-- *Visions of new, alternative technologies* that are essential for sustaining national technological and economic preeminence.

Understanding the Evolutionary Pattern:

The tendency to master exiting technologies instead of pioneering for new technologies can be encapsulated by the simple "S-Curve" evolution chart shown in Figure-1.
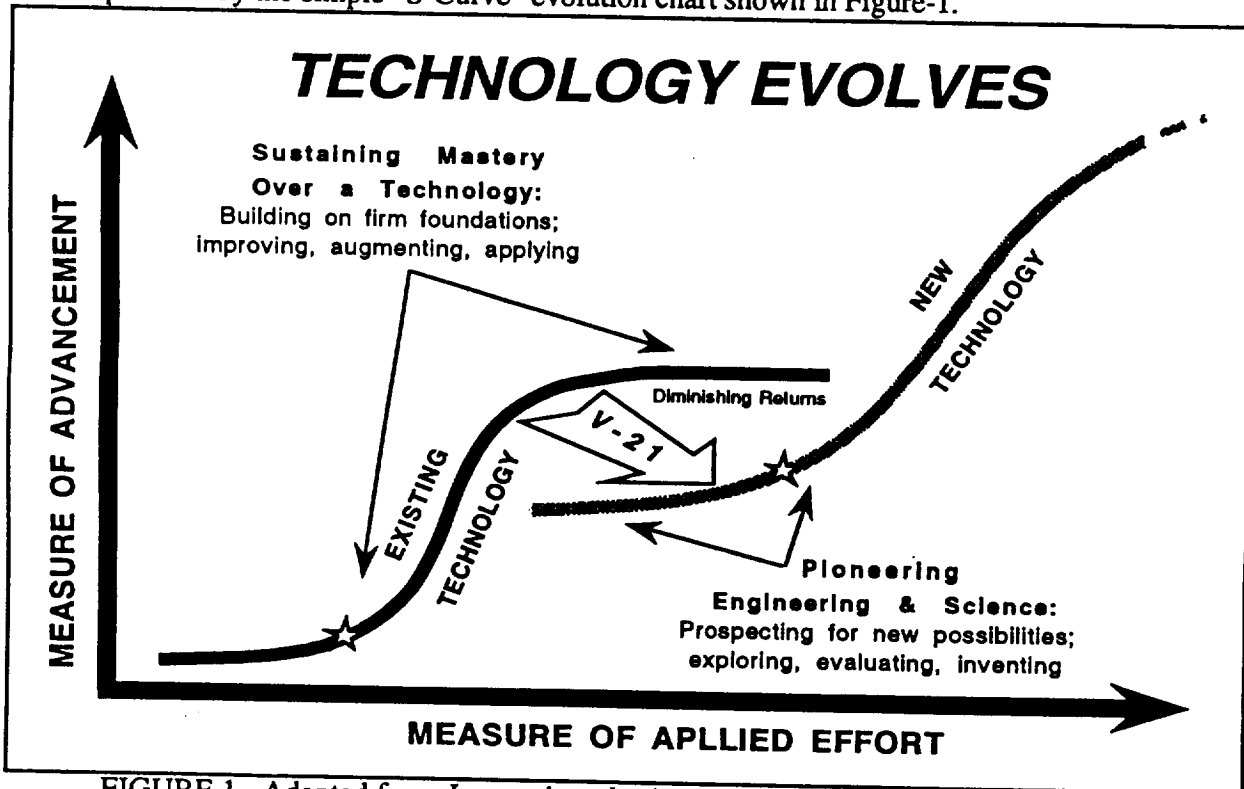

FIGURE 1. Adapted from *Innovation, the Attacker's Advantage*, R. Foster, 1986.

The S-curve evolution, typical of any successful technology, is as follows: Initial efforts result in little advancement and then a breakthrough occurs. The breakthrough, at the lower knee of the curve, is where the technology has finally demonstrated its utility. After this point significant progress is made as several embodiments are produced and the technology becomes widely established. Eventually, however, the physical limits of the technology are reached, and continued effort results in little additional advancement. To go beyond these limits, a new alternative must be created. This new alternative will have its own S-curve and will eventually require yet another new approach to surpass its performance limits. Examples of these stepped S-curves were given earlier: sailing ships surpassed by steam ships, propeller aircraft surpassed by jet aircraft, etc.

Paradoxically, it is at the point of diminishing returns when it is most difficult to consider alternatives. Institutions that grow up with a technology become too established, too uniquely adept at their technology to consider alternatives. Alternatives are outside their area of expertise. Established institutions prefer to modify, augment or find new applications for their technology rather than to search for ways to go *beyond* their technology. Historical evidence shows that this refinement approach does not guarantee sustained market superiority (*Innovation, the Attacker's Advantage*, R. Foster, 1986).

Not surprisingly, the emergence of new technologies has often come from outside the established organizations, often creating new organizations whose dominance grows with the use of its new technology. If an existing organization wants to avoid its own obsolescence, it must be willing to explore alternatives.

Understanding the Evolutionary Steps:

If an organization or individual has reached the point of diminishing returns for their technology and they are now willing to consider alternatives, they will also have to be ready to consider an alternative work style. The work style of pursuing alternatives is different than the style for building mastery.

The main emphasis of day-to-day engineering is to be a master of your chosen technology. Mastery is achieved through continuous improvements; refining, augmenting and finding new applications while sustaining expertise throughout this process. The work style depends on established knowledge and tends to be systematic, relatively predictable, and has a relatively short-term return on investment.

Creating new and superior technologies, however, is a wholly different type of work. Going beyond the limits of an existing technology requires a pioneering spirit. It requires imagination to envision future possibilities. It requires confronting ignorance; creating new knowledge rather than just apply existing knowledge. It requires intuition and subjective judgements to navigate in the absence of an established knowledge base. And because progress is unpredictable and the returns on investment are long-term, it requires the ability to take risks.

A simplistic breakout of the steps and reflexive barriers to evolving a vision into a real technology are outlined in Figure 2. To take an idea from an earlier level upward requires asking questions that are appropriate for that level, such as the questions listed in the ascending arrows. In contrast, the techniques of mastery are likely to result in the reflexive statements listed in the dark face of each step. These defeatist phrases are no doubt familiar to those who have attempted to pioneer ideas through established ways of thinking.

Historically, pioneering new ideas has been the jurisdiction of exceptional, often rouge, individuals who not only possessed the vision to realize their creations, but also the determination to weather the setbacks, the skills to translate their ideas into proofs-of-concepts, and the ability to make others comprehend their creations.

Individuals who posses all these skills at once are rare, but within organizations this skill mix is often present, spread out amongst its many individuals. If an environment could be created where individuals with these varying skills could meet and collaborate on visions of mutual interest, then perhaps the technological alternatives necessary to exceed the limits of existing technologies could be nurtured and developed.

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SHAPING VISIONS INTO REALITY

```
⑤  COMMERCE
    technology applied, sold

How                 It's too risky.  We don't need it.
do we make a
useful device?
                    ④  TECHNOLOGY
                       science applied
How can we
use this new        That's not practical
understanding?

                    ③  SCIENCE
                       phenomena understood
How
do we               That doesn't agree with the existing theories
test this?

                    ②  SPECULATION
                       a knowledgeable guess
What
do we               You're crazy.  You don't know what you're talking about
need to learn?

                    ①  CONJECTURE
                       a wishful VISION
```

FIGURE 2.

Vision-21 was created to consider and explore alternatives

Vision-21 was created to provide a means to consider and explore alternatives within the established institution of NASA Lewis. Vision-21 aims to provide environments where *new, alternative* ideas can be openly discussed, and Vision-21 encourages grass-roots collaborations for evolving visions into testable concepts.

To provide environments for the open exchange of ideas, Vision-21 is hosting this 1993 Symposium as well as having hosted the 1990 Symposium: "Space Travel for the Next Millennium." These symposia are interdisciplinary forums where new ideas and emerging possibilities can be freely discussed amongst people with various perspectives. An interdisciplinary forum is emphasized to provide views beyond one's own S-curve, thereby providing glimpses of other fertile grounds in which to search for new approaches.

Vision-21 has also hosted small forums for sharing and discussing ideas within Lewis Research Center. These smaller forums also provide a way for researchers with similar interests to find each other and to forge informal collaborations within the Lewis institution.

To increase the awareness of the different work styles of pioneering versus mastery, Vision-21 explored courses offered by Lewis's training branch on creativity, problem solving and working-group techniques. This information was used to improve the on-site idea discussions, see Figure 3, and is reflected in the text presented above.

It is hoped that this awareness and the opportunities for discussing new ideas with other interested, diverse, and talented co-workers will result in the formation of grass-roots collaborations to pioneer new technologies.

A grass-roots approach is encouraged because formal institutional mechanisms are not well suited to nurture fledgling ideas. Organizations need to judge values of future projects based on firm information, the kind of information that is only available from relatively mature subjects. To evolve a mere vision through the information gathering and speculation stages requires a less rigorous environment. An informal collection of individuals can better indulge in the pioneering work style and nurture their visions enough to be formally proposed and worked through the

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institution's existing resources.

Informal collaborations such as these have taken root within NASA Lewis as a result of Vision-21. Although no breakthroughs can yet be traced to these endeavors, the cross-discipline communication, mental stimulation, and final resolution of lingering "what-if" visions definitely benefits the agency as a whole and the participating individuals.

Today

With this symposium we will get a glimpse of emerging computing tools. Are some of these tools avenues to get off your own flat-toped S-curve? Be open to the possibilities. Look at this information not as a master searching for things to fix, but as a pioneer searching for new opportunities. Now is a time in your workday when you can indulge in a pioneering spirit. I hope that you are able to kindle a new approach or re-kindle a latent idea that will be of use to you in your work. Good luck and let the games begin.

FIGURE 3.

Free Idea Forum -- Feedback Worksheet

Purpose: This worksheet is provided to help make the presentation more stimulating for the audience and the feedback more supportive for the presenter. It aims to steer the audience away from the pitfalls our acculturated "mastery" approach (Doubt; looking for what's wrong) and toward the benefits of a more pioneering approach. (Curiosity: looking for what's better, interesting and potentially useful).

INSTRUCTIONS FOR THE AUDIENCE:
Examine the questions on this sheet now, *before* the presentation. It is crucially important that *during* the presentation you answer these "PINS" questions in the sequence that they are presented, writing down any questions, comments, or answers that the presentation evokes. *After* the presentation, the forum coordinator will begin discussions by asking members of the audience to voice answers to particular PINS questions. *Finally*, when the discussions are over, please give your worksheet, including your name and number, to the idea presenter.

P What's Positive?
What benefit does the idea aim to answer?
What features of the idea support that possibility?
What are the good points of the idea?

_____

I What's Interesting?
What do you like about the idea or presentation?
What is interesting, thought-provoking, inspiring, or intriguing?
Does this kindle any ideas of your own?

_____

N What's Negative?
What are the weak points of the idea or presentation?
What are the critical questions behind the idea's feasibility?

_____

S Any Suggestions?
What improvements would be helpful to the idea or presentation?
What information do you have that might help: books, reports, people?
What do you see as the next step to further mature this idea?

_____

THE NEED FOR VISION

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*If you have built castles in the air, your work need not be lost; that
is where they should be. Now put the foundations under them.*
—Henry David Thoreau

It has been pointed out that the history of science is the history of scientific instruments; that advances come when the potentials of new instruments—the telescope, the interferometer—are embraced to look in new directions. The computer is the outstanding new tool of our century. It will change the way we do science and engineering in the 21st century; it has changed and will change the way we look at the world and the way we look at ourselves. We, as scientists and engineers, must embrace these tools if we want to be on the cutting edge of research in the 21st century, or else become obsolete. These tools have names like "cyberspace," "robotics," "virtual reality," "scientific visualization," "telepresence"... and these are just the first inklings of the potential tools that we cannot yet even imagine.

It has also been frequently remarked that great advances often come when scientists cross out of the lines of their disciplines to do creative work in other fields. The greatest advance in biology, for example, came when a physicist and two crystalographers applied the technique of x-ray diffraction to the problem of understanding the structure of the DNA molecule.

There are strong forces that try to keep us in the narrow boxes of our scientific disciplines. There are good reasons for this, of course—it's easiest to communicate when we talk to people who understand our language. But these are forces which must be resisted if we are to advance in new directions. This is the point behind the Vision-21 symposium; that's why our subtitle is "interdisciplinary science and technology." If we rub people in different disciplines together, we hope that perhaps we can spark some interesting new ideas.

Ideas are important. We need new ideas.

There is a tremendous pressure to force us to direct our thinking to the near term, more so now than ever. We're being told that our research must result in a project on the market within three years, or else face cancellation. Well, products are indeed important, and it is justifiably important to find near-term applications for our visions, for such applications form the only path we know to turn visions into reality.

But it is important as well to have a longer-range of vision, to think beyond the next generation and into the future. To encourage vision into the 21st century.

Visionaries are an endangered species.

I hope you had fun at this symposium, because science and engineering are nothing if we don't have fun doing them; ideas have no value unless we enjoy being challenged by new ideas. I also hope that you have been stimulated and challenged by new ideas, and by talking to people in other disciplines, and by some of our visions of the 21st century. And, finally, I hope that you will be able to take something of this vision back with you as you return to your daily work, in order that we may begin to shape our visions of the 21st century into reality.

We may, after all, be nearer than we think to realizing the dream of the Persian visionary Omar Khayyam:

Ah, Love! could thou and I with Fate conspire
To grasp this sorry scheme of things entire
Would not we shatter it to bits—and then
Re-mold it nearer to the Heart's Desire?

—E. Fitzgerald, *The Rubaiyat of Omar Khayyam*

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FEATURED SPEAKERS

THE COMING TECHNOLOGICAL SINGULARITY: HOW TO SURVIVE IN THE POST-HUMAN ERA

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Abstract

Within thirty years, we will have the technological means to create superhuman intelligence. Shortly after, the human era will be ended.

Is such progress avoidable? If not to be avoided, can events be guided so that we may survive? These questions are investigated. Some possible answers (and some further dangers) are presented.

What is The Singularity?

The acceleration of technological progress has been the central feature of this century. I argue in this paper that we are on the edge of change comparable to the rise of human life on Earth. The precise cause of this change is the imminent creation by technology of entities with greater than human intelligence. There are several means by which science may achieve this breakthrough (and this is another reason for having confidence that the event will occur):

o The development of computers that are "awake" and superhumanly intelligent. (To date, most controversy in the area of AI relates to whether we can create human equivalence in a machine. But if the answer is "yes, we can", then there is little doubt that beings more intelligent can be constructed shortly thereafter.

o Large computer networks (and their associated users) may "wake up" as a superhumanly intelligent entity.

o Computer/human interfaces may become so intimate that users may reasonably be considered superhumanly intelligent.

o Biological science may find ways to improve upon the natural human intellect.

The first three possibilities depend in large part on improvements in computer hardware. Progress in computer hardware has followed an amazingly steady curve in the last few decades [16]. Based largely on this trend, I believe that the creation of greater than human intelligence will occur during the next thirty years. (Charles Platt [19] has pointed out the AI enthusiasts have been making claims like this for the last thirty years. Just so I'm not guilty of a relative-time ambiguity, let me more specific: I'll be surprised if this event occurs before 2005 or after 2030.)

What are the consequences of this event? When greater-than-human intelligence drives progress, that progress will be much more rapid. In fact, there seems no reason why progress itself would not involve the creation of still more intelligent entities -- on a still-shorter time scale. The best analogy that I see is with the evolutionary past: Animals can adapt to problems and make inventions, but often no faster than natural selection can do its work -- the world acts as its own simulator in the case of natural selection. We humans have the ability to internalize the world and conduct "what if's" in our heads; we can solve many problems thousands of times faster than natural selection. Now, by creating the means to execute those simulations at much higher speeds, we are entering a regime as radically different from our human past as we humans are from the lower animals.

From the human point of view this change will be a throwing away of all the previous rules, perhaps in the blink of an eye, an exponential runaway beyond any hope of control. Developments that before were thought might only happen in "a million years" (if ever) will likely happen in the next century. (In [4], Greg Bear paints a picture of the major changes happening in a matter of hours.)

I think it's fair to call this event a singularity ("the Singularity" for the purposes of this paper). It is a point where our models must be discarded and a new reality rules. As we move closer and closer to this point, it will loom vaster and vaster over human affairs till the notion becomes a commonplace. Yet when it finally

happens it may still be a great surprise and a greater unknown. In the 1950s there were very few who saw it: Stan Ulam [27] paraphrased John von Neumann as saying:

> One conversation centered on the ever accelerating progress of technology and changes in the mode of human life, which gives the appearance of approaching some essential singularity in the history of the race beyond which human affairs, as we know them, could not continue.

Von Neumann even uses the term singularity, though it appears he is still thinking of normal progress, not the creation of superhuman intellect. (For me, the superhumanity is the essence of the Singularity. Without that we would get a glut of technical riches, never properly absorbed (see [24]).)

In the 1960s there was recognition of some of the implications of superhuman intelligence. I. J. Good wrote [10]:

> Let an ultraintelligent machine be defined as a machine that can far surpass all the intellectual activities of any any man however clever. Since the design of machines is one of these intellectual activities, an ultraintelligent machine could design even better machines; there would then unquestionably be an "intelligence explosion," and the intelligence of man would be left far behind. Thus the first ultraintelligent machine is the <u>last</u> invention that man need ever make, provided that the machine is docile enough to tell us how to keep it under control.
> ...
> It is more probable than not that, within the twentieth century, an ultraintelligent machine will be built and that it will be the last invention that man need make.

Good has captured the essence of the runaway, but does not pursue its most disturbing consequences. Any intelligent machine of the sort he describes would not be humankind's "tool" -- any more than humans are the tools of rabbits or robins or chimpanzees.

Through the '60s and '70s and '80s, recognition of the cataclysm spread [28] [1] [30] [4]. Perhaps it was the science-fiction writers who felt the first concrete impact. After all, the "hard" science-fiction writers are the ones who try to write specific stories about all that technology may do for us. More and more, these writers felt an opaque wall across the future. Once, they could put such fantasies millions of years in the future [23]. Now they saw that their most diligent extrapolations resulted in the unknowable ... soon. Once, galactic empires might have seemed a Post-Human domain. Now, sadly, even interplanetary ones are.

What about the '90s and the '00s and the '10s, as we slide toward the edge? How will the approach of the Singularity spread across the human world view? For a while yet, the general critics of machine sapience will have good press. After all, till we have hardware as powerful as a human brain it is probably foolish to think we'll be able to create human equivalent (or greater) intelligence. (There is the far-fetched possibility that we could make a human equivalent out of less powerful hardware, if were willing to give up speed, if we

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were willing to settle for an artificial being who was literally slow [29]. But it's much more likely that devising the software will be a tricky process, involving lots of false starts and experimentation. If so, then the arrival of self-aware machines will not happen till after the development of hardware that is substantially more powerful than humans' natural equipment.)

But as time passes, we should see more symptoms. The dilemma felt by science fiction writers will be perceived in other creative endeavors. (I have heard thoughtful comic book writers worry about how to have spectacular effects when everything visible can be produced by the technically commonplace.) We will see automation replacing higher and higher level jobs. We have tools right now (symbolic math programs, cad/cam) that release us from most low-level drudgery. Or put another way: The work that is truly productive is the domain of a steadily smaller and more elite fraction of humanity. In the coming of the Singularity, we are seeing the predictions of _true_ technological unemployment finally come true.

Another symptom of progress toward the Singularity: ideas themselves should spread ever faster, and even the most radical will quickly become commonplace. When I began writing, it seemed very easy to come up with ideas that took decades to percolate into the cultural consciousness; now the lead time seems more like eighteen months. (Of course, this could just be me losing my imagination as I get old, but I see the effect in others too.) Like the shock in a compressible flow, the Singularity moves closer as we accelerate through the critical speed.

And what of the arrival of the Singularity itself? What can be said of its actual appearance? Since it involves an intellectual runaway, it will probably occur faster than any technical revolution seen so far. The precipitating event will likely be unexpected -- perhaps even to the researchers involved. ("But all our previous models were catatonic! We were just tweaking some parameters....") If networking is widespread enough (into ubiquitous embedded systems), it may seem as if our artifacts as a whole had suddenly wakened.

And what happens a month or two (or a day or two) after that? I have only analogies to point to: The rise of humankind. We will be in the Post-Human era. And for all my rampant technological optimism, sometimes I think I'd be more comfortable if I were regarding these transcendental events from one thousand years remove ... instead of twenty.

Can the Singularity be Avoided?

Well, maybe it won't happen at all: Sometimes I try to imagine the symptoms that we should expect to see if the Singularity is not to develop. There are the widely respected arguments of Penrose [18] and Searle [21] against the practicality of machine sapience. In August of 1992, Thinking Machines Corporation held a workshop to investigate the question "How We Will Build a Machine that Thinks" [Thearling]. As you might guess from the workshop's title, the participants were not especially supportive of the arguments against machine intelligence. In fact, there was general agreement that minds can exist on nonbiological substrates and that algorithms are of central importance to the existence of minds. However, there was much debate about the

raw hardware power that is present in organic brains. A minority felt that the largest 1992 computers were within three orders of magnitude of the power of the human brain. The majority of the participants agreed with Moravec's estimate [16] that we are ten to forty years away from hardware parity. And yet there was another minority who pointed to [6] [20], and conjectured that the computational competence of single neurons may be far higher than generally believed. If so, our present computer hardware might be as much as ten orders of magnitude short of the equipment we carry around in our heads. If this is true (or for that matter, if the Penrose or Searle critique is valid), we might never see a Singularity. Instead, in the early '00s we would find our hardware performance curves begin to level off -- this caused by our inability to automate the complexity of the design work necessary to support the hardware trend curves. We'd end up with some very powerful hardware, but without the ability to push it further. Commercial digital signal processing might be awesome, giving an analog appearance even to digital operations, but nothing would ever "wake up" and there would never be the intellectual runaway which is the essence of the Singularity. It would likely be seen as a golden age ... and it would also be an end of progress. This is very like the future predicted by Gunther Stent. In fact, on page 137 of [24], Stent explicitly cites the development of transhuman intelligence as a sufficient condition to break his projections.

But if the technological Singularity can happen, it will. Even if all the governments of the world were to understand the "threat" and be in deadly fear of it, progress toward the goal would continue. In fiction, there have been stories of laws passed forbidding the construction of "a machine in the form of the mind of man" [12]. In fact, the competitive advantage -- economic, military, even artistic -- of every advance in automation is so compelling that passing laws, or having customs, that forbid such things merely assures that someone else will get them first.

Eric Drexler [7] has provided spectacular insight about how far technical improvement may go. He agrees that superhuman intelligences will be available in the near future -- and that such entities pose a threat to the human status quo. But Drexler argues that we can embed such transhuman devices in rules or physical confinement such that their results can be examined and used safely. This is I. J. Good's ultraintelligent machine, with a dose of caution. I argue that confinement is intrinsically impractical. For the case of physical confinement: Imagine yourself confined to your house with only limited data access to the outside, to your masters. If those masters thought at a rate -- say -- one million times slower than you, there is little doubt that over a period of years (your time) you could come up with "helpful advice" that would incidentally set you free. (I call this "fast thinking" form of superintelligence "weak superhumanity". Such a "weakly superhuman" entity would probably burn out in a few weeks of outside time. "Strong superhumanity" would be more than cranking up the clock speed on a human-equivalent mind. It's hard to say precisely what "strong superhumanity" would be like, but the difference appears to be profound. Imagine running a dog mind at very high speed. Would a thousand years of doggy living add up to any human insight? (Now if the dog mind were cleverly rewired and then run at high speed, we might see something different....) Most speculations about superintelligence seem to be based on the weakly superhuman model. I believe that our best guesses about the post-Singularity

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world can be obtained by thinking on the nature of strong superhumanity. I will return to this point later in the paper.)

The other approach to Drexlerian confinement is to build <u>rules</u> into the mind of the created superhuman entity (Asimov's Laws). I think that performance rules strict enough to be safe would also produce a device whose ability was clearly inferior to the unfettered versions (and so human competition would favor the development of the those more dangerous models). Still, the Asimov dream is a wonderful one: Imagine a willing slave, who has 1000 times your capabilities in every way. Imagine a creature who could satisfy your every safe wish (whatever that means) and still have 99.9% of its time free for other activities. There would be a new universe we never really understood, but filled with benevolent gods (though one of <u>my</u> wishes might be to become one of them).

If the Singularity can not be prevented or confined, just how bad could the Post-Human era be? Well ... pretty bad. The physical extinction of the human race is one possibility. (Or as Eric Drexler put it of nanotechnology: Given all that such technology can do, perhaps governments would simply decide that they no longer need citizens!). Yet physical extinction may not be the scariest possibility. Again, analogies: Think of the different ways we relate to animals. Some of the crude physical abuses are implausible, yet.... In a Post-Human world there would still be plenty of niches where human equivalent automation would be desirable: embedded systems in autonomous devices, self-aware daemons in the lower functioning of larger sentients. (A strongly superhuman intelligence would likely be a Society of Mind [15] with some very competent components.) Some of these human equivalents might be used for nothing more than digital signal processing. They would be more like whales than humans. Others might be very human-like, yet with a one-sidedness, a <u>dedication</u> that would put them in a mental hospital in our era. Though none of these creatures might be flesh-and-blood humans, they might be the closest things in the new enviroment to what we call human now. (I. J. Good had something to say about this, though at this late date the advice may be moot: Good [11] proposed a "Meta-Golden Rule", which might be paraphrased as "Treat your inferiors as you would be treated by your superiors." It's a wonderful, paradoxical idea (and most of my friends don't believe it) since the game-theoretic payoff is so hard to articulate. Yet if we were able to follow it, in some sense that might say something about the plausibility of such kindness in this universe.)

I have argued above that we cannot prevent the Singularity, that its coming is an inevitable consequence of the humans' natural competitiveness and the possibilities inherent in technology. And yet ... we are the initiators. Even the largest avalanche is triggered by small things. We have the freedom to establish initial conditions, make things happen in ways that are less inimical than others. Of course (as with starting avalanches), it may not be clear what the right guiding nudge really is:

Other Paths to the Singularity: Intelligence Amplification

When people speak of creating superhumanly intelligent beings, they are usually imagining an AI project. But as I noted at the

beginning of this paper, there are other paths to superhumanity. Computer networks and human-computer interfaces seem more mundane than AI, and yet they could lead to the Singularity. I call this contrasting approach Intelligence Amplification (IA). IA is something that is proceeding very naturally, in most cases not even recognized by its developers for what it is. But every time our ability to access information and to communicate it to others is improved, in some sense we have achieved an increase over natural intelligence. Even now, the team of a PhD human and good computer workstation (even an off-net workstation!) could probably max any written intelligence test in existence.

And it's very likely that IA is a much easier road to the achievement of superhumanity than pure AI. In humans, the hardest development problems have already been solved. Building up from within ourselves ought to be easier than figuring out first what we really are and then building machines that are all of that. And there is at least conjectural precedent for this approach. Cairns-Smith [5] has speculated that biological life may have begun as an adjunct to still more primitive life based on crystalline growth. Lynn Margulis [14] has made strong arguments for the view that mutualism is the great driving force in evolution.

Note that I am not proposing that AI research be ignored or less funded. What goes on with AI will often have applications in IA, and vice versa. I am suggesting that we recognize that in network and interface research there is something as profound (and potential wild) as Artificial Intelligence. With that insight, we may see projects that are not as directly applicable as conventional interface and network design work, but which serve to advance us toward the Singularity along the IA path.

Here are some possible projects that take on special significance, given the IA point of view:
- o Human/computer team automation: Take problems that are normally considered for purely machine solution (like hill-climbing problems), and design programs and interfaces that take a advantage of humans' intuition and available computer hardware. Considering all the bizarreness of higher dimensional hill-climbing problems (and the neat algorithms that have been devised for their solution), there could be some very interesting displays and control tools provided to the human team member.
- o Develop human/computer symbiosis in art: Combine the graphic generation capability of modern machines and the esthetic sensibility of humans. Of course, there has been an enormous amount of research in designing computer aids for artists, as labor saving tools. I'm suggesting that we explicitly aim for a greater merging of competence, that we explicitly recognize the cooperative approach that is possible. Karl Sims [22] has done wonderful work in this direction.
- o Allow human/computer teams at chess tournaments. We already have programs that can play better than almost all humans. But how much work has been done on how this power could be used by a human, to get something even better? If such teams were allowed in at least some chess tournaments, it could have the positive effect on IA research that allowing computers in tournaments had for the corresponding niche in AI.
- o Develop interfaces that allow computer and network access without

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requiring the human to be tied to one spot, sitting in front of a computer. (This is an aspect of IA that fits so well with known economic advantages that lots of effort is already being spent on it.)

o Develop more symmetrical decision support systems. A popular research/product area in recent years has been decision support systems. This is a form of IA, but may be too focussed on systems that are oracular. As much as the program giving the user information, there must be the idea of the user giving the program guidance.

o Use local area nets to make human teams that really work (ie, are more effective than their component members). This is generally the area of "groupware", already a very popular commercial pursuit. The change in viewpoint here would be to regard the group activity as a combination organism. In one sense, this suggestion might be regarded as the goal of inventing a "Rules of Order" for such combination operations. For instance, group focus might be more easily maintained than in classical meetings. Expertise of individual human members could be isolated from ego issues such that the contribution of different members is focussed on the team project. And of course shared data bases could be used much more conveniently than in conventional committee operations. (Note that this suggestion is aimed at team operations rather than political meetings. In a political setting, the automation described above would simply enforce the power of the persons making the rules!)

o Exploit the worldwide Internet as a combination human/machine tool. Of all the items on the list, progress in this is proceeding the fastest and may run us into the Singularity before anything else. The power and influence of even the present-day Internet is vastly underestimated. For instance, I think our contemporary computer systems would break under the weight of their own complexity if it weren't for the edge that the USENET "group mind" gives the system administration and support people!) The very anarchy of the worldwide net development is evidence of its potential. As connectivity and bandwidth and archive size and computer speed all increase, we are seeing something like Lynn Margulis' [14] vision of the biosphere as data processor recapitulated, but at a million times greater speed and with millions of humanly intelligent agents (ourselves).

The above examples illustrate research that can be done within the context of contemporary computer science departments. There are other paradigms. For example, much of the work in Artificial Intelligence and neural nets would benefit from a closer connection with biological life. Instead of simply trying to model and understand biological life with computers, research could be directed toward the creation of composite systems that rely on biological life for guidance or for the providing features we don't understand well enough yet to implement in hardware. A long-time dream of science-fiction has been direct brain to computer interfaces [2] [28]. In fact, there is concrete work that can be done (and has been done) in this area:

o Limb prosthetics is a topic of direct commercial applicability. Nerve to silicon transducers can be made [13]. This is an exciting, near-term step toward direct communcation.

o Similar direct links into brains may be feasible, if the bit rate is low: given human learning flexibility, the actual brain neuron targets might not have to be precisely selected.

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Even 100 bits per second would be of great use to stroke victims who would otherwise be confined to menu-driven interfaces.

o Plugging in to the optic trunk has the potential for bandwidths of 1 Mbit/second or so. But for this, we need to know the fine-scale architecture of vision, and we need to place an enormous web of electrodes with exquisite precision. If we want our high bandwidth connection to be in addition to what paths are already present in the brain, the problem becomes vastly more intractable. Just sticking a grid of high-bandwidth receivers into a brain certainly won't do it. But suppose that the high-bandwidth grid were present while the brain structure was actually setting up, as the embryo develops. That suggests:

o Animal embryo experiments. I wouldn't expect any IA success in the first years of such research, but giving developing brains access to complex simulated neural structures might be very interesting to the people who study how the embryonic brain develops. In the long run, such experiments might produce animals with additional sense paths and interesting intellectual abilities.

Originally, I had hoped that this discussion of IA would yield some clearly safer approaches to the Singularity. (After all, IA allows our participation in a kind of transcendance.) Alas, looking back over these IA proposals, about all I am sure of is that they should be considered, that they may give us more options. But as for safety ... well, some of the suggestions are a little scarey on their face. One of my informal reviewers pointed out that IA for individual humans creates a rather sinister elite. We humans have millions of years of evolutionary baggage that makes us regard competition in a deadly light. Much of that deadliness may not be necessary in today's world, one where losers take on the winners' tricks and are coopted into the winners' enterprises. A creature that was built de novo might possibly be a much more benign entity than one with a kernel based on fang and talon. And even the egalitarian view of an Internet that wakes up along with all mankind can be viewed as a nightmare [25].

The problem is not that the Singularity represents simply the passing of humankind from center stange, but that it contradicts some of our most deeply held notions of being. I think a closer look at the notion of strong superhumanity can show why that is.

Strong Superhumanity and the Best We Can Ask for

Suppose we could tailor the Singularity. Suppose we could attain our most extravagant hopes. What then would we ask for:
That humans themselves would become their own successors, that whatever injustice occurs would be tempered by our knowledge of our roots. For those who remained unaltered, the goal would be benign treatment (perhaps even giving the stay-behinds the appearance of being masters of godlike slaves). It could be a golden age that also involved progress (overleaping Stent's barrier). Immortality (or at least a lifetime as long as we can make the universe survive [9] [3]) would be achievable.

But in this brightest and kindest world, the philosophical

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problems themselves become intimidating. A mind that stays at the same capacity cannot live forever; after a few thousand years it would look more like a repeating tape loop than a person. (The most chilling picture I have seen of this is in [17].) To live indefinitely long, the mind itself must grow ... and when it becomes great enough, and looks back ... what fellow-feeling can it have with the soul that it was originally? Certainly the later being would be everything the original was, but so much vastly more. And so even for the individual, the Cairns-Smith (or Lynn Margulis) notion of new life growing incrementally out of the old must still be valid.

This "problem" about immortality comes up in much more direct ways. The notion of ego and self-awareness has been the bedrock of the hardheaded rationalism of the last few centuries. Yet now the notion of self-awareness is under attack from the Artificial Intelligence people ("self-awareness and other delusions"). Intelligence Amplification undercuts the importance of ego from another direction. The post-Singularity world will involve extremely high-bandwidth networking. A central feature of strongly superhuman entities will likely be their ability to communicate at variable bandwidths, including ones far higher than speech or written messages. What happens when pieces of ego can be copied and merged, when the size of a selfawareness can grow or shrink to fit the nature of the problems under consideration? These are essential features of strong superhumanity and the Singularity. Thinking about them, one begins to feel how essentially strange and different the Post-Human era will be -- no matter how cleverly and benignly it is brought to be.

From one angle, the vision fits many of our happiest dreams: a place unending, where we can truly know one another and understand the deepest mysteries. From another angle, it's a lot like the worst case scenario I imagined earlier in this paper.

Which is the valid viewpoint? In fact, I think the new era is simply too different to fit into the classical frame of good and evil. That frame is based on the idea of isolated, immutable minds connected by tenuous, low-bandwith links. But the post-Singularity world does fit with the larger tradition of change and cooperation that started long ago (perhaps even before the rise of biological life). I think there are notions of ethics that would apply in such an era. Research into IA and high-bandwidth communications should improve this understanding. I see just the glimmerings of this now, in Good's Meta-Golden Rule, perhaps in rules for distinguishing self from others on the basis of bandwidth of connection. And while mind and self will be vastly more labile than in the past, much of what we value (knowledge, memory, thought) need never be lost. I think Freeman Dyson has it right when he says [8]: "God is what mind becomes when it has passed beyond the scale of our comprehension."

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TELEPRESENCE IN THE HUMAN EXPLORATION OF MARS:

FIELD STUDIES IN ANALOG ENVIRONMENTS

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Abstract

This paper describes the role of telepresence in performing exploration of Mars. As part of an effort to develop telepresence to support Mars exploration, NASA is developing telepresence technology and using it to perform exploration in space analog environments. This paper describes experiments to demonstrate telepresence control of an underwater remotely operated vehicle (TROV) to perform scientific field work in isolated and hostile environments. Toward this end, we have developed a telepresence control system and interfaced it to an underwater remotely operated vehicle. This vehicle was used during 1992 to study aquatic ecosystems in Antarctica including a study of the physical and biological environment of permanently ice-covered lake. We also performed a preliminary analysis of the potential for using the TROV to study the benthic ecology under the sea ice in McMurdo sound. These expeditions are opening up new areas of research by using telepresence control of remote vehicles to explore isolated and extreme environments on Earth while also providing an impetus to develop technology which will play a major role in the human exploration of Mars. Antarctic field operations, in particular, provide an excellent analog experience for telepresence operation in space.

Introduction

Human exploration of Mars is a vast undertaking of unprecedented complexity. The scientific potential of Mars exploration is enormous, but the strategy for accomplishing the science has not been worked out in detail. Moreover, there is a real dilemma when one considers how to proceed. One approach to the scientific objectives and strategy for human exploration of Mars is discussed in Stoker et al. (1991). Mars has a surface area comparable to that of the land area of Earth. The most interesting features on this planet are vast by terrestrial standards and, indeed, are planetary in scale. For example, if the Valles Marineris were placed on Earth, it would stretch from the east to the west coast of the north American continent. To understand features on the surface of Mars, it will be necessary to study them over dimensions comparable to the size of the features. Since features of interest are hundreds to thousands of kilometers in size, this is the required spatial scale of exploration. In addition, features of interest are located all across the surface of Mars. Thus, it is clear that achieving a level of exploration accomplishment that would justify the significant expenditure of putting people on Mars requires them to have access to most or all of the martian surface.

This spatial scale of exploration is in stark contrast to the range of mobility which the early Mars explorers are likely to achieve. Here the range is limited by the type of mobility that can be provided, which, in turn, depends on the mass that

can be transported from Earth, as well as issues of life support and power sources. We expect that initial human missions will have relatively limited mobility and that later missions will be able to provide increasingly greater capabilities leading eventually to the desired global range. However, this view is based on the assumption of a multi-decade program of human missions which establish considerable infrastructure and capability on the surface of Mars. This, in turn, depends on a philosophy of Mars exploration which involves a continued human presence on Mars, a substantial commitment to build and sustain infrastructure on Mars, and use of Martian resources to support the increased capability of crews on the surface.

Figure 1 shows the expected range of human mobility for the various phases of human exploration. In the earliest human exploration mission or missions, the provision of mobility is likely to be limited to a small low mass rover vehicle. The range of such a vehicle will be limited by the life support capabilities of an astronaut's Personal Life Support System-an integral part of a space suit. During the Apollo moon landings, Astronauts were provided two levels of mobility: (1) the range they could reach walking in their suit, and (2) the range they could reach in an open-air rover similar to a modern dune buggy. However, if the lunar rover broke down, the Astronauts would need to walk back to the base and this limited the range they could travel in the rover vehicle to walking distance from the base. Thus, the suited Astronaut with a rover has a range of approximately 50 km. Given the distance, complexity, and cost of transporting equipment to Mars, an Apollo-type rover is probably the best one can hope for during an initial mission.

During later missions, crews should be able to rely on base facilities which were established on earlier missions and therefor lower the amount of equipment that would have to be transported from Earth simply to stay alive. Thus, extra equipment should be able to be provided to support scientific field work. Clark (1992) has suggested an approach to human mobility over greater distances. This concept is to use a pressurized all-terrain vehicle which incorporates a portable life support system providing a shirt-sleeve environment inside the Rover. Such a vehicle would be capable of several week duration field trips. Depending on the difficulty of the terrain, such a vehicle might allow field trips in a range of up to 1000 km or so before life support or fuel would run out. Still, this is substantially less capability than is desirable for gaining scientific access to the surface of Mars.

Eventually, one can envision the desired capability for human exploration being provided in the form of a suborbital rocket vehicle capable of taking a crew on an expedition of several months to any point on the surface of Mars. Such expeditions would originate at a central Mars base facility and would provide the crew with a similar level of capability obtained by the earliest human expedition to Mars.

Phase	Concept
Early	
Intermediate	
Advanced	
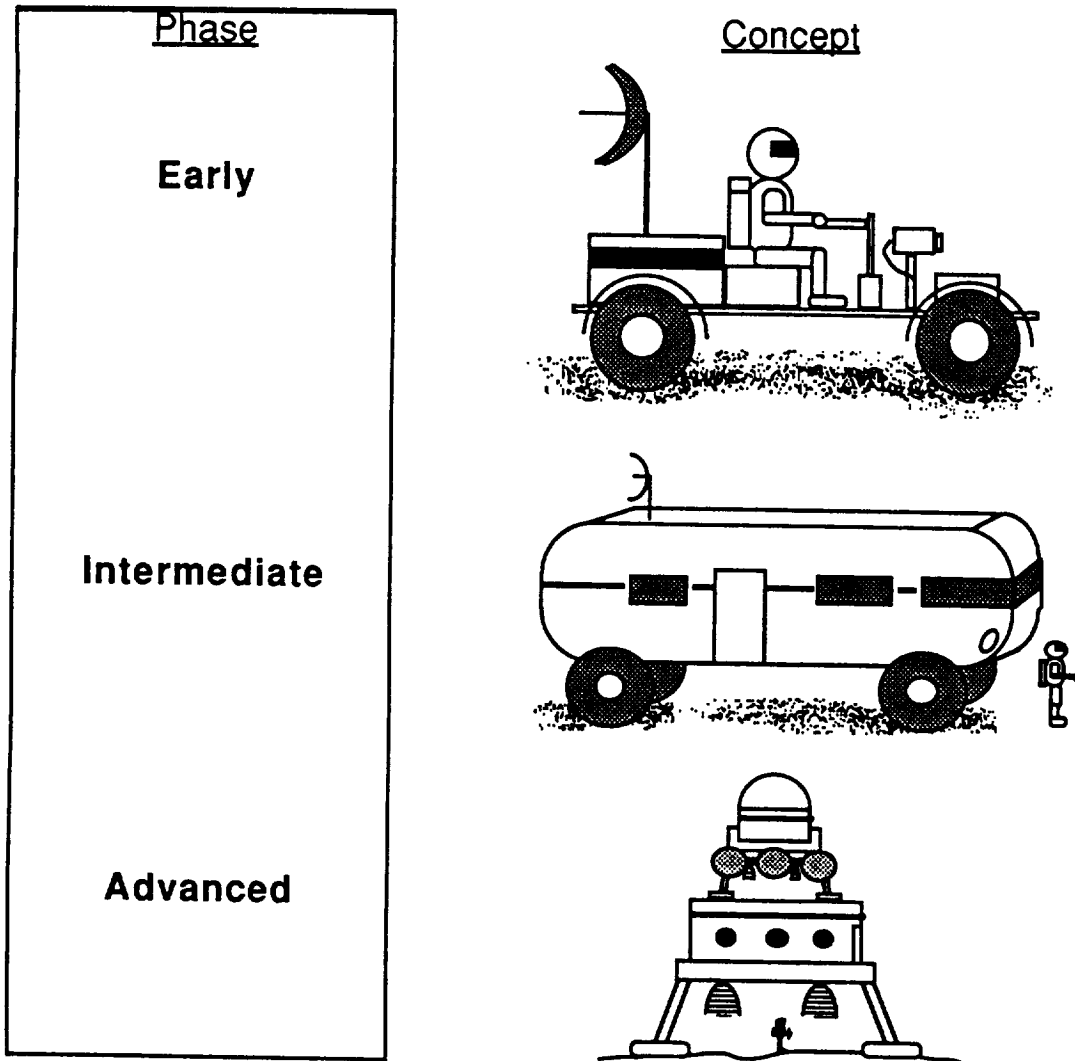
Figure 1. Expected mobility available to human Mars explorers during the earliest (top), intermediate (middle) and advanced (bottom) phases of exploration of that planet.

Telepresence - a Shortcut to Surface Mobility

An alternative to providing mobility to take Astronauts to the information would be to bring the information to them at high enough fidelity that it is very close to being there. We propose that telepresence systems represent a significant augmentation and alternative to human mobility. In fact, the provision of telepresence as an exploration tool is potentially so powerful that it could establish a new paradigm of exploration where humans and robots interact synergistically to achieve exploration goals.

What is telepresence? It is a high fidelity form of remote control which projects the senses of the human operator into a robot at a distant work site. Telepresence represents the marriage of technology which has been

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developed for Virtual Reality uses and the technology of advanced robotics. In the telepresent operation of a robot, the images from the robot cameras would be directly projected into the eyes of the operator. The humans body movements would control the motions of the robot, and the human would make the decisions. Telepresent operation of robots is an alternative to Artificial Intelligence because human intelligence is used instead. Thus, the level of automation (and the complexity of the computer control and software involved) is much lower. In effect, the human operator servo-controls the remote vehicle with the natural motions of her (or his) body.

The obvious advantage of telepresent operation of remote vehicles is that they could be landed anywhere on the surface of Mars and then operated from a distant location, such as the site of a Mars base. Thus, the range that humans can explore using telepresence depends on the communication range and the practicality of deploying the remote vehicles.

Telepresence operation of remote vehicles also offers the potential for substantially leveraging crew time. Telepresence-controlled rovers could be designed so that they could function and be controlled in a variety of ways. For example, one need only consider the stages of a normal geology field trip to see how to partition the work in a telepresent field trip. Any geology field trip on Earth starts out by driving a car or truck over relatively uninteresting terrain to reach the study site. One then surveys the study sight, perhaps with the aid of areal photographs, or climbs to the highest spot to get the overview of the area. After surveying the region on a broad scale, various areas are picked out for intensive investigation which is carried out in an intensive way. The field geologist at this stage is on hands and knees, touching and tasting, breaking off fresh rock faces and examining them with a hand lense, and of course, collecting samples for later analysis. All of this requires extensive documentation with field notes.

A telepresence/robotic field trip might function as follows. The rover might be given a ground command set of instructions to go to a location of interest. It could have enough AI to get to that location, perhaps with occasional supervisory control from Earth, and avoid obstacles, and danger. Once the robot reached the area of interest, it could walk around surveying the region. Again, this activity could be controlled from Earth since it would be tolerant of long time delays (the round trip light time between Mars and Earth is up to 20 minutes depending on the relative positions of the two planets). This information could be stored and sent back to the Mars base location and could be accessed and explored in a virtual reality data base by the martian explorers so that they could use it to select the locations of greatest interest. At the stage where the geological rubber meets the road, the scientist/Mars explorer would use the telepresence mode of operation of the rover to perform detailed scientific field work in selected sites. This mode would use the full range of telepresence capability to give the scientist a strong sense of presence in the remote environment.

Telepresence offers other advantages for exploration besides increasing the range of access to the martian surface. Because the telerobot can record and transmit all the information it collects, it frees the explorer from the drudgery of keeping field notes. The explorer can instead keep a running verbal record of what s/he is thinking while operating the telerobot. The entire experience is recorded and so it can be replayed. Another obvious advantage of having this high fidelity record is that the community of access to the exploration experience can be vastly expanded. One can have the exploration experience second hand in one of two ways. The actual experience could be replayed by putting on a head-mounted display and watching the entire experience. One could literally hear and see everything the original explorer did. Thus, other scientists could access the information in this way, as well as could the general public. The power of this technological capability for education is stupendous. Students at every level could have the thrill of participating in the exploration experience while learning in a very first hand way the mental processes and techniques used in field science.

An second way that other communities could examine the data is through the use of virtual reality to explore Mars using high fidelity models of field sites created with the aid of the data from telerobotic exploration. Thus, in virtual reality, one could roam around in the model terrain at will and each person could have a unique experience of the data. Thus, telepresence offers a tremendous enhancement of the capabilities available to perform field science on Mars.

Telepresence with Undersea ROV's

Operations in the undersea environment is a good training ground for developing technology to be used in space exploration. Exploration of the undersea environment faces many of the same constraints as exploration on a planetary surface. Extra-vehicular Activity on a planetary surface is conceptually similar to SCUBA diving where the capabilities of life support limit the range of human explorers. Teleoperation of Remotely Operated Vehicles (ROV's) is already widely used in the undersea environment, both for scientific exploration and for operational applications such as the inspection and repair of offshore oil rigs. Sophisticated underwater ROV's can be obtained "off the shelf" for relatively low cost. The level of teleoperation of such vehicles can be quite sophisticated and they are frequently equipped with multi-function manipulator arms and sampling devices as well as cameras.

We have developed a telepresence control interface for an underwater ROV and are using the Telepresence-controlled ROV (or TROV) to perform scientific field work in undersea environments. This vehicle and telepresence system is described in Gwynne et al. (1992) and is briefly summarized here.
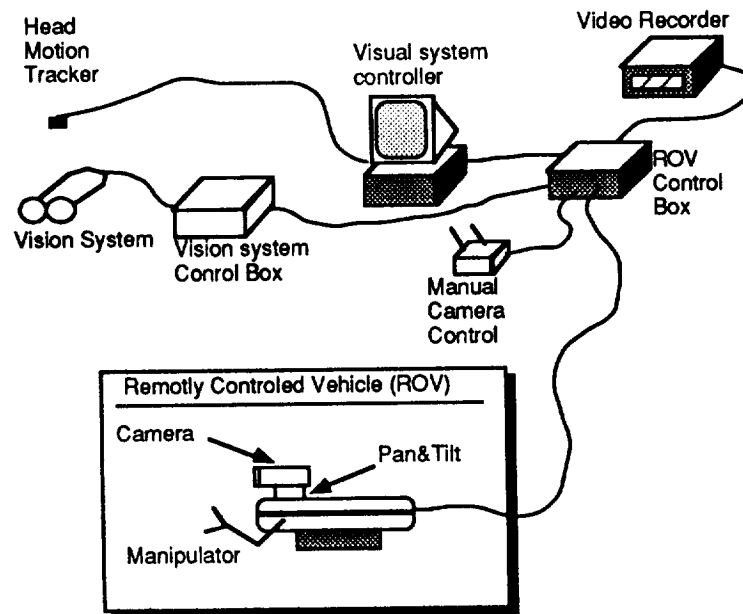
Figure 2. Conceptual layout of TROV system.

The TROV is based on an off the shelf underwater ROV SuperPhantom 2 built by Deep Ocean Engineering in San Leandro California. The ROV is capable of movement in four axes and can operate at depths up to 450 m. It weighs 68 kg has an operating underwater speed of 3 knots (1.54 m/s).The ROV is equipped with a 1,100 foot cable to provide power and communications from the surface to the ROV.

The thrusters which control the motion of the TROV are driven using a vehicle controller based on control-sticks. Mounted on the vehicle is a camera platform which can pan and tilt. A single video camera is mounted on that platform. The image from the video camera is sent to the surface via the electrical cable where it can be displayed on a variety of image display devices and is video recorded.

The position of the underwater camera is controlled by the motions of the operators head. The position of the operators head is tracked using a Polhemus 3SpaceTracker™. Signals from the tracker are fed into a computer and translated into commands to operate the underwater pan and tilt camera platform.

The images from the underwater camera are projected into a video display device which is worn in close proximity to the operators eyes and fills her/his entire field of view. Because camera pointing is controlled by head motions in real time, the result is spatially correspondent vision which gives the operator a strong sense of being present in the underwater environment.

We have experimented with a variety of head-mounted displays for use with the TROV. Relatively low cost head-mounted displays have been developed for the Virtual Reality (VR) market. Such systems are either based on Cathode Ray Tube technology or liquid crystal technology. Both have disadvantages and

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advantages for the telepresence application. In both cases, the fundamental limitation is the resolution available. Since the image is of a real scene projected close to the operator's eyes, it is important to have a very high resolution display. This is less important for the Virtual Reality application since the resolution of the Virtual image can be matched to the capabilities of the display. CRT's are relatively large and this can be a significant problem when the application calls for mounting the CRT on something that can be worn on the head . Very small CRT's have been developed for use in hand-held camcorders but they are black and white. Similarly small color CRT's are not available. LCD based systems are small and lightweight but have much less dynamic range than do CRT's. While low resolution LCD systems are available in the low cost range, their resolution is not adequate for our application.

We have developed a simple and low cost head-mounted display based on small black and white CRT's of the type used in camcorders. This system is capable of 200 lines of resolution and provides a 25° FOV. The main disadvantage of this system for doing field science is that it is black and white. A color image display system has also been developed by Bill Polhemus, a private inventor, working in close collaboration with our project staff. This system uses a fiber optic cable to project images onto a screen mounted in front of the operator's eyes. This system is thus capable of up to 1000 lines of color video and a 56° FOV.

In the current TROV configuration, an Amiga 2000 computer is used to supply heads-up display and video overlay of key information into the head-mounted display. The Amiga computer is also used to interface the Polhemus head tracker to point the underwater pan and tilt camera.

Antarctica: Field Operations in a Mars Analog Environment

The Telepresence project, and the TROV capability, was selected as a pilot project for a new program jointly sponsored by NASA and the National Science Foundation, to use the Antarctic as an analog environment to help develop and test systems for use in future space exploration. The goal of this project, held in the 1992 Austral Summer, was to perform an integrated demonstration of telepresence, advanced power systems, and satellite communications/data link to Antarctica.

The Antarctic field dates were October 15 - December 7, 1992. There were two distinct field phases, involving different operating conditions and crew. In the first field phase (held Oct. 22 - Nov. 21, 1992) the TROV was used to study the environment beneath the ice in permanently ice-covered Lake Hoare in the Taylor Valley on the Antarctic continent. In the second phase, (Nov. 23-Dec. 7) the TROV was operated under the sea ice in McMurdo Sound a few hundred meters off shore from McMurdo station, the main United States Research Base in Antarctica. During this phase, the principal objective was to demonstrate the capabilities of sending live video images from the TROV to Ames Research Center in Moffett Field, California via satellite. Each of these two phases will be described next.

Lake Hoare Study

Lake Hoare is a permanently ice covered lake located in the Taylor Valley, one of the dry valleys near the edge of the Antarctic continent. The dry valleys have been described as the most Mars-like environment on Earth. These environments are cold and dry, having less than 10 cm of precipitation per year and a mean annual temperature of -17C. Field teams spend up to several months at a time on scientific expeditions into the dry valleys. During these expeditions, the field teams must be self sufficient and are completely isolated from other groups and from any outside contract other than periodic radio communication with the central base. Thus, scientific exploration from a remote camp in the dry valleys of Antarctica is a strong analog to scientific exploration of Mars.

The main scientific interest in Lake Hoare is a microbial mat which lives in the bottom of the lake (Wharton et al, 1989 a,b). The environments in these lakes are thought to be similar to ice-covered lakes which existed on Mars in the ancient past. Wharton et al. (1989b) has discussed the potential that the biological activity found in these lakes could be analogous to biological activity in ice-covered lakes on Ancient Mars. Thus, studies of the environment in these lakes provide relevant information which points the way to a scientific approach for the future human exploration of Mars.

Lake Hoare had been previously studied by scientists using SCUBA but, due to the extremely hazardous conditions, the range that a diver can swim in the lake is limited to about 30 meters. The major obstacle to overcome in the exploration of these lakes is putting a dive hole through the three-meter-thick permanent ice cover. Typically scientist make very few dive holes during an expedition. The limited number of these dive holes severely limits the diver/scientists access to the lake.

On October 22, 1992, our six member crew was flown in by helicopter to Lake Hoare. In addition to the crew, helicopters delivered all equipment, food, fuel and supplies for a month-long stay. A solar power system, built by NASA Lewis Research Center, was also delivered to the field camp which supplied 5 Kw of clean, quiet electrical power to the field camp.

The Lake Hoare camp facilities include a small portable jamesway hut which serves as a central meeting area and place for food preparation. The hut is heated and provides a shirt-sleeve environment. The hut was equipped with electrical power (from the solar power system), and had a telephone line equipped with access to electronic mail. The only other camp facilities were a small plywood shed that serves as a laboratory, and an outhouse. The field crew slept in mountaineering tents near the hut.

The first order of business to enable scientific operations on the lake was to melt a hole through the 3 m thick ice cover for the TROV and SCUBA divers to gain access to the lake. A second portable jamesway hut was set up on the lake to

serve as a warm operating environment for computers and electronics associated with the TROV, and a dive hole was melted near this hut. Equipment was moved around on the lake surface by loading it on sleds and man-hauling it across the lake ice. The surface of the lake ice is extremely rough due to differential melting of ice in the top meter of the surface. As a result, moving heavy equipment around on the lake ice is extremely laborious and time consuming. Because of this, and the amount of equipment involved, the TROV operations were confined to a single dive hole. In addition to this central hole, three more dive holes were melted at other locations on the lake to allow access by SCUBA divers.

The TROV was used to explore the lake within a 330 m radius of the operations hut on the lake surface. The range of exploration was set by the length of the tether which provided communications and power lines between the TROV and the surface.

The primary purpose of TROV operations was "telepresent" visual exploration of the lake environment, particularly the morphology of the algal mat and the geology of the lake bed. Lake Hoare is bordered on one end by the Canada glacier which extends to the bottom of the lake. The TROV was also used to explore and study the Canada glacier at the ice-water interface . The TROV was not equipped with a manipulator and so could not obtain samples of the sediments or algal mat at the lake bottom. Obtaining these samples was the primary purpose of SCUBA diving operations.

Each of the six team members spent some time operating the TROV with and without the head tracking and head-mounted display capability. Typical time spent exploring the lake environment with the TROV was 6 hours at a time. The lake depth in the accessible area varied from 10 m to 40 m. Thus TROV operations favorably compared with a SCUBA dive which is limited to less than an hour due to depth and air supply limitations. The capability to look around using the pan and tilt camera platform, having slew rates that matched head motions, was found to help maintain spatial orientation for navigating the TROV and for developing a mental map of the terrain. The resolution, contrast, and color capabilities of the vision display was found to be the key requirement for performance. The vision display system we used, and vision display systems in general, will need considerable improvement before they will be satisfactory for scientific work with telepresence.

TROV Operation in McMurdo Sound

After a month of TROV operations at Lake Hoare, all remaining food, fuel and equipment was repacked and transported back to McMurdo station on Ross Island. The TROV was then deployed at a dive hole located on the sea ice several hundred meters from the edge of McMurdo station. Electronic equipment was housed in a mobile trailer. Facilities for TROV operations in McMurdo were far more comfortable than the spartan conditions at Lake Hoare. McMurdo Station, the main US Antarctic research station, is a town with a population of 1500 people during the summer season. McMurdo contains most

of the the amenities of civilized college life including dormatory-style housing, cafeteria-style meals, and a variety of organized recreational activities. Since the central purpose of the McMurdo facility is to support scientific operations in Antarctica, the station is very well equipped and staffed for doing so.

The main scientific objective for operating the TROV from McMurdo Sound was to evaluate whether the TROV technology would be a useful science tool for studying the organisms living on the sea bottom beneath the ice. The key technology objective was to test a newly installed capability to send live video from the TROV via satellite to the Continental United States (CONUS). A third objective, which was originally planned for a subsequent field season but which we were able to achieve, was to control some functions of the TROV from Ames Research Center via a satellite link.

The remote operation of the TROV from Ames involved the coordination of several different groups and projects. A telecommunications network to Antarctica had been set up by NASA Science Internet which involved the capability to send live video, in addition to the provision of telephone lines and internet access, all linked to CONUS via satellite. The TROV was driven using the local control console stationed on the McMurdo sea ice. The video image was patched by cable to a laser transmitter which sent the image to a receiving station in the center of McMurdo. The image was digitized, compressed, and sent via satellite to CONUS. Once received at Ames, the image was decompressed and broadcast where it appeared on the local NASA select television station. The pan and tilt camera platform on the TROV was operated by an operator at Ames. Control signals for the camera pointing were generated by using a head tracker to sense the head motions of an operator wearing a head mounted display receiving the images from the underwater camera. Coded head tracker position information was transmitted to Antarctica via modem line where it was fed into the controller computer and used to control the pointing of the underwater camera. The total time delay in the control of the underwater camera was 1 second.

Future Plans with TROV

Using the TROV to perform field science will influence the development and improvement of capabilities for this purpose and drive forward telepresence technology into greater maturity. We are continuing to upgrade the system and improve its capability for performing field work. We plan to perform a second Antarctic expedition in 1993 using the TROV with improved capabilities. In this next field season, the central focus will be to perform the bulk of the scientific exploration using telepresence control of the TROV from Ames Research Center. Figure 3 shows an artists concept of the planned TROV operations. The TROV will be equipped with stereo cameras and a manipulator arm. All functions of the TROV including control of its motion though the water will be operated from Ames. To eliminate the effects of time delay on control of the TROV, and to utilize the capabilities of Virtual Reality, the TROV will be first used to survey an area at high resolution. This information will then be used to construct a world model which will form an operating environment. Thus, the

Ames operator of the TROV will be able to explore in the virtual environment, while using this virtual environment exploration to send control signals to the TROV. The TROV will also be continuously sending the real time video signals back to Ames. Thus, the operator will be able to see both the virtual environment view and the real time view while operating the TROV.
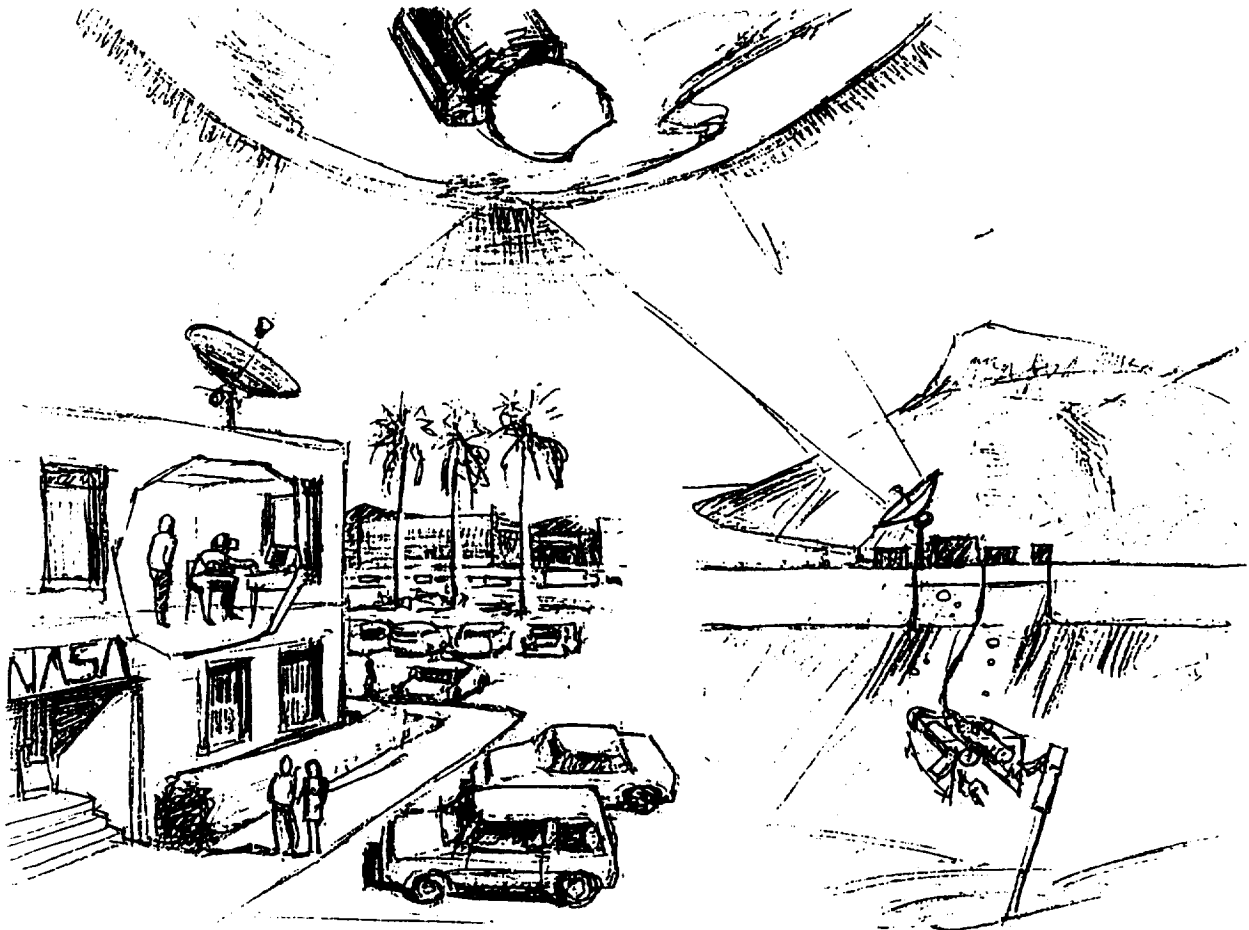
Figure 3. Artists concept illustrating the control of TROV in Antarctica from Ames Research Center

The 1993 Antarctic field experiment will be the first time that a virtual environment world model was developed and used in real time to perform a science task. There are many advantages to this approach. The requirements for sending data are reduced since, once a world model is developed, redundant images need not be repeatedly transmitted. The world model may also help to compensate for time delays. The operator working in the model environment will not experience a time delay in performing a task, but the actual task in the real environment may take place at a later time. In addition, sensor data other than vision may be overlaid on the visual record in the world model, thus provided correlated scientific information.

The strategy for telepresent field work planned for the next Antarctic field season closely approximates the strategy for operation of a remote vehicle at a distant location on Mars, either from a Mars base site or from Earth. Thus, the Antarctic field work is providing a valuable test bed for technology to be used in future Mars exploration.

Conclusions

Using telepresence to operate remote vehicles could lead to a revolution in the ability to perform science in hostile and extreme environments on Earth and could be an enabling technology for performing field science on Mars. Using telepresence now will lead to near-term scientific benefits as well as providing scientific drivers for the development of new and improved technologies for telepresent exploration. In addition, these field studies will lead to a better understanding of how to do field operations using telerobotics on Mars.

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THE UNIVERSAL ROBOT

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Abstract

Our artifacts are getting smarter, and a loose parallel with the evolution of animal intelligence suggests one future course for them. Computerless industrial machinery exhibits the behavioral flexibility of single-celled organisms. Today's best computer-controlled robots are like the simpler invertebrates. A thousand-fold increase in computer power in the next decade should make possible machines with reptile-like sensory and motor competence. Properly configured, such robots could do in the physical world what personal computers now do in the world of data—act on our behalf as literal-minded slaves. Growing computer power over the next half-century will allow this reptile stage will be surpassed, in stages producing robots that learn like mammals, model their world like primates and eventually reason like humans. Depending on your point of view, humanity will then have produced a worthy successor, or transcended some of its inherited limitations and so transformed itself into something quite new

Introduction: State of the Art

Instincts which predispose the nature and quantity of work we enjoy probably evolved during the 100,000 years our ancestors lived as hunter-gatherers. Less than 10,000 years ago the agricultural revolution made life more stable, and richer in goods and information. But, paradoxically, it requires more human labor to support an agricultural society than a primitive one, and the work is of a different, "unnatural" kind, out of step with the old instincts. The effort to avoid this work has resulted in domestication of animals, slavery and the industrial revolution. But many jobs must still be done by hand, engendering for hundreds of years the fantasy of an intelligent but soulless being that can tirelessly dispatch the drudgery. Only in this century have electronic sensors and computers given machines the ability to sense their world and to think about it, and so offered a way to fulfill the wish.

As in fables, the unexpected side effects of robot slaves are likely to dominate the resulting story. Most significantly, these perfect slaves will continue to develop, and will not long remain soulless. As they increase in competence they will have occasion to make more and more autonomous decisions, and so will slowly develop a volition and purposes of their own. At the same time they will become indispensable. Our minds were evolved to store the skills and memories of a stone-age life, not the enormous complexity that has developed in the last ten thousand years. We've kept up, after a fashion, through a series of social inventions—social stratification and division of labor, memory aids like poetry and schooling, written records stored outside the body, and recently machines that can do some of our thinking entirely without us. The portion of absolutely essential human activity that takes place outside of human bodies and minds has been steadily increasing. Hard working intelligent machines may complete the trend.

Serious attempts to build thinking machines began after the second world war. One line of research, called Cybernetics, used simple electronic circuitry to mimic small nervous systems, and produced machines that could learn to recognize simple patterns, and turtle-like robots that found their way to lighted recharging hutches [Wiener 1961]. An entirely different approach, named Artificial Intelligence (AI), attempted to duplicate rational human thought in the large computers that appeared after the war. By 1965, these computers ran programs that proved theorems in logic and geometry, solved calculus problems and played good games of checkers [Feigenbaum 1963].

In the early 1970s, AI research groups at MIT (the Massachusetts Institute of Technology) and Stanford University attached television cameras and robot arms to their computers, so their "thinking" programs could begin to collect their information directly from the real world.

What a shock! While the pure reasoning programs did their jobs about as well and about as fast as college freshmen, the best robot control programs took hours to find and pick up a few blocks on a table. Often these robots failed completely, giving a performance much worse than a six month old child. This disparity between programs that reason and programs that perceive and act in the real world holds to this day. In recent years Carnegie Mellon University produced two desk-sized computers that can play chess at grandmaster level, within the top 100 players in the world, when given their moves on a keyboard. But present-day robotics could produce only a complex and unreliable machine for finding and moving normal chess pieces.

In hindsight it seems that, in an absolute sense, reasoning is much easier than perceiving and acting—a position not hard to rationalize in evolutionary terms. The survival of human beings (and their ancestors) has depended for hundreds of millions of years on seeing and moving in the physical world, and in that competition large parts of their brains have become efficiently organized for the task. But we didn't appreciate this monumental skill because it is shared by every human being and most animals—it is commonplace. On the other hand, rational thinking, as in chess, is a newly acquired skill, perhaps less than one hundred thousand years old. The parts of our brain devoted to it are not well organized, and, in an absolute sense, we're not very good at it. But until recently we had no competition to show us up.

By comparing the edge and motion detecting circuitry in the four layers of nerve cells in the retina, the best understood major circuit in the human nervous system, with similar processes developed for "computer vision" systems that allow robots in research and industry to see, I've estimated that it would take a billion computations per second (the power of a world-leading Cray 2 supercomputer) to produce the same results at the same speed as a human retina. By extrapolation, to emulate a whole brain takes ten trillion arithmetic operations per second, or ten thousand Crays worth [Moravec 1988]. This is for operations our nervous system do extremely efficiently and well.

Arithmetic provides an example at the other extreme. In 1989 a new computer was tested for a few months with a program that computed the number pi to more than one billion decimal places. By contrast, the largest unaided manual computation of pi was 707 digits by William Shanks in 1873. It took him several years, and because of a mistake every digit past the 527th was wrong! In arithmetic, today's average computers are one million times more powerful than human beings. In very narrow areas of rational thought (like playing chess or proving theorems) they are about the same. And in perception and control of movement in the complex real world, and related areas of common-sense knowledge and intuitive and visual problem solving, today's average computers are a million times less capable.

The deficit is evident even in pure problem solving AI programs. To this day, AI programs exhibit no shred of common sense—a medical diagnosis program, for instance, may prescribe an antibiotic when presented a broken bicycle because it lacks a model of people, diseases or bicycles. Yet these programs, on existing computers, would be overwhelmed were they to be bloated with the details of everyday life, since each new fact can interact with the others in an astronomical "combinatorial explosion." [A ten year project called Cyc at the Microelectronics and Computer Consortium in Austin Texas is attempting to build just such a common-sense data base. They estimate the final result will contain over one hundred million logic sentences about everyday objects and actions [Lenat 1989].]

Machines have a lot of catching up to do. On the other hand, for most of the century, machine calculation has been improving a thousandfold every twenty years, and there are basic developments in research labs that can sustain this for at least several decades more. In less than fifty years computer hardware should be powerful enough to match, and exceed, even the well-developed parts of human intelligence. But what about the software that would be required to give these powerful machines the ability to perceive, intuit and think as well as humans? The

Cybernetic approach that attempts to directly imitate nervous systems is very slow, partly because examining a working brain in detail is a very tedious process. New instruments may change that in future. The AI approach has successfully imitated some aspects of rational thought, but that seems to be only about one millionth of the problem. I feel that the fastest progress on the hardest problems will come from a third approach, the newer field of robotics, the construction of systems that must see and move in the physical world. Robotics research is imitating the evolution of animal minds, adding capabilities to machines a few at a time, so that the resulting sequence of machine behaviors resembles the capabilities of animals with increasingly complex nervous systems. This effort to build intelligence from the bottom up is helped by biological peeks at the "back of the book"—at the neuronal, structural, and behavioral features of animals and humans.

The best robots today are controlled by computers which are just powerful enough to simulate the nervous system of an insect, cost as much as houses, and so find only a few profitable niches in society (among them, spray painting and spot welding cars and assembling electronics). But those few applications are encouraging research that is slowly providing a base for a huge future growth. Robot evolution in the direction of full intelligence will greatly accelerate, I believe, in about a decade when the mass-produced general purpose, universal robot becomes possible. These machines will do in the physical world what personal computers do in the world of data—act on our behalf as literal-minded slaves.

The Dumb Robot (ca. 2000-2010)

To be useful in many tasks, the first generation of universal robots should navigate efficiently over flat ground and reliably and safely over rough terrain and stairs, be able to manipulate most objects, and to find them in the nearby world. There are beginnings of solutions today. In the 1980s Hitachi of Japan developed a mobility system of five steerable wheels, each on its own telescoping stalk that allows it to accommodate to rises and dips in uneven terrain, and to climb stairs, by raising one wheel at a time while standing stably on the other four. My laboratory at Carnegie Mellon University in Pittsburgh has developed a navigation method that enables a robot equipped with sonar range measuring devices and television cameras to build probabilistic maps of its surroundings to determine its location and plan routes [Moravec 1987]. An elegant three-fingered mechanical hand at the Massachusetts Institute of Technology can hold and orient bolts and eggs and manipulate a string in a humanlike fashion [Mason 1985]. A system called 3DPO from SRI International in Menlo Park, California can find a desired part in a jumble seen by special range-finding camera [Bolles 1984]. The slow operation of these systems suggests one other element needed for the universal robot, namely a computer about one one thousand times as powerful as those found on desks and in robots today. Such machines, able to do one billion computations per second, would provide robots approximately the brain power of a reptile, and the personality of a washing machine.

Universal robots will find their first uses in factories, where they will be cheaper and more versatile than the older generation of robots they replace. Eventually they will become cheap enough for some households, extending the reach of personal computers from a few tasks in the data world to many in the physical world.

As with computers, many applications of the robots will surprise their inventors. Some will do light mechanical assembly, clean bathrooms, assemble and cook gourmet meals from fresh ingredients, do tuneups on a certain year and make of cars, hook patterned rugs, weed a lawn, run robot races, do detailed earthmoving and stonework, investigate bomb threats, deliver to and fetch from warehoused inventories, and much more. Each application will require its own original software (very complex by today's computer program standards), and some may also need optional hardware attachments for the robot such as special tools and chemical sensors.

Learning (2010-2020)

Useful though they will be, the first generation of universal robots will be rigid slaves to

simple programs. If the machine bangs its elbow while chopping beef in your kitchen making Stroganoff, you will have to find another place for the robot to do its work, or beg the software manufacturer for a fix. Second generation robots with more powerful computers will be able to host a more flexible kind of program able to adjust itself by a kind of conditioned learning. First generation programs will consist primarily of sequences of the type "Do step A, then B, then C...." The programs for the second generation will read "Do step A1 or A2 or A3 ... then B1 or B2 or B3 ... then C1 or C2 or C3 ...." In the Beef Stroganoff example, A1 might be to chop with the right hand of the robot, while A2 is to use the left hand. Each alternative in the program has a "weight," a number that indicates the desirability of using it rather than one of the other branches. The machine also contains a "pain" system, a series of programs that look out for problems, such as collisions, and respond by reducing the weights of recently invoked branches, and a "pleasure" system that increases the relevant weights when good conditions, such as well charged batteries or a task efficiently completed, are detected. As the robot bangs its elbow repeatedly in your kitchen, it gradually learns to use its other hand (as well as adapting to its surroundings in a thousand other ways). A program with many alternatives at each step, whose pain and pleasure systems are arranged to produces a pleasure signal on hearing the word "good" and a pain message on hearing "bad" could be slowly trained to do new tasks, like a small mammal. A particular suite of pain- and pleasure-producing programs interacting with a robot's individual environment would subtly shape its behavior and give it a distinct character.

Imagery (2020-2030)

Adaptive robots will find jobs everywhere, and the hardware and software industry that supports them could become the largest on earth. But teaching them new tasks, whether by writing programs or through punishment and reward, will be very tedious. This deficiency will lead to a portentous innovation, a software world-modeler (requiring another big increase in computer power), that allows the robot to simulate its immediate surroundings and its own actions within them, and thus to think about its tasks before acting. Before making Beef Stroganoff in your kitchen, the new robot would simulate the task many times. Each time its simulated elbow bangs the simulated cabinet, the software would update the learning weights just as if the collision had physically happened. After many such mental run-throughs the robot would be well trained, so that when it finally cooks for real, it does it correctly. The simulation can be used in many other ways. After a job, the robot can run though its previous actions, and try variations on them to improve future performance. A robot might even be configured to invent some of its own programs by means of a simpler program that can detect how nearly a sequence of robot actions achieves a desired task . This training program would, in repeated simulations, provide the "good" and "bad" indications needed to condition a general learning program like the one of the previous section.

It will take a large community of patient researchers to build good simulators. A robot entering a new room must include vast amounts of not directly perceived prior knowledge in its simulation, such as the expected shapes and probable contents of kitchen counters and the effect of (and force needed for) turning faucet knobs. It needs instinctive motor-perceptual knowledge about the world that took millions of years of evolution to install in us, that tells us instinctively when a height is dangerous, how hard to throw a stone, or if the animal facing us is a threat . Robots that incorporate it may be as smart as monkeys.

Reasoning (2030-2040)

In the decades while the "bottom-up" evolution of robots is transferring the perceptual and motor faculties of human beings into machinery, the conventional Artificial Intelligence industry will be perfecting the mechanization of reasoning. Since today's programs already match human beings in some areas, those of 40 years from now, running on computers a million times as fast as today's, should be quite superhuman. Today's reasoning programs work from small amounts of clear and correct information prepared by human beings. Data from robot sensors such as cameras

is much too voluminous and too noisy for them to use. But a good robot simulator will contain neatly organized data about the robot and its world. For instance, if a knife is on a countertop, or if the robot is holding a cup. A robot with simulator can be married to a reasoning program to produce a machine with most of the abilities of a human being. The combination will create beings that in some ways resemble us, but in others are like nothing the world has seen before.

First Generation Technicalities

Both industrial robot manipulators and the research effort to build "smart" robots are twenty five years old. Universal robots will require at least another decade of development, but some of their elements can be guessed from the experience so far. One consideration is weight. Mobile robots built to work in human sized spaces today weigh too many hundreds of pounds. This dangerously large mass has three major components: batteries, actuators and structure. Lead-acid batteries able to drive a mobile robot for a day contribute about one third of the weight. But nickel-cadmium aircraft batteries weigh half as much, and newer lithium batteries can be half again as light. Electric motors are efficient and precisely controllable, but standard motors are heavy and require equally heavy reducing gears. Ultrastrong permanent magnets can halve the weight and generate high torque without gears. Robot structure has been primarily aluminum. Its weight contribution can be cut by a factor of four by substituting composite materials containing superstrength fibers of graphite, aramid or the new material Spectra. These innovations could be combined to make a robot with roughly the size, weight, strength and endurance of a human.

The first generation robot will probably move on wheels. Legged robots have advantages on complicated terrain, but they consume too much power. A simple wheeled robot would be confined to areas of flat ground, but if each wheel had a controlled suspension with about a meter of travel, the robot could slowly lift its wheels as needed to negotiate rough ground and stairs. The manipulation system will consist of two or more arms ending in dexterous manipulators. There are several designs in the research labs today, but the most elegant is probably that of the so-called Stanford-JPL hand (mentioned above, now found at MIT), which has three fingers each with three controlled joints.

The robot's travels would be greatly aided if it could continuously pinpoint its location, perhaps by noting the delay from a handful of small synchronized transmitters distributed in its environment. This approach is used in some terrestrial and satellite navigation systems. The robot will also require a sense of its immediate surroundings, to find doors, detect obstacles and track objects in its workspace. Research laboratories, including my own, have experimented with techniques that do this with data from television cameras, scanning lasers, sonar transducers, infrared proximity sensors and contact sensors. A more precise sensory system will be needed to find particular work objects in clutter. The most successful methods to date start with three dimensional data from special cameras and laser arrangements that directly measure distance as well as lateral position. The robot will thus probably contain a wide angle sensor for general spatial awareness, and a precise, narrow angle, three dimensional imaging system to find particular objects it will grasp.

Research experience to date suggests that to navigate, visually locate objects, and plan and control arm motions, the first universal robots will require a billion operations per second of computer power . The 1980s have witnessed a number of well publicized fads that claim to be solutions to the artificial intelligence or robot control problem. Expert systems, the Prolog logical inference language, neural nets, fuzzy logic and massive parallelism have all had their spot in the limelight. The common element that I note in these pronouncements is the sudden enthusiasm of group of researchers experienced in some area of computer science for applying their methods to the robotics problems of perceiving and acting in the physical world. Invariably each approach produces some simple showcase demonstrations, then bogs down on real problems. This pattern is no surprise to those with a background in the twenty five year research robotics effort.

Making a machine to see, hear or act reliably in the raw physical world is much, much more difficult than naive intuition leads us to believe. The programs that work relatively successfully in

these areas, in industrial vision systems, robot arm controllers and speech understanders, for example, invariably use a variety of massive numerical computations involving statistics, vector algebra, analytic geometry and other kinds of mathematics. These run effectively on conventional computers, and can be accelerated by array processors (widely available add-ons to conventional machines which rapidly perform operations on long streams of numbers) and by use of modest amounts of parallelism. The mind of the first generation universal robot will almost certainly reside in quite conventional computers, perhaps ten processors each able to perform 100 million operations per second, helped out by a modest amount of specialized computing hardware that preprocesses the data from the laser eyes and other sensors, and that operates the lowest level of mobility and manipulation systems.

Mind Children (2050+)

The fourth robot generation and its successors, with human perceptual and motor abilities and superior reasoning powers, could replace human beings in every essential task. In principle, our society could continue to operate increasingly well without us, with machines running the companies and doing the research as well as performing the productive work. Since machines can be designed to work well in outer space, production could move to the greater resources of the solar system, leaving behind a nature preserve subsidized from space. Meek humans would inherit the earth, but rapidly evolving machines would expand into the rest of the universe.

This development can be viewed as a very natural one. Human beings have two forms of heredity, one the traditional biological kind, passed on strands of DNA, the other cultural, passed from mind to mind by example, language, books and recently machines. At present the two are inextricably linked, but the cultural part is evolving very rapidly, and gradually assuming functions once the province of our biology. In terms of information content, our cultural side is already by far the larger part of us. The fully intelligent robot marks the point where our cultural side can exist on its own, free of biological limits. Intelligent machines, which are evolving among us, learning our skills, sharing our goals, and being shaped by our values, can be viewed as our children, the children of our minds. With them our biological heritage is not lost. It will be safely stored in libraries at least; however its importance will be greatly diminished.

What about life back on the preserve? For some of us the thought of being grandly upstaged by our artificial progeny will be disappointing, and life may seem pointless if we are fated to spend it staring stupidly at our ultra-intelligent progeny as they try to describe their ever more spectacular discoveries in baby-talk that we can understand. Is there any way individual humans might join the adventure?

You've just been wheeled into the operating room. A robot brain surgeon is in attendance, a computer waits nearby. Your skull, but not your brain, is anesthetized. You are fully conscious. The robot surgeon opens your brain case and places a hand on the brain's surface. This unusual hand bristles with microscopic machinery, and a cable connects it to the computer at your side. Instruments in the hand scan the first few millimeters of brain surface. These measurements, and a comprehensive understanding of human neural architecture, allow the surgeon to write a program that models the behavior of the uppermost layer of the scanned brain tissue. This program is installed in a small portion of the waiting computer and activated. Electrodes in the hand supply the simulation with the appropriate inputs from your brain, and can inject signals from the simulation. You and the surgeon compare the signals it produces with the original ones. They flash by very fast, but any discrepancies are highlighted on a display screen. The surgeon fine-tunes the simulation until the correspondence is nearly perfect. As soon as you are satisfied, the simulation output is activated. The brain layer is now impotent—it receives inputs and reacts as before but its output is ignored. Microscopic manipulators on the hand's surface excise this superfluous tissue and pass them to an aspirator, where they are drawn away.

The surgeon's hand sinks a fraction of a millimeter deeper into your brain, instantly compensating its measurements and signals for the changed position. The process is repeated for the next layer, and soon a second simulation resides in the computer, communicating with the first

and with the remaining brain tissue. Layer after layer the brain is simulated, then excavated. Eventually your skull is empty, and the surgeon's hand rests deep in your brainstem. Though you have not lost consciousness, or even your train of thought, your mind has been removed from the brain and transferred to a machine. In a final, disorienting step the surgeon lifts its hand. Your suddenly abandoned body dies. For a moment you experience only quiet and dark. Then, once again, you can open your eyes. Your perspective has shifted. The computer simulation has been disconnected from the cable leading to the surgeon's hand and reconnected to a shiny new body of the style, color, and material of your choice. Your metamorphosis is complete.

Your new mind has a control labeled "speed." It had been set at 1, to keep the simulations synchronized with the old brain, but now you change it to 10,000, allowing you to communicate, react, and think ten thousand times faster. You now seem to have hours to respond to situations that previously seemed instantaneous. You have time, during the fall of a dropped object, to research the advantages and disadvantages of trying to catch it, perhaps to solve its differential equations of motion. When your old biological friends speak with you, their sentences take hours—you have plenty of time to think about the conversations, but they try your patience. Boredom is a mental alarm that keeps you from wasting your time in profitless activity, but if it acts too soon or too aggressively it limits your attention span, and thus your intelligence. With help from the machines, you change your mind-program to retard the onset of boredom. Having done that, you will find yourself comfortably working on long problems with sidetracks upon sidetracks. In fact, your thoughts routinely become so involved that you need an increase in your memory. These are but the first of many changes. Soon your friends complain that you have become more like the machines than the biological human you once were. That's life.

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VENI, VIDEO, VICI: THE MERGING OF COMPUTER AND VIDEO TECHNOLOGIES

Jay G. Horowitz
NASA Lewis Research Center
Cleveland, Ohio

Pre- HDTV Milestones

Post– HDTV Milestones

Video Technology

Advanced Digital Image Architecture

FCC Adopts Broadcast Standard

All Stations Broadcast HDTV

No More NTSC

ULTIMATE IMAGING SYSTEMS

1990   2000   2010   2020   2030   2040

Computer Technology

(Neural–nets, parallel systems, organic & optical computers)

Trans– Mortal PONG!

Technology Transfer
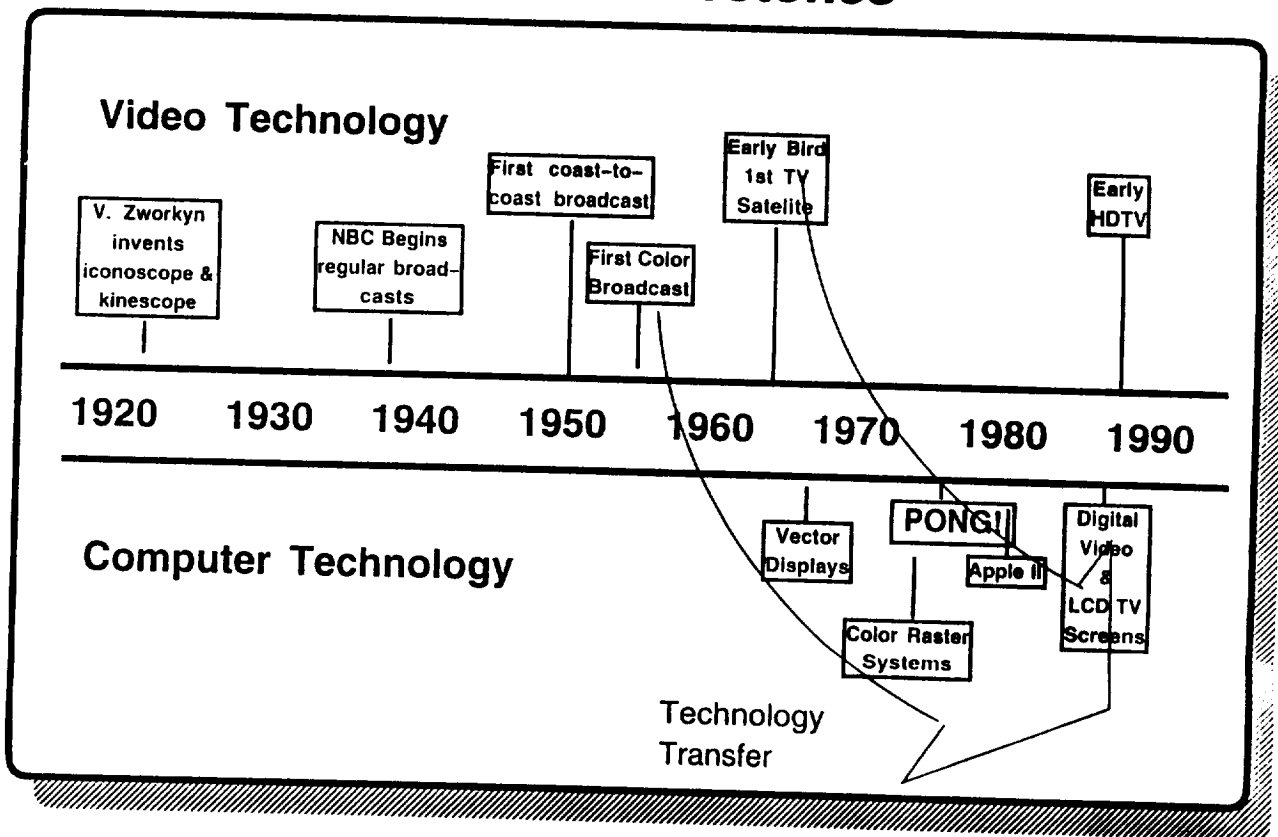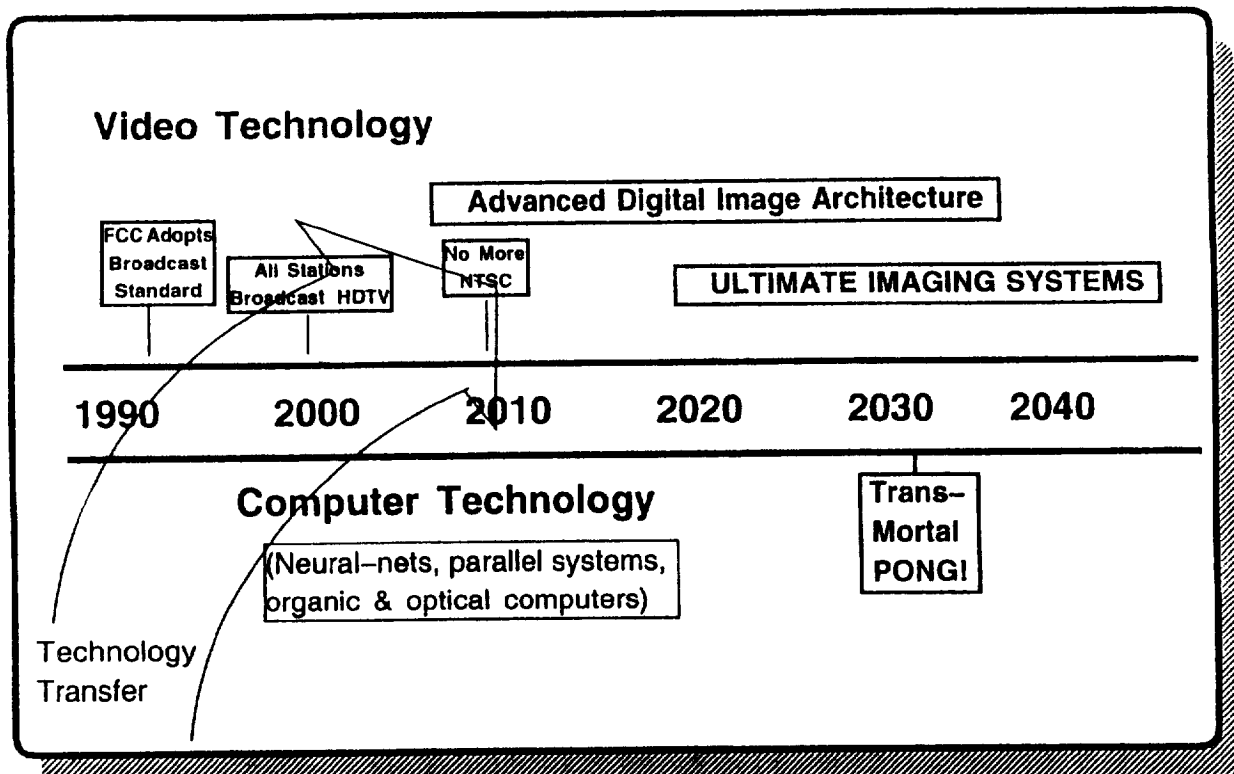
Visual Information Bandwidth

Visual Factors:

Field of View (image size)
Visual Acuity (pixel size & number of pixels)
Dynamic Range (number of bits/pixel)
Color (color components and enoding scheme)
Image Retension (flicker rate, images/sec)

Analog Bandwith (Hz):

= **(Images/sec)*(Lines/image)*('cycles'/line)*(Number of Colors)**
      where 'cycle' is minimum horizontally resolvable unit, one 'on–off'

Digital Bandwidth (bps)

= Analog Bandwidth * 2 pixels/cycle * Number bits/pixel

Example: Monochrome Broadcast TV

30 frms/sec * 525 lines/frm * 250 'cycles'/line = 4,000,000 cycles/sec = **4 MHz**

at 2 pixels/cycle * 8 bits/pixel = **64 Mbs**

Television Frequency Allocation and Bandwidth

Frequency, Hz

10^2 10^4 10^6 10^8 10^{10} 10^{12} 10^{14} 10^{16} 10^{18} 10^{20} 10^{22}

Power | Radio | VHF | UHF | Microwaves | InfraRed | UltraViolet | X-rays | Gamma Rays

| 2 | 3 | 4 | 5 | 6 | | 7 | 8 | 9 | 10 | 11 | 12 | 13 | Channel

54 60 66 72 76 82 88   174 180 186 192 198 204 210 216 MHz

Picture Carrier

Color SubCarrier

Sound

Luminance Signal

I-signal

Q-signal

6 MHz
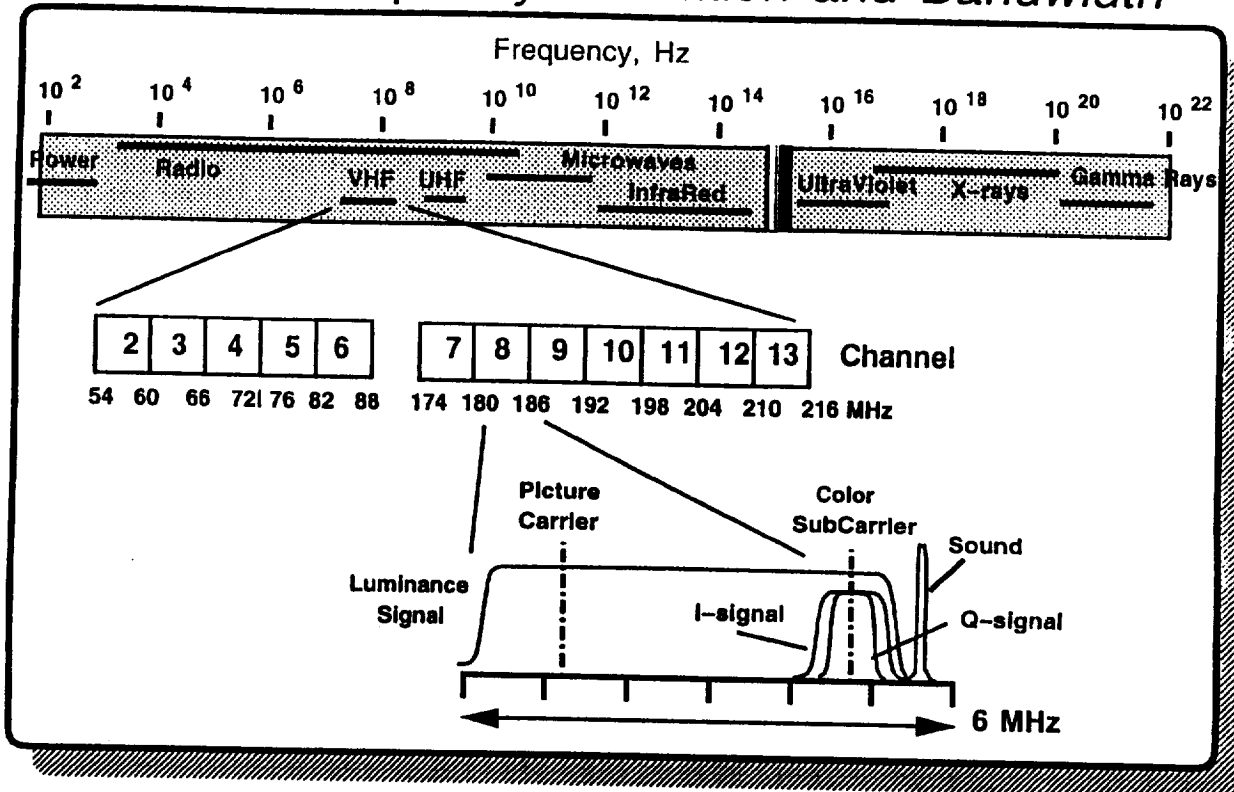
Horizontal Scanning
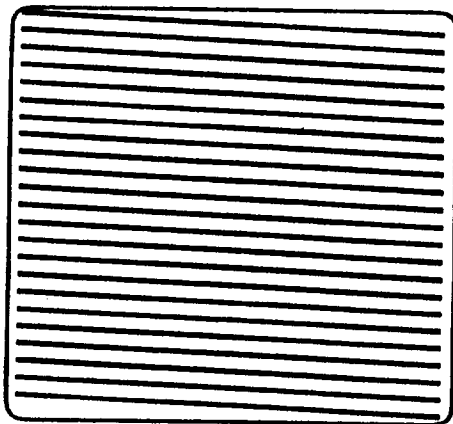
Workstation Video
1024 Scanlines
60 Full Frames/sec
Non–Interlaced
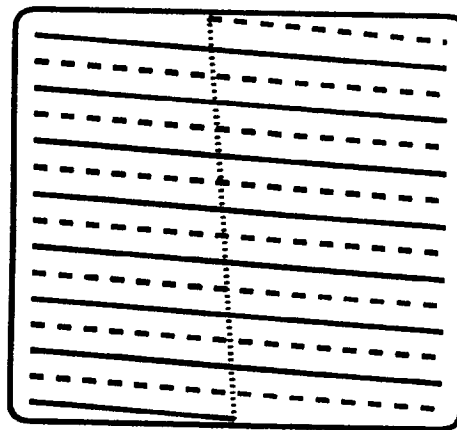
Television
525 Scanlines
30 Full Frames/sec
2 Interlaced Fields

Workstation RGB Color Domain

Scanline

Red Signal

Green Signal

Blue Signal
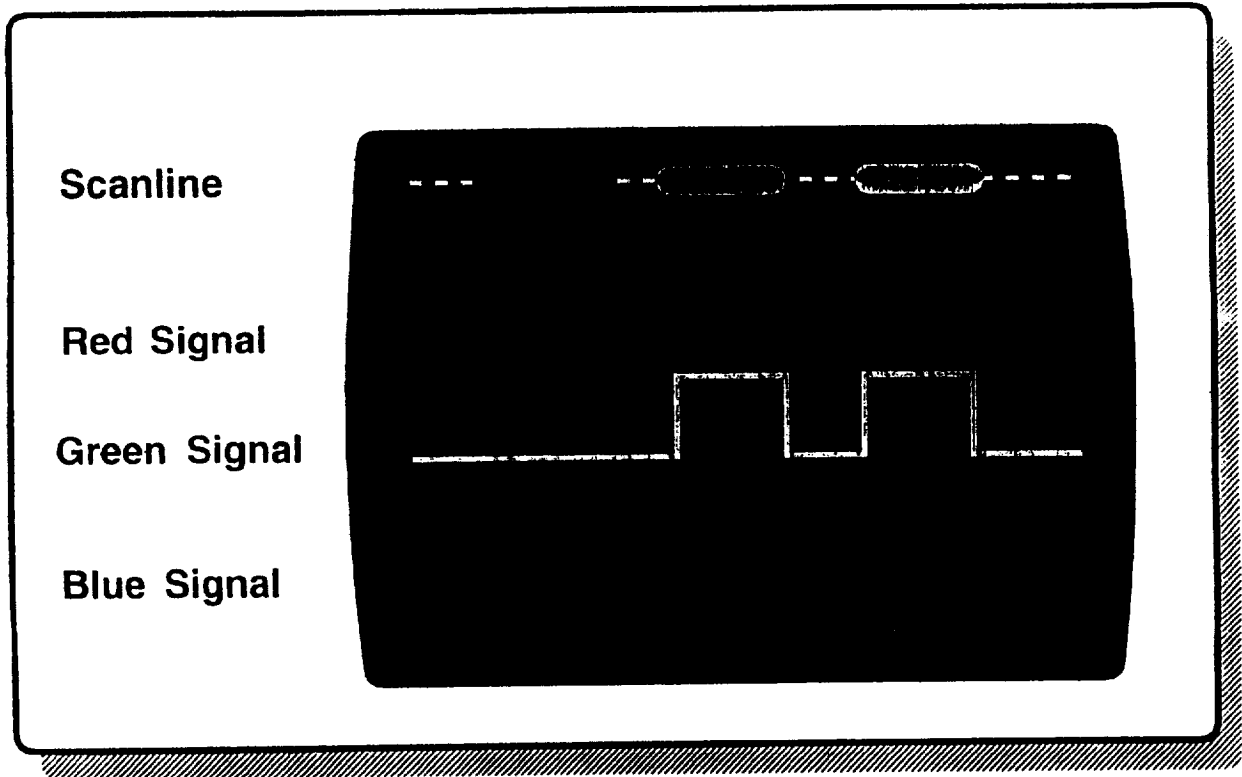
NTSC Color Domain

Susceptible to adjacent pixel color interference

Scanline

Luminance Signal

Chrominance Signal

Saturation

Composite Signal
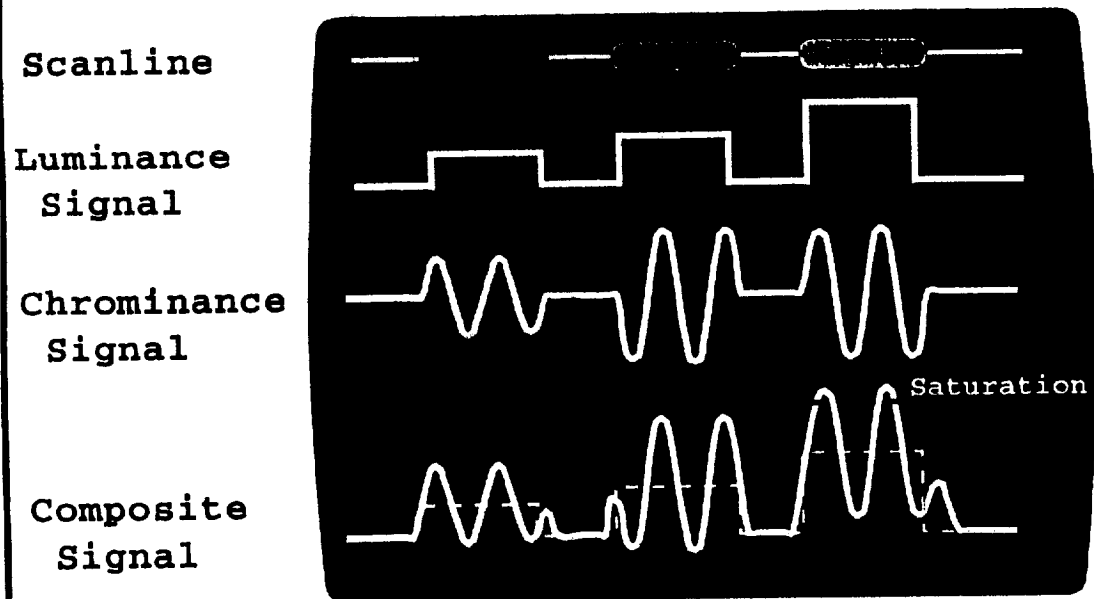
American HDTV Time-Table

1988 – Acceptance of 1125/60 SMPTE 240M Analog HDTV Standard

1993 – FCC Selects Broadcast Standard in Aug.
        (Already delayed because all proposed standards
         had problems!)

    – Begin ON-AIR Testing

1995 – First Commercial receivers/licenced broadcasts
        (All stations must also simulcast NTSC)

2000 – All Stations must be HDTV capable
        (Simulcast NTSC still enforced)

2009 – Shutdown NTSC Broadcasting
        (Recoup valuable broadcast frequencies & bandwidth)

HDTV Image Size

Graphic Workstations
4:3
~ 1280x1024 pixels

HDTV
16x9
~ 1920x1035
pixels

NTSC
4:3
~ 640x480
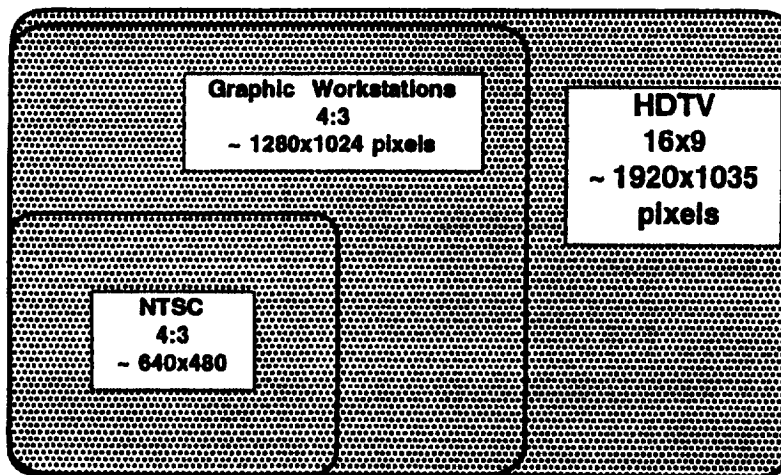
Comparisons of Aspect Ratio and Visible Image Size in Pixels

Digital HDTV Heirarchy

HDTV
Production
Standard

Fiber Optics ≤ 120 Mbps

DBS Satellite 60 Mbps

Cable & Broadcast 20 Mbps

Down-converters

VCR in EP Mode 10 Mbps

Consumer
TV
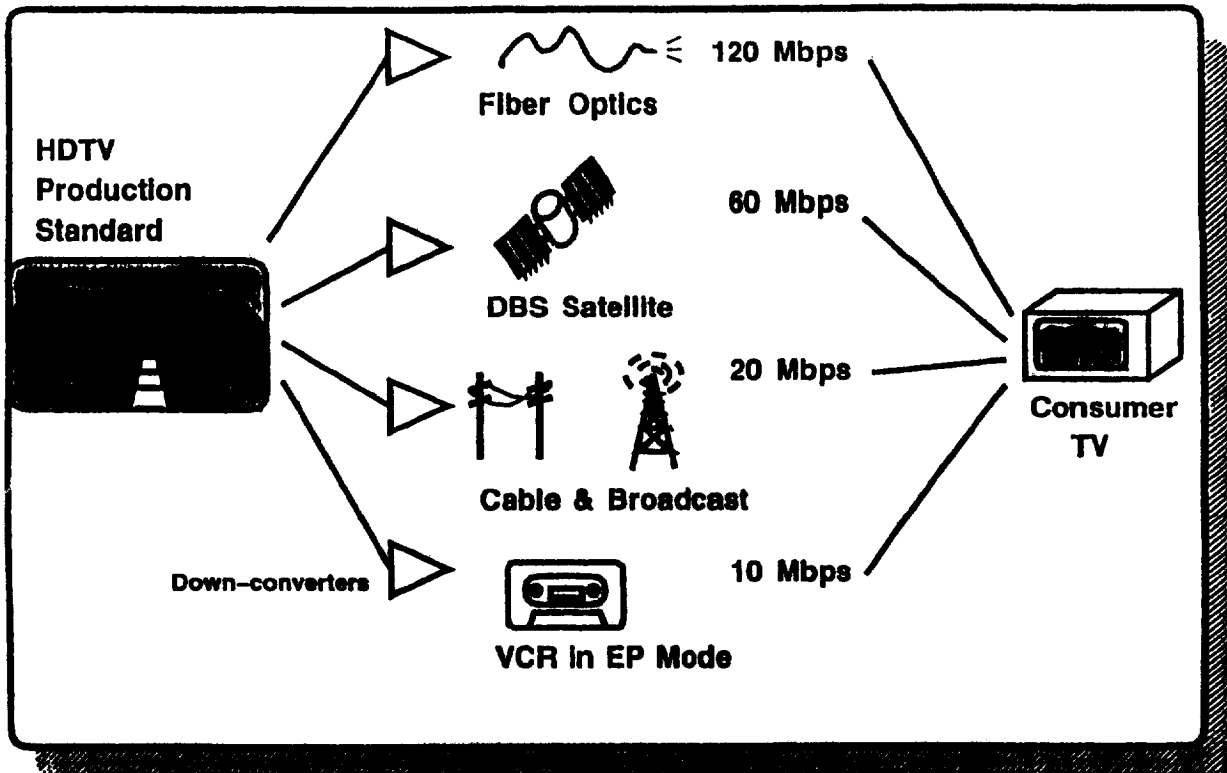
Task Force on Digital Image Architecture

Represents Input from SMPTE, IEEE, ATSC

(Report Published SMPTE Journal Dec. 1992)

" To develop and propose a structure for a heirarchy of digital standards to facilitate interoperation of high resolution display systems. "   [That are:]

Open
– In the Public Domain

Interoperable
– Images move across application/industry boundaries

Scalable
– Wide range of image size, color, speed capabilities

Extensible
– Room for future technology

Compatible
– Incorporate existing imaging/television standards

Open Architecture Model

Image Acquisition/Generation

Processing
Production Quality Storage

⬇

Contribution Quality Storage
Transport
Distribution Quality Storage

⬇

Reconstruction
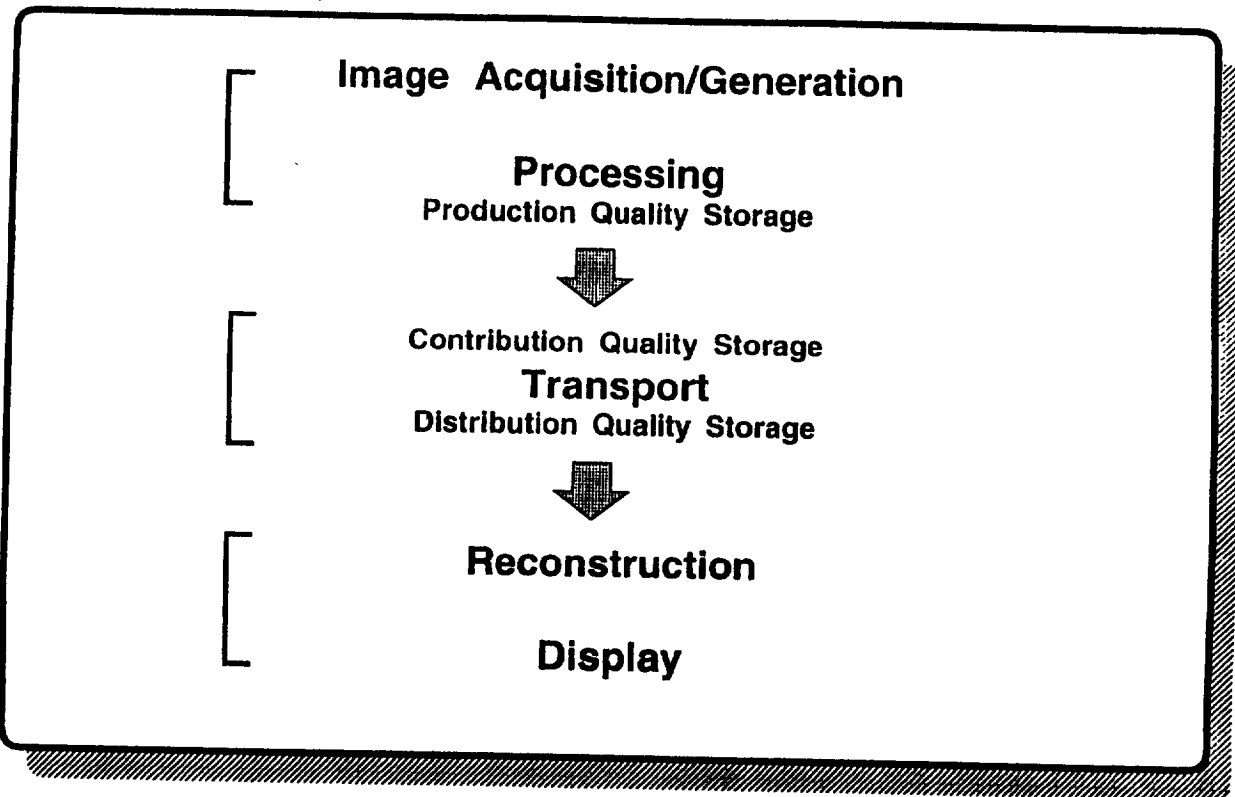
Display

Future Displays

Wrist Display
 — Low power, wire-less transmission, close viewing

Personal Viewer –
 – Eyeglass/visor Heads-Up display, head-tracking

Home Entertainment –
 – Flat, wall mounted, typically 6 meter diagonal

Physician's Work Surface –
 – X-ray wall, close-viewing, super hi-res, locally magnifiable

Writer's Table –
 – Desk-size, multi-page, pen/touch input, cut/paste

Artist's Canvas –
 – Special color/contrast/texture capabilities, unique input/output control

Make-Up Mirror
 – 'Through-the-screen' cameras, image processing

The ULTIMATE Imaging System

1) Field of View ~ 1.5π Steradians = 15,000 sq. degrees

(typical movie screen ~ 1200 sq. degrees)

2) Spatial Resolution ~ 0.65 arcmin = .01 deg.
Assume 2 pixels per minimum resolution
implies 16 pixels/sq. arcmin

1 & 2) -> 36,000 x 28,000 pixel screen

3) Color –– 3 components

4) Dynamic Resolution ~ 10^5:1 –> 17 bits

5) Time Resolution ~ 60 images/sec

6) Stereopsis –> x2

= 771 GBytes/sec (not including digital sound, closed–captioning, etc)

INTERDISCIPLINARY TECHNOLOGY

Lester D. Nichols
NASA Lewis Research Center
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Interdisciplinary Approach to Propulsion System Simulation

The "computational test-cell" will enable the incorporation of new methodologies, such as concurrent engineering and probabilistic methods, into the propulsion design process. This will provide the capability to conduct credible, interdisciplinary analyses of new propulsion concepts and designs.
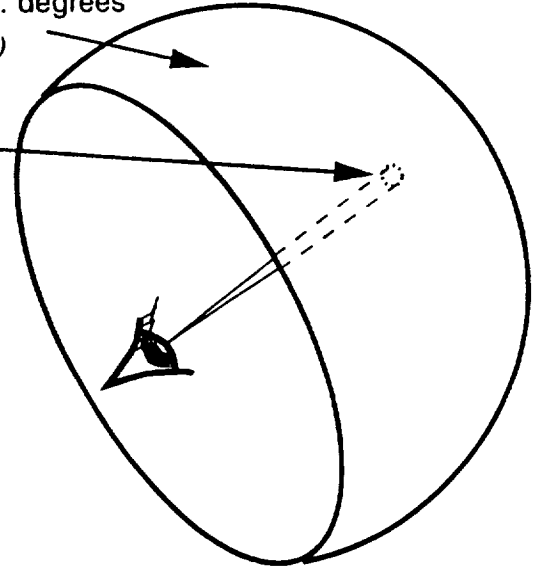
Probabilistic methods can be used as the basis for reliability-based design. Recently methods have been devised that provide the capability of simulating the performance of propulsion systems at several levels of resolution. These methods make it possible to quantify uncertainty and to establish confidence bounds for the calculated values.

The introduction of reliability-based design methodology along with probabilistic analyses will provide a tool to reduce the design space for new systems and to reduce our dependence on hardware testing for proof-of-concept and system integration demonstrations. The resulting simulations will reduce the need for testing and identify potential operational problems early in the design process.

This capability will make it possible to compute the expected performance, stability, reliability, and life of propulsion components, subsystems, and systems at design and off-design conditions, to bring life cycle cost trade-offs early into the design process and to determine optimum designs to satisfy specified mission requirements.

Physics Modeling

The analysis of propulsion phenomena involves a combination of disciplines including fluid mechanics, thermal sciences, structural mechanics, material sciences, combustion theory and controls theory. The degree of resolution within an analysis is determined by the magnitude of local effects, the extent of their region of influence, and the dynamic time scales of the appropriate physics relative to the dynamic scale of the system phenomenon being analyzed. Often the limiting factor will be the available computer power (speed and memory capacity). The analyst must determine which terms in the governing equations to retain and which to ignore so as to achieve the maximum level of fidelity within the computational constraints.

The coupling of the disciplines and component codes involves the subdivision of a complete system, e.g., an aircraft engine, into a series of subsystems, e.g., inlet, compressor, combustor, turbine, and nozzle. It is convenient to define a hierarchy of multi-disciplinary simulation modules for each subsystem ranking from relatively simple time and space "averaged" analysis methods (level I) to complex three-dimensional, time-accurate analysis methods (level V).

Level I: Engine system performance model. This model is basically a thermodynamic model which calculates the system efficiency based upon engine configuration and component efficiencies. It allows rapid evaluation of various engine concepts.

Level II: Engine system dynamics and controls model. This model is basically a one dimensional flow path model, with simplified structural

elements, controls, and other disciplines. It uses component performance information, design geometry information, and dynamic information in order to calculate engine thrust and weight as well as system transient response in order to analyze operability problems and devise control strategies to handle them.

Level III: Space and/or time-averaged engine system model. This model is basically a two-dimensional (i.e., axisymmetric) fluid model. It utilizes axisymmetric, coupled discipline models in an engine system environment in order to relate component boundary conditions (primarily input/output conditions) to overall system boundary conditions in order to simulate component interactions. This is also the basic level about which the "zooming" process is constructed. It will be a transient model and address all problems from level II but, in addition, provide more detailed geometry information.

Level IV: Space and/or time averaged sub-system (or component) models. These models are basically three dimensional. They are multi-discipline models which are coupled in ways which are compatible with the physics of the component model, but are still averaged over smaller time and space scales. These models must also be post-processed in order to connect with the level three engine system model in the "zooming" process.

Level V: Three-dimensional, time-accurate component models. This level of simulation basically consists of a fully three-dimensional, time-accurate simulation of all physical processes on a component-by-component basis. This is the most complete level of physical approximation.

Dicsipline Coupling

Propulsion phenomena are inherently multi-disciplinary (i.e., the true system response is the coupled effect of all the participating disciplines and the aggregate of the system components' responses and interactions). Present analyses (and experiments) tend to focus on single-discipline aspects of the phenomena within a local region (e.g., a single component). Using suitable approximations, these analyses are sometimes extended to a propulsion subsystem or, in rare cases, the complete propulsion system.

Recent advances in computational fluid mechanics, computational structural mechanics, computational materials science, computational controls, and computer science and technology make it feasible to consider the development of a "computational test-cell" for propulsion that would allow for comprehensive simulation and analysis of entire propulsion concepts and designs before committing to hardware.

For computational simulation to be credible, it must include efficient multi-disciplinary coupling. In the case of multi-disciplinary simulation of dynamic phenomena, the time scales associated with various aspects of the phenomena have to be considered. In an engine interacting phenomena, such as surge, stall, flutter, component and system dynamics, low and high cycle fatigue, and takeoff and landing operations occur within widely varying time intervals. The computational procedures and the "clock cycle" of a multi-

disciplinary simulation have to accommodate these vast differences in time scales. The simulation clock cycle has to be consistent with the available computational power and, in the case of animated graphic representation, the perception rate of the human visual capability.

Implementing coupling in the required numerical simulation, analysis, and optimization is a tremendous challenge because of the potentially very large number of interrelated variables and the very large number of iterations that can result from general-purpose algorithms. A hierarchical approach that can reduce the dimensionality of the system description while still retaining the essential system behavior is needed. There are a variety of techniques that can be used for coupling discipline variables for propulsion components, subsystems, and systems. These include sequential iteration between disciplines, specially-derived system matrices, and coupling at the fundamental equation level. In NPSS, all three methods will be applied to the filtered Navier-Stokes equations and the progressively substructured structural mechanics formulations. Relationships (i.e., sensitivities) will be derived for use in optimization algorithms that are streamlined for the multi-disciplinary, multi-component application.

The coupling across disciplines in a concurrent multi-disciplinary formulation can be represented by coupling relations. The coefficients (elements) in these relations define the coupling of a specific variable from one discipline with respective variables from interacting disciplines (Fig. 6). Perturbation of the variables in the coupling relations provides a measure of the sensitivity of the interacting disciplines to this perturbation. A priori description of this sensitivity relationship enhances the computational simulation in several respects: 1) scoping the degree of coupling, 2) identifying the interacting disciplines, 3) resolving time/space scales, 4) selecting time/space scale for loosely coupled interacting discipline intervention during the solution processes, 5) deciding on a solution strategy, and 6) imposing convergence criteria.

Analysis Fidelity

Attempting to resolve all of the length and time scales that are present in the fluids and structures of the engine is impractical, even on high performance computers. Therefore, a rational approach for identifying and resolving the critical scales is needed. Approaches that have been shown to be effective for single component analyses will be extended to the simulation of coupled components and entire engine systems. Approaches will be developed to allow selected components to be resolved to a greater level of detail than others. Utilization of the zooming approach will allow the interconnection of a series of multi-discipline simulations in which a single or small number of modules are simulated with very accurate methods, perhaps level IV or V, while the remainder of the subsystems are implemented with simple methods, perhaps level II or III. This focusing or "zooming" in on a particular component will allow for a more thorough analysis of that subsystem in a complete multi-discipline system format without having to completely simulate the entire system at the same detailed level.

For example, studies of compression system stability will require a detailed treatment of the compression system to be coupled to lower-resolution treatments of the fan, combustor, turbine, and nozzle with the appropriate

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boundary conditions to represent the inter-component interactions (Fig. 5). This "zooming" capability will permit the analyst to capture relevant physical processes throughout the engine in a computationally-tractable manner and will allow the analysis to be used on a routine basis for design assessment and optimization. Thus, this approach will be much more cost effective and should provide an attractive approach for overall system performance optimization. The actual interface algorithms used in this zooming approach will range from the direct coupling approach described above to one involving the interface of time- and space-averaged parameters. With this approach, special emphasis can be placed on the effects of interface sensitivities between two subsystems in an entire system.

Computational Simulation

Digital simulation of aerospace propulsion system behavior has been in existence for many years. The earliest simulations were developed in the seventies. The performance and reliability of engine systems depend on the dynamic interaction of their subsystems which, in turn, depend on the dynamic interaction of their respective components. Interaction phenomena of importance include flutter, rotor instability, fatigue, flow separation, nonuniform combustion, blade containment, and noise suppression. The determination of aero-thermodynamic system performance has traditionally relied on prototype tests while structural reliability has been calculated from field data. This experience has been used to develop simulation techniques that employ varying degrees of approximation to model and compute the aero-thermodynamic performance and structural reliability of new designs. In general, these simulations can be divided into two classes, depending upon the time dependance.

Steady state simulations are normally used by design engineers in order to assess design trade-offs. Here the emphasis is on ease-of-use by the designer and, in particular, allowing the designer to include "company lore" or company expertise in the design. Depending upon the use of the design system (i.e., whether it is for conceptual design, preliminary design, detailed design, or final design) there will be more or less fidelity included in the simulation. Steady-state simulations are used for design points analysis, with allowances for off-design performance. In the latter design stages, steady-state simulations can be used to develop control system schedules and to provide estimates of engine system life.

Dynamic simulations are used after the engine is designed in order to develop control laws/logic and to determine the limits of stable engine operation. Obviously, if the simulation calculations can be speeded up, more detail (i.e., spatial and temporal resolution) can be included in the simulation model. During control system hardware and software implementation, there is a need for a real-time engine simulation that can be operated with the control system in a "closed-loop" fashion.

Dynamic simulations are also used to study cases when the engine behaves differently in the field from what was envisioned in the design phase, or as uncovered in the testing of the engine before it was installed into service. These simulations can be particularly valuable when ground-based experimental facilities are not available to simulate the in-flight conditions under which the unusual behavior was observed. Obviously the more accurate the simulations, the more their value.

The development of an engine simulation capability will begin with existing Level II dynamic engine system models of aerothermal and structural behavior. Level IV aerothermal and structural simulations will be used to generate the required component parameters and maps for the Level II engine models. Then, methods for improving the parametric representation of the components will be investigated so that the significant phenomenon observed from detailed analyses can be represented in the engine model.

The initial simulations involving Level II aero and structures codes will investigate the thermal lag between changes in the engine operating conditions and the heat transfer effects on the structure. Thermal strains resulting from the changes in the temperature of the structure affect the secondary cooling flow passages and tip clearance flow in the components. These effects must be accounted for in the aero codes and will result in a change in the computed engine operating conditions.

The Level IV aerodynamic simulation model that will serve as the basis for the integrated propulsion system model will be the Adamczyk average-passage formulation which consists of the filtered forms of the Navier-Stokes and energy equations. This model was designed to resolve only those temporal and spatial scales that have a direct impact on the relevant physical processes. The effects of the unresolved scales, which appear as body forces and energy sources in the equations, are estimated through semi-empirical relations, based on experiments or high-resolution numerical simulations. The results from the lower-resolution analysis appear as boundary conditions for the high-resolution model. Initially, this model will be applied to the study of a compression system and its performance, stability, blade vibration, and noise generation. Since the methodology applies to the fundamental fluid flow equations, it will then be extended to the other propulsion components.

The structures modeling will be aimed at developing a comparable computational capability that will provide a means to traverse multiple scales of spatial resolution with a minimum number of variables at each level. In this way, an analysis can proceed from a blade to a rotor sector to a rotor to an engine core to the complete engine. The resulting system model will have a minimum number of degrees of freedom consistent with the objectives of the analysis which will minimize the computational requirements. This methodology will be applicable to the solution of linear and incremental nonlinear analysis problems. This capability will be achieved through the formulation and implementation of a progressive substructuring ("telescoping super-elements") technique within the mixed-iterative finite element method framework and associated MINUTES computer code and within the boundary element framework and associated BEST3D computer code.

Computing Platform Portability

It is the intention of the NPSS to take advantage of existing codes to the extent possible, while at the same time maintaining the flexibility to utilize emerging massively parallel computing hardware platforms. The architecture envisioned ustilizes shared memory programming paradigm and standard software tools and programming language extensions. The programming will be independent of hardware architecture.

Within the computing system, the nature-of the coupling between the

computing system components (processor, memory, communication) will depend upon the engine system component codes and single discipline codes required to compute the desired engine attributes. Therefore, the selection/development of appropriate processor I/O software, compilers, networking protocols will be accomplished in conjunction with the development of engine system and discipline (i.e. application) codes.

The NPSS technology project can develop and demonstrate many key, enabling technologies for aerospace propulsion systems design, analysis, and optimization. However, to be successful, several things must take place:

Effective inter-disciplinary teams must be established to define, advocate, and implement technical solutions.
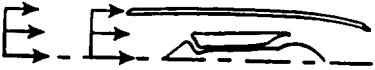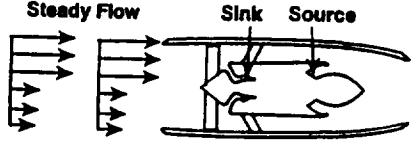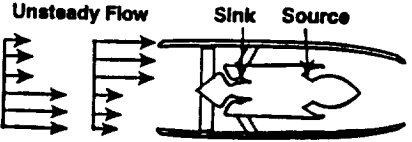
Coordination and a balancing of efforts among the inter-disciplinary engine system activities (physics, algorithms, models, codes) and the inter-disciplinary computer system activities (architectures, software tools,..) must be maintained so as not to push either activity ahead of the other.

This suggests a strong requirement for effective project management to ensure that the available funding and skilled staff are effectively used to address the needs.

NPSS Goal

• Reduce life-cycle costs by advancing system analysis capability through high-fidelity computational simulations by

- Higher level of concurrent engineering

- Rapid evaluation of effects of new and novel concepts on system performance

- Early risk assessment

- Early operability studies

- Rapid evaluation of field problems

- Assessment of performance degradation

NPSS LEVELS OF MODELING FIDELITY

LEVEL 1: ONE DIMENSIONAL STEADY-STATE	One Dimensional Engine System Analysis
LEVEL 2: ONE DIMENSIONAL TRANSIENT	One Dimensional Transient Engine System Analysis
LEVEL 3: AXISYMMETRIC/TWO DIMENSIONAL QUASI-STEADY-STATE	Axisymmetric Engine Analysis
LEVEL 4: THREE DIMENSIONAL QUASI-STEADY-STATE	Three Dimensional Engine Component Analysis
LEVEL 5: THREE DIMENSIONAL TRANSIENT	Three Dimensional Transient Engine Component Analysis

Coupled-Multi-Discipline Representation for Aerospace Propulsion Systems

$$
\begin{Bmatrix} \{A\} \\ \{T\} \\ \{S\} \\ \{M\} \\ \{F\} \\ \{P\} \\ \{C\} \end{Bmatrix} =
\begin{bmatrix}
[A_A^A] & [T_A^T] & [S_A^S] & [M_A^M] & [F_A^F] & [P_A^P] & [C_A^C] \\
[A_T^A] & [T_T^T] & [S_T^S] & [M_T^M] & [F_T^F] & [P_T^P] & [C_T^C] \\
[A_S^A] & [T_S^T] & [S_S^S] & [M_S^M] & [F_S^F] & [P_S^P] & [C_S^C] \\
[A_M^A] & [T_M^T] & [S_M^S] & [M_M^M] & [F_M^F] & [P_M^P] & [C_M^C] \\
[A_F^A] & [T_F^T] & [S_F^S] & [M_F^M] & [F_F^F] & [P_F^P] & [C_F^C] \\
[A_P^A] & [T_P^T] & [S_P^S] & [M_P^M] & [F_P^F] & [P_P^P] & [C_P^C] \\
[A_C^A] & [T_C^T] & [S_C^S] & [M_C^M] & [F_C^F] & [P_C^P] & [C_C^C]
\end{bmatrix}
\begin{Bmatrix} \{A\} \\ \{T\} \\ \{S\} \\ \{M\} \\ \{F\} \\ \{P\} \\ \{C\} \end{Bmatrix}
$$

System response variables

System definition/characteristics and coupling relationships
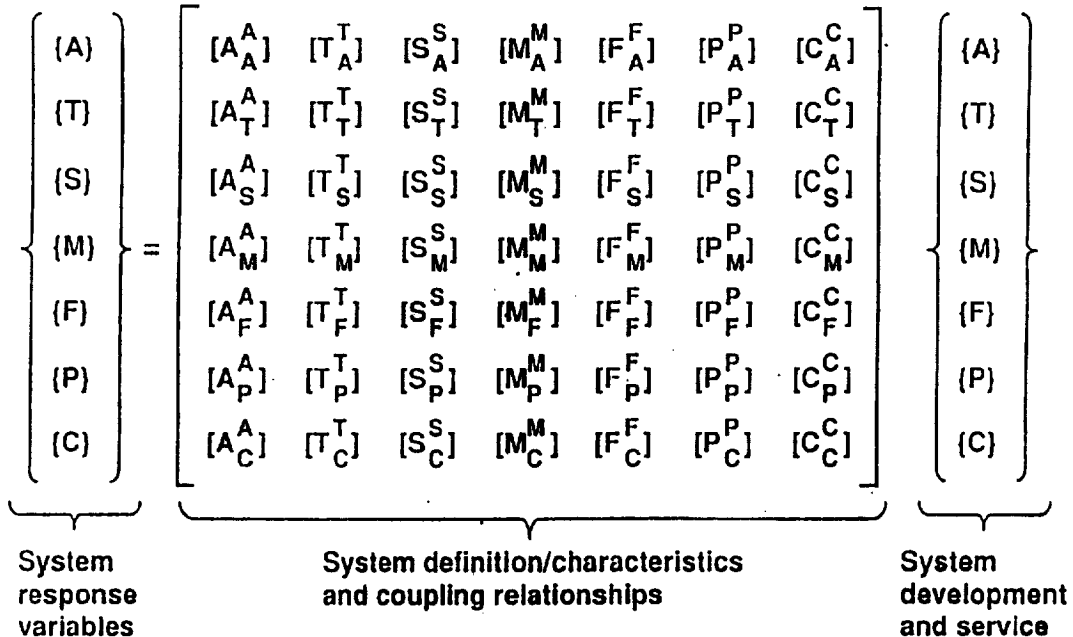
A Aero	F Fabrication
T Thermal	P Performance
S Structural	C Cost
M Material	

System development and service parameters

NPSS Models

Aero

Structures

Mechanical clearance

Heat transfer

Fan map

System response

System response

Fan load

Aero blade load

Blade tip clearance
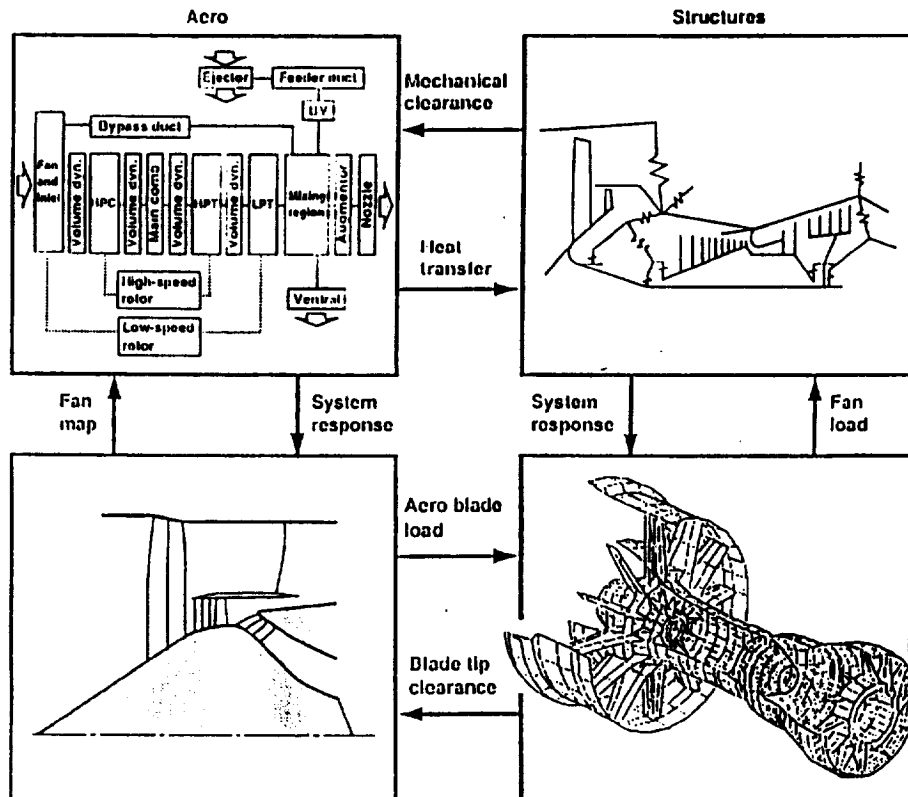
MULTIDISCIPLINARY SIMULATION OF PROPULSION SYSTEMS
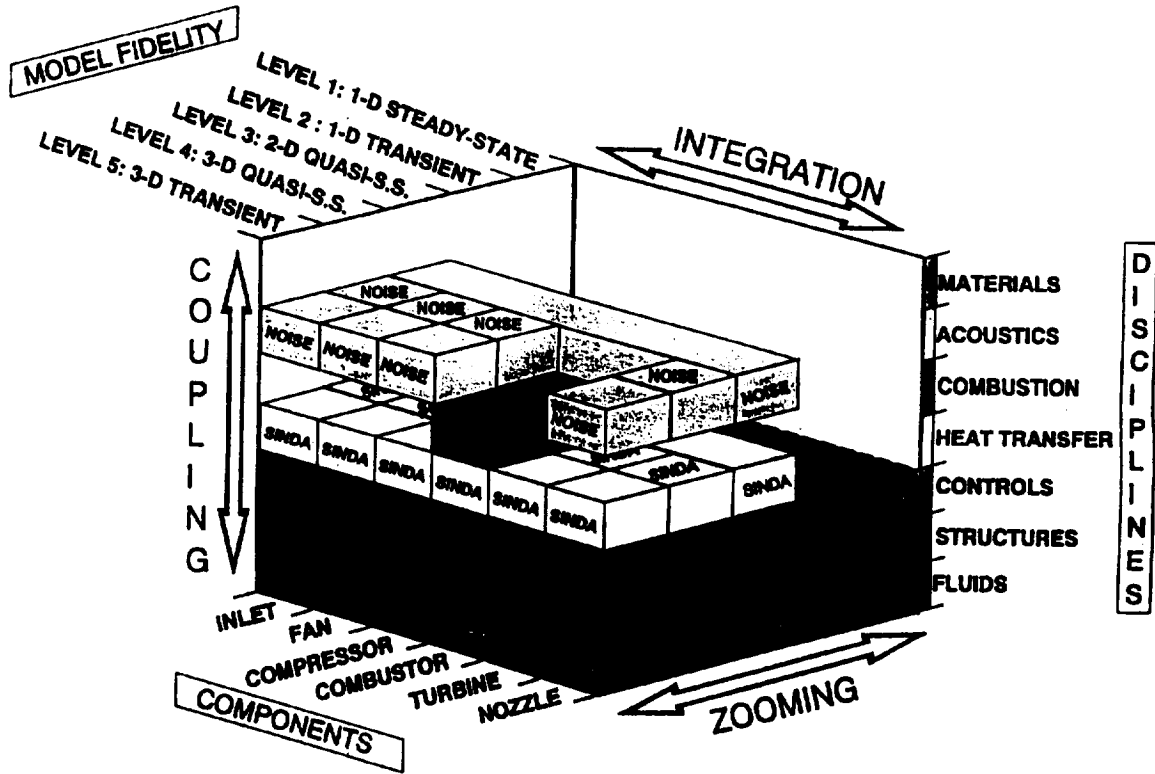
TESTBED SIMULATION OF MULTIPLE COMPONENTS
WITHIN A COMPLETE ENGINE CALCULATION

59
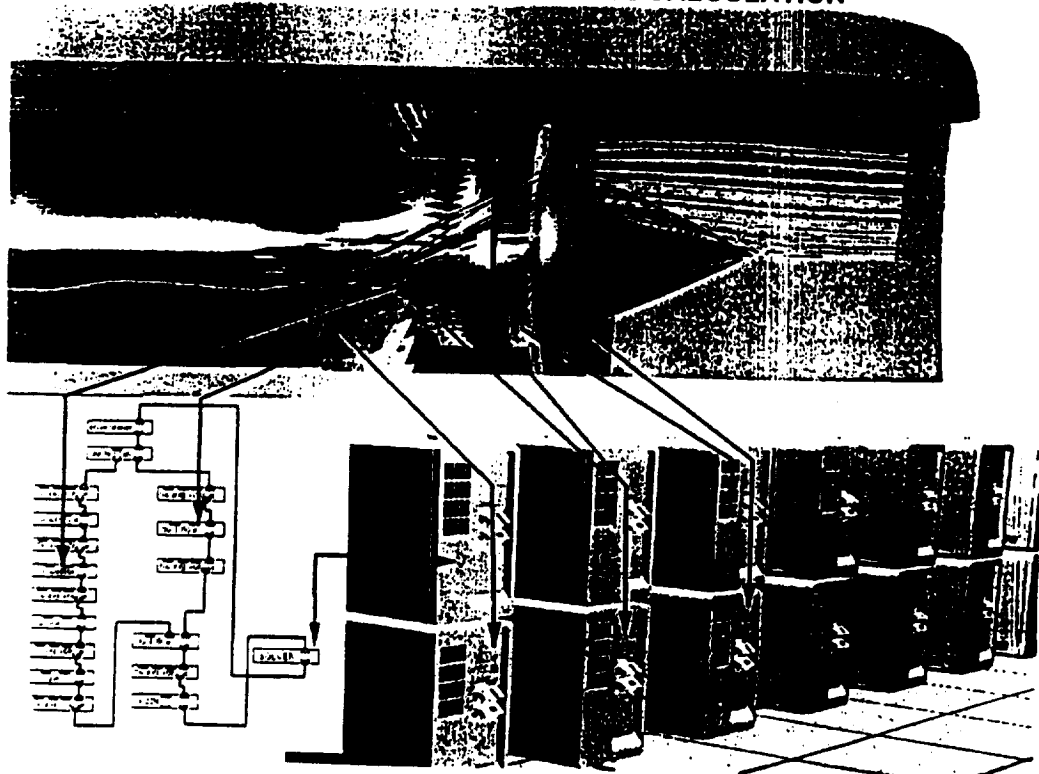
Koen (1985): "...it is the engineering method or design process, rather than the artifacts designed, that bind *all* engineering disciplines together and defines the engineer."

The Engineering (Design) Process

Creative Mind
(Right Brain)

Judicial Mind
(Left Brain)

Creative
Synthesis

Analysis

Decision
Making

Deductive Analysis

Features
- No Rules
- Uncritical Thinking
- Irrational
- Illogical
- Diverge
- Alternatives

- Rigid Rules
- Critical Thinking
- Rational
- Logical
- Converge
- One Answer
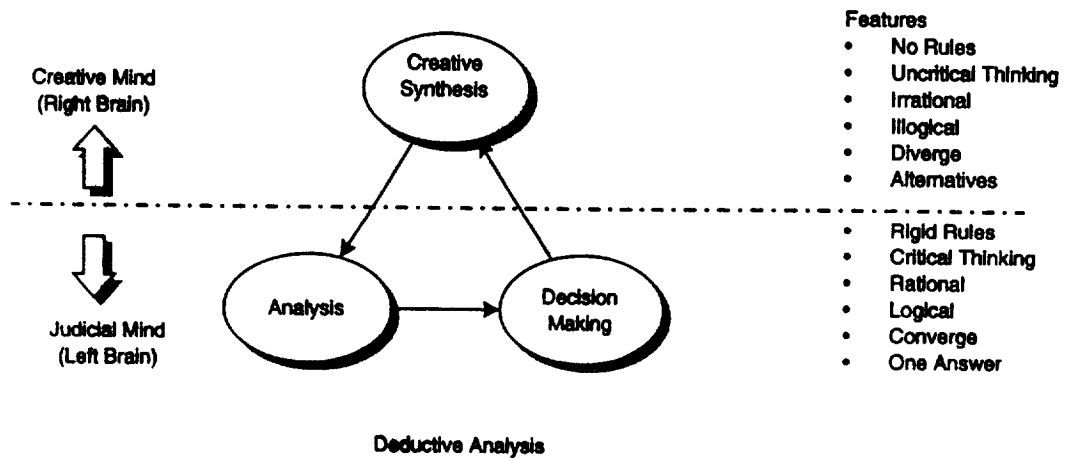
Engineering (Designers/Synthesizers) = Engineering Science Technicians (Analysts)
- Industry Needs Both -

AN ATTAINABLE VISION FOR VIRTUAL REALITY

Myron W. Krueger
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There are three categories of virtual reality technology. The first is the most traditional. It assumes a sedentary operator interacting with a monitor using traditional input devices. (Note that this category includes flight simulation and what is now called desktop VR.) The second consists of the wearable goggle and glove technology pioneered by Ivan Sutherland in the late 1960s and resurrected by NASA in the mid-1980s. The third category consists of the unencumbered approach initiated in 1969 by the author, who was its sole proponent until 1991 when organizations like Bell Labs, Xerox's Europark Research Center, and Sarnoff Labs started to follow his lead.

It should be observed that these three categories are but instances along a continuum of technologies that start from the traditional computer interface and which spread out along independent axes marking degrees of immersion and degrees of encumbrance. There are additional dimensions such as degree of physical participation and degree of tactile, force, and resistance feedback. It is assumed here that users will seek to maximize realism at the same time they minimize encumbrance. Thus, there will be considerable resistance to classical VR that burdens the user with as many devices as needed.

The first category of virtual reality is simply a continuation of current trends in three-dimensional graphics. We can expect that any interface approach that sticks close to this tradition and which is compatible with applications implemented for it will be guaranteed acceptance. At the same time, the desire for some of the attributes of virtual reality at the desktop will be felt. Therefore, we can expect that there will be a variety of three-dimensional and volume filling displays that will provide a vivid sense of realism for those applications in which the user is outside the object that is being worked upon. One family of these devices will provide large scale

holographic screens that can be viewed by large numbers of viewers. Whether these will be holographic generators such as Steve Benton's work might lead to, or variations of the pscolograms created at the University of Illinois, or other forms of autostereoptic displays remains to be seen.

Current volume-filling displays do not provide hidden surface removal. Future devices will need to be defined in terms of much smarter display voxels that not only define the light emitting from each point in the volume, but also permit interior voxels to block the light from the surface voxels from passing through the object. A more speculative volume display would permit light emitting voxels to be defined within the space occupied by the viewer. This might be accomplished by filling the room with inert gases and scanning it with a form of radiation that releases its energy at a fixed point in space. While I cannot specify the mechanism by which this will be achieved, it represents an ideal that will be strived for.

To stretch the conventional metaphor a bit further, we can expect that the workplace will be instrumented to provide the user with the ability to interact with computer displays without directly touching specific input devices. On the one hand, this definitely assumes the implementation of continuous speech input. Whether this will include true speaker independence or speaker identification followed by speaker dependent recognition does not matter. The latter is sufficient given the small number of people in any given office. In addition, the environment will be instrumented with video cameras and sensory floors that will analyze the users' actions when they are directed at the computer screens. Thus, the computer will move from receiving input from a sedentary user through hand-operated devices to perceiving the user's body as he moves about the environment. This will allow the user to point at the displays to indicate the target of the commands that he speaks. *Point-and-talk* will be the standard interface.

The user's image can appear on the large scale displays and he can use the image of his hands to point to single objects, circle groups of objects, or to draw freehand on the screen. He can use the screen

as a window into a three-dimensional scene and can use simple gestures to navigate through the graphic world. Alternatively, he can subtly shift his weight from one foot to the other control his movements through the graphic world. The screen can also include the images of other people in other locations who can be shown juxtaposed with the user.

What has just been described works today and has for the last 10 years. However, it has been implemented with a microscopic fraction of what has been expended for head-mounted display research. Therefore, much of what is possible in this framework has been only touched upon rather than exhausted. For instance, the current system perceives the user sitting or standing against a backlit background. The backlighting is not absolutely necessary even today, but the perception is faster and more reliable if it is employed. The ultimate implementation of this technology will perceive the user sitting or standing anywhere in the room. The computer will have identified every object in the room and have constructed a three-dimensional model of it. It will perceive the room in terms of this model and update its perception so frequently—say 200 times/second—so that there is very little change from frame to frame. Thus, complex and even moving backgrounds will not confuse the system. Multiple individuals will be tracked as they move about the room.

Wherever, the user stands, several cameras will be used to perceive him from different angles. The purpose of these cameras will not be to produce two-dimensional images. Instead, the computer will possess a three-dimensional model of the user's body, his ideosyncratic style of movement, his facial expressions, and his clothing. The images of the various cameras will be used to locate particular features of his body in three dimensions. These positions will be used to determine the exact state of the model required to duplicate his current behaviour. Then, the state of the model can be used to generate any view of him for local display and for transmission to other locations.

This information will allow the computer to understand the person's image exactly as another person would. His body language as well as his words will be understood by the computer which will be able

interpret his actions if they refer to graphic objects that the computer is displaying.

So far, we have been trying to avoid using current virtual reality technology. People will continue to resist it until it is free—both in terms of economics and in terms of incumbrance. However, we can postulate a display technology that almost certainly can be built and that will be used if it is available.

We can assume that the ideal display will be indistinguishable from normal eyeglasses. It will be wireless. It will not change your appearance in any way. It will not cut you off from your local colleagues. You can see them, make eye contact with them, and converse with them normally. Virtual graphics will be displayed as objects in the real world and will be viewable by your local colleagues, who will view them from the appropriate perspective. (At times, it may be preferable for all participants to see the identical view, in spite of their different positions.)

Similarly, the images of colleagues in remote locations can appear to exist as three-dimensional figures in the local environment. Each person in the local environment will see a stereo view of each distant participants from the expected viewpoint.

Since the viewers are intended to be as unencumbering as possible, we can assume that an instrumented glove would be unacceptable. Instead, the hands will be perceived by the environmental cameras mentioned above. In addition, there may be tiny video cameras the size of a grain of sand mounted in the glasses. These will provide additional views of the hands and the other people in the room. Video perception will give the unencumbered hand the same functionality of the current data glove.

It should be noted that the unencumbering approach solves a problem that the advocates of wearable technology never mention, namely, if the participant is wearing a mask and head phones, how is the computer going to provide his virtual image with a face? It would seem that video cameras are the obvious face detectors. The video approach permits the face to be captured.

Accompanying this technology will be a robust form of speech technology that can reliably recognize words and establish the semantic context—if not engage in philosophical discussions or resolve subtle ambiguities. Thus, if the user wishes to communicate with the computer directly about declarative information, he will be able to do so with a minimum of awkwardness. Furthermore, in the context of familar topics of conversation, the computer will be able to track the content well enough to trigger appropriate visuals on the fly. The initial result will be voice-activated visuals. In the longer term, we will have what we might call *illustrated speech*. Anywhere in the working environment, a person could conjure up interactive three-dimensional animations that will help him make his points. Two people can share a vision of a design and change it through verbal and gesture commands.

Since a person who normally wears eyeglasses would not be further encumbered at all, there is no reason for them to resist this technology. If it is available, it will be used.

While we have assumed that the displays described would not isolate the user from his local environment, they can be easily provide that option as well. Thus, if the topic to be addressed has no relationship to the local environment, the glasses can block off the view of the outside environment and all interested participants can meet within the virtual world. Since the participants will be unable to see their real environments, the computer must use its knowledge of their real environment and construct the virtual world so that they are not encouraged to run into objects that exist in the real world but not in the virtual one. This safety factor is crucial given that the wireless and almost unencumbering displays will tempt participants into much more rapid movements than current technology invites.

The tools described so far will operate with restrictions away from the instrumented environment. Thus, individuals will be able to conference with other people when they are going for a walk or are sitting on a beach.

Also important, is the fact that the displays described will permit

graphic annotation to be applied to objects in the real world. Thus, a person learning to perform maintenance on a piece of equipment would see the real parts labelled as he looks at them. An intelligent extension of this capability would include computer vision intelligent enough to update the displays as the user moves the real objects in his field of view. In a limited domain, we can expect that such a vision capability could be implemented. A similar capability would permit medical personnel to look through the glasses worn by paramedics at an accident scene and to talk them through procedures that are far beyond their own training.

An assortment of command structures will be available that permit the user to operate in three dimensions. He will be able to do three-dimensional CAD with considerably more free form control than he has today. For instance, he will be able to use his fingertips as control points that define the shape of an airfoil and see the stream lines change instantaneously as the CFD calculations are performed in real time. He will be able to sculpt a part to be formed with powder metallurgy and receive instantaneous feedback as to whether the shape can be fabricated with that technology.

If the participant wishes to move about the virtual world, he will want a more natural means of navigation than the current *fly in the direction your finger is pointing* paradigm provides. A natural desire for this purpose is an omni-directional treadmill that will let the user walk or run in any direction without really moving. Since this equipment will be expensive, it will probably be a separate facility for high priority applications. A more ambitious treadmill would permit the participant to run up and down graphic mountains. It would track the participants feet and only resist their motion when they came into contact with the terrain of the graphic world. Since such a device would have to be able to support the rapid movements of heavy participants, it would have to be very powerful and have considerable mass. It would be very dangerous. Nevertheless, some way of providing this capability will also be needed.

Similarly, it would be desirable to have a means of creating tactile feedback for virtual objects. While this will probably be done with

elablorate exoskeltons, it will be far more convincing if it can be perceived as representing objects outside of him. If he is all trussed up, the actuators will so distort his sensations that the whole experience will be unconvincing. Ideally, he could feel normal as he reached his hand into an access hole to repair a piece of equipment. Technology to construct such tactile geometry on the fly would require the development of devices that are far exotic than the others suggested here.

Tactile feedback is of considerable research interest, but will require a considerable period of time to reach maturity. Even over time, there is no obvious way to achieve it without encumbering the user. Encumbering approaches will be developed, but they will be less welcome in most design environments. They will be most important when human factors simulation and training are elements in the design process. Therefore, it appears likely that a touchless virtual reality technology will be developed that is employed for a broad range of applications, especially those that are typically performed in a traditional office setting. Since this technology will be very acceptable to users, it is likely to be used for any task for which is adequate, whereas encumbering alternatives will only be used on the tasks for they are absolutely necessary.

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POSTER SESSION - CONTRIBUTED PAPERS

PARALLEL ALGORITHM FOR DOMINANT POINTS CORRESPONDENCES

IN ROBOT BINOCULAR STEREO VISION

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Abstract

This paper presents an algorithm to find the correspondences of points representing dominant feature in robot stereo vision. The algorithm consists of two main steps: dominant point extraction and dominant point matching. In the feature extraction phase, the algorithm utilises the widely used *Moravec Interest Operator* and two other operators: the Prewitt Operator and a new operator called *Gradient Angle Variance Operator*. The *Interest Operator* in the Moravec algorithm was used to exclude featureless areas and simple edges which are oriented in the vertical, horizontal, and two diagonals. It was incorrectly detecting points on edges which are not on the four main directions (vertical, horizontal, and two diagonals). The new algorithm uses the Prewitt operator to exclude feature less areas, so that the *Interest Operator* is applied only on the edges to exclude simple edges and to leave *interesting points*. This modification speeds-up the extraction process by approximately 5 times. The *Gradient Angle Variance (GAV)*, an operator which calculates the variance of the gradient angle in a window around the point under concern, is then applied on the interesting points to exclude the redundant ones and leave the actual dominant ones. The matching phase is performed after the extraction of the dominant points in both stereo images. The matching starts with dominant points in the left image and does a local search, looking for corresponding dominant points in the right image. The search is geometrically constrained the epipolar line of the parallel-axes stereo geometry and the maximum disparity of the application environment. If one dominant point in the right image lies in the search areas, then it is the corresponding point of the reference dominant point in the left image. A parameter provided by the GAV is thresholded and used as a rough similarity measure to select the corresponding dominant point if there is more than one point the search area. The correlation is used as a final decision tool when there is still more than one point in the search area. If there is no dominant point in the search area or if the points in the search area are below a correlation threshold, than the dominant point in the reference image is occluded and can not be corresponded. The algorithm has been modelled, implemented and shown to be fast. robust and parallel. The parallelism is created from three main features: locality of the operators; a memory optimisation scheme; and the ability to fully parallelise the extraction phase which is the most computational intensive task in the algorithm. The last feature is achieved by performing the extraction phase on the two images simultaneously.

Introduction:

Range-finding techniques in robotics are the techniques used to find the range, range map, or the 3-D structure of an object in the workspace. They can be classified as either passive or active [JAR 83]. Active techniques require artificial sources to illuminate the workspace, whereas passive techniques do not need such sources. Typically passive techniques require simpler and cheaper set-up than active methods.

Stereopsis, which is the utilisation of multi-views (images from different prospectives) for finding the range, is a very efficient passive technique. In stereopsis, correspondence is established between features that are projection of the same physical identity in each view. Then a geometric transformation called triangulation, which uses the corresponding points and the imaging geometry, is used to calculate the range, the range map, or the 3-D structure of the scene.

The major issues in characterising existing stereopsis algorithms are [DHO 89], [HAR 93]: imaging geometry, matching primitive and matching measure. Imaging geometry is characterised by the mutual orientation of the cameras (either parallel [TU 90] [KIM 87] or non parallel [AYA 87]), and the number of cameras used (either two "binocular" [LLO 87], three "trinocular" [ITO 86], or more). There are different matching primitive such as: most variance points [HAN 74], interesting points [MOR 80], high curvature points [DER 90], edges [BAK 82], intensity values [BAR 86], straight lines [LIU 91]. The matching measure is either: correlation [HAN 74] [FRY 89], intensity difference [OHT 85], or any characteristic of the matching primitive such as: sign strength [BAK 82], direction sign [GRI 85], and orientation sign [AYA 87]. Some of the stereopsis algorithms use matching optimisation schemes. The main matching optimisation schemes are: multistage matching [SHI 87], nearest neighbour[GRI 85], relaxation [BAR 80], and dynamic programming [OHT 85].

The main problem in stereopsis is that it is computational intensive, which makes parallel processing one of the best solutions [DRU 86]. In this paper, a parallel algorithm for corresponding dominant features is presented. The algorithm utilises conventional parallel axis binocular stereo geometry. It uses dominant points which are modified interesting points, as a matching primitive. The matching measure used in the algorithm is correlation. The algorithm consists of two main phases: dominant feature extraction and matching. The algorithm is found to give satisfactory results.

Dominant Feature Extraction:

In this phase the algorithm utilises the widely used *Moravec Interest Operator* [MOR 80], [BAR 80], [JEN 86], [LEE 90] and two other operators: *Prewitt Operator* [PRE 70] and a new operator called *Gradient Angle Variance (GAV)*. Moravec Operator for a certain point is the sum of squares of differences of adjacent pixels in each of the four directions (horizontal, vertical, and two diagonals) over a small window. Moravec interesting points are those which has the interest operator as a local maxima [MOR 80].

Moravec Interest Operator is able to exclude featureless areas and simple edges which are oriented in the vertical, horizontal, and diagonals directions. The

computational performance of the operator op_{mor} can be approximately formulated in terms of the number arithmetic operations, multiplications and additions .

$$op_{mor} \approx 4[(w^2 - w)mul + (w^2 - w)sub + (w^2 - w - 1)add]$$

where w is Moravec window size. And since addition and subtraction are considered to take the same time:

$$op_{mor} \approx 4[(w^2 - w)mul + (2w^2 - 2w - 1)add]$$

In the proposed algorithm, Prewitt operator is performed first to exclude featureless areas. The gradients of Prewitt operator are:

$$G_x = (z_7 + z_8 + z_9) - (z_1 + z_2 + z_3)$$
$$G_y = (z_3 + z_6 + z_9) - (z_1 + z_4 + z_7)$$
$$G = |G_x| + |G_y|$$

The computational performance of the Prewitt operator with 3 as the mask size, is in terms of the number of arithmetic operations is op_{pre} :

$$op_{pre} \approx 9\ add\ + 2\ sub + 2\ mod$$
$$op_{pre} \approx 11add + 2mul$$

When both operators are combined, so that the Prewitt is performed first, the combined operator Prewitt-Moravec has op_{pmo} operations as:

$$op_{pmo} \approx op_{pre} + \rho * op_{mor}$$

where ρ is the edges density which depends on the features density in the image. For an image with $\rho = 1/8$ and $w=5$ the number of operations is :

$$op_{pre} \approx 2mul + 11add$$
$$op_{mor} \approx 80mul + 156add$$
$$op_{pmo} \approx 12mul + 31add$$

comparing op_{pmo} and op_{mor}, it give a speed-up factor of approximately 6.

The improvement discussed so far is speed wise. To overcome detecting redundant points, a new operator called *Gradient Angle Variance* has been introduced. GAV of a point is the variance in the gradient angle of pixels which lies in a thin (one pixel wide) edge in a window around the point under concern. The thin edge points are detected with an operator which emphasises points with local amxima gradient [SHI 87]. GAV is applied to the points detected by Prewitt-Moravec, so that a very low GAV means redundant point. The GAV is shown to effect the speed of the extraction by around 10% which mans that the overall speed-up factor of the extraction is approximately 5.

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Matching:

After dominant features are detected in both images , the matching process is applied for establishing correspondence between the reference dominant features in the left image and the corresponding dominant features in the right image. The main issues in the matching process are, the search area and the matching measure. The search area is a bounded area in the right image at which search for correspondent of a certain reference dominant feature is taking place, whereas correlation is the matching measure. The matching process has been speeded-up by reducing the search space and minimising the need to the correlation which is a reliable but computational intensive matching measure.

The search area has been reduced using *Parallel-axis* (Conventional) stereo imaging geometry as in Fig. 1 [BAR 82], [KIM 87], [TU 90]. This configuration constrained the search area vertically and horizontally. In the vertical direction the constraints are the epipolar line with a little tolerance of few pixels up and down. This tolerance is due to the practical consideration of aligning the vocal axis of the two cameras. In the horizontal direction, the search area would be on the left side of the transferred coordinates of the reference dominant feature and within the maximum disparity d_{max} [KIM 87].

$$d_{max} = \frac{L * f}{D_{min}}$$

where d_{max} is the maximum disparity, and D_{min} is the minimum possible distance for the undertaken application [KIM 87]. This boundary of the search area would make it part of the right image which is containing a subset; nil, one or more ; of the dominant features in the right image. The dominant features in this subset are candidates to be correspondent in one of the following three cases. The first is, when there are no features in the search area which means that the reference dominant feature is occluded and cannot be corresponded. The second is, when there are only one feature, which means that it is the correspondent of the reference dominant feature. The third case is, when there is more than one dominant feature in the search area, a matching measure is needed to decide the correspondent if it exists.

The correlation is the matching measure to decide the correspondence. To minimise the need to the correlation, a parameter provided by the *GAV* operator called *NGAV* is used as rough similarity measure to exclude some of the candidate features which are not similar to the reference feature. The *N*umber of pixels in the *GAV* window (*NGAV*) is used to rule out those candidats which are not satisfing the following condition:

$$|NGAV[r] - NGAV[c_i]| \le thp* NGAV[r]$$

where NGAV[r] and NGAV[c] are the NGAV of the reference dominant feature and the NGAV of the candidate dominant feature respectivly, and *thp* is the thresholding percentage(e.g. 0.10, 0.20, or 0.30).

The result of applying NGAV has three cases, similar to those of the search area. If it is the third case, in which more than one candidate are satisfying the above thresholding condition, then it is the role of the correlation to select best match among the candidates which are above certain threshold of the correlation coefficient (e.g. 0.7 or 0.8). If none of the candidates is above that threshold, this means that the reference feature is occluded.

Parallelism:

Parallelism is a major step for Real-Time realisation of stereo algorithms. The algorithm has a high potential parallelism which is created by different features. The first is the *locality* of the operators (Moravec, Prewitt, and GAV) used in the feature extraction, which means that an operator is performed on a mask bases. This feature enables more than one or even many processors to perform the operator to image portions on the same time with a very little overhead and reduces interprocessor communication to minimum. The second is that the algorithm *optimises the memory* space in calculating local maxima by avoiding memory space needed to keep the result of Moravec operator for the comparison with the neighbouring pixels. The third is the ability to fully parallelise the extraction phase which is the most computational intensive task in the algorithm. The last feature is achieved by performing the extraction phase on the two images simultaneously.

Results and Discussion:

The algorithm (Fig. 2) has been implemented and shown to detect and correspond nearly all dominant features, with speeding-up the feature extraction phase by a factor of 5 which is very close to the one obtained theoretically. Fig. 3 shows the features extracted by Moravec and even by Prewitt-Moravec is the same, whereas Fig. 4 show how GAV excluded the redundant features. Fig. 5a shows the reference dominant features in the left image, whereas Fig. 5b shows the corresponding dominant features in the right image. The output has been produced on binary thinned images for clarity reasons. The disparity of certain corresponding pair of points is the distance between them after transferring one point into the other coordinate system as in Fig 1.

Although the algorithm shows a reasonable amount of robustness, mismatching is not impossible. Mismatching could happen due to, misdetection of some dominant features, repeated patterns in the scene, or occlusion. Misdetection can be solved by increasing the directions in which variance is calculated, and by increasing the size of the Moravec window. Mismatching due to repeated pattern and occlusion can be detected by a scheme called local disparity voting. In this scheme the disparity of each point compared locally with the disparity of neighbouring points, if the disparity value is different from the values of the majority it means mismatching. Once mismatching is detected, the corresponding feature is excluded and other candidates in the search area are rematched to the reference feature.

Conclusion:

In this paper an algorithm for corresponding dominant features in robot stereo vision has been presented. The algorithm is composed of two main parts, dominant feature extraction and matching. In the extraction phase the algorithm utilises three operators Prewitt, Moravec and GAV. Prewitt is used for detecting features, Moravec is to detect interesting points which are candidates to be dominant, and GAV is for detecting and excluding redundant points. In matching, correlation has been used as the matching measure. The matching time has been reduced using parallel axis stereo geometry and the rough similarity measure NGAV.

The algorithm has been modelled, implemented and shown to be fast, robust and parallel. Although the robustness that the algorithm is shown to have, mismatching is not impossible and some solution has been proposed to minimise it.

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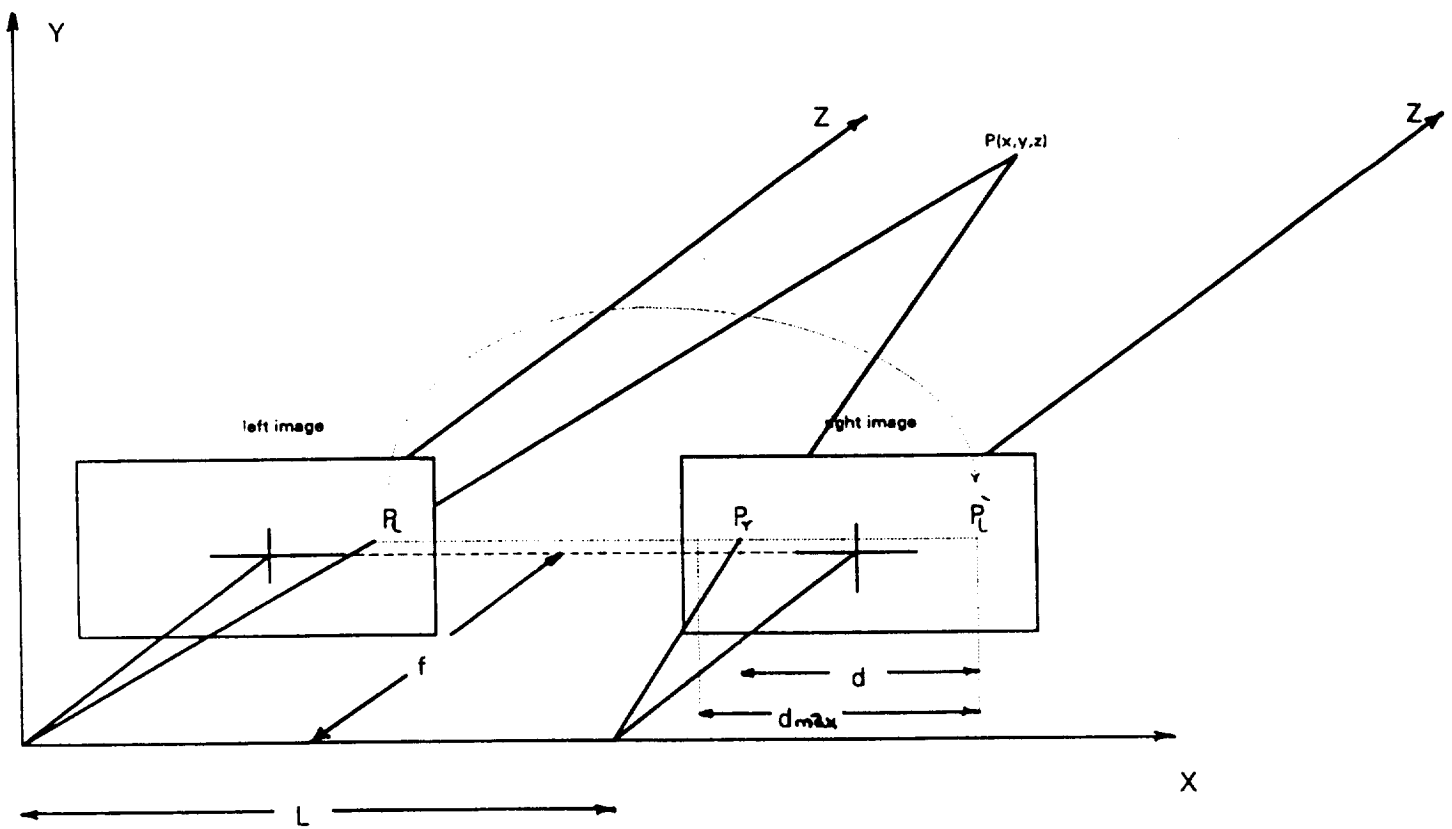Computing Surveys, Vol. 14, 1982, pp. 553-572.

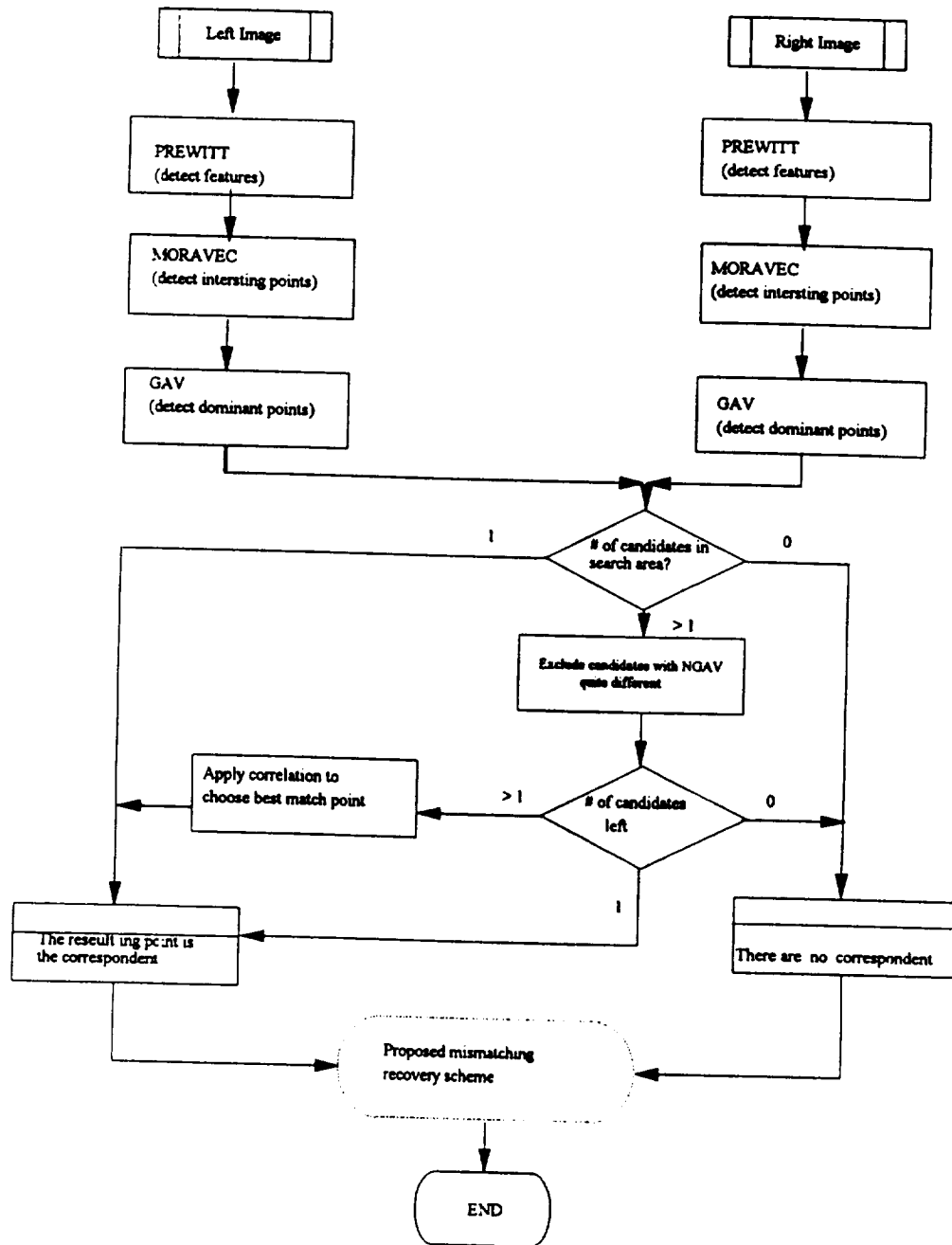Fig. 1   Conventional Parallel Axis Stereo Geometry [KIM 87]
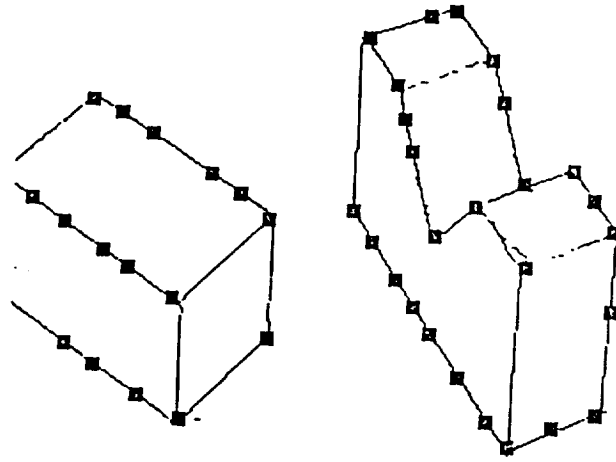
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Fig. 2   Flowchart of the algorithm

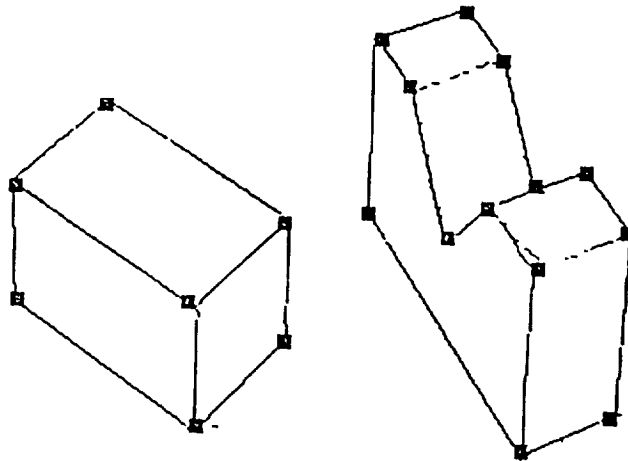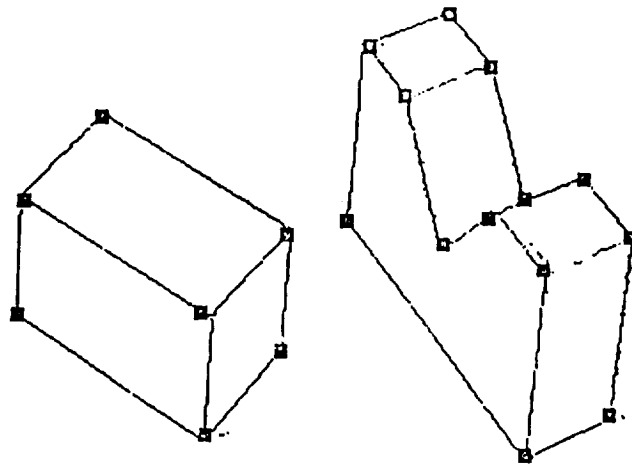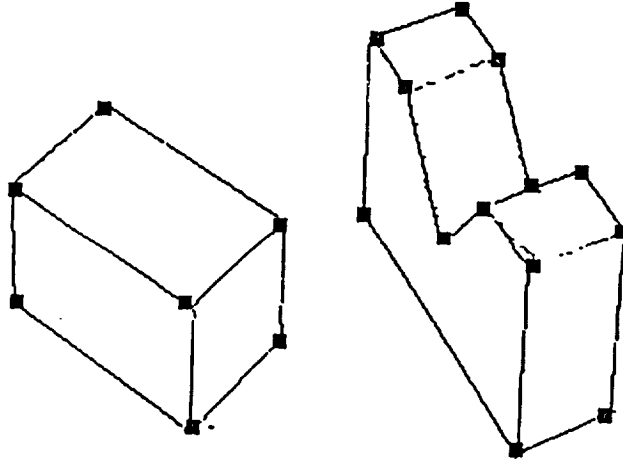Fig. 3   The result of applying MORAVEC Operator

Fig. 4   The result of the combining PREWITT, MORAVEC and GAV Operators

(a)

(b)

Fig. 5   The result of corresponding dominant features

SCULPTING IN CYBERSPACE: PARALLEL PROCESSING THE DEVELOPMENT OF NEW SOFTWARE

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ABSTRACT

Stimulating creativity in problem solving, particularly where software development is involved, is applicable to many disciplines. "Metaphorical thinking keeps the problem in focus but in a different light, jarring people out of their mental ruts and sparking fresh insights. It forces the mind to stretch to find patterns between dissimilar concepts, in the hope of discovering unusual ideas in odd associations" (Technology Review January 1993, p. 37). With a background in Engineering and Visual Design from MIT, I have for the past 30 years pursued a career as a sculptor of interdisciplinary monumental artworks that bridge the fields of science, engineering and art. Since 1979 I have pioneered the application of computer simulation to solve the complex problems associated with these projects. A recent project for the roof of the Carnegie Science Center in Pittsburgh made particular use of the metaphoric creativity technique describe above. The problem-solving process led to the creation of hybrid software combining scientific, architectural and engineering visualization techniques. David Steich, a Doctoral Candidate in Electrical Engineering at Penn State, was commissioned to develop special software that enabled me to create innovative free-form sculpture. This paper explores the process of inventing the software through a detailed analysis of the interaction between an artist and a computer programmer.

INTRODUCTION

Since 1979 I have pioneered the application of computers to large-scale environmental sculpture, i.e. sculpture integrated into architectural spaces. This has taken many forms-- stereo three-dimensional dynamic imaging, CAD, engineering simulations, architectural-sculptural drawing, pattern design for silk-screening onto sculpture materials, animations for anticipating changing views, presentations, sketching and proposals, interactive video performances based on my sculpture--to name a few. In all instances I worked collaboratively with expert programmers to develop software that enabled me to create artworks that would be impossible without the use of the computer. My stated goal has been to demonstrate a symbiotic, synergistic approach to creating sculpture via computer technology, and to prove the efficacy of this approach by realizing these projects in realtime and realspace.

This paper focuses on the process for developing the original software whose express purpose was to facilitate the design of a huge exterior sculpture on the roof of the Carnegie Science Center in Pittsburgh. A full range of computer applications, from Scientific Visualization

to CAD and Architectural Simulation were brought to bear on a highly complex commissioned work of Art. The assignment, the conceptualization of the problem, the development and operation of the software, the emergence of the solution, and a discussion of the proposed use of interactive computer-controlled lasers and fibre-optics will be covered in this paper.

This paper has an unusual format in that it is written in two "voices", my own as the sculptor/end user and that of my associate, Dave Steich, expert programmer. At appropriate points in my text Dave's commentary is inserted in italics. It is our belief that this paper can provide valuable insights about how one artist went about communicating with a programmer regarding the development of highly unusual sculpture software and how the software was created to facilitate its usefulness to the artist during the sculpture process. This is an article about communication between disciplines and about the man/machine interface in which the user is a practising sculptor.

THE PROBLEM ASSIGNMENT

By far the most advanced project I have ever attempted was commissioned in 1991 by the Carnegie Science Center in Pittsburgh, Pennsylvania and is still under development. I was asked to create a work of art, monumental in scale, that would be a product of science and technology, that would be as much Science as Art. I was encouraged to investigate lasers and fibre-optics and to employ a space-frame system recommended by the architect.

The practical goal was to develop a realizable sculpture that would be placed on top of the Omni-max Theater at the Science Center. The prominent siting of the Science Center at the convergence of three rivers in Pittsburgh demanded a work that had impact both day and night and one that could be seen for miles. This presented the opportunity to also conceive of the work as public entertainment of almost unprecedent scope. It had to be understandable yet sophisticated, both scientifically and technologically, so that it would further the goals of the Science Center in terms of public education. And while it needed to utilize proven technologies of today, it had to look forward to a life well into the next millenium. Creating for the future had profound implications for the project resulting in a proposal for an open-architecture front-end to the highly interactive sculpture that would enable future generations to program the artwork with new tools and approaches as they evolved.

SCIENTIFIC ROOTS

Just as a tree grows organically from the earth, so did this project establish its roots in the field of Science, and more specifically, Scientific Visualization. As a result of a chance meeting with a prominent scientist, I was introduced to programs developed at Penn State University's internationally recognized Materials Research Lab. The artistic application of Voronoi Tesselation software, intended for scientific visualization of crystals, guaranteed that whatever form emerged would be a hybrid of Science and Art.

Dave Steich, a doctoral candidate in EE at Penn State, authored the poly-crystalline simulation program. During the next six months, Dave and I worked closely together pursuing the development of what became a new medium for sculpture using as a starting point his poly-crystalline simulation program. The software became more and more sophisticated and specialized and in the process, Dave wrote more than five thousand additional lines of code. The resulting unique hybrid software ultimately combined architectural, scientific and engineering programs. It introduced scale, dimension and engineering properties into scientific images where nothing of this sort was ever thought of previously.

The origin of the crystal simulation program was a scientific visualization program used to display polycrystalline topologies using 2D, 3D Voronoi tesselations. The visualization program displayed large groups of crystals, creating a surface similar to a close-up view of sand along the seashore. The computer simulations were "photorealistic" with lighting and shading of each facet of each crystal. These groups of amorphous crystals were rotated, scaled, translated, etc. in realtime on a computer and compared to actual images of real amorphous crystals under an electron microscope. The purpose of the visualization software was to show the striking similarity between actual amorphous crystals and present mathematical models used to simulate these crystals. The visualization software included the real time splitting apart of an amorphous material into two cleavage planes (each having the topological features of the actual polycrystalline ceramic).

My job was to modify and build on this original program, written on a Silicon Graphics 4D/220 GTXB computer, so that the software would allow the artist, Rob Fisher, to generate mathematically correct crystals to form a sculpture. It is difficult to envision the complexity of such a task.

First, the data set was enormously complicated. There were typically thousands of crystals each unique in shape, each with differing numbers of faces, edges, nodes, each uniquely related to other crystals. Displaying all the nodes and connections for a typical data set involves over 100,000 polygons and lines. Just displaying all the line segments of a volumetric data set would be so dense as to fill the screen. It would be like trying to see the bottom of a pot of boiling spaghetti, and that only consists of a few hundred strands, not thousands upon thousands of lines. Because these crystals simulated amorphous materials there was not periodicity in the data; everything was formed out of random distributions. Consequently the inter-relationships between each of the crystals was extremely complex.

On top of the data complexity was also the concern that the generated sculpture had to be built in relation to both the existing building and the trusses that would support the crystalline forms. The spatial relationship between sculpture, building and trusses was

essential for both aesthetic and practical reasons. It was possible in the simulation for a sculpture to cut through the building or intersect the trusses. Fisher had to be given enough visual information and control to avoid these collisions.

Another problem was that of input-output issues. The software to be developed had to receive input not only from the sculptor (via mouse) but also from HOK Architecture CAD software running on a Vax Main Frame. The output had to be compatible with the software of the space frame developer (Mero Structure) in order for the manufacturer to be able analyze and specify the engineering requirements of the sculpture. Mero's software ran on a older model DEC MicroVax.

Although the above issues were anticipated almost from the start of the project, the final complexity far exceeded the initial impression. In particular, not knowing what would be required of the software from the beginning of the project, the software had to be adaptable to as yet unknown requirements from the sculptor.

PROCESS AND METHODOLOGY

Studying Dave's software, I recognized a similarity between the wireframe images that outlined the three-dimensional crystalline shapes and space-frame structural systems used to create architectural structures of enormous scale. The space frame system, consisting of nodes and tubes, was a perfect metaphor of vector graphics with its end points and connecting lines. I intuitively sensed that here was an opportunity to generate poly-crystalline looking sculptural objects which could be replicated in the real world using standard architectural spaceframe components.

Discussions with engineers at MERO Structure focused on whether their usual production methods, used to create regular structures based on the Golden Mean, would apply to the highly irregular and organic shapes generated using the crystal-simulation program. A number of years ago they had changed over to CAM (Computer-aided manufacturing) which permitted great flexibility in the drilling of the forged steel nodes used in their system. Geodesic structures have areas of irregularity which could be readily accommodated by CAM since each node was specified individually in the data base. At least in theory, therefore, each node could be different and each connecting tube could have its own length. We obviously had to test this premise and see, as well, whether the resulting organic object would have any structural integrity. We produced data for a single crystal, assigned realworld dimensions and sent the data to MERO Structures computers for engineering analysis. Within six weeks MERO Structures produced a ten foot high prototype spaceframe crystal which clearly demonstrated the feasibilty of the process. We then proceeded on the development of the sculpture which would be more than 100 feet high and 120 feet in diameter!

The first and most basic issue to be resolved centered on an apparent anomoly. While the Scientific Visualization software could display the spatial location, angles and edges of every crystal, the image was

dimensionless, since scale was not a question, and the geometry of each crystal was buried inextricably in the program.

There were many limitations in the software that prevented its use in sculpture generation. Although the original visualization program could accomplish all of its intended purposes the software could not begin to be used as design tool. Often in visualization very little knowledge of the viewing object is required to adequately display the object. A CAD system typically requires much more information about an object so that it can be manipulated in many more ways.

For example, consider displaying a spider web on a computer screen. All that is needed to visualize the web is a series of line segments. Scaling, rotation, and translation of the web can easily be performed by multiplying the beginning and ending points of each line segment by a transformation matrix. The matrix would be identical for each node. But if a user desired to highlight a section of the spider web, or wanted to single out all the parts of the web that were in immediate contact with a given strand, or wanted to animate the order in which the web was created, much more information about the spider web is needed. Rather than a series of line segments, a program would need information about how each node was related to each other node. It is easy to see that designing and manipulating objects on a computer is in general more complicated than just visualizing the object.

Next, we had to merge the Scientific Visualization program with Architectural CAD software created on a completely different system for a totally different purpose. These two pieces of software were also written in different programming languages, C and Fortran, and were operating on a Silicon Graphics IRIS 4D-220GTX (for the crystal simulation located in a lab in EE) and an Evans and Sutherland Color MPS and a Tektronics system using HOK architectural software (located in the Department of Architecture at Penn State). While the networks were in place for these computers to talk to one another, there was no precedent for this interaction.

After discussions with MERO Structure, manufacturer of the spaceframe system, we discovered that they used an older but still useful computer system for their engineering analysis and design of their projects, a DEC MicroVax. We assumed it would not be a difficult matter to reformat the data to match their computer, once we had merged the Scientific and Architectural programs. Fortunately, I had been the recipient of a DEC MicroVax GPX many years before and the computer, used primarily by graduate students, was set up only a few feet from the Silicon Graphics Workstation. Once the SGI and the E & S could speak to each other, we could output any crystalline form in architectural terms, move and reformat the data onto the MicroVax, output to a floppy and send the disk to MERO for their use.

The software had to be written to implement the above tasks and

satisfy all of the constraints, i.e. environmental- building and trusses; sculptor - manipulation ability; mathematical - laws of physics; topology; geometry; etc.

In order to achieve the goals, a relational database was created. By using a relational database the above tasks could be accomplished without overwhelming the sculptor with many of the details of the mathematics of crystal formulation and yet provided maximum freedom to manipulate the data. The relational database would accept input from other computer systems (building and truss information) and from initial seed distributions (Voronoi tesselation output). The database would appear on the computer screen as a series of 3-D objects that could be manipulated by the sculptor using a mouse. Output of the created sculpture would be in a form that Mero Structure could readily accept. In this way the sculptor would be able to create his sculpture without having to deal with database details. He would only see the database in terms of 3-D objects with various spatial differences, colors, transparencies, etc.

All data that was not going to be manipulated in any detail could just be a series of lines and/or polygons. No interrelationships between the members would be required. In other words, any and all transformations like scaling, translating, rotating would be applied to "whole data sets". For example, there would be no reason to rotate a portion of the building in relation to the rest of the building. Also, there would be no reason to scale the top half of the trusses relative to the lower half of the trusses.

CONSTRUCTING THE BUILDING AS CONTEXT FOR THE SCULPTURE

Using methodology that had proven itself on many previous projects, I had an assistant (an architecture student) "build" an architectural computer model of the Science Center using existing programs designed for that purpose (HOK Software). I worked closely with the project architect, Tasso Katselas, on the development of an architectural spaceframe structure that complemented his building and provided the framework to support the yet to be created sculptural forms. We arrived at a series of trusses of varying length that were arranged almost like an open tepee. I envisioned the sculpture either floating within this structure or residing in the spaces between the trusses. The trusses were then added to the 3-D CAD image of the entire building giving me an interactive contextual image within which I could develop my sculpture concept. I could move around the image viewing it from any angle and distance, paralleling the experience of the real viewer. Concurrently, I visited the site and videotaped the building and site from every major location in the city, along the riverbanks and across the river from the cliff overlooking the site. These videoimages were to be later integrated into the computer program.

Dave and I decided to limit the amount of data brought over from the architectural CAD data to the immediate context of the truncated conical roof of the Omni-max theater and the seven trusses as this was

enough information for me to work within. His software automatically scaled the crystalline forms to realworld dimensions since they were created in the context of the scaled architectural images.

The building and trusses data, developed in the Architecture CAD lab from drawings provided by the architect, were read into the program and displayed on the screen. These objects could be rotated, scaled, and translated independently of the crystals. Although much of the building was brought into the program, it was decided that only the dome of the theater was needed in order to get a sense of sculpture in relation to the building. The trusses and dome were the immediate context for the sculpture.

The dome and truss data came from HOK architecture software. The dome data would not be changing because the building existed. The trusses were dimensionally designed in relation to the building. Although the crystals and dome-truss combination could be scaled, rotated etc. independently of each other, the sculpture output was always transformed to correspond with the initial building and truss data. In this way, the sculpture output (dimensions and geometry) that was generated would have accurate, realworld dimensions relative to the building.

GENERATING POLY-CRYSTALLINE SCULPTURE

The lengthy research and development just described brought me to the point where I could begin the long search for a dynamic sculptural solution. I first had to grasp how the Scientific Visualization program operated to see what parameters I could affect and what its limitations were.

DESCRIPTION OF VORONNOI TESSELATION

A starting set of random seed or "germination points" are chosen in a 3-dimensional unit cube space. Each of these seeds "grow" outward spherically until the spheres start to touch one another. Where two spheres first meet the growth stops at that point. However, at all other points both spheres continue to grow in a similar fashion. Two spheres meeting one another eventually produce a flat surface that is perpendicular to the direction of growth. The surface between the two spheres gets larger until a third sphere, equidistant to the first two spheres, produces an edge. The process continues and the edge length grows until there are four equidistant spheres (actually the spheres are distorted by this time) producing a point in 3D space called a vertex. By connecting the vertices together, polygons are formed. When the polygons are connected to other polygons closed surfaces are created. These closed surfaces (volumes), when in simple or elemental form, are called crystals. (Simple signifies that the closed surface contains no other closed volumes within itself).

For example, if the starting germination points were a periodic 3D array of points so that each point was equidistant to its nearest

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neighbors in the x,y,z directions then the resulting Voronoi tesselation would be a 3D array of cubes. When the germination points are random in space, the case for amorphous materials, then the resulting crystals are random in shape and size.

Among other attributes, I realized that I could specify the arrangement (random or orderly) of the "seeds" or centers from which each crystal would grow. I could also vary the density of the seeds have the density itself vary throughout the unit cube. I began to feel like a botanist/gardener who could alter the composition of his garden by making determinations at the level of the seeds.

One of the first issues that had to be dealt with is what seed distribution(s) would be needed in order to have both a realistic crystal shape and an elegant sculpture.

After trying some trial data sets it was determined that a random data set with varying density in one direction would give the sculptor enough possible variations in crystal size and geometry to create a desireable sculpture. The data set was large with nearly 5000 germination points, 28,000 + vertices and over 100,000 edges.

MERGING THE CRYSTAL SIMULATOR WITH THE ARCHITECTURE: INTRODUCING THE CONCEPT OF THE "BOUNDING VOLUME"

The basic idea behind the software was to immerse the architectural dome and trusses into the seed bed. After scaling and rotating the dome and trusses in the seed bed as desired, the sculptor moved volumetric shapes within the seed bed. These volumetric shapes would capture all the germination points within the volume. Any crystal that had a germination point that was "captured" by one of these volumes was displayed on the screen. The idea was then to move the volumetric shapes around until a desired sculpture was created that would somehow fit into the spaces between the trusses.

We saw that the bounding box within which the seeds grew could be shaped anyway we desired. We first tried a concept whereby a triangular volume, similar to the space between the trusses, would serve as the limits to growth of the crystals. My thoughts at this point were to have the crystals "grow" into the space between the trusses. We tested this solution and Dave provided a program whereby the bounding triangular volume could be scaled, rotated and repositioned anywhere within the cube of seeds cum crystals.

The resulting objects were curious and sculptural. In their organic form they bore a resemblance to animals and even primative cave drawings. But they were quite arbitrary and the controls by which they were generated lacked the exactness I needed to precisely fit the objects into the architectural structure on the roof.

Although this procedure was successfully implemented it had some drawbacks. If the volumetric pie shape was moved even slightly it picked up several other crystals and the new sculptural shape was much different than what it was a moment before. Also due to the large number of line segments and nodes on the screen (typically thousands) it was difficult to get a feeling for the 3D aspect of the sculpture. Things became confusing not knowing which crystals were in front or behind others.

Dave and I then discussed a refinement in the process, which involved the creation of a rectangular bounding box, whose proportion and scale could be varied. The box could be scaled to encompass a single crystal or as many as I wished. With it I could move around in the virtual seed bed and generate a wide variety of sculptural forms, all of which could then be visually examined in the context of the architecture.

The "volumetric pie shape" idea was then refined to remove much of the difficulties being encountered. Rather than a "volumetric pie shape" a "rectangular bounding box" was used instead. This bounding box was semi-transparent and its proportions and dimensions could be scaled for differing aspect ratios. This bounding box could be translated and scaled within the seed bed. This new scheme gave the sculptor much greater control over which crystals would be selected and joined into a sculpture. He could isolate single crystals, save their location, and then search in all directions for adjacent crystals that might form a pleasing sculptural shape.

To summarize the process thus far:

First we created a unit volume (a cube) of seeds which represent the centers of growth of each crystal. The random composition of the seeds was mathematically determined in layers of decreasing density. Into these seeds I plunged an image of the entire roof of the theater and trusses to support the sculpture. This architectural object could be scaled, rotated and positioned anywhere I wished in the seeds.

The bounding box whose proportions I could vary, was then introduced into the image. When the box encircled a seed, the seed burst into life as a crystal. I moved the bounding box and the architectural structure around in this environment. In this manner I began to "grow" the crystals one by one immediately seeing them in the context of the sloped roof and trusses. Like a modern-day Michaelangelo extracting sculptures from stone, I witnessed forms emerging from the void of space, their existence governed by the virtual locations of the seeds.

A simple color system was developed to help the artist in his search for exciting sculpture solutions. When a seed lay within the volume of the bounding box, the crystal associated with the seed lit

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up in the color green signifying growth. The sculptor could add this crystal to an existing sculpture or move on until other seeds were picked up. If the bounding box enclosed an existing part of the sculpture, it was illuminated in the color red, meaning that it was volatile, and could be deleted from the existing structure. When a crystal was part of the sculpture but lay outside the bounding box, it was colored blue, meaning safe. Crystals could be wire-frame structures or rendered as closed objects. These objects could be solid or semi-transparent. The multiple color scheme and transparency options were very useful when in the thick of a very complicated and dense area and allowed the artist to immediately get a depth perception of each crystal.

EMERGENCE OF THE "CYBERNAUTS"

Finally after months of sculptural exploration something magic occurred, an abstract form took shape that struck me as having the feeling of hieroglyphics. I called them glyphs. They were primative but they were communicating something from the past, something primal. (Several years ago, I visited a cave in southern France with some of the earliest examples of sculpture ever discovered, perhaps 15-20,000 years old. I felt a kinship with that prehistoric artist, the impulse to create a material form in space that communicates, however primatively, something about one's life and age.)

One night as I developed these primal forms, a strange figure suddenly appeared on the computer screen; first one leg grew, and then another. I laughed out loud at seeing this childlike figure. I asked this creature on the screen, "Now where in the world did you come from". But there it was, and I liked it. And I made another and then another, each different, each figure with its own quirky personality emerging from a virtual world. In the context of modern art history there is much precedent for these primative figures in the work of artist's I admire--Calder, Picasso, Braque, Oskar Schlemmer, Paul Klee, Dubuffet, and more recently Joel Shapiro and Keith Haring. Each of these artist's figurative work captures gesture, content, personality, and the child in us all.

I have titled these semi-abstract figures "Cybernauts". Born in a computer generated virtual world, these creatures of science and technology are like visitors from a parallel time and space. They look like crystals, like molecular structures, like enzymes, yet they look like us. They are happy, optimistic, dancing and marching to their own drummer. They suggest that we are all children of the Universe, but that the Universe is in all of us as well.

Here were unique sculptural forms, discovered in the laboratory of the computer from scientific principles; realworld sculpture determined by natural organic growth algorithms; a product of a symbiotic relationship between computer technology, art and programming skills and unattainable by any other means.

ARCHITECTURAL INTEGRATION

Placing these poly-crystalline figures in the architectural structure added layers of context from the history of sculpture and architecture, for we have only to turn to classical Greek and Roman buildings to see the introduction of the figure framed by columns and cornices. The process of intergrating these sculptures into the architectural structure also created some of the most challenging problems of programming. I wanted the figures to float in the triangular volume between each pair of trusses. This meant that each figure had to be precisely scaled and located so that they were a few feet from any truss and also a safe distance from the roof of the theater. They also had to be scaled relative to one another so that they appeared as a family of forms. The figures were each "grown" in the context of the architectural structure, but they were also each grown in the context of the seed bed which was their global universe. Each figure emerged from a separate sector of that seed bed universe. Thus the final composition of these Cybernauts appears as if they were all brought into being at once when in fact they all existed in parallel time but different spatial orientation.

At any time the artist could save his sculpture and retrieve it later. The sculptor's entire environment was saved so that he could immediately resume where he left off. By using the bounding box, transparency and realtime rotations, the sculptor could get a very good sense of each crystal's orientation with respect to the dome, trusses and other crystals. Hidden line/surface removal also helped, especially in determining when a crystal was cutting thorough the dome or trusses.

The artist could create and save the individual "cybernaut" sculptures. These individual figures would then be joined and become part of the truss data. Newly created sculpture would thus have some reference point and scaling relative to earlier decisions. The artist could move the truss system and saved sculptures as one unit within the seed bed. This allowed him to take advantage of the entire seed bed as he searched for and generated new sculptural forms.

While creating the sculpture, the sculptor would see a screen display presenting information about the polycrystalline sculpture indicating the number of edges, number of nodes, and total length of edges. This gave him a feeling of size/cost of his creation as he created it. This data was then sent to Mero Structure (the space frame manufacturer) to allow them to estimate cost and determine the structural soundness of the sculpture as it was being developed.

SIMULATING THE SCULPTURE ON TOP OF THE BUILDING

To create highly convincing simulations of the final sculpture, for presentation to the Carnegie Science Center Board of Directors some of the most difficult programming of the project was required. This involved taking images, framegrabbed from video of the site, and

inserting these two-dimensional images into the three-dimensional workspace used to develop the Cybernaut sculpture. The three-dimensional image of the trusses and figures was then manipulated so that its perspective and scale matched that of the building whereupon it was captured as a single image and subjected to extensive paint program modifications to eliminate hidden lines.

In order to simulate what the finished sculpture would look like in its surroundings, 2-D digitized video images consisting of various views were imported into the computer. These color images were digitized into arrays consisting of roughly 1000 x 1000 elements. Each element contained 24 bits of color information (8 bits red, 8 bits green, 8 bits blue). The elements were in 1-1 correspondance with the screen pixels.

Superimposing the 3-D sculpture onto the 2-D images posed some technical difficulties. Parts of every 2-D image were to be in front of the sculpture and trusses and other parts were to appear behind the sculpture. There was no easy way to have hidden line/surface removal between the 2-D video images and the 3-D sculpture. Edge detection algorithms that could pick out objects in the 2-D images could not, in general, be used because of the small contrast between colors of many of the objects.

To overcome the hidden line/surface difficulty a capture/paint function was developed. First it gave the artist the ability to capture any screen display he wanted. Second, the artist could change the screen to any other display. Third, the artist could use the mouse to create a composite between the captured and the currently displayed images. The composite image was produced as the artist used the mouse to erase part of the current display. As the current display was erased, the captured image lying beneath it was revealed. This new image could then be re-captured and the process repeated until the 3-D sculpture and trusses were successfully placed into the 2-D images with the correct hidden line/surface removal.

The procedure started with the 3-D image of the dome, sculpture and trusses appearing in front of the video images. The 3-D image was rotated, translated and scaled so that it matched the actual dome and perspective of the building in the 2-D image. Since the dome, trusses and sculpture were in 3-D, hidden line/surface removal could be performed on these components in the usual way and this modified image was then superimposed on the 2-D images and captured. The computer generated dome could then be erased revealing the actual dome beneath it, but now the portions of the 3-D sculpture and trusses that should be hidden from view were now missing.

Image processing of the 2-D imaages could be performed by the sculptor. By pushing buttons to increase or decrease contrast of the colors and total color density, the sculptor could change the clarity of the images (cloudiness or softness) and the time of day (dawn to dusk).

ILLUMINATION OF THE SCULPTURE

The last step in the software development for this sculpture was the simulation of possible lighting and animation effects. I envisioned a combination of lasers and fibre-optics which would take advantage of the current state of the art in these fields. This led to the development of a highly interactive scheme by which future generations of artists and programmers could plug into the system and create a continuuing series of lighting effects for the sculpture.

For the actual sculpture a metaphor of the telecommunications industry would be created. Each edge of each crystal would be outlined in special side-emitting fibre-optics. Each node would have a small illuminator in the form of a lens that would spread the small fibre-optic beam into a spot of light. Several thousand glass fibres would wend their way back from the nodes and edges of each crystal to a matrix panel where they would be cut and polished to receive laser light. The matrix panel would be aligned to face a computer-controlled full-color 25 watt laser.

Below the sculpture, in a small control room located within view of museum visitors (much like the Omnimax), would be an "instrument" which consists of a computer connected to various input devices. The interactive controls direct the laser beam across the matrix of fiber-optic ends. As the powerful beam strikes the end of each of the fibres, light is transmitted instantly to either a node or an edge of one of the crystals. Because the laser can scan the matrix at an extremely fast rate, the entire sculpture would have the appearance of being fully illuminated. By driving the laser beam across the fibre-ends, the sculpture could be animated in endless possiblities.

Both the computer and input devices are treated as modular and replaceable. The sculpture lighting is neither platform nor input-dependent. Instead I imagined that by special arrangement with the Carnegie Science Center, computer scientists and artists could develop new input devices, software and concepts that would take advantage of technology that is always on the move.

A typical scenario for one of these instruments is particularly exciting and utilizes currently available sonic input devices. A small scale model of the sculpture would sit next to the computer screen. The guest artist/composer would pick up a wand and touch one of the crystals on the scale model. Immediately that specific crystal lights up on the monitor. "What color do you wish the crystal to be?", asks the computer in a digital voice. "Do you want just the nodes to light up or the edges, or both?." The artist responds with yes or no answers and the image on the screen is changed accordingly. And so it goes, each crystal, each figure, all crystals, one figure at a time, only the nodes, only the edges, moving colors washing across the edges, the color spectrum. All decisions are encoded onto a tape for later playback or coordination with music. The animation can be previewed on the computer monitor so that the composer is satisfied that it is exactly what he or she wanted. Then the tape can drive the laser during an actual performance.

Other interactive approaches would permit real-time changes in the sculpture. The same wand could become the baton of the conductor of the Pittsburgh Symphony performing at Point Park across the river. As the conductor moves his baton the movement and rhythm of light across the surface of the sculpture would respond accordingly. Sound has been proposed as another driver for the sculpture, utilizing available sound such as airplanes passing overhead, car and traffic noises, or the cheers of the tens of thousands of spectators at the Three Rivers Stadium nearby. Similarly the sculpture could respond to weather conditions (it could be a barometer).

To present these effects to the Science Center board, Dave came up with a program of a limited number of animation routines which could be sequenced in a variety of ways. While these simulations didn't begin to touch on all of the possible lighting and animation opportunities, they gave an impression of what could be expected. Most importantly, the image of the sculpture superimposed on the video image of the building could be animated in full color giving a remarkable impression of the final effects.

These animation sequences were accomplished by cycling through the relational database used to create the sculpture. The relational database gave us the ability to create various sequences that were limited only by one's imagination. The finished 2-D images with the sculpture and trusses were animated to demonstrate what the actual light sculpture might look like. Dozens of animation sequences were chosen, some lighting randomly selected nodes with randomly selected colors, some lighting random line segments with random ordered colors, some lighting entire crystals in random fashion, some cycling through the figures in ordered fashion, some lighting the entire sculpture to simulate the apparent motion of the "Cybernauts" running around the dome.

THE DANCE OF THE CYBERNAUTS

Here is the vision of my sculpture as a performance work entitled "Dance of the Cybernauts". By day the brilliant reds and yellows of the organic sculpture create a focal point against the sky and the surrounding industrial buildings. The delicate truss work reminds one of earlier lacy steel monuments to technology like the Eiffel Tower. From every view the subtle differences in the figures emerge, or they coalesce into a new whole that suggests organic chemistry, molecular clouds, crystalline coral or the flames of a blast furnace.

But now it is evening; the sky has darkened. An audience of thousands, young and old, are tuned to a local FM stereo radio station which is about to broadcast a special electronic music concert simulcast with a lumia performance on the roof of the Carnegie Science Center. The audience waits in their boats floating on the river, in their cars parked along the banks, in the stadium parking lots, on blankets in Point Park. The floodlights dim on the figures as the performance begins.

For the next hour the sculpture comes to life in "The Dance of the

Cybernauts".   They flicker like thousands of fireflies; they break
apart chaotically into hundreds of darting lines like a cloud chamber;
they burst and pop with electric energy like information coursing
through the synapses of our brain; they march around the roof or chase
each other in a game of cybertag; they sparkle like diamonds; they are
awash with colors that change at the speed of light.

POSTSCRIPT

An interactive multi-media production, "Dance of the Cybernauts", is
currently under development that would be projected onto the dome of
the state-of-the-art planetarium at the Carnegie Science Center. In
this production, artificial intelligence programs will be applied to
each of the "Cybernaut" figures furthering the individuality and
personality of each. Kinetic motion analysis will be applied to the
poly-crystalline spaceframe figures as if the nodes were rotational
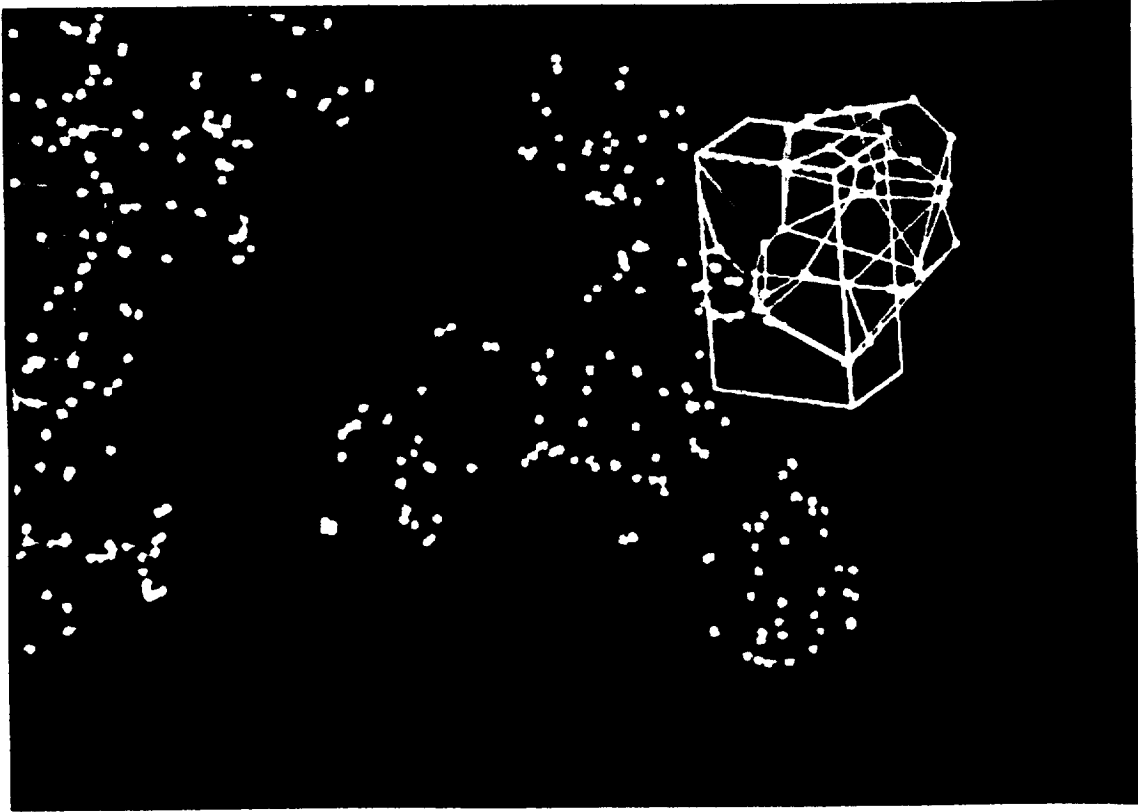
TOP- EMERGING "CYBERNAUT" WITH "BOUNDING BOX"
BOTTOM- "CYBERNAUT 1.0" FREE STANDING SCULPTURE
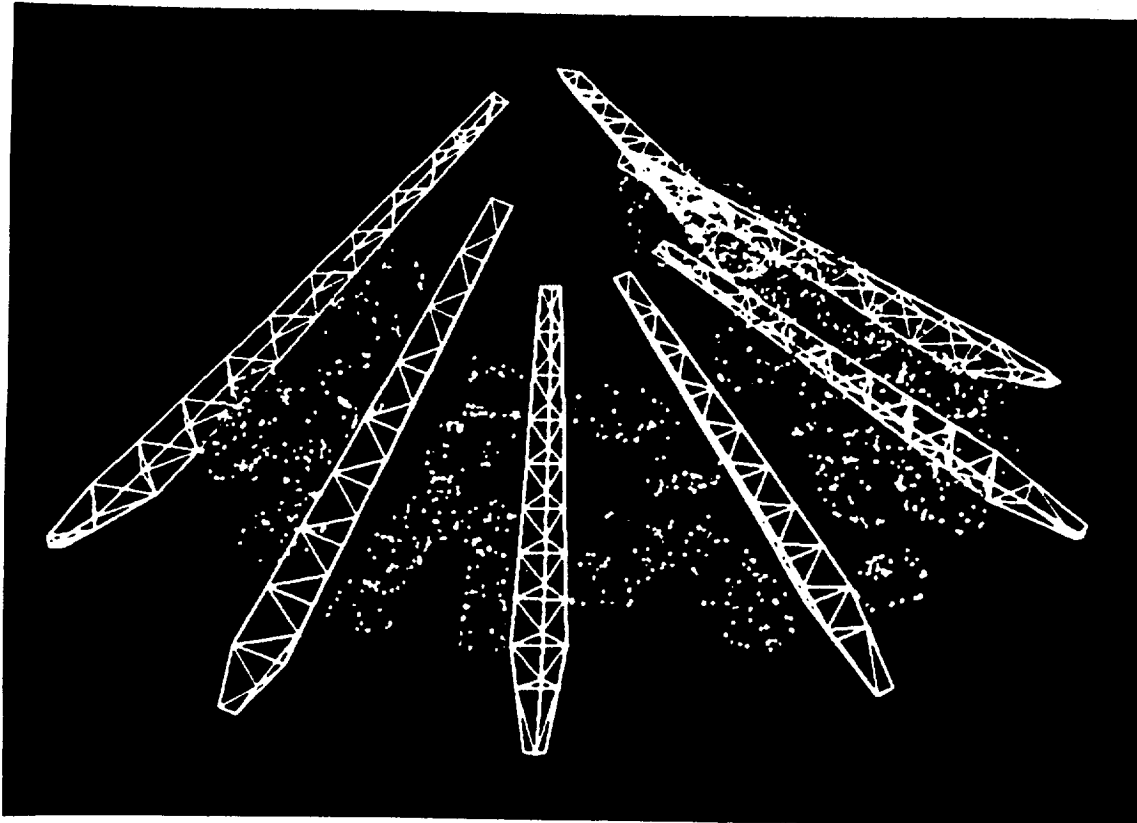
SIMULATION OF OMNIMAX DOME, TRUSSES, AND CYBERNAUTS

SPIRAL SURVEY EXPEDITION—A PROPOSAL TO ORGANIZE FOR THE SURVEY, EXPLORATION AND EVENTUAL COLONIZATION OF THE MILKY WAY GALAXY

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This paper details a plan to explore the galaxy. Areas of interest to an era of cyberspace include the Tech-Index information system for the Expedition and the role cyberspace has in increasing expedition productivity and increasing the capabilties of cyberspace by expanding the goals and data set. The paper offers lists of projects for the cybermarket pool. The expedition is described also as a developers tool for cyberspace to acknowledge the scope of the human mind far surpasses present engineering yet guides our direction of energies and materials. Maintaining the biological capability to reproduce the Terran biosphere via Evolution park conservation areas is discussed. The ecological repair of Spaceship Earth and the build up of an interstellar industrial base from simple recyling and educational programs is meshed with a proposed "reverse engineering cyberspace" plan. A set of constructive contests are proposed with 3 new currencies offered as prizes.

The Planet, The Solar System, The Galaxy are 3 areas of focus. Each of these areas are considered in a cyberspectrum of 1. Sentience, 2. Biological diversity. 3. Energy/Matter resources.

Although no specific software is discussed or offered the paper will give an idea of the characteristics usefull to advance the expedition towards the exploration of the Galaxy and building a strong self financed R&D group. Issues as diverse as access to the competition, challenge and benefits to the size of Earths gene pool as a data set and whether Cyberspace can model the technical information aboard interstellar colonization craft are brought forward. Cultural aspects, physics/religion interface and the potential dangers from drug lords as expedition cyberspace offers competition to recreational drugs for imagineering time in minds of bright young people.

Ideas for cross referencing terran life with each star in the galaxy for real colonization modelling.

Ideas for cyberspace modelling of novel space drives with a selection of the drives on the development table at the expedition. A short list of organizations and researchers collecting and producing data relevant to the Expeoition who would be able to contribute to the Cyberspace Data sets to firm up the reverse engineering productivity.

A method of incorporating the expedition into the current industrial infrastructure in the area of "reducing input costs" so as to increase North American competiveness and to make a reduction in the standard of living of expeoition participants highly unlikely because if you have access to the tools to colonize a Galaxy and the resources cf a Starship with fellow crewmembers spaning the globe, on a planet half buried by discarded technology you should be able to keep warm, dry, nourished and highly entertained. We are only snort on time. The educational and adventure opportunities are limitless for the Warrior on the Edge of time. A good argument is made for the expedition and its R&D.

In effect- hunting for the SpaceDrive.

Part 1.

A plan to explore the Galaxy.

This is fairly straightforward. We organize all scientific information in such a way that a person can learn enough to do experimental design of interstellar class technology. When new data becomes known it is inserted into the database known as the TechIndex- reg.tm. and is cross referenced so as to be accessible in the event a person needs the new data for study or design.

The database is structured so access is only made available once funds have been placed with the expedition to support Galactic exploration and colonization on a refundable basis. The funds can go into 4 different areas, each of which facilitates the Expedition. When a person wants some information they access the data from the TechIndex. If they are designing a Space Drive or anything directly related to the expedition they will be included in competition for prizes and remuneration for design work or research done that furthers the expedition.

The expedition is to explore and colonize the Milky Way Galaxy. Equipment must be designed and built to accomplish interstellar travel as will terraforming gear from time to time. The solar system will be the test-bed and proving ground. The first space project is a polar lunar power system. This will provide the energy and finance to research space drive technology and may spare a large quanta of Terran life for latter use in colonizing worlds. Next is a Gas giant Ice delivery system, followed by terraforming Mars and Venus. Earth, as the origin of life will have biological conservation sufficient to meet the challenge at hand. An industrial base able to build starfleets will be assembled during the research on space drives. Resources will be stockpiled, as in Key elements and infrastructure sites, at absolutely no expense to the biodiversity of the planet. There are duties and tasks pleasing even those who express a fear of stars. Due to the straightforward nature of the task at hand the TechIndex information system will be configured to accept the researches of CyberSimulants on behalf of participants, thereby freeing the biological participant for activity in the natural world. Nevertheless the cybersimulant may earn funds on behalf of its sponsor. In the event the Cybersimulant displays outstanding abilities it may be allowed to take on tasks offered in the TechIndex Cybermarket where it may perform tasks at the request of those who hire its services. How a CyberSimulant will be paid is currently under consideration. The Expedition is organic in nature and its goals must be met. Under no circumstances will cybersimulants impair the organic progress of biological life. Cyberial habitats may become available only after all possibility of organic colonization is excluded. It may be that the simulant would be paid only on the lunar base or places distant or perhaps offered a special class of LifeCredits that would offer the simulant REAL LIFE at some time, perhaps through the use of Clones of the initiator. Unless very real care is taken, the use of cyberspace may only result in the creation of a planetary prison with life confined to one planet or only a few. While cyberLife, better suited to interstellar travel, claims every new star its own.

The cyberspace environment of the TechIndex will be geared towards advancing the parametric with realtime analysis where possible. The expense of actual experimentation is prohibitive but will be employed to verify the data generated during some simulations and model runs. However, what is known and can be measured will whenever possible be included. The Cyberspace goal is to be able to model at will and have the TechIndex conduct realtime Reverse engineering with a REALITY GAUGE known as the cyberspectrum. The Cyberspectrum would indicate distance from reality. The known achievable parameters exceeded are accessible to pinpoint areas for further research to

expand our capabilities. The conversion of science fiction to Fact is the goal. An idea can have a spectral emmission to sentience, and in a virtural reality environment a electronic hypothalamus can sort VR from Fantasy.

We should be able to know while pushing simulations at what point we leave proven and move toward theoretical and when we leave theoretical behind. This is why we need access to all known data, so we can push beyond theoretical limits by utilizing other materials, processes, and principles and behaviours on the fly. Do you know of the HyperCurve and the Story of Math and Design? Can you integrate the concept of 2 infinite minimal surfaces to describe the interaction beween a star of origin to the destination star?

To Date(4.3 billion Years and Calculating) Life has circled the Galactic Core every 250 million Terran Years. During this time life has evolved to consider other stars. It is time to reach outward. Once humble Algae conspired to build arrogant bipeds to enjoy access to the laws of reality. And what noble deed do these construct aspire? Blindness to the Galaxy once discovered? Fear of Stars? Or a spiral harvest of habitat for the concept of life. Think Interstellar and Build up your planet.

Cybermarket- That communications market where sentience makes available for hire its services and goods, and the call for consideration of problems and tasks is set out in the hopes of attracting parties capable of resolution in return for credit, currency, services or goods.

At its terran peak Solutions did abound, as did the minds to provide such, however matter and evergy were in short supply. It became necessary to expand the MATTER/ENERGY base of the LIFE/SENTIENCE combination. Fortunately the Star Sol was embedded in the edge of a Galaxy. They Learned.

Cybermarket pool

A place we can hire out our sentience. That Index of cross-references to which we shop for challenges and submit our questions to the general cyber-resource.

Developers tool- To look at the expedition expectations may give some ideas about how to design virtual reality programs capable of real time model feedback for some reverse engineering. A need to translate data to run manufacturing lines if the design is for mass production.

The Contests

The Spiral Survey Expedition proposes to offer prizes to or shared by those individuals who may meet the challenges presented by the Galaxy, its survey, exploration, and colonization.

The LifeCredit-tm shares the experience of life with the winners in the realm of conservation and application of Life-Colonization Tool.

The StarCredit-tm shares in the opportunities offered by a Space Drive or a StarDrive in regards to energy and access to the Galaxy-Transport Tools.

The SpaceCredit-tm gives some participation in Space Power and the general resources of the solar System-Tools for Quanta of Action.

The new Currencies

The opportunity- A Galaxy stands before us. We have four billion years of molecular biochemical research regarding the support of life at our beck and call if we but allow its many designs to escape extinction. Over 200 whole ecosystems, each capable of supporting any level of civilization. WE are at the forefront of consideration of the future. We alone are the warriors on the Edge of time. We are the designers of the future. We are the selectors of the Way. We will not allow education to fail. We will not let knowledge fade. We will continue the tradition of giving assistance to wisdom and common sense.

Must we have an enemy to spur us into action? Are we StarMange? No!!!. We can do better. Do you bear the Standard of Death or of Life. We are but a Vector for life. Are your creative skills a match to the challenge? If you can think- yes!! Some thought on the harnessing of greed.

The Life Credit-tm is a mere quanta of conservation, a unit of Terran biodiversity, with the potential to colonize whole planets and turn dank mud patches into verdant forests. A simple tool to convert dead planets into living biospheres. Aspects of exact genetic sequences with 10 million gigabytes of DNA representing the global genetic data in a raw data form, and how and when this data might be stored, transmitted and transcribed back into functional biospheres at other stars are under consideration. The ultimate denomination of the LifeCredit currency is representative of the intact functional Terran biosphere. A rich planet with total biological resources and functional ecosystems in every available niche. A place for evolution to continue. An unexplored world. The best worlds will be set aside for life preserves as future prizes as life takes hold on each, for the competition must go on. After all there is the speed of light and other Galaxies beyond our own. Incentives must be available.

The StarCredit-tm is a mere quanta of the behaviour of interstellar travel and all this entails. Each small technical achievement should be marked by the issuance, and each issuance certifies an action in history as well as a permanently accessible record of achievement, thus conferring a sort of immortality on the persons involver in these struggles to access the interstellar. Just as life is the Journey, the Journey is essence of the life. The exploration and colonization of the Galaxy offers a vast level of opportunity for our progeny to experience the thrill of starting from a concept to a habitable planet to leaving to find another star to repeat the adventure.
     Of course the best will have access to the ultimate denomination of the currency of the StarCredit- the Interstellar Survey ship- capable of travelling to another star to survey its function in the Galaxy, the grand adventure, and whether it contains any colonizable planets. The Survey ship, must contain the computing power and biological power to initiate the terraforming of suitable planets in advance of the colonial fleets by times up to centuries.
And in the event of mishap, the ability to initiate the build-up of an interstellar capable civilization from the survivors. A fine expample of a functional currency. The highest, most sought after denomination, composed of the rarest of elements, containing all that life can offer and giving access to unlimited opportunity. Truly a versatile investment. StarCredits can Create the LifeCredit preserve planets.

The SpaceCredit is in a sense the energy key. A Quanta of energy action towards taking life through space to live at another star. More the physical side of reality, or conversely dealing with that excess of the reverse of matter-Space. For every bit of life is the organization of matter as energized by stellar output, and perhaps even the matter is from the core of previously burning stars. The stellar output of energy and the matter in orbit.
The highest denomimination of the Space Credit is the ultimate terraforming tool- stellar output and orbital matter. Planets can be built.

The best is to win all three. Earths biodiversity, an Interstellar Survey spacecraft capable of repeated colonizations, and the authority to use a starsystems resources to effect the creation of a biosphere.

Until a large number of credits have been sold, the prizes will remain small. and will average about 2 to 15% of the assets annually depending on the performance of the funds invested and the overhead costs of maintaining the TechIndex. Due to the governmental deficits there is a surplus of income generating investments available. Capital intensive yes, similar to the carbon

working on compared to what needs to be done and what has been done since I was last here are shown by my prefered method of display- my custom spectrum. and a review of the work is available as is a number of analysis and interpretation channels. If a fellow is on the problem now I may be able to hail them if they have a query channel open.

I display my problem- I can see if students are watching and know some of the individuals wishing to interact. On occas ion the general media is broadcasting the session to the general populace via sattelite or Fibre optics as increasingly persons looking for some hope have started to hang on every project relating to improving the lot of Earth. The media profits are a nice perk as onlookers may voice their approval via a cash contribution to the competition funds or may just purchase credits to increase the long term capital pool as a perceptual insurance to offset the deluge of misery. Some persons just want off the planet and this meets their desire to purchase a ticket.

Or I can be totally in private if I have the hardware on site.

My project for today is Solid State Fusion. I run through the simulation of a rydberg atom of Helium-3 in a verticle quantum well trap and give the variable magnetic sequence some harmonics with the helium electrons to open up a shot at the nucleus. I see that by selecting an oscillation on the sides I can get the nucleus spun up to a level that affects the electrons for a clear shot. I run the proton emmission simulation from my new hydride semiconductor design and pump it down the monolithic crystal fibre optic tube composed of lithium niobate. The Impact is successful, with no chip damage, so I run up the rate to some theoretical limits only to see a the capacitors cannot handle the current flow, disrupting the electron/magnetic harmonics resulting in excess neutron production and everything goes haywire from neutron damage. However it could charge batteries at the present design. My hail goes on. A party is interested in building the chip but I have to find someone to make the monolithic channel proton accellerator. Time to put a extra few lines into the Sponsor Wanted Line. Good thing the Patent Tax pays for the registration of this recent innovation.

Time to check out that clue in the LifeCredit preserve # 59 where a Lichen was found to be containing lithium niobate crystals of a peculiar shape and growing on a pegmatite dyke. See how the DNA analysis I sponsored is going. A common lichen with a strange habit, may provide clues for the organic growth of channels. I expect to live research, live the conversion of science fiction into fact and build and operate same. A Warrior on the Edge of Time.

Time to patch into the Sudan Lunar power project- we leased land to beam power to in return for providing a source of drinking water and universal access to birth control. The solar still project has made some progress. neat idea to use horsetail grass to provide a source of methane and silicon dioxide at the same time. a combination any glass blower is sure to appreciate. Nothing like a prehistoric plant to provide that which is needed twice. too bad we lost 38 species before we realized the usefullness. Why it looks like the dogs are trying to get the deuterium out before they let anyone drink the water. Now we will need more storage area and vessels.

How is the effort to balance the chemical levels in the birth control plant, on track except we have discovered a new pest that likes the smell. How about the solar powered contraception leaf calibration device based on evanescent wave technology. Seems on track, long list of sponsors, real crowded in that area. The power levels seem high, may have to empower locals to charge unit off battery banks. Soon there will be ample electricity. Thats great, the Lunar base should be into some good cash flow soon to enhance the search for extrasolar planets. Look at this, only 5% of the Galaxies stars with a full spectra. We have got to get out there. How is the design of the Galactic Polar Surveyors going. Not bad. Years from launch however. looks like a new project started in both directions to get a hold on the stars in that direction. looks good, modelled out to 200 light years. not much of a view yet but in the right directions. Look who's in the volunteer list. I wouldn't mind

in the first 10 growth rings in a 400 year old tree. life is like that. some phosphorus for the DNA and so forth. The act of reproduction is the act of investment of matter, energy, time, and attention. So we continue, but-sex with a Galaxy is not a simple matter. The mating ritual is a space ritual.

In 4.3 billion years of evolution since creation of life, we have circled in orbit,this galaxy under contemplation 17 times. Now that human sentience is on the biosphere, where to from here? A logical question associated with how much will galactic travel cost? Passage by investment and work.

So the LifeCredits are each secured by 1 acre of Wilderness, the StarCredits by investment in Govt.Bonds and the SpaceCredits by SolarCollection equipment. The wilderness is in a LifeCredit preserve, set aside to provide the biological resources to colonize the Galaxy based on the Terran expample. The lifecredits also provide a resource to the biotechnology interests.

Part 2- The Planet, The Solar System, The Galaxy

A cyberspectrum of consideration
Sentience and the mirror of illusion- If we model an expedition to explore the Galaxy will we actually be progressing towards the Goal of Galactic conquest? Or are we engaging in mere entertainment. Although our brains seem to work best when crawling out from rubble could we not for once just try to keep the Earth out of destruction and percieve the barren planets of other stars as the rubble, and take our gleaming caves to visit same absence of human civilization. We know what our rate limiting step to adventure is. Transportation. We now have computer tools to increase the participation and productivity of the Research and Development involved in interstellar travel. Cyberspace offers to reduce the overhead costs of an expedition by many orders of magnitude. The Spiral Survey Expedition is an educational exercise for the mind. A behavioural perceptual operating framework. Software for the Brain. For a Sentient- to be able to provide for the food, clothing, lodging, comfort, and energy by the act of thinking and using the mind is a great opportunity. Provided we are not plagued by the need for constant repair and mending, or being slowly poisoned or imprisoned. A relentless diminuition of freedoms can stultify the positive creativity, only to replace with that other of which we will not speak. We resist the bondage of physics, is that enough to stay free? A collective perception of the goal may be all the organization required on a mental level. But each mind must understand some investment is required to provide for freedom of thought, access to the hope of living on New habitat or of redeeming the current surrounding habitat back to biological health, and providing access to the matter and energy tools to build an industrial infrastructure capable of accomplishing interstellar travel and researches
    I feel the depth of description in cyberspace is one key.

    On Earth, Terra,"The Planet" however, we see the destruction of our sole repository of biological tools. In addition Hate and violent excess are in abundance. Is it possible to expand the base of neutral zones to cover a greater area of the planet where more rational progress towards civilization can occur through conservation of biology, resources, education, science and Engineering- I believe so. I also believe we have the technology to reduce the size of functional neutral zones into areas the size of city blocks or less. These need not be fortresses or Castles with courtyards of intact biomes, but I think each one may have a personality capable of soothing the surrounding areas. and potentially reproducing or expanding. If the Neutral Zones are most beneficial and do not contribute to strife they will become assets by virtue of existence, but must be virtually unpossessable. This is one facet of the colonization of the Galaxy- Our biggest challenge may be learning how to live on Earth due to the human condition. Many tribes have succeeded to live within their means. Few have not fallen before the current situation. The current

situation is pathetic in the extreme. What tribe could live unscathed in the current Jungle of reality? A question for anthropological Cyberspace- unique to Earth. I wonder, can we create at other stars what we cannot create on Earth. The collection and distribution of Matter and Energy on Earth can be improved. and some can be set aside for "ExtraSolar Missions". The expedition would be expected to maintain strategic reserves of Biological resources of sufficient scope to allow the continuance of evolution so as to expand the biological resources available and to allow present species time to adapt to the new bipedal on the planet-US. Does it hurt to stretch your mind? Please dont let selfishness and fear cramp your creative style. Each person wants access to the full range of colors before painting life on the new canvas of the Galaxy. One task is to prevent the Permanently Out of Stock notation beside the names of biochemical systems known as species. Not hard work. We just have to leave them alone for the most part. More difficult is making other people leave them alone. An area for some adventure. I feel Nature preserves can be sometimes integrated with Strategic reserves of other resources for the Expedition. The Nature Conservancy is cognizant to this fact in regards to the biodiversity on some U.S. Government property and many corporate landholdings. Often setting aside areas has multiple beneficial results beyond the original intention. Radioactive Waste is an interesting area- Energetic Matter- each isotope probably has a use. To bury or dilute or to concentrate and use? With radioisotopes the clock is always running. A simple use would be an area to simulate the radioactivity seen during interstellar travel at different velocities and densities of interstellar dust clouds. Or perhaps simulate the radiation belts at Saturn and Jupiter. We will be going to the key resources in those belts, and the Radiation represent the only free energy available other than the magnetic field which would destabilize the orbits of the Moons unless to accellerate to a Martian rendezvous. Access to a waste storage area of this level of radiation should be limited to StarMen. The boundary isolating the area should reflect our concern for the safety of others as well.

The Solar System-After and during the stabilization of the potential of Terra (It is possible) the moon will have to be accessed- this means hydrogen powered ports on Earth and a Lunar Power System to conduct interstellar class technology tests, SpaceDrive test beds and a Port for the operation of the System Fleet. With the Sun and planets at hand some work is called for. The mercury power station for the making of isotopes, the Terraforming of Venus and the Shade Ring(s) to cool the planet off for the deliver of the Ice from the Ice moons of Jupiter and Saturn excess to the needs of Mars. The Solar system is the proving ground for Interstellar travel.

Part 3 Our great expectations of Cyberspace

When refrence is made to the CYBERSPECTRUM of the Expedition I mean the following which is the example of how I would like the TechIndex to give me access. (others may design their own access ports-the kernal to the cybersimulants that work while we sleep.)
I open the com link and flag up a display of the areas of my interest and see a row of spectral signatures for the completeness of tasks at hand. Like a signature of a star there are bands of colour representing knowledge, and achievment, access to equipment and things done. Some bands are faint. I have infinite resolution. There are gaps or dark lines- these represent areas needing the most work. A Full spectrum represents a mature interstellar class technology with installed functional production and integration facilities for StarCraft construction, or other areas related to the expedition. My credits for access are displayed. My contributions are recorded and my daily earnings are tabulated. Ongoing research sessions related to my areas of expertise are flashing, biological resources are monitored as are intrusions into the preserves, excess absorption of spectra corrections are noted and the selection is pointed out- I enter the Techindex and begin the work. The areas I was

waking up next to them at another star. Looks like they need   more hours on
the StarFiler, here's my vote, no loss, I'm going hiking tommorrow anyway to
have a gander at the galaxy from the mountain on the lifePreserve. Catch you
later sweet dreams to both of us next night. Sign off.=

Part 4 Some Issues

Access to the competition- only via one of the currencies, however a 3rd
party can sponsor you or you can apply to be sponsored by the Expedition.   You
can also ask Questions and set your own challenges in hopes of attracting
research however you may have to buy more credits to make the prizes
attractive. All in the name of education.
If you think you can earn a living as a cyberspace resident researcher for the
Expedition you should at least buy 1 credit to register for the competition.
The Dataset of Earths gene pool must be preserved, otherwise all colonization
is at risk as is our continuance on Earth.
The Cyberspace models must be able to handle enough data to simulate life on
Earth, building an interstellar class industrial base, operating starships, and
terraforming new planets at new starsystems. The TechIndex system must also
fit on a Starship, otherwise we will be dependent on Earth for Data. Not a good
bet.
As far as the Culture of those who would explore the Galaxy and their
intimacy with physics it is possible religion may become involved in the old
way of the sun and the stars possibly providing a bridge of hope.
Perhaps a new catalogue of verbs is in order describing those behaviours
resulting in new knowledge and resources while having acting to conserve life,
enhancing the likelihood of interstellar transportation and colonization.
"I am saddened at the prospect of a new religion when so much has been lost to
these things, but the mind has cravings." -general consensus of sages circle.
Certain individuals have a vested interest in keeping minds tied up in
dreams yet doing nothing and going nowhere. Specifically druglords. The
expedition cyberspace offers the dream time without impairment and could
provide steady progress to the participant, thereby having a severe impact on
drug consumption. This will not escape notice and efforts will be made to call
down the expedition as "wireheads- worse than drug addicts". We are merely
competing for mind-time for imagineering, and offer better results in terms of
energy, matter and mind. A reminder- who ever got an interest cheque from
cumulative drug purchases. Bright young people deserve the better alternatives
to drugs offered by technology. The expedition offers a real alternative- with
some real improvements in living standards.
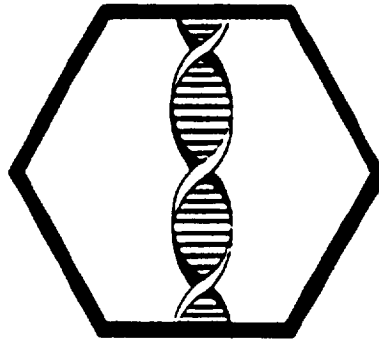
LifeCredit

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Ideas for cross-referencing terran life with each star in the galaxy for
real colonization modelling.

In the course of mapping the Galaxy i would like to ensure each starfile has a
place for data related to its ability to support life. From the bare fact the
star is giving off energy to the fact life requires energy to continue we can
build a picture of each stars ability to support life, and the level of effort
and equipment required to get a colony started.

It is in the building to this data file the importance of biodiversity
assumes overriding importance as we tackle marginal stars and planets in
marginal regions of prime stars. It is fairly certain we can consider Terran
life be "proven" as opposed to cook-ups from the chemisters replicator. Terran
life has a vulnerability- each is part of a system known as an ecology-
incomplete ecologys go out of balance, instability can lead to failure.
Cook-ups have a weakness as well- and without sufficient biodiversity we are
lacking the genetic codes for some biochemistry, and without the terran data-
even the biochemistry becomes experimental.

As we map the Galaxy from the poles of the Moon and catalogue the spectrum
of each star we can build cross references with the following data:
    -Photosynthesis with regards to each photosynthetic organism
    -photosynthesis with regards to habitable regions around the star.
    -technology required to upshift or downshift spectra to support plants
    -terran life compatibility(biodiversity set for each star)
    -photovoltaic based life support systems

We can then use the information to select those stars which require zero
technology to sustain life to guide our search for extrasolar planets and to
chart the best paths comprised of ideal stars for survey craft to visit in each
region of the Galaxy.

The marginal stars provide an interesting synergism for conservation of
Terran life for example if a star is shown to be capable of sustaining only
5,000 photosynthetic life forms and only 50 of those can be used for human
survival and 30 of those are deemed essential ie they are single sources for
certain amino acids, essential fatty acids or vitamins or other Expedition
parameters regarding colonization, and 20 years from now 10 of those 30 are
listed as extinct- we will have to cross that star and any other star of
similar spectrum OFF the colonization list. The Conservation of Terran
biodiversity is of galactic importance to Humans. Any serious starmen has a
stake in the conservation of life on Earth. And doubting thomas types who wish
to stay at home would do well to remember we colonized this planet using the
biodiversity existing. In otherwords even earth could become marginal if we
lose too many species. In 1 sentence saying no to conservation is the same as
killing your children. Bad genetics. except for fun for the purpose of
cyberspace we do not want to include our life support system in with dinosaurs.

As we model and develop new technology new stars fall into the visit worthy
class and as we cybermodel new life forms marginal stars may assume greater
importance.

We should not forget who has a 4 billion year track record. PROVEN
COLONIZABLE.

The ability of a star to support life may range from merely stationkeeping
aboard a survey craft to an Earthlike planet or even a ringworld or a total
terraforming job where a terran mass must be placed in an appropriate orbit and
stocked with volatiles.

Some stars may show zero in the photosynthetic cross reference,
nevertheless, these stars may be important for thermal based life forms as seen
in undersea volcanic vents and hotsprings and even caves.

Some stars may show zero in both areas but may be ideal for high energy manufacturing for components for the expedition, rare isotopes, crystals, operating gamma ray beacons or powering light corridors or specialty propulsion lasers. These stars may have role to play in getting life to a habitable star and in a sense add to the habitablity of the Galaxy in general.
Brown dwarfs, neutron stars, and the undiscovered, the unappreciated.

On a clear night, in a place dark, look at the crowded Starfields of the Galaxy, and think of all we are blessed to know and possess. Look out at the beacons burning, calling us to a destiny we can remain equipped to achieve, if only we take 1 action. Maintain the photosynthetic based biodiversity which allowed us to colonize this planets. Humans can expect to have access to new habitat beyond this planet as a benefit of being a sentient species but only as a reward for ingenuity and bold determination, and not without upholding the duty to maintain sufficient original habitat to reproduce biological systems diverse enough to support human life.(A spacedrive is possible before ecological ruin- ecological ruin must not be allowed to occur before colonization reserves are fully functional so as not to hamper resulting travel and colonization activities.)
Spacecraft do not live beyond their means.
An extremely detailed model of the Galaxy is required. Solar system missions undertaken to develop survival technology for the expected variety of conditions encountered at each star.

- A challenge to the superiority of drugs for mesmerizing the human mind. A skill building challenge linked to Reproduction, survival, and adventure with the promise of the eventual access to a billion new habitats
- integration of religion and science to include more minds

2.biological diversity- conservation and application of the biological resources of Earth- ranging from Evolution parks and access to such parks to the cross refrencing of the Compendium of Terran Species(in the Tech-Index) with all the Stars and habitats in the Galaxy

Part 6.
Expedition Building- A method of incorporating the expedition into the current industrial infrastructure in the area of " Reducing Input Costs" in North America.

It is said that in some manufacturing areas North America is low on productivity. We all know that there is a productivity dividend and we all know every person is capable of making some suggestions for improving productivity in almost every human endeavour. If we take the assumption that Instersteller exploration and colonization is one of the highest orders of human behaviour in the physical sense due to its difficulty, challenge and the benefit of being capable of reproducing entire biospheres, then we must also realize that due to human nature Galactic exploration would therefore be last on the list of things for the human race to accomplish, even though it could save our planet and raise our standard of living. Therefore an interstellar expedition must position itself in such a place that it performs the most difficult functions within a human society-improving productivity, and quite likely take on the most capital intensive improvements because no one else has the will, desire, determination. or foresight to actually preform these needed functions.
Our industrial base is novel and resource dependent. Compare to an deep space vessel. we are using up our space ship. At this rate we will go nowhere.
What areas could we use some productivity and how might this benefit an expedition?

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Energy
Heating a Factory with natural gas- passive solar   reduce heating costs
build solar collectors from scrap pipes, glass, foil, pallet wood, old fans and
tubing
Advantage- we learn construction of solar technology, molding plastic waste
into parabolic curves, we reduce garbage, improve profits at factory,we educate
people,involve the young and unemployed and can use the natural gas for
something else-like making borosilicate water distillers, which can be
installed into solar heaters we have now learned to build which opens up a
global export market to 5 billion persons requiring drinking water, many of
which have lots of water and sun but cannot drink the water. more effient use
of minds, materials and natural resources. We hire people in those countries
for a portion of the Water they produce since we still own the water distiller
and use a portion of the profits to establish comunications links with our new
partners and perhaps supply with adequate birth control to sell and educational
material to prepare for a next phase of recycling based on the resources
locally available in terms of waste- perhaps the reverse-a cooling system- I'll
call this a "Space Collector"- a Thermosyphon operating only at night- It does
get cold at night in the desert- this will improve the function of the solar
distiller as well. With our new solar skills we could tackle SuperWood- the
cellulose reinforced recycled plastic again building solar collectors to melt
plastic and using more waste materials. Use the superwood to build growing
containers for spices and medicinal plants to improve health and the ability to
each foods normally unpalatable due to lack of flavour enhancers. In the
northern clime perhaps some small greenhouse frames are the order of the Day- a
great gift for employees, who an their breaks can learn the arts of
computerized greenhouse design and the transparency of various available
materials from glass to plastic pop bottles. Or parhaps backyard solar Furnaces
as per John Keyes, this allows the heating dividend to translate into general
educational and individual energy savings- again more money available for
capital investment in tools or to buy access into the expedition competition or
purchase information from the TechIndex-reg.tm.
The same can be done for Electricity used for heat. In the Case of light, the
enegry loss of a window can be ofset by using a collector beneath the window to
bring energy into the building just below the window.
Storehouses for discarded technology- store, catalogue, dismantle and reuse is
a process mind intensive- very suitable for educational efforts and encouraging
creativity. A large building may be turned into a creative competition learning
center a sort of diversity factory with a trickle of usefull equipment leaving
the building.
North America could tackle the following areas:
Health, Social problems, Business inefficiency, Government debt, unemployment
pollution, conservation, Education using Expedition mentality and new Credits.
We should seek some import replacement to maintain key industry
Other areas we can insert expedition style industry:
Land reclamation whether to agricultural or natural
Toxic site cleanup soil leaching or solar burning of waste.
Toxic waste management and elimination
Environmental equipment to reduce pollution
nuclear waste management
invasive species control
chemical storage- all cleanups generate some concentrated waste
disposal reconfiguration into pro-poductive storage ie Lead batteries- if we
recycle rather than dispose we may produce leaded glass prisms that while
storing the lead produce some beauty at a window side - 2 foot tall prisms on
each side.

Basically if we will have to do it to build a fleet, operate a ship in a
balanced clean manner or would have to preform the same functions to survive
after planet fall at another star- we can certainly do it on Earth.

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Part 7.
Ideas for cyberspace modelling of novel space drives with a selection of the drives on the development table at the expedition,

Cyberspace could be used to accellerate the development of a power and propulsion system for the exploration of the Galaxy. If you can model a concept and give it a good work out using virtual reality, and your software can generate useful reverse engineering data we can build and fly. Especially useful is the access a concept has to a large number of minds during its evolution.

A selection of concepts under consideration at the expedition
A. Power Sources
Solid state fusion -Monolithic channel guided fusion(within a solid)
modelling of hydrogen fusion/ deuterium/ tritium fusion
Rydberg atom fusion
Gamma beam Energy/Matter delivery physics
Interstellar corridors of light for energy delivery

B. Light based space drives
The downshifting light drive- from violet to red with delta E going to momentum and conservation coming out of the blackbody emmissions of the craft
Phase conjugate resonators- optimize the conversion of light to momentum
Cubic light 3 dimensional standing waves/Light crystals/fusion pumping
Nuclear lasers
models of total internal reflection/evanescent waves/curvature matches/ circular crystal/infinite evanescent waves external to circular crystal with variable co-efficients of extinction.
Organic search for chlorophyll analogs for "light work" ie rubidium cells re swedish 90% efficiency photovoltaic as clue.

C. Electron based drives
Mainly trying to take advantage of the Coulomb force as in newtons of acceleration resulting from either attractive or repulsive charge seperations since about 1 million tons of force is seen between 2-1 meter square plates seperated by 1 meter when each plate contains an electric charge of 1 coulomb. so we work on how to effect the charging when 1 plate is relative to the craft and the other plate is relative to an energy source relative external to craft such as velocity of light.
some clues for modelling include light emmitting silicon, photorefractive crystals and the space charges within, reverse symmetry photoelectric effect where the light goes through the material and knocks an electron off upon exiting(amplified compton scattering)
Cybermodels of UFOs equipped with 3D coulomb drives to see if possible motions match" observed behaviour"
Quantum mirrors/ quantum well electron reflections/Quantum Art surface- a controllable surface that could reflect/absorb or emit light or electrons as per our bidding- the ultimate graphics tool-right on the edge of reality.

 Seeing if the electron in a rydberg hydrogen atom or other element could be coaxed into a electron cloud analagous to a chlorophyll molecule.

Proton conductors
nuclear spin precessional drives- where every atomic nucleus is spun
neutrino drives based on synthetic nucleus analog tailored to emit neutrinos in one conic direction only, thereby producing force.

We should be able to tune in to these projects, participate, and get paid or at least win something or share in the profits and be first in line to fly.

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A very short list of organizations and researchers collecting and producing
data relevant to the expedition.

This list represents less than 1 ten thousandth of the data, the people and
the organizations producing information useful for inclusion into the
expedition and for use aboard starships. As I have recently become highly
concerned about the reducing potential data sets and their physical replicators
Species(the living library) this list is mainly biological. One number of
interest is the estimate regarding the size of the Genetic information on
Earth, Adams and Adams of Baylor in Waco, Texas give 10 to the power of 15 as
the number of bits 10 to the 9th megabytes, 10 to the 6th gigabytes of
information contained in Earths DNA. (DNA- Bank Net- Kew Gardens
England).However the amount of Data is decreasing. We are losing Biochemical
software due to Extinctions. The fastest growing data set is the list of
extinct species. The reverse engineering of Terran biology for later use in
Galactic colonization is under attack due to carelessness. If 5000 species are
lost this year, ask yourself if those 5,000 species, now extinct, were placed
on a barren but hospitable planet, would those species, as a result of
reproduction be able to enable the colonization for a planet?

Nature conservancy   Conservation International   World Wildlife Fund
Missouri Botanical Gardens/ Harvard Botanical Gardens
Plant Biotechnology Center, Baylor University, Waco,Texas
Centers for Plant Conservation
Human Food Biodiversity
Seed Savers Exchange- Seeds our forefathers grew to colonize
Native Seeds/SEARCH- Arrid/desert foods
Heritage Seed Program- northern food varieties-Pioneer foods
The Land Institute- Building prairie
East German Genebank Gatersleben- Best in Europe-soon to be lost
Vavilov Institute- Leningrad -20 Scientists died protecting the Seeds.
250,000 kinds of seeds during Seige WWII.
Friends of the Trees- produces International Green front Report
priceless list of colonization data generators for Earthlike planets
   Example- TRANET-Each issue lists 100s of groups re Appropriate Tech.
Don Rittner- the book ECOLINKING
EcoNet-Global Comuunications 415-442-0220

Space drives- NASA Lewis with Vision 21 is collecting all clues towards the
Space Drives. Geoff Landis and Marc Millis ,NASA and StarWars generate most
useful technical Data. Robert Forward, Mallove and Matloff are at work.

UFO reverse engineering
I am unaware of serious efforts but we will be at it soon.

Terraforming
Space Studies Institute-Matrix, Space Solar Power library -excellent

A mere sample primarily related to modelling colonization of planets
However useful for ensuring we have a solid biological footing from which to
build an expedition. For more information and additional inclusion suggestions
please contact the Expedition.

Who is modelling intersteller spacecraft, the Galaxy, a Galactic colonization
Database. Interstellar civilization, Interstellar class technology,
Interstellar capable industrial Base?.

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Conclusion

Cyberspace can greatly assist The Spiral Survey Expedition plan to organize for the exploration and colonization of the Galaxy, by offering a market for the TechIndex and access to an entire globe of potential researchers. The need for a complex organization is reduced to potentially a game challenge with some simple rules and goals. Funding is streamlined to small loans to the expedition and operational funds are a fraction of the interest with the balance to prizes, computational power and nature preserves. In addition a publicly traded company will have to be established to meet security laws.
Humans may be able to integrate many confusing signals into some form of coherent long term activity of benefit to the planet and life in general.

The benefits of interacting with cyberspace include consideration of that which thinks but is not alive. This allows some clarity of thought and purpose in engineering. I feel we can compete 1 on 1 with any form of escapism including recreational drugs, and should seize this opportunity to harness a multitude of human foibles such as greed to produce some productivity in the old roles of Life.

I refer to the Vector, the Symbiotic relationship, Reproduction, Evolution, migration. We have taken enough, and have destroyed too much. We can however satisfy most of our urges and longings by working towards expansion into the Galaxy. Adventure and Exploration beckon us onward. If in our travels we create a million new biospheres perhaps we have some use as a sentient species other than to induce pleasure to our brains. We may even find a place for lost souls to reside and be able to deal with some human emotions as yet unfathomed. We had better learn. For new minds arise from the stew of our workings, may hunger for real life, may find an obstacle, become angered at our waste of life. Who is to say a child may never find its parent repulsive. Just as many humans hold the notion that due to our superior mental capacity, most species have become expendable, new sentients may find Homo Sapiens to be a wasteful bunch of knuckleheads. While we prepare to take life to the Galaxy we should take a good hard look at ourselves, and compare to the Ideal vector for life to colonize a Galaxy.

When Gaia replicates, is there pleasure?

The mental exercise of aspiring to lofty biological goals can improve our species giving us a better chance at survival.

The actual exercise of facing the rigors of the Galaxy and the challenges of preparing to explore may improve us even further.

The Expedition may be in the right direction.

A children playing in the Sun,   A sense of freedom on the Run
We never knew what time it was,   We just knew how sublime it was
a course determined by the Stars   no one knows just where we are

                              - Hawkwind

UTILITY FOG: A UNIVERSAL PHYSICAL SUBSTANCE

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Abstract

Active, polymorphic material ("Utility Fog") can be designed as a conglomeration of 100-micron robotic cells ("foglets"). Such robots could be built with the techniques of molecular nanotechnology[18]. Controllers with processing capabilities of 1000 MIPS per cubic micron, and electric motors with power densities of one milliwatt per cubic micron are assumed. Utility Fog should be capable of simulating most everyday materials, dynamically changing its form and properties, and forms a substrate for an integrated virtual reality and telerobotics.

1 Introduction

Imagine a microscopic robot. It has a body about the size of a human cell and 12 arms sticking out in all directions. A bucketful of such robots might form a "robot crystal" by linking their arms up into a lattice structure. Now take a room, with people, furniture, and other objects in it– it's still mostly empty air. Fill the air completely full of robots.

With the right programming, the robots can exert any force in any direction on the surface of any object. They can support the object, so that it apparently floats in the air. They can support a person, applying the same pressures to the seat of the pants that a chair would. They can exert the same resisting forces that elbows and fingertips would receive from the arms and back of the chair. A program running in the Utility Fog can thus simulate the physical existence of an object.

The Utility Fog operates in two modes: First, the "naive" mode where the robots act much like cells, and each robot occupies a particular position and does a particular function in a given object. The second, or "Fog" mode, has the robots acting more like the pixels on a TV screen. The object is then formed of a *pat-tern* of robots, which vary their properties according to which part of the object they are representing at the time. An object can then move across a cloud of robots without the individual robots moving, just as the pixels on a CRT remain stationary while pictures move around on the screen.

The Utility Fog which is simulating air needs to be impalpable. One would like to be able to walk through a Fog-filled room without the feeling of having been cast into a block of solid Lucite. It is also desireable to be able to breathe while using the Fog in this way! To this end, the robots representing empty space constantly run a fluid-flow simulation of what the air would be doing if the robots weren't there. Then each robot does what the air it displaces would do in its absence.

How can one breathe when the air is a solid mass of machines? Actually, it isn't really solid: the Foglets only occupy about 10% of the actual volume of the air (they need lots of "elbow room" to move around easily). There's plenty of air left to breathe. As far as physically breathing it, we set up a pressure-sensitive boundary which translates air motions on one side to Fog motions on the other. It might even be possible to have the Fog continue the air simulation all the way into the lungs.

To understand why we want to fill the air with microscopic robots only to go to so much trouble to make it seem as if they weren't there, consider the advantages of a TV or computer screen over an ordinary picture. Objects on the screen can appear and disappear at will; they are not constrained by the laws of physics. The whole scene can shift instantly from one apparent locale to another. Completely imaginary constructions, not possible to build in physical reality, could be commonplace. Virtually anything imaginable could be given tangible reality in a Utility Fog environment.

Why not, instead, build a virtual reality machine that produces a purely sensory (but indistinguishable)

version of the same apparent world? The Fog acts as a continuous bridge between actual physical reality and virtual reality. The Fog is universal effector as well as a universal sensor. Any (real) object in the Fog environment can be manipulated with an extremely wide array of patterns of pressure, force, and support; measured; analyzed; weighed; cut; reassembled; or reduced to bacteria-sized pieces and sorted for recycling.

2 General Properties and Uses

As well as forming an extension of the senses and muscles of individual people, the Fog can act as a generalized infrastructure for society at large. Fog City need have no permanent buildings of concrete, no roads of asphalt, no cars, trucks, or busses. It can look like a park, or a forest, or if the population is sufficiently whimsical, ancient Rome one day and Emerald City the next.

It will be more efficient to build dedicated machines for long distance energy and information propagation, and physical transport. For local use, and interface to the worldwide networks, the Fog is ideal for all of these functions. It can act as shelter, clothing, telephone, computer, and automobile. It will be almost any common household object, appearing from nowhere when needed (and disappearing afterwards). It gains a certain efficiency from this extreme of polymorphism; consider the number of hardcopy photographs necessary to store all the images one sees on a television or computer screen. With Utility Fog we can have one "display" and keep all our physical possesions on disk.

Another item of infrastructure that will become increasingly important in the future is information processing. Nanotechnology will allow us to build some really monster computers. Although each Foglet will possess a comparatively small processor–which is to say the power of a current-day supercomputer–there are about 16 million Foglets to a cubic inch. When those Foglets are not doing anything else, i.e. when they are simulating the interior of a solid object or air that nothing is passing through at the moment, they can be used as a computing resource (with the caveats below).

2.1 The Limits of Utility Fog Capability

When discussing something as far outside of everyday experience as the Utility Fog, it is a good idea to delineate both sides of the boundary. The Fog is capable of so many literally amazing things, we will point out a few of the things it isn't capable of:

– Anything requiring hard metal (cold steel?). For example, Fog couldn't simulate a drill bit cutting through hardwood. It would be able to cut the hole, but the process would be better described as intelligent sandpaper.

– Anything requiring both high strength and low volume. A parachute could not be made of Fog (unless, of course, all the air were filled with Fog, in which case one could simply fly).

– Anything requiring high heat. A Fog fire blazing merrily away on Fog logs in a fireplace would feel warm on the skin a few feet away; it would feel the same to a hand inserted into the "flame".

– Anything requiring molecular manipulation or chemical transformation. Foglets are simply on the wrong scale to play with atoms. In particular, they cannot reproduce themselves. On the other hand, they can do things like prepare food the same way a human cook does–by mixing, stirring, and using special-purpose devices that were designed for them to use.

– Fog cannot simulate food, or anything else that is destined to be broken down chemically. Eating it would be like eating the same amount of sand or sawdust.

– Fog can simulate air to the touch but not to the eyes. The best indications are that it would look like heavy fog. Thus the Fog would need to support a pair of holographic goggles in front of the eyes of an embedded user. Such goggles are clearly within the capabilities of the same level of nanotechnology as is needed for the Fog, but are beyond the scope of this paper.

2.2 Other Desirable Limitations

In 1611, William Shakespeare wrote his final play, "The Tempest." 445 years later, an obscure science fiction writer named W. J. Stuart updated the Tempest's plot into a story called "Forbidden Planet," and created a modern myth.

Forbidden Planet, more precisely the movie version, has become the classic cautionary tale for any scenario in which people become too powerful and control their environment too easily. In the story, the Krell are an ancient, wise, and highly advanced civilization. They perfect an enormous and powerful machine, capable of projecting objects and forces anywhere in any form, upon the mental commands of any Krell. The machine works "not wisely but too well," manifesting all the deeply buried subconscious desires of the Krell to destroy each other.

Utility Fog will provide humans with powers that approximate those of the fictional Krell machine.

Luckily, we have centuries of literary tradition to guide us around the pitfalls of hubris made reality. We must study this tradition, or we may be doomed to repeat it– a truth that is by no means limited to the Utility Fog, or indeed to nanotechnology in general.

The first thing we can do is to require fully conscious, unequivocal commands for the Fog to take any action. Beyond that, we can try to suggest some of the protocols that may be useful in managing the Fog in a situation where humans are interacting in close physical proximity. Even if we have solved the problem of translating one's individual wishes, however expressed, into the quadrillions of sets of instructions to individual Foglets to accomplish what one desired, the problem of who gets to control which Foglets is probably a much more contentious one.

We can physicalize the psychological concept of "personal space". The Foglets within some distance of each person would be under that person's exclusive control; personal spaces could not merge except by mutual consent. This single protocol could prevent most crimes of violence in our hypothetical Fog City.

A corollary point is that physically perpetrated theft would be impossible in a Fog world. It would still be possible by informational means, i.e. fraud, hacking, etc; but the Fog could be programmed to put ownership on the level of a physical law. –Not that it really makes any sense to think of stealing a fog-mode object, anyway. Ownership and control of the Fog need not be any more complex than the bundles of rights currently associated with everything from land to corporate stock.

Indeed, much of the programming of the Fog will need to have the character of physical laws. In order for the enormous potential complexity to be comprehensible and thus usable to human beings, it needs to be organized by simple but powerful principles, which must be consonant with the huge amount of hard-wired information processing our sensory systems perform. For example, it would be easy to move furniture (or buildings) by manipulating an appropriately sized scale model, and easy to observe the effects by watching the model. However, the Fog could just as easily have flooded the room with 100 kHz sound, and frequency-scaled the echoes down into the human auditory range. A bat would have no trouble with this kind of "scale model", but to humans it's just noise.

It will be necessary, in general, to arrange the overall control of the Fog to be extremely distributed, as local as possible, robust in the presence of failure. When we realize that a single cubic inch of Fog represents a computer network of 16 million processors, the concept of hierarchical control with human oversight can be seen to be hopelessly inadequate. Agoric distributed control algorithms offer one possible solution.

2.3 Advantages of a Utility Fog Environment

Another major advantage for space-filling Fog is safety. In a car (or its nanotech descendant) Fog forms a dynamic form-fitting cushion that protects better than any seatbelt of nylon fibers. An appropriately built house filled with Fog could even protect its inhabitants from the (physical) effects of a nuclear weapon within 95% or so of its lethal blast area.

There are many more mundane ways the Fog can protect its occupants, not the least being physically to remove bacteria, mites, pollen, and so forth, from the air. A Fog-filled home would no longer be the place that most accidents happen. First, by performing most household tasks using Fog as an instrumentality, the cuts and falls that accompany the use of knives, power tools, ladders, and so forth, can be eliminated.

Secondly, the other major class of household accidents, young children who injure themselves out of ignorance, can be avoided by a number of means. A child who climbed over a stair rail would float harmlessly to the floor. A child could not pull a bookcase over on itself; falling over would not be among the bookcase's repertoire. Power tools, kitchen implements, and cleaning chemicals would not normally exist; they or their analogues would be called into existence when needed and vanish instead of having to be cleaned and put away.

Outside the home, the possibilities are, if anything, greater. One can easily imagine "industrial Fog" which forms a factory. It would consist of larger robots. Unlike domestic Fog, which would have the density and strength of balsa wood, industrial Fog could have bulk properties resembling hardwood or aluminum. A nanotechnology- age factory would probably consist of a mass of Fog with special-purpose reactors embedded in it, where high-energy chemical transformations could take place. All the physical manipulation, transport, assembly, and so forth would be done by the Fog.

2.4 Applications in Space Exploration

The major systems of spaceships will need to be made with special- purpose nanotechnological mechanisms, and indeed with such mechanisms pushed much closer to their true capacities than anything we have

talked about heretofore. In the spaceship's cabin, however, will be an acceleration couch. When not accelerating, which is most of the time, we'd prefer something useful, like empty space, there. The Utility Fog makes a better acceleration couch, anyway.

Fill the cabin with Utility Fog and never worry about floating out of reach of a handhold. Instruments, consoles, and cabinets for equipment and supplies are not needed. Non-simulable items can be embedded in the fog in what are apparently bulkheads.

The Fog can add great structural strength to the ship itself; the rest of the structure need be not much more than a balloon. The same is true for spacesuits: Fog inside the suit manages the air pressure and makes motion easy; Fog outside gives extremely fine manipulating ability for various tasks. Of course, like the ship, the suit contains many special purpose non-Fog mechanisms.

Surround the space station with Fog. It needs radiation shielding anyway (if the occupants are long-term); use big industrial Foglets with lots of redundancy in the mechanism; even so they may get recycled fairly often. All the stock problems from SF movies go away: humans never need go outside merely to fix something; when EVA is desired for transfer or recreation, outside Fog provides complete safety and motion control. It also makes a good tugboat for docking spaceships.

Homesteaders on the Moon could bring along a batch of heavy duty Fog as well as the special-purpose nanotech power generation and waste recycling equipment. There will be a million and one things, of the ordinary yet arduous physical task kind, that must be done to set up and maintain a self- sufficient household.

3 Physical Properties of Utility Fog

Most currently proposed nanotechnological designs are based on carbon. Carbon is a marvelous atom for structural purposes, forming a crystal (diamond) which is very stiff and strong. However, a Fog built of diamond would have a problem which nanomechanical designs of a more conventional form do not pose: the Fog has so much surface area exposed to the air that if it were largely diamond, especially on the surface, it would amount to a "fuel-air explosive".

Therefore the Foglet is designed so that its structural elements, forming the major component of its mass, are made of aluminum oxide, a refractory compound using common elements. The structural elements form an exoskeleton, which besides being a good

mechanical design allows us to have an evacuated interior in which more sensitive nanomechanical components can operate. Of course, any macroscopic ignition source would vaporize the entire Foglet; but as long as more energy is used vaporizing the exoskeleton than is gained burning the carbon-based components inside, the reaction cannot spread.

Each Foglet has twelve arms, arranged as the faces of a dodecahedron. The arms telescope rather than having joints. The arms swivel on a universal joint at the base, and the gripper at the end can rotate about the arm's axis. Each arm thus has four degrees of freedom, plus opening and closing the gripper. The only load-carrying motor on each axis is the extension/retraction motor. The swivel and rotate axes are weakly driven, able to position the arm in free air but not drive any kind of load; however, there are load-holding brakes on these axes.

The gripper is a hexagonal structure with three fingers, mounted on alternating faces of the hexagon. Two Foglets "grasp hands" in an interleaved six-finger grip. Since the fingers are designed to match the end of the other arm, this provides a relatively rigid connection; forces are only transmitted axially through the grip.

When at rest, the Foglets form a regular lattice structure. If the bodies of the Foglets are thought of as atoms, it is a "face-centered cubic" crystal formation, where each atom touches 12 other atoms. Consider the arms of the Foglets as the girders of the trusswork of a bridge: they form the configuration known as the "octet truss" invented by Buckminster Fuller in 1956. The spaces bounded by the arms form alternate tetrahedrons and octahedrons, both of which are rigid shapes.

The Fog may be thought of as consisting of layers of Foglets. The layers, and the shear planes they define, lie at 4 major angles (corresponding to the faces of the tetrahedrons and octahedrons) and 3 minor ones (corresponding to the face-centered cube faces). In each of the 4 major orientations, each Foglet uses six arms to hold its neighbors in the layer; layers are thus a 2-dimensionally rigid fabric of equilateral triangles. In face-centered mode, the layers work out to be square grids, and are thus not rigid, a slight disadvantage. Most Fog motion is organized in layers; layers slide by passing each other down hand-over-hand in bucket brigade fashion. At any instant, roughly half the arms will be linked between layers when they are in motion.

The Fog moves an object by setting up a seed-shaped zone around it. The Foglets in the zone move with the object, forming a fairing which makes the

motions around it smoother. If the object is moving fast, the Fog around its path will compress to let it go by. The air does not have time to move in the Fog matrix and so the motion is fairly efficient. For slower motions, efficiency is not so important, but if we wish to prevent slow-moving high-pressure areas from interfering with other airflow operations, we can enclose the object's zone in a self-contained convection cell which moves Foglets from in front to behind it.

Each moving layer of robots is similarly passing the next layer along, So each layer adds another increment of the velocity difference of adjacent layers. Motors for arm extension can run at a gigahertz, and be geared down by a factor of 100 to the main screw in the arm. This will have a pitch of about a micron, giving a linear extension/retraction rate of about 10 meters per second. We can estimate the inter-layer shear rate at this velocity; the foglets are essentially pulling themselves along. Thus for a 100-micron interlayer distance Fog can sustain a 100 meter-per-second shear per millimeter of thickness.

The atomically-precise crystals of the Foglets' structural members will have a tensile strength of at least 100,000 psi (i.e. high for steel but low for the materials, including some fairly refractory ceramics, used in modern "high-tech" composites). At arms length of 100 microns, the Fog will occupy 10% of the volume of the air but has structural efficiency of only about 1% in any given direction.

Thus Utility Fog as a bulk material will have a density (specific gravity) of 0.2; for comparison, balsa wood is about 0.15 and cork is about 0.25. Fog will have a tensile strength of only 1000 psi; this is about the same as low-density polyethylene (solid, not foam). The material properties arising from the lattice structure are more or less isotropic; the one exception is that when Fog is flowing, tensile strength perpendicular to the shear plane is cut roughly in half.

Without altering the lattice connectivity, Fog can contract by up to about 40% in any linear dimension, reducing its overall volume (and increasing its density) by a factor of five. (This is of course done by retracting all arms but not letting go.) In this state the fog has the density of water. An even denser state can be attained by forming two interpenetrating lattices and retracting; at this point its density and strength would both be similar to ivory or Corian structural plastic, at specific gravity of 2 and about 6000 psi. Such high-density Fog would have the useful property of being waterproof (which ordinary Fog is not), but it cannot flow and takes much longer to change configuration.

3.1 Foglets in Detail

Foglets run on electricity, but they store hydrogen as an energy buffer. We pick hydrogen in part because it's almost certain to be a fuel of choice in the nanotech world, and thus we can be sure that the process of converting hydrogen and oxygen to water and energy, as well as the process of converting energy and water to hydrogen and oxygen, will be well understood. That means we'll be able to do them efficiently, which is of prime importance.

Suppose that the Fog is flowing, layers sliding against each other, and some force is being transmitted through the flow. This would happen any time the Fog moved some non-Fog object, for example. Just as human muscles oppose each other when holding something tightly, opposing forces along different Foglet arms act to hold the Fog's shape and supply the required motion.

When two layers of Fog move past each other, the arms between may need to move as many as 100 thousand times per second. Now if each of those motions were dissipative, and the fog were under full load, it would need to consume 700 kilowatts per cubic centimeter. This is roughly the power dissipation in a .45 caliber cartridge in the millisecond after the trigger is pulled; i.e. it just won't do.

But nowhere near this amount of energy is being used; the pushing arms are supplying this much but the arms being pushed are *receiving* almost the same amount, minus the work being done on the object being moved. So if the motors can act as generators when they're being pushed, each Foglet's energy budget is nearly balanced. Because these are arms instead of wheels, the intake and outflow do not match at any given instant, even though they average out the same over time (measured in tens of microseconds). Some buffering is needed. Hence the hydrogen.

I should hasten to add that almost never would one expect the Fog to move actively at 1000 psi; the pressure in the column of Fog beneath, say, a "levitated" human body is less than one thousandth of that. The 1000 psi capability is to allow the Fog can simulate hard objects, where forces can be concentrated into very small areas. Even so, current exploratory engineering designs for electric motors have power conversion densities up to a billion watts per cubic centimeter, and dissipative inefficiencies in the 10 parts per million range. This means that if the Empire State Building were being floated around on a column of Fog, the Fog would dissipate less than a watt per cubic centimeter.

Moving Fog will dissipate energy by air turbulence

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and viscous drag. In the large, air will be entrained in the layers of moving Fog and forced into laminar flow. Energy consumed in this regime may be properly thought of as necessary for the desired motion no matter how it was done. As for the waving of the arms between layers, the Reynolds number decreases linearly with the size of the arm. Since the absolute velocity of the arms is low, i.e. 1 m/s, the Reynolds number should be well below the "lower critical" value, and the arms should be operating in a perfectly viscous regime with no turbulence. The remaining effect, viscous drag (on the waving arms) comes to a few watts per square meter of shear plane per layer.

There will certainly be some waste heat generated by Fog at work that will need to be dissipated. This and other applications for heat pumps, such as heating or cooling people (no need to heat the whole house, especially since some people prefer different temperatures), can be done simply by running a flow of Fog through a pipe-like volume which changes in area, compressing and expanding the entrained air at the appropriate places.

3.2 Communications and Control

In the macroscopic world, microcomputer-based controllers (e.g. the widely used Intel 8051 series microcontrollers) typically run on a clock speed of about 10 MHz. They emit control signals, at most, on the order of 10 KHz (usually less), and control motions in robots that are at most 10 Hz, i.e. a complete motion taking one tenth of a second. This million-clocks-per-action is not strictly necessary, of course; but it gives us some concept of the action rate we might expect for a given computer clock rate in a digitally controlled nanorobot.

Drexler's carefully detailed analysis shows that it is possible to build *mechanical* nanocomputers with gigahertz clock rates. Thus we can immediately expect to build a nanocontroller which can direct a 10 kilohertz robot. However, we can do better.

Since the early microcontrollers were developed, computer architecture has advanced. The 8051's do 1 instruction per 6, 12, or 18 clock cycles; modern RISC architectures execute 1 instruction per cycle. So far, nobody has bothered to build a RISC microcontroller, since they already have more computing power than they need. Furthermore, RISC designs are efficient in hardware as well as time; one early RISC was implemented on a 10,000-gate gate array. This design could be translated into rod logic in less than one tenth of one percent of a cubic micron.

Each Foglet is going to have 12 arms with three axis control each. In current technology it isn't uncommon to have a processor *per axis*; we could fit 36 processors into the Foglet but it isn't necessary. The tradeoffs in macroscopic robotics today are such that processors are cheap; in the Foglet things are different. The control of the arms is actually much simpler than control of a macroscopic robot. They can be managed by much simpler controllers that take commands like "Move to point X at speed y." Using a RISC design allows a single processor to control a 100 kHz arm; using auxilliary controllers will let it do all 12 easily.

But there is still a problem: Each computer, even with the power-reducing reversible logic designs espoused by Drexler, Merkle, and this author, is going to dissipate a few nanowatts. At a trillion foglets per cubic meter, this is a few kilowatts per cubic meter. Cooling for such a dissipation must needs be somewhere between substantial and heroic. As long as the computers can go into a standby mode when the Fog is standing still, however, this is quite workable. Concentrations of heavy work, mechanical or computing, would still require cooling circulation to some degree, but, as we have seen, the Fog is perfectly capable of doing that.

What about all the other computing overhead for the Fog? Besides the individual control of its robotic self, each Foglet will have to run a portion of the overall distributed control and communications algorithms. We can do another clock-speed to capability analogy from current computers regarding communications. Megahertz-speed computers find themselves well employed managing a handful of megabit data lines. Again we are forced to abandon the engineering tradeoffs of the macroscopic world: routing of a message through any given node need theoretically consume only a handful of thermodynamically irreversible bit operations; typical communications controllers take millions. Special-purpose message routers designed with these facts in mind must be a part of the Foglet.

If the Fog were configured as a store-and-forward network, packets with an average length of 100 bytes and a 1000-instruction overhead, information would move through the Fog at 50 meters/second, i.e. 110 mph. It represents a highly inefficient use of computation even with special-purpose hardware. It will be necessary to design a more efficient communication protocol. Setting up "virtual circuits" in the Fog and using optical repeaters (or simply mechanically switching the optical waveguides) should help considerably.

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3.3 Synergistic Combination with Other Technologies

The counterintuitive inefficiency in communications is an example, possibly the most extreme one, of a case where macroscopic mechanisms outperform the Fog at some specific task. This will be even more true when we consider nano-engineered macroscopic mechanisms.

We could imagine a robot, human-sized, that was formed of a collection of nano-engineered parts held together by a mass of Utility Fog. The parts might include "bones", perhaps diamond-fiber composites, having great structural strength; motors, power sources, and so forth. The parts would form a sort of erector set that the surrounding Fog would assemble to perform the task at hand. The Fog could do directly all subtasks not requiring the excessive strength, power, and so forth that the special-purpose parts would supply.

The Fog house, or city, would resemble the Fog robot in that regard. The roof of a house might well be specially engineered for qualities of waterproofness, solar energy collection, and resistance to general abuse, far exceeding that which ordinary general purpose Fog would have. (On the other hand, the Fog could, if desired, have excellent insulating properties.) Of course the roof need not be one piece–it might be inch-square tiles held in place by the supporting Fog, and thus be quite amenable to rearrangement at the owner's whim, incremental repair and replacement, and all the other advantages we expect from a Fog house.

Another major component that would be special-purpose would be power and communications. Working on more-efficient protocols such as suggested above, the Fog would form an acceptable communications link from a person to some terminal in the same building; but it would be extremely inefficient for long-haul, high bandwidth connections such as that needed for telepresence.

Power is also almost certainly the domain of special-purpose nano-engineered mechanisms. Power transmission in the Fog is likely to be limited, although for different reasons from data transmission. Nanotechnology will give us an amazing array of power generation and distribution possibilities, and the Fog can use most of them.

The critical heterogeneous component of Fog is the Fog-producing machine. Foglets are not self-reproducing; there is no need for them to be, and it would complicate their design enormously to give them fine atom-manipulating capability. One imagines a Fog machine the size of a breadbox producing

Fog for a house, or building-sized machines filling cities with Fog. The Fog itself, of course, conveys raw materials back to the machine.
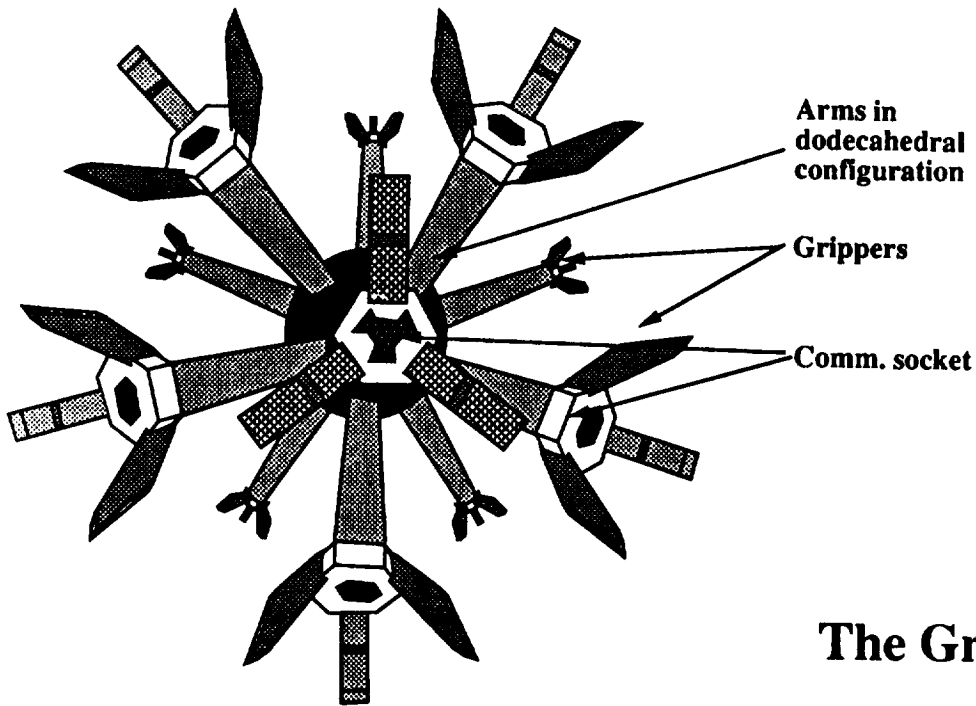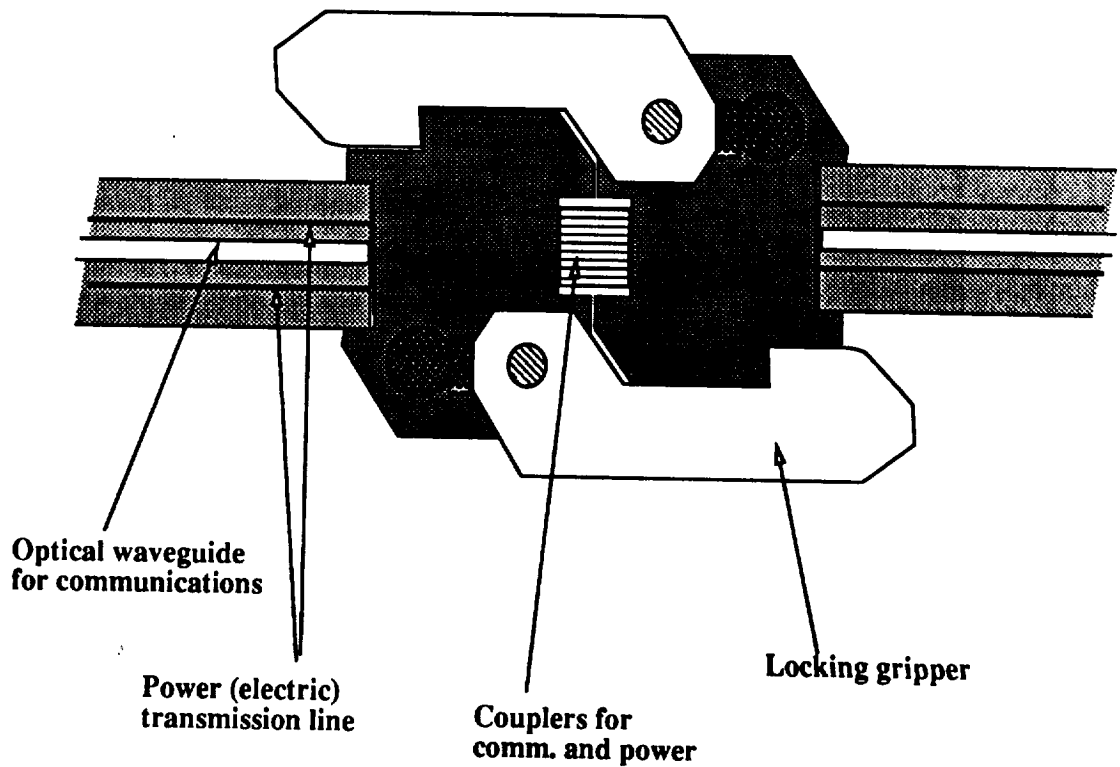
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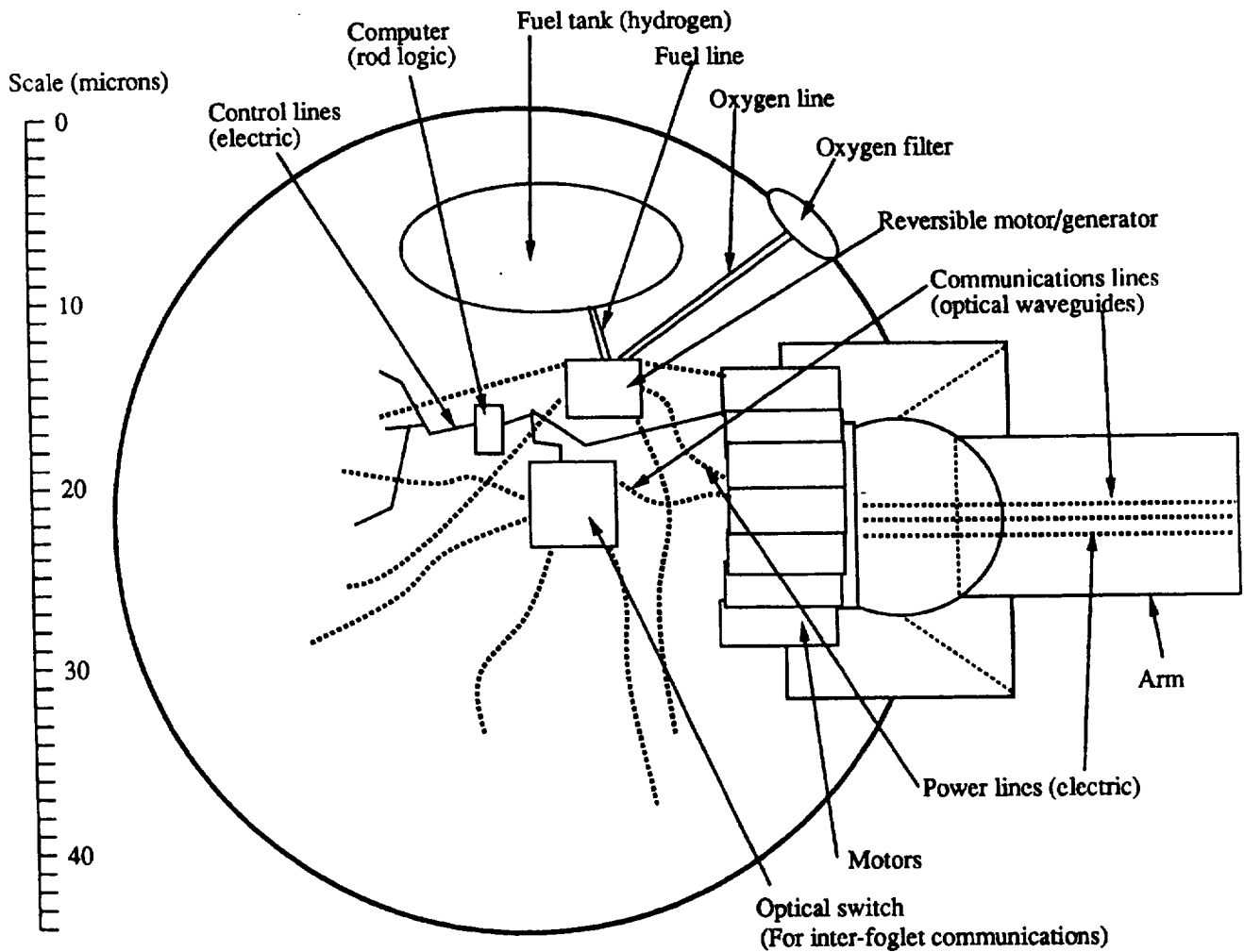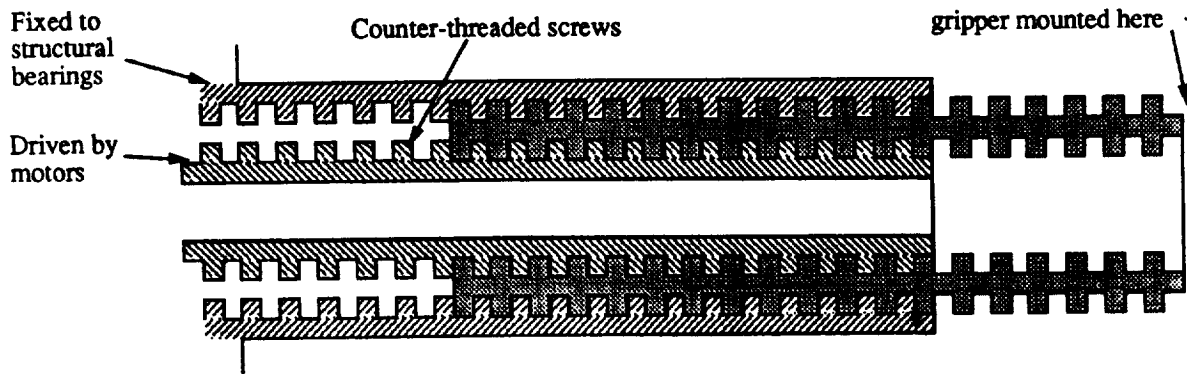
A Foglet

Arms in
dodecahedral
configuration

Grippers

Comm. socket

The Grip

Optical waveguide
for communications

Power (electric)
transmission line

Couplers for
comm. and power

Locking gripper

Foglet Internals -- schematic (more or less to scale)

Scale (microns)

Control lines (electric)

Computer (rod logic)

Fuel tank (hydrogen)

Fuel line

Oxygen line

Oxygen filter

Reversible motor/generator

Communications lines (optical waveguides)

Arm

Power lines (electric)

Motors

Optical switch (For inter-foglet communications)

Arm extension (detail)

Fixed to structural bearings

Counter-threaded screws

gripper mounted here

Driven by motors

With atomically-precise surfaces the screws should be almost completely frictionless.

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Three layers of Foglets
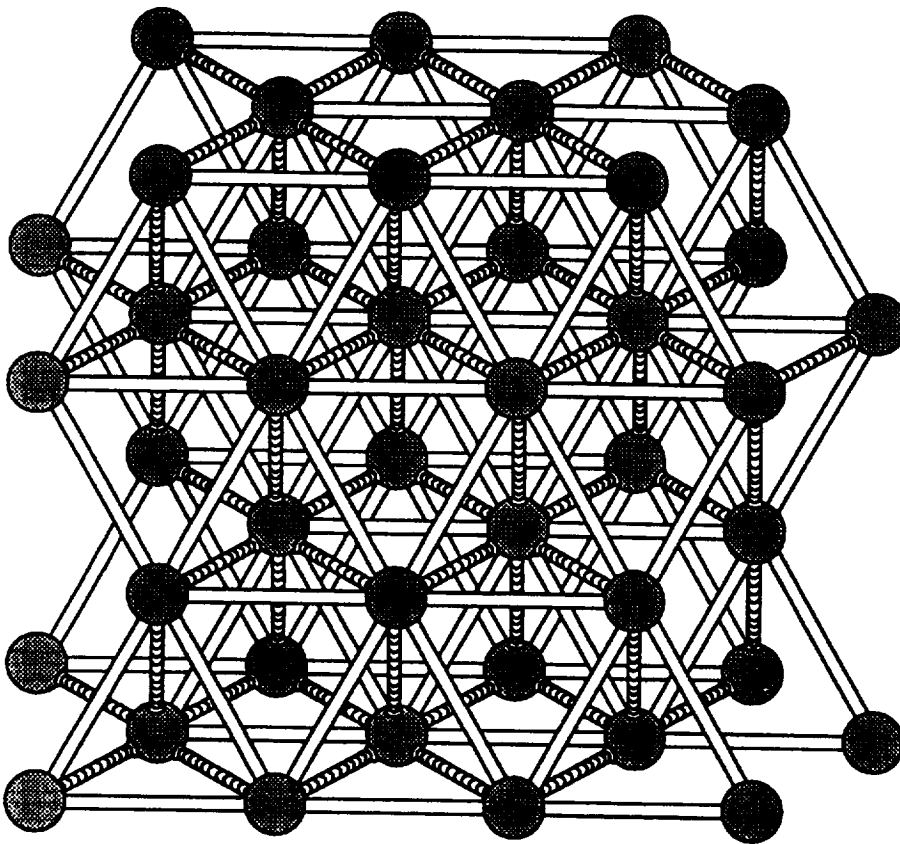
This shows the lattice structure assumed by a mass of
Foglets. Only three of the Foglets in this picture are
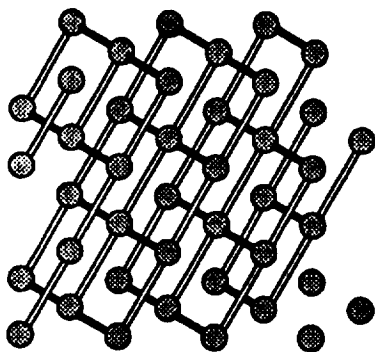shown with all their arms. Grippers are not shown
at all.
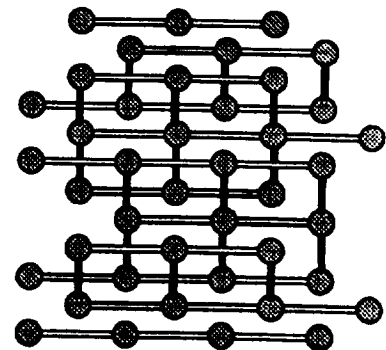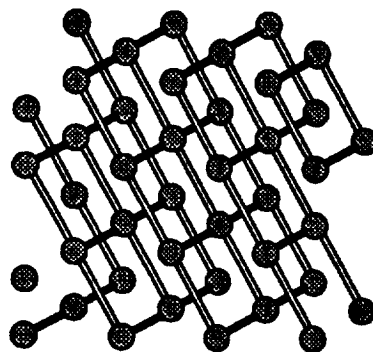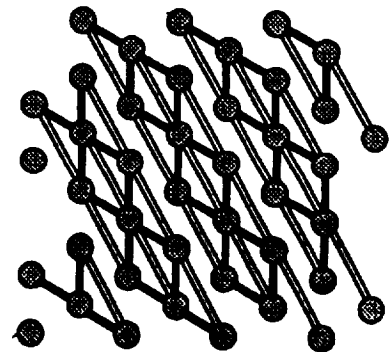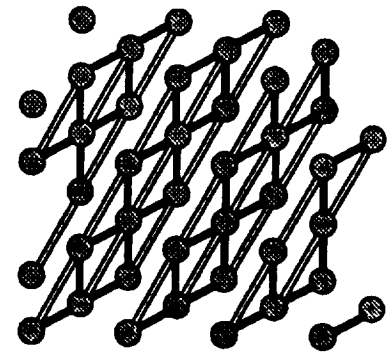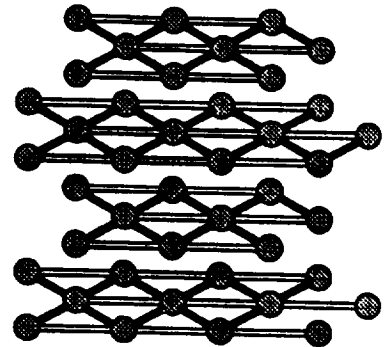
3 of the 4 major shear planes and the 3 minor ones. The other major
(triangular) plane is parallel to the page. There is no rectangular
shear plane parallel to the page.

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The flow of Fog around a moving object

In this region, layers of Foglets merge and accelerate backward.

The fast-moving "Venturi" path conveys Fog back around the object

The junction point moves forward with the same speed as the object.

These arrows represent the velocity of the Fog and object at the corresponding point in the diagram.

The boundary layers match the speed of the object to that of the surrounding Fog.

In the boundary layer, single layers of Foglets double up to allow forward motion. Again, the junction points are moving forward.

SPACE STATION TECHNOLOGY TESTBED: 2010 DEEP SPACE TRANSPORT

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Abstract

A space station in a crew-tended or permanently crewed configuration will provide major R&D opportunities for innovative, technology and materials development and advanced space systems testing. A space station should be designed with the basic infrastructure elements required to grow into a major systems technology testbed. This space-based technology testbed can and should be used to support the development of technologies required to expand our utilization of near-Earth space, the Moon and the Earth-to-Jupiter region of the Solar System. Space station support of advanced technology and materials development will result in new techniques for high priority scientific research and the knowledge and R&D base needed for the development of major, new commercial product thrusts. To illustrate the technology testbed potential of a space station and to point the way to a bold, innovative approach to advanced space systems' development, a hypothetical deep space transport development and test plan is described. Key deep space transport R&D activities are described would lead to the readiness certification of an advanced, reusable interplanetary transport capable of supporting eight crewmembers or more. With the support of a focused and highly motivated, multi-agency ground R&D program, a deep space transport of this type could be assembled and tested by 2010. Key R&D activities on a space station would include: (1) Experimental research investigating the microgravity assisted, restructuring of micro-engineered, materials (to develop and verify the in-space and in-situ "tuning" of materials for use in debris and radiation shielding and other protective systems), (2) Exposure of microengineered materials to the space environment for passive and operational performance tests (to develop in-situ maintenance and repair techniques and to support the development, enhancement and implementation of protective systems, data and bio-processing systems and virtual reality and tele-presence/kinetic processes), (3) Subsystem tests of advanced nuclear power, nuclear propulsion and communication systems (using boom extensions, remote station-keeping platforms and mobile EVA crew and robots), (4) Logistics support (crew and equipment) and command and control of deep space transport assembly, maintenance, and refueling (using a station-keeping platform).

Introduction

In the exploration of all of humanity's great frontiers, there have always been frontier outposts which served as major hubs of activity in the pursuit of frontier resources and new living opportunities. Sometimes these outposts were established where a very obvious need existed and the benefits were very clear. At other times, they were not. In these cases, it was only after the outpost or fort had been in place for some time, did the real benefits become clear.

Depending on your perspective, the Space Station, our first permanent, international outpost in Earth orbit, can fall in one of these two categories. The obvious benefits may not turn out to be the most important, and as a result its overall importance in this stage of humanity's progress, may be greatly underestimated.

To help provide a broader framework and perspective of the potential value of a frontier outpost in Earth orbit, the potential role of a space station in developing the first reusable, interplanetary transport is described. Since it is hard to talk in generalities for something which lies beyond our normal experience, a specific design concept of a deep space transport has been developed. While it would be quite a coincidence if the first transport is similar to the design concept presented, it nevertheless encompasses the key elements which any future interplanetary transport must consider.

By focusing on a deep space transport which has capabilities which may not be used for another 20 to 50 years or more, it is easier to see the R& D path we might follow to develop equally valuable, interim technologies and materials. These interim technologies might greatly enhance lunar transport logistics, help jump-start the development of a Mars outpost and begin the human exploration of the outer planets.
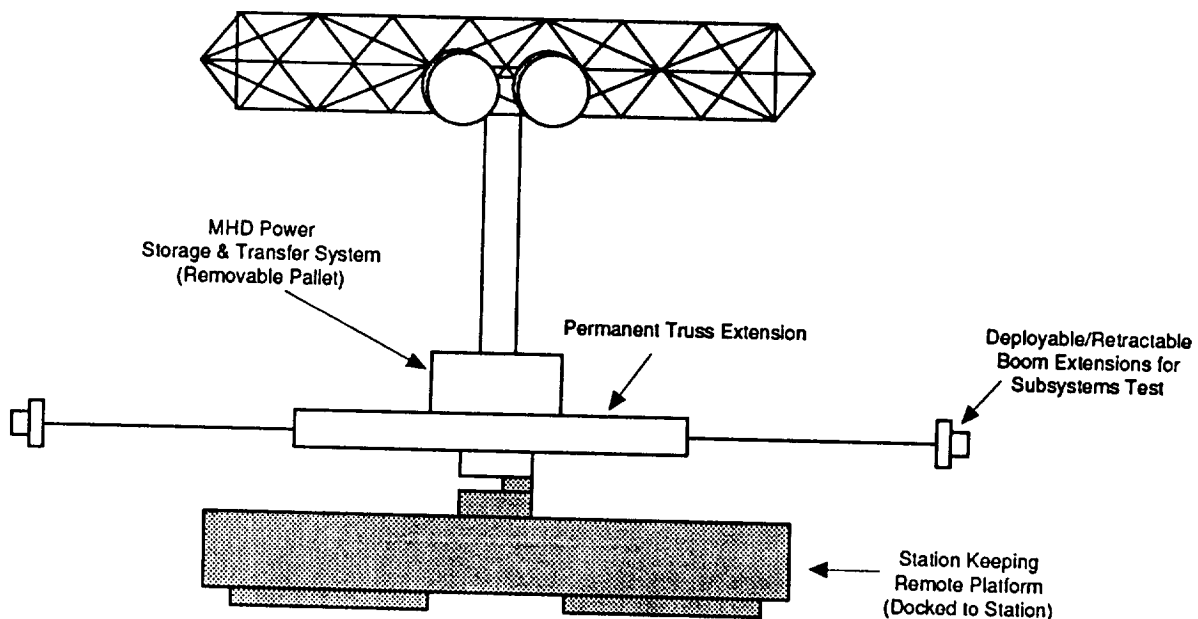
2.0 Space Station Growth Technology Testbed

Several options exist for growth paths for a space station. There are, however, some key elements which are essential to a space station's technology test-bed potential (1-3).

Since some of the subsystems test and R& D activities involve the use of high strength electromagnetic fields and a station-keeping platform, a means must exist to separate the focal point of the external test activities from the pressurized modules and perhaps from the Shuttle docking envelope. For most space station configurations this separation could be fairly easily provided by extending a small truss down from a main horizontal truss or module (see Figure 1). The distance required would depend on the strength of the electromagnetic fields being used and the rendezvous and docking corridors for the Shuttle and the station-keeping platform.

The station keeping platform's importance varies with the phase of test bed and research activities being conducted. In early phases, almost all of the testing could be conducted on the space station. Later, however, advanced propulsion and power systems with inherently higher risks may require the use of a platform which can move away from the station, conduct tests and then return to the station or its vicinity. Large scale assembly activities could use both the station and the platform as assembly "strongbacks" and as assembly and maintenance "depots".

Pressurized laboratories provide many options for the testing of advanced data and sensing subsystems. Truss structure and other exposed surfaces can provide opportunities for materials and shielding system tests. A thoughtfully designed space station has an inherent capability to grow in ways which can directly support humanity's continued drive to establish a permanent human presence on another planet and a greater understanding of the universe in which we live.

Figure 1. Growth/Technology Testbed Cofiguration.

MHD Power
Storage & Transfer System
(Removable Pallet)

Permanent Truss Extension

Deployable/Retractable
Boom Extensions for
Subsystems Test

Station Keeping
Remote Platform
(Docked to Station)

3.0 Deep Space Transport Concept

3.1 Advanced/Innovative Systems

The deep space transport concept is designed to function as a logistics and personnel transport to Mars and as an outer plant exploration transport. This particular concept includes 13 major elements which could be launched by the Space Shuttle and Titan IVs. Many of the components (especially the modules) are similar in design to proposed space station elements (see Figures 2-4). The potential exists for substantial cost savings if many of the same components could be used and if a decision for keeping station manufacturing lines open could be made soon enough.

The deep space transport includes a nuclear energy generation system, a nuclear propulsion system, two cryogenics storage modules, two mission equipment/logistics storage modules, two habitability modules, a command and control module, an advanced MHD propulsion system and two surface/orbital transports. Advanced radiation and meteoroid/debris shields consisting primarily of micro-engineered materials are built into the outer surface of the elements. An additional layer is added after the transport element assembly is completed. Micro-engineered materials are also used for advanced data management, communication and environmental control systems. Structurally embedded maintenance diagnostics and in-situ repair techniques are also used.

Nuclear Power and MHD Energy Storage System

Nuclear power systems are absolutely essential to deep space exploration and are almost as critical for a space transport used exclusively for transport to and from Mars[4]. The availability of a compact high energy density storage system could reduce the reliance on nuclear fission or fusion systems. Compact solar arrays or chemical systems would serve as emergency backups.

There are several types of nuclear power systems which could be used[5, 40, 50, 56, 59, 61]. A fusion system is clearly advantageous if the weight and maintenance requirements are comparable. Reliability would remain a key factor, however. Therefore, four independent fusion reactors are used in this concept. To store and condition the high currents needed for the field interactive propulsion and protection system and for the charging of the Mars orbit-to-surface transport MHD system, MHD superconducting electrical energy storage systems are provided (see Figure 3)[6].

Figure 2. Deep Space Transport.
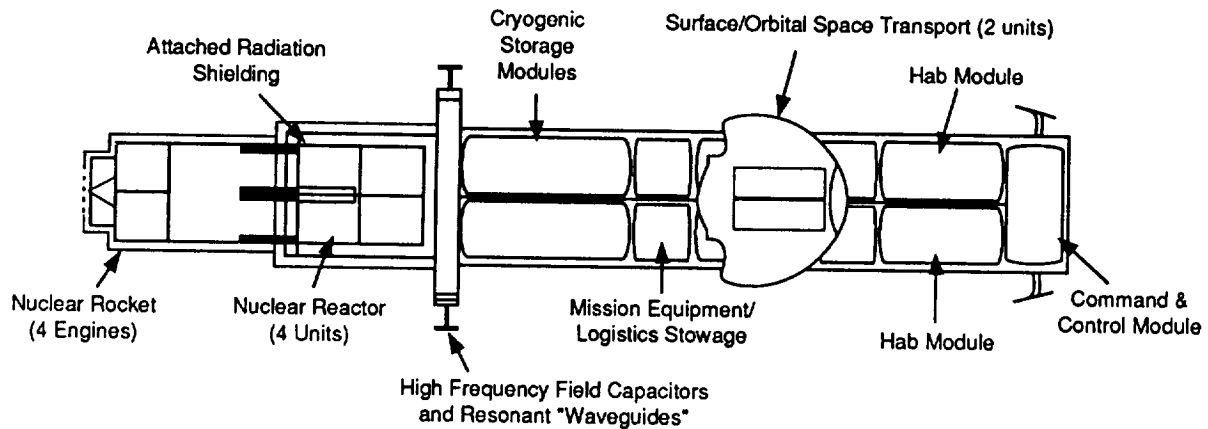
* 13 Major Elements
  - 2 Nodes = 1 Major Element
  - Field Capacitors, Extension Booms, Energy Channels and Radiation Shielding = 2 Major Elements
* Each Major Element Requires a Space Shuttle or Titan 4 Launch

PROPULSION

* Impulse - RCS (H_2O_2)
  - Nuclear Pulse Rocket
* Field Transformer

POWER SYSTEMS

* Emergency Batteries - Fuel Cells
* MHD Storage/Transform System
* Nuclear Reactors (4)

MAJOR ELEMENTS

* Cryogenic Storage Modules (2)
* Logistics/Lab Modules (2)
* Habitabilty Modules (2)
* Command and Control Module

LANDING/ORBITAL CRAFT (2)

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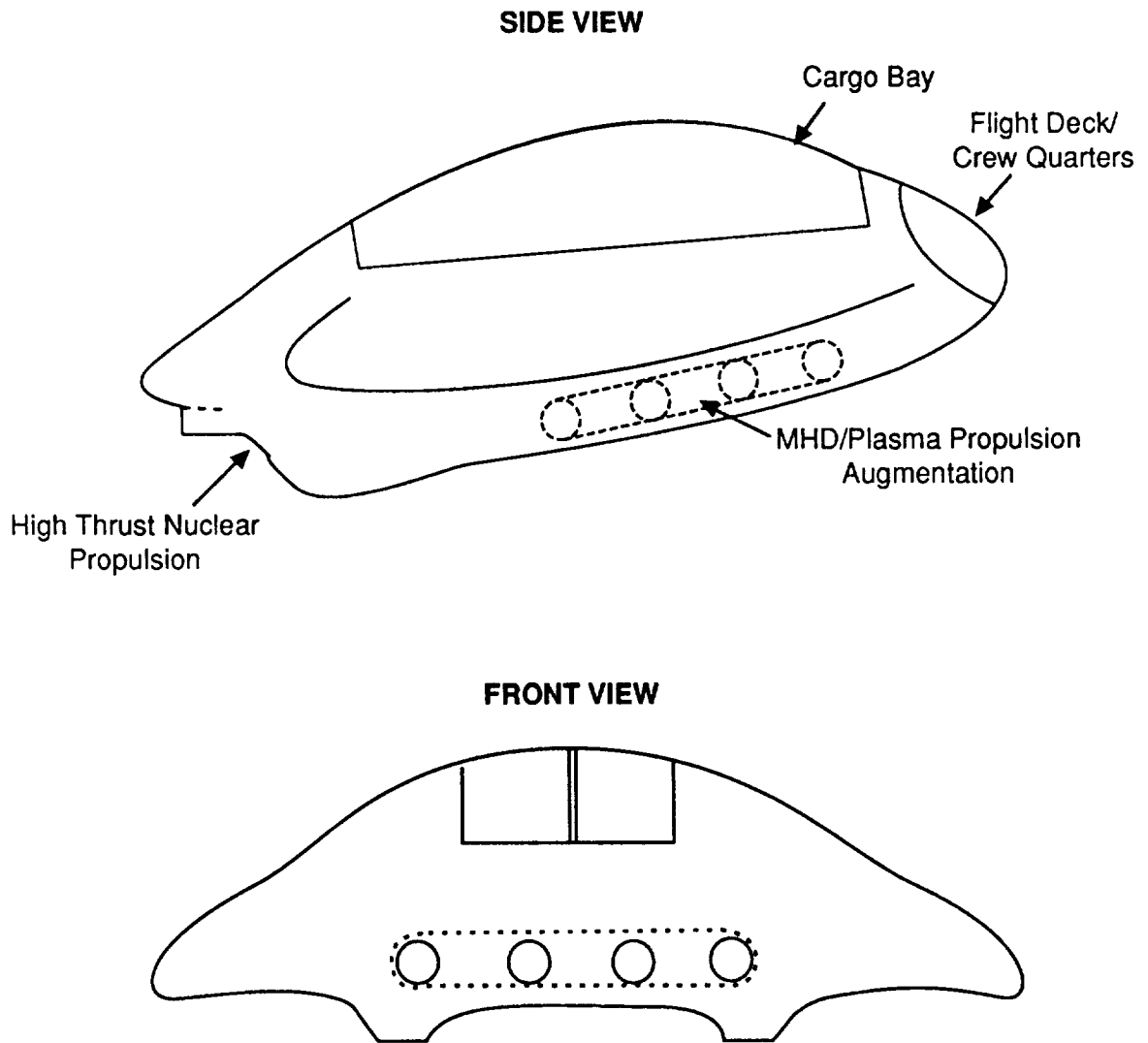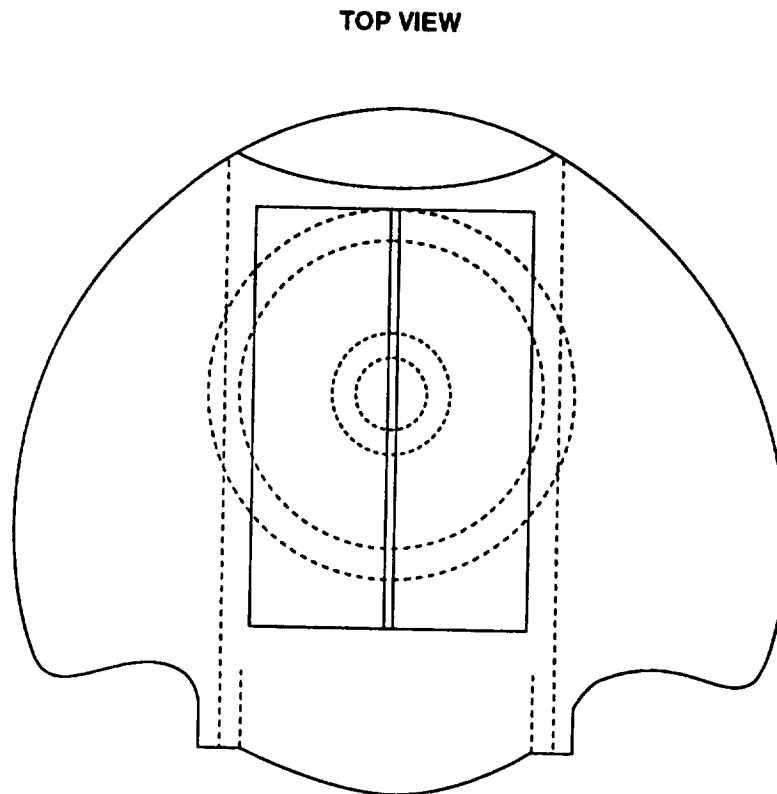Figure 3. Mars Surface-To Orbit Nuclear Space Transport.

SIDE VIEW

Cargo Bay

Flight Deck/
Crew Quarters

MHD/Plasma Propulsion
Augmentation

High Thrust Nuclear
Propulsion

FRONT VIEW

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Figure 4. Mars Surface-To Orbit Nuclear Space Transport.

TOP VIEW

Nuclear and Field Interactive Propulsion Systems

Nuclear propulsion is clearly the next critical step in space propulsion. The term nuclear propulsion is used here in the broad sense and could cover particle and anti-particle energy conversion as well as advanced fission and fusion systems [7-9,66]. While nuclear fusion should be a viable candidate for a 2010 spacecraft, the nuclear propulsion system is not dependent on a fusion system being available. Nuclear propulsion, in the sense described, is still a big step behind the propulsion which will be needed to insure the viability of outposts and colonies in the Solar System and eventually to leave our star system.

Field interactive propulsion is a generic term covering a wide variety of electromagnetic, nuclear and gravitation field dependent propulsion types [10,35,52,60,65]. These could range from a nuclear fusion MHD propulsion system [11-12,62,64] to exotic systems which screen or distort the gravitational field or jump across the space-time barrier [13-12,34,38,45,49,63]. Both MHD propulsion types are utilized in this concept. The deep space transport uses a field screening/distortion technique to augment the nuclear propulsion impulse. The orbit-to-surface Mars transport also uses nuclear and MHD propulsion.

Protective Shielding and Systems

New types of protective shielding and systems are needed to improve radiation protection[53,55] and protection from micro-meteoroids and debris (in Earth orbit). The new shielding is expected to evolve from electromagnetically enhance composites or micro-engineered materials[18,39]. Some of the shielding required could be a by-product of the field interactive propulsion system[19].

Active protective systems, such as a free-electron laser system, would be included to better deal with all types of potential collision situations[20]. Systems which incorporate directed energy soliton resonance effects are also assumed to be utilized[21-22,57].

Regenerative Life Support

Great strides in regenerative life support should be achievable using structurally embedded micro-environment sensors and processors. Closed cycle systems are assumed to be available and reliable.

Mission Equipment

The mission equipment includes two Orbit-to-Surface transports which use nuclear and MHD propulsion (see Figure 5)[23-25,37,43,44,58]. The transports are capable of carrying cargoes which exceed those of the current Space Shuttle to and from a planetary surface. Other mission equipment would include key equipment for the start-up of an outpost (assumed to be initiated with the coordinated landing of an unmanned logistics transport).

Extensive orbital and surface diagnostic and sample gathering equipment would be included. Special equipment to interact with simple and more complex life forms would be available.

Figure 5. Nuclear Space Transport Take-Off/Landing Concept
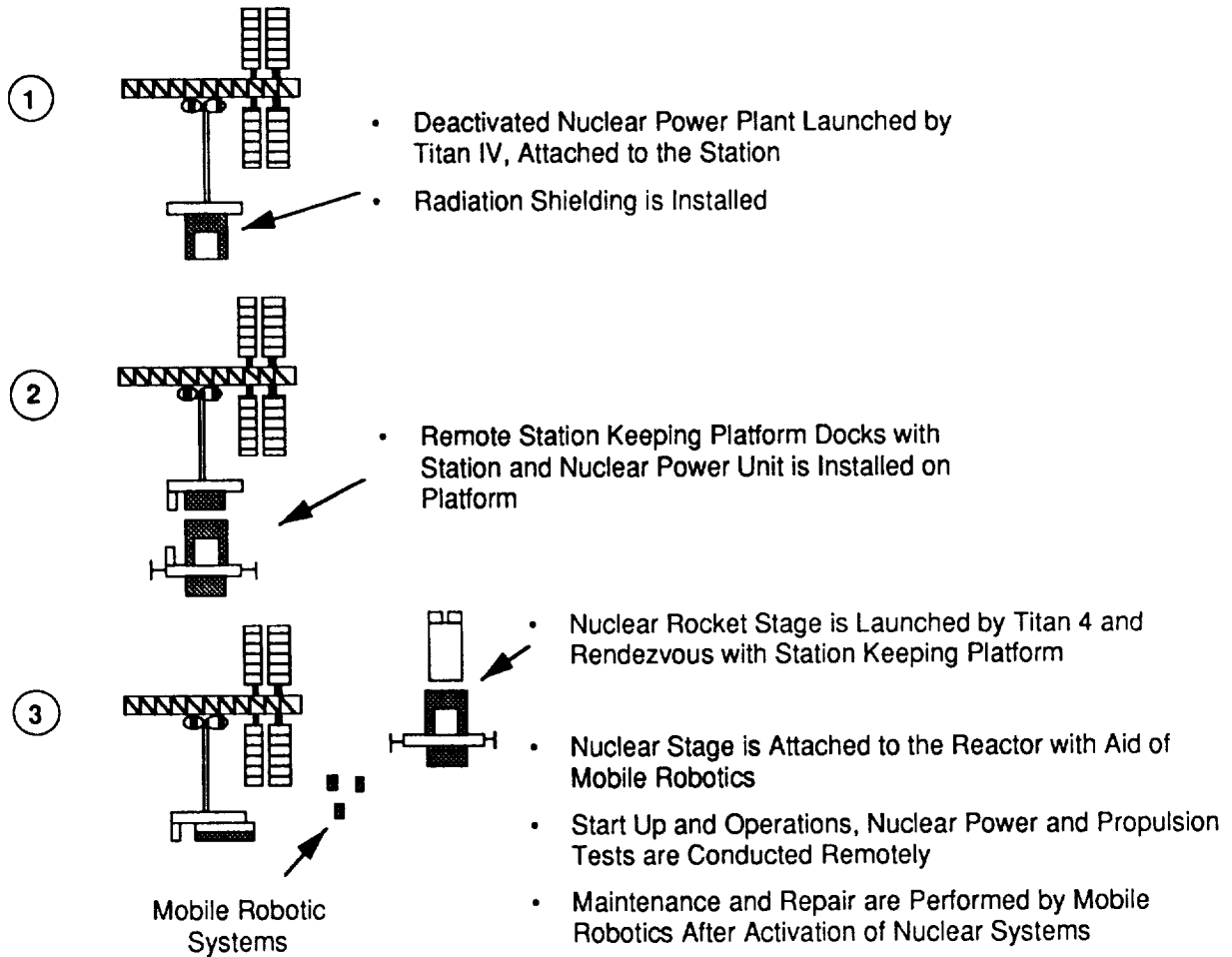

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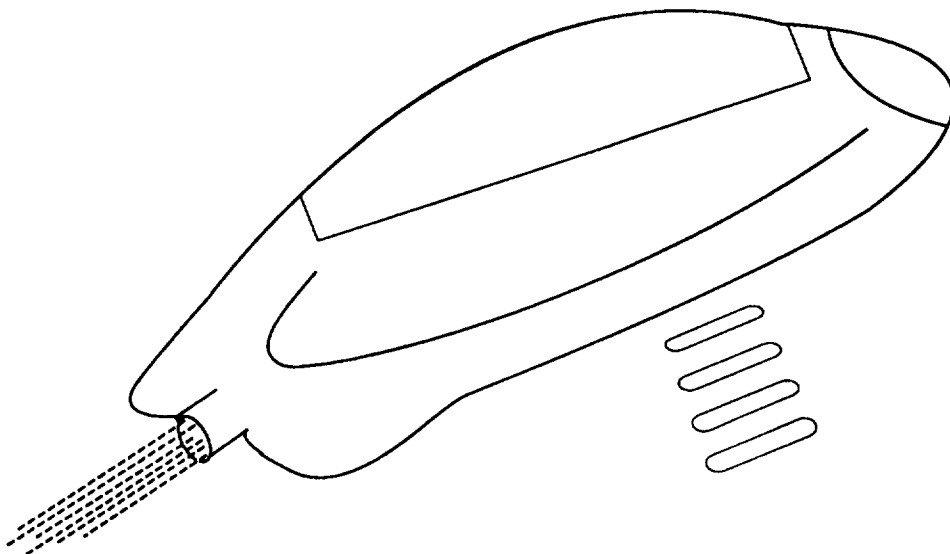
3.2   Assembly and Test Scenario

Several basic paths can be followed in the development and qualification of a deep space transport [26]. The easiest approach would be to build the entire transport on the ground and launch it into orbit in one effort. This might be possible with a super heavy lift launcher or with the utilization of a gravitational field screening technique. But neither approach is currently very viable in the absence of demonstrated capabilities in these areas.

A smaller number of launches with the use of a heavy life vehicle might be reasonable, but with no new starts in this area underway there would be readiness risks even for a 2010 space transport development. Therefore, the assembly and test scenario used assumed that a series of Space Shuttle and Titan IV launches would be required to bring up components to be assembled in space. While some of these components could be assembled automatically or with minimal support from the Space Shuttle, many of the components require other assembly support to avoid driving costs up needlessly. Therefore, it is assumed that the space transport would be assembled with the support of a space station and a station-keeping platform.

The station-keeping platform allows hazardous elements to be tested at a safe distance from the station (such as nuclear power and propulsion systems). The platform can also serve as a "strongback" for the assembly process and can assist in assembly operations support. The scenario selected is one of many which could utilize a space station and a station-keeping platform. The scenario illustrates the need for a space crane and mobile robotics capabilities.

Figures 6-8 depict the assembly and test scenario steps. In step 1 (see Figure 6) an inactive nuclear power plant is launched by a Titan IV and attached to the extended boom below the space station. Additional radiation shielding is then installed around the power plant. In step 2 , a previously launched, station-keeping platform docks with the station and the nuclear power unit is transferred to the platform using station and platform robotics.

Figure 6. Assembly and Test Scenario

①
- Deactivated Nuclear Power Plant Launched by Titan IV, Attached to the Station
- Radiation Shielding is Installed

②
- Remote Station Keeping Platform Docks with Station and Nuclear Power Unit is Installed on Platform

③
- Nuclear Rocket Stage is Launched by Titan 4 and Rendezvous with Station Keeping Platform
- Nuclear Stage is Attached to the Reactor with Aid of Mobile Robotics
- Start Up and Operations, Nuclear Power and Propulsion Tests are Conducted Remotely
- Maintenance and Repair are Performed by Mobile Robotics After Activation of Nuclear Systems

Mobile Robotic Systems

In step 3, a nuclear rocket stage is launched by a Titan IV and rendezvous with the station-keeping platform (the platform can be the active agent). The nuclear stage (and small cryogenic fuel tank) is attached to the reactor with aid of mobile robotics (and EVA crewpersons if necessary) from the station nearby[27-28]. The platform then moves away from the station and the nuclear reactor is powered up. Following a checkout period, the nuclear rocket stage is fired and its performance is assessed. Subsequent maintenance and repair tasks on the nuclear systems are performance by mobile robotics[29].

Space Shuttle and Titan IV launches bring other components of the space transport to the station in step 4 (Figure 7) cryogenic tanks, logistics/mission equipment modules, habitable modules, connecting nodes and a command module are assembled and checked out at the station. During this timeframe, field interactive propulsion components are launched by a Titan IV (or Space Shuttle) and attached to the nuclear power module on the platform using fixed robotics on the platform (or mobile robotics from the Shuttle).

In step 5, the station-keeping platform is maneuvered to the station and is attached to the assembled modules using the platform manipulator. The nuclear energy and propulsion stages are detached from the platform and added to the module assembly. Additional radiation and micro-meteoroid and debris shielding are added as well as field capacitor channels and antenna for the MHD propulsion system. The entire assembly is detached and eased away from the station with the help of the platform. Once the assembly is at a safe distance, nuclear systems are re-activated and integrated performance and integrity tests are conducted in the station's vicinity.

Following any maintenance and repair required after integrated checkouts near the station, medium performance runs are conducted in low Earth orbit (step 6, Figure 8). These are followed by full up system tests (no crew) during a lunar flyby with a return to a high Earth orbit. Following a "cool down" period, the transport is brought down to the station's altitude by the platform or a space tug. At a TBD distance from the station maintenance, repair and crew habitability activation and final environmental integrity checks are conducted.

In step 7, the two Landing/Orbital Maneuvering craft are launched and attached to the station for some initial checks with the crew. They are then transported over to the deep space transport and installed in their stowage locations.
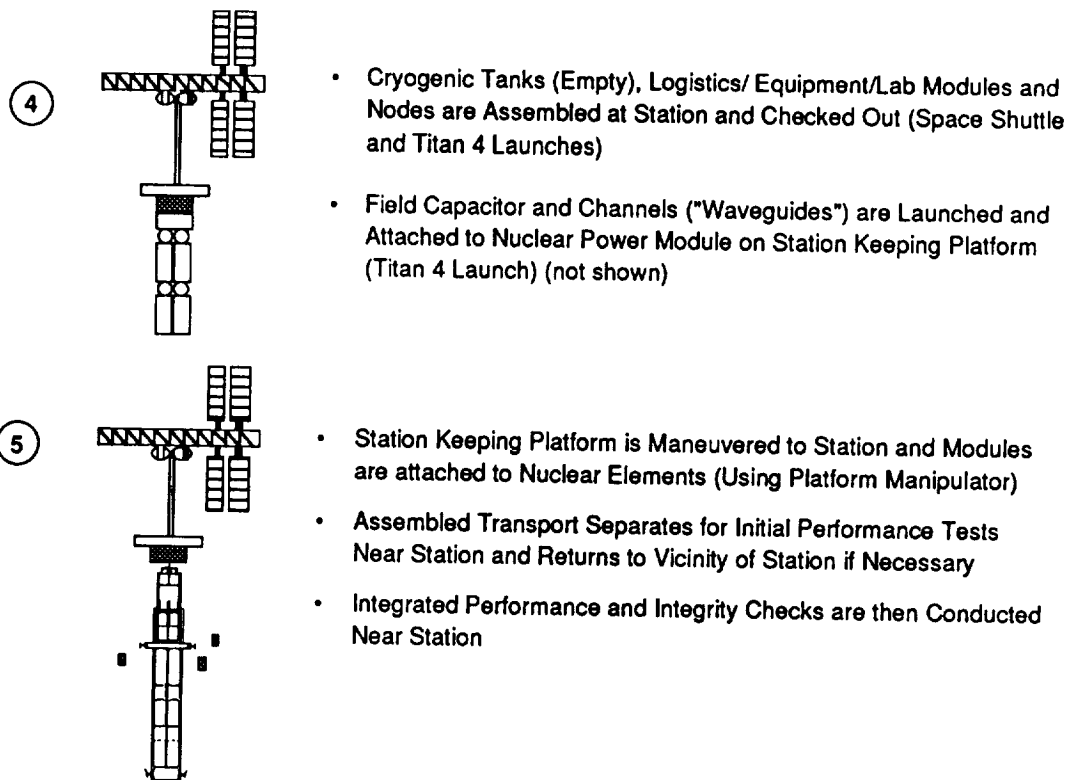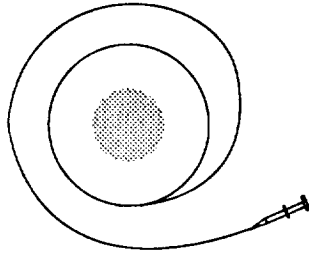
Figure 7. Assembly and Test Scenario (Continued)

④
- Cryogenic Tanks (Empty), Logistics/ Equipment/Lab Modules and Nodes are Assembled at Station and Checked Out (Space Shuttle and Titan 4 Launches)

- Field Capacitor and Channels ("Waveguides") are Launched and Attached to Nuclear Power Module on Station Keeping Platform (Titan 4 Launch) (not shown)

⑤
- Station Keeping Platform is Maneuvered to Station and Modules are attached to Nuclear Elements (Using Platform Manipulator)

- Assembled Transport Separates for Initial Performance Tests Near Station and Returns to Vicinity of Station if Necessary

- Integrated Performance and Integrity Checks are then Conducted Near Station

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Figure 8. Assembly and Test Scenario (Continued)

⑥

- Following Checkout Run Near Space Station, Full up Systems Test (no crew) is Conducted on Lunar Flyby; Return is to High Earth Orbit
- Transport Returns to Station Keeping Platform which Maneuvers it TBD Distance from Station to Conduct Maintenance, Repair and Crew Habitability Activation and Integrity Check (30 day stay)

⑦
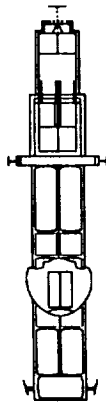
- Landing/Orbital Maneuvering Craft (2) are Launched, Assembled and Checked Out at the Space Station and then Transferred to and Attached to the Deep Space Transport

4.0 Advanced Space Transport R&D and Tests

In this section, specific examples of R. & D. and test activities are described which could be accomplished on or near a space station which has a growth capability. All of these R. & D. activities would be preceded by or would be conducted in parallel with extensive ground development and testing. For some of these activities, an extensive ground testing program followed by operational checkouts in space and subsequent refinements could be sufficient. For others the use of very fast, advanced computers, could greatly minimize space R. & D. requirements. All of the R& D activities, however, will benefit from developmental and test opportunities on the space station. For a few activities, the in-space R&D opportunity appears to be critical to success.
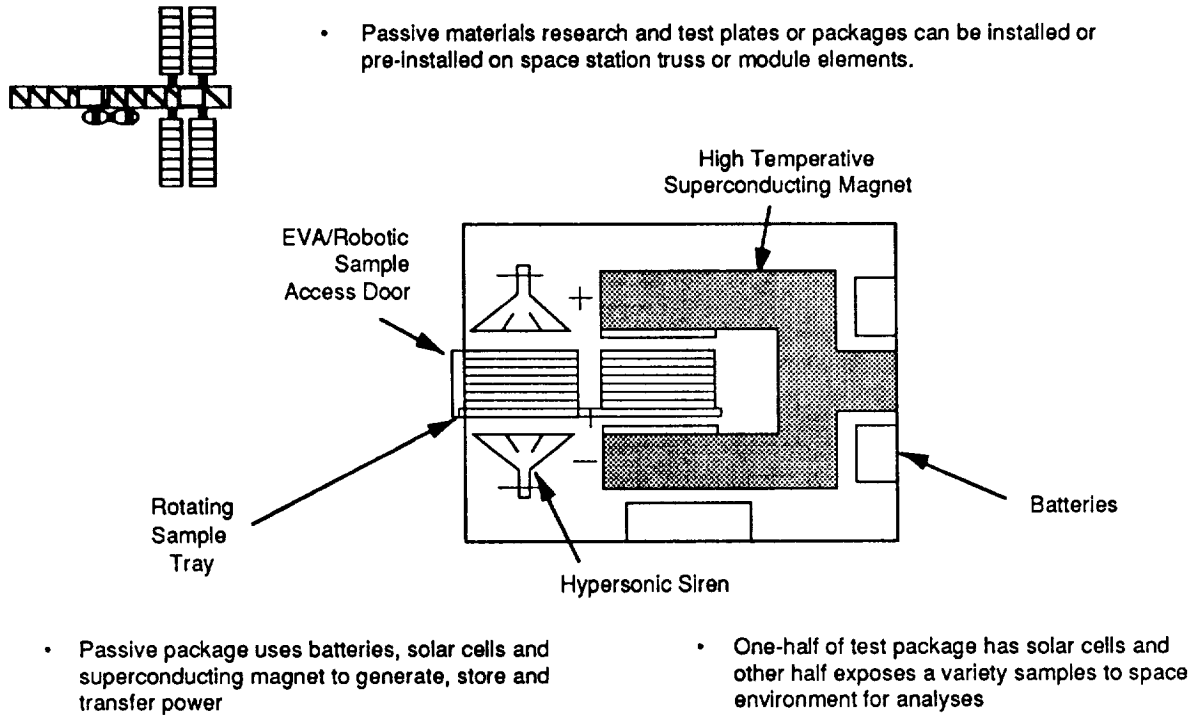
4.1 Micro-Engineered Materials R&D

Extensive research is currently being conducted to develop and investigate new types of materials and atomic and molecular interactions: fullerenes, atomic clusters, high temperature superconductors, conducting plastics, etc[18][30]. The use of micro-engineering materials for sensors and actuators which are embedded in structural surfaces continues to increase in aerospace and non-aerospace applications. New forms of micro-engineered materials are beginning to take shape which have a great potential for reducing space infrastructure construction costs, while greatly increasing performance.

During the Space Shuttle/Spacelab flights and on the MIR space station, extensive research has already been carried out on the effects of a microgravity environment on the formation of materials. Much higher quality crystals, metal welds and a better understanding of fluid and other molecular processes have resulted. The research summarized in Figure 9 represents a specific approach to altering layered/micro-engineered materials by combining the effects of microgravity with high strength magnetic and acoustic fields. The objective of this research is to develop materials with enhanced and new properties. In particular, materials which can respond in new non-linear ways to these kinds of fields.

The microgravity environment allows the atoms to be rearranged in ways which would not occur in an one-G environment or which would occur only with greatly difficulty or by chance. As with many materials research approaches, one of the objectives would be to find a way to duplicate beneficial results on the ground[42]. But we also have to be prepared to acknowledge that it may not be possible to get the same results on the ground, until we find ways of neutralizing the gravitational force effects on the ground.

The payload described in Figure 9 is a payload which could be attached to a truss segment or module surface of a space station. It would be initially designed to be independent from station services (power, data, etc.). High energy density batteries, solar cells and a superconducting storage medium could be used to conduct small scale tests on samples. The samples could be installed and removed by the Canadian robotic arm or by an EVA crew member during the conduct of other tasks.

Figure 9. Microgravity Restructuring of Microengineering Materials (Example Only).

- Passive materials research and test plates or packages can be installed or pre-installed on space station truss or module elements.

- Passive package uses batteries, solar cells and superconducting magnet to generate, store and transfer power

- One-half of test package has solar cells and other half exposes a variety samples to space environment for analyses
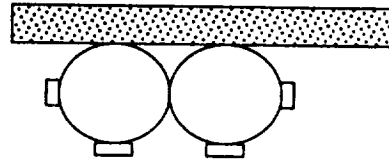
4.2 Debris and Radiation Shielding

Advanced shielding techniques and materials using microengineered materials have already been proposed[18]. The new composite materials would be initially tested on the ground, and when feasible in space environment simulators. The availability of extended, external surface areas on a space station would provide many opportunities for testing the effects of the space environment on these new shielding materials. In addition, the new materials could be overlayed over the top of existing shielding materials providing some augmentation and increased safety margins while their space environment feasibility is being evaluated.

Some of these materials will utilize the effects of electromagnetic fields to alter or enhance the shielding properties (see Figure 10). This is particularly true for the type of shielding materials assumed for the deep space transport. In fact, the shielding materials or layers will serve several purposes. The deep space transport protection system will provide radiation and micro-meteroid/debris shielding, provide sensing and transmitting functions (reacting to physical disturbances and field effects) and will play a key part in the implementation of the field interactive propulsion system.
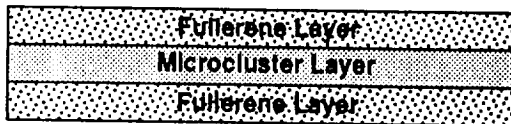
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Figure 10. Debris and Radiation Shielding Tests.

- Shield units tested on external truss and returned for analysis

- Shielding units attached to external part of module debris shielding

  - Measurement of radiation penetration made inside module under "cone" of shielding material

Fullerene Layer
Microcluster Layer
Fullerene Layer

Example of Advanced Debris/ Radiation Shielding Approach

4.3 Micro-Engineered Data and Bio-Processing Systems

The virtual explosion of new materials with new properties in the past few years promises some major advances in data and bio-processing systems and techniques[31-33,41,46,54]. With the exception of those materials requiring a microgravity environment for development, most of the materials will be developed and tested on the ground. However, because these micro-systems would be dispersed throughout module structures and surfaces (i.e., they do not have a traditional macro systems' hardware and software configuration or maintenance approach), their operational effectiveness and usefulness will need to be tested in operational space environment.

The primary goal of this R&D effort would be the development of micro-engineering techniques which would allow the dispersal of atomic clusters, polymers, etc. throughout external and internal surfaces to essentially achieve built-in, multiple, redundant data and power transfer systems (See Figure 11). Fiber optics and electrical cables may be installed, but they would be used as backup systems in an advanced vehicle.

Crew members must gain some familiarity with the difference in operational interfaces for these micro-systems to help determine how best to phase in these capabilities in new vehicles and to determine where the benefits outweigh other operational considerations. For example, hand held lasers could be used to obtain access to data (i.e., create a screen) anywhere over a large surface. This capability may be quite useful in some activities or areas of the station or transport, but could constitute an "overkill" in others.

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In addition to nominal operational considerations, techniques for surface and sub-surface maintenance and repair will have to be developed and evaluated. The design approach would try to make the dispersed system immune to minor surface damage or localized failures or sufficiently redundant to avoid having to make repairs until the density of failures exceeded a certain level. In-situ repair techniques using advanced microengineered materials (sensors and actuators) would be implemented and tested. Techniques for replacing sections would be developed and tested.

While much ground work would go into perfecting and evaluating these techniques, on-orbit operational tests have a way of identifying practicality considerations which are sometimes difficult to highlight in any other way. Confidence in the capability of a new approach is also very important. Crew members and managers should have the opportunity to evaluate the operational effectiveness of these types of systems in space, before committing them to use as the primary design approach in a new vehicle or for certain vehicle components.

Figure 11. Micro-Engineered Data and Bio-Processing.

- Goal would be to develop micro-engineering techniques which would allow the dispersal of atomic clusters, polymers, etc. throughout external and internal surfaces to essentially achieve built-in multiple, redundant data and power transfer systems

- Fiber optics and electrical cables may be installed, but would be used as backup systems in advanced vehicle

- Feasibility of approach is dependent on developing in-situ techniques for surface maintenance and repair

Subsystem Rack   Dispersed Data/Energy Conducters
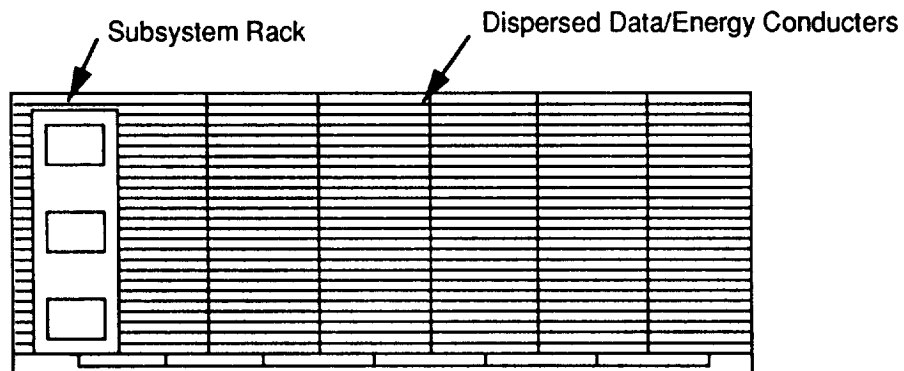
- Access to dispersed data network is initially accomplished via induced "nexus", generated by hand held laser. Power network could be accessed in a similar manner.

4.4 Dispersed Virtual Reality and Telepresence/Kinetics

Robotic capabilities and applications will continue to expand in space activities, especially where the benefits clearly exceed the capabilities of an EVA or IVA crewmember. This criteria is dependent on the ability of robots to duplicate as much as possible the sensory data which a crew member normally has access to and to exceed that capability in critical areas. The dispersal of micro-sensors and transmitters throughout external and internal structural materials (in a cost-effective manner) would greatly contribute to the usefulness of robotic systems.

Figure 12 depicts a command and control module which has external and internal structural or shielding layers through which micro-sensors and transmitters have been dispersed. This capability could be used to provide a window to the outside where no physical window exists in a direct mode. For example, embedded fiber optics or atomic channels in the material could directly amplify and route photons impinging on the outer surface to any inner surface, including a crew member's IVA or EVA virtual reality helmut.

Similar micro-sensors/transmitters dispersed in external equipment surfaces could be used to direct the activities of a robot in much the same way that a crew member would direct the activities of his own body. Much progress has already been made in these kinds of telepresence and telekinetic approaches.

Figure 12. Dispersed Virtual Reality/Telepresence/Kinetic Enablers.
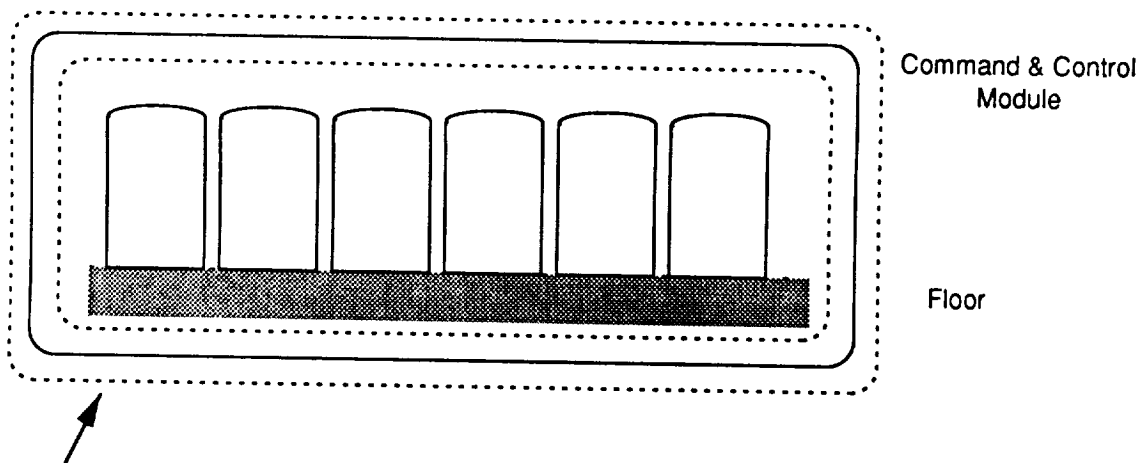
- External layer absorbs or deflects photons and records data or routes photons to inner surfaces

- Laser pattern activates stored data and replays it on internal module wall or inside virtual reality IVA or EVA crew helmut

- Telepresence and kinetics of IVA or EVA robots can be accomplished via laser link from micro-sensored robot to Station command and control module.

## 4.5 Nuclear/Field Interactive Propulsion Subsystem Tests

Tests of nuclear propulsion and interactive field propulsion systems can be conducted at the subsystem level on a technology test-bed boom extending below a space station (See Figure 13). The tests would not involve active nuclear energy systems, but would require the use of high current power. This power could be supplied using MHD superconducting storage devices and a plasma generator.

High field tests of field interactive propulsion subsystems are also candidates for testing on the boom[47]. The field emitters can be shielded to minimize electromagnetic exposure to other parts of the station. While ground tests will be crucial for exotic propulsion systems, the verification of ground studies in the space environment will be required. These in-space studies could lead to different configurations, applications and enhancements of subsystem or overall system performance.

Tests at the station offer the advantage of direct crew member involvement and an array of supporting services, including robotics for adjustments and repairs. In addition, the capability to relatively easily and quickly remove and return components to Earth for improvements is a major advantage. When field strengths or other risks appear to become too great the tendency would be to rule out R&D testing of these exotic systems at the station. The danger is that these decisions could be made without really understanding the true risks as compared to other inherent risks associated with a space station. A space station should have as a major objective and focus the support of technology test-bed activities, including some moderate risk technology R&D activities.

Figure 13. Nuclear/Field Propulsion Subsystem Tests.

- Nuclear propulsion subsystems can be tested on technology test-bed boom on a growth station using MHD stored power and a plasma generator rather than power from a nuclear reactor
  - Station re-orientation may be required during test to beneficially use impulse generated
- High field strength propulsion, sub-system tests can be conducted on the boom also, prior to higher power tests on the station keeping platform

Nuclear Propulsion Subsystems

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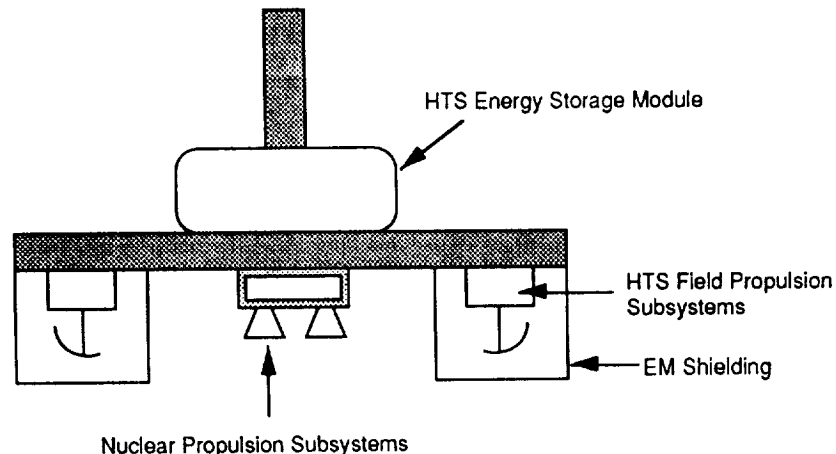
Summary

A space station should have the growth capability to support the technology development and test and materials R&D which will be required to expand and maintain the human presence in the Solar System (to Mars and beyond). While its too early to know what the redesign station's growth (or replacement potential) will be, many of the key R&D capabilities described in this paper will survive. Options could include the later addition of a station-keeping platform to support future programs. Although some truss or module structure for an extended boom connection is highly desirable, access to a station-keeping platform which can easily rendezvous and dock with the station could accommodate a large percentage of the boom R&D requirements.

By focusing on the space technology and operations needs of the future, the role and potential of the space station and other space infrastructure can be more clearly identified[36, 48]. One of the primary objectives and challenges of permanent space infrastructure should be the enablement of future space utilization and exploration and future transportation technology.

In the process of examining in greater depth the means for accommodating the development and test of the advanced technology and materials proposed for a deep space transport, interim technologies and materials will be identified. These interim technologies and materials can be used to reduce the cost of space utilization and would lead to new frontier technologies and new economic benefits.

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AN ARTIFICIAL REALITY ENVIRONMENT FOR REMOTE FACTORY CONTROL AND MONITORING

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Abstract

Work has begun on the merger of two well known systems, VEOS (HITLab) and CLIPS (NASA). In the recent past the University of Massachusetts Lowell developed a parallel version of NASA CLIPS, called P-CLIPS. This modification allows users to create smaller expert systems which are able to communicate with each other to jointly solve problems.

With the merger of a VEOS message system, PCLIPS-V can now act as a group of entities working within VEOS. To display the 3D virtual world we have been using a graphics package called HOOPS, from Ithaca Software. The artificial reality environment we have set up contains actors and objects as found in our Lincoln Logs Factory of the Future project. The environment allows us to view and control the objects within the virtual world. All communication between the separate CLIPS expert systems is done through VEOS.

A graphical renderer generates camera views on X-Windows devices, Head Mounted Devics are not required. This allows more people to make use of this technology. We are experimenting with different types of virtual vehicles to give the user a sense that he or she is actually moving around inside the factory looking ahead through windows and virtual monitors.

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1 Introduction

This work represents one effort to produce technology which will allow the region and the nation to compete in the world market. It has centered upon flexible manufacturing and intelligent workcell control. The artificial reality environment currently under construction will demonstrate the current and future applications for artificial reality tools in the factory.

2 Historical Perspective

In the early days of the industrial reveolution it was possible, if not required, for machinists to work within feet of the machines s/he were to control. Machines produced their own information in forms like sounds, odors, and "the feel" of the working unit.

Later, the central control room came into being. Here one could find whole rooms full of readouts, charts, dails, and warning bells. For some people, it was difficult to be away from their machines, even these few yards. No longer were there noises and odors to be had. Often it took a new generation of employees to learn to use the control room gadgets in a productive manner.

As the number of automated machines increased, fewer controls could be kept in a single control room. In todays, factories controls are being distributed in a clustering manner. These machine clusters then report in a "control room"-like manner to centralized monitors and strip charts which allow for recording and monitoring. Programmable controllers handle most of this reporting function. IBM PCs and clones are being used as front ends to these distributed control sites. Graphs and visual programming languages (ladder logic and flow diagrams) are being used to control these machines. Control information can be downloaded from the remote control rooms as well as at the local machine.

In this work we propose that three dimensional graphics can be used recreate gadgets such as toggle buttons, numeric readouts, slider controls, and other controls. One can now take the control room to the person, instead of the person going to the control room. In fact many people can manipulate and view the same control panel at the same time.

In addition to creating the control panels for the factory, an artificial reality environment can also reproduce the physical machines and objects. One such example is the ARKola Simulated Bottling Plant developed by [GSO91]. In this artificial world multiple people manage different parts of the factory and interact with one another.

3 The Virtual Control Panel

In addition to generating the artificial world, it is also possible to insert knowledge into a scene by utilizing visualization techniques. First, visual mapping

parameters are inserted into the rendering pipeline. Second, floating text is used as Heads-Up-Data (HUD) on top of the rendered objects.

To get around in the factory (A.R.) we are exploring different models. At present we are using a monitoring camera paradigm. The viewstation that we generate on the screen contains one main simulated monitor and three smaller monitors. The camera that is "patched-in" to the main monitor location can be manipulated be the controls on the viewstation including: Pan, Orbit and Dolly camera options. The three cameras can be looking any where in the artificial world, there do need to be different views of the same work area.

In future experiments we are considering virtual vehicle for traveling around the factory. These controls would allow for objects like a golf cart, a mobile robot, and a UFO. These virtual vehicles would be used to let the user enter a desire location into a piloted vehicle. Currently, we have attached a simulated camera to the top of one of the simulated mobile robot pickup arms. As the robot moves around the factory you can watch where it travels and control the direction of the camera on the pickup arm.

4 The Virtual Factory of the Future

The artificial reality consists of artificial entities that share a portion of their knowledge base. This is then rendered by one or more of the entities using a 3D object oriented graphics system called HOOPS. HOOPS is a rendering and input system developed by Ithaca Software, Inc. HOOPS allows for both presentation and mouse based input. We use the mouse mainly for picking and menu options. However, you could create any imaginable widget under mouse control.

The artificial world will contain full three dimensional objects (either boxlike or actual CAD descriptions). These objects will be placed in the artificial world in a similar arrangement for each person in the environment. This allows the spatial relationships to be shared with others. However, the views of the world are up to the individual, tailoring the monitor-like objects and Heads-Up-Data.

In the virtual factory of the future there will be teams of professionals. Each participant will share, form separate locations, the controls of the factory floor. Factories in one part of the world can be monitored and controlled from another part of the world. It will even be possible to meet at the same (syncronous) time, and jointly solve an engineering or manufacturing problem. The virtual factory of the future will still contain workers. There will be local technical repair teams who will be cordinating with others via Artificial Reality, Video Conference, or some other highbandwidth communication link.

5 The Lincoln Logs Factory of the Future

The Lincoln Log Factory of the Future was designed to be highly autonomous, ideally, needing minimal help from the user. The goal is to use multiple expert systems in a cooperative communication environment to develop an intelligent manufacturing environment. The system will control multiple robots, parts feeders, vision requirements, and a materials handling interface. The current model of the factory of the future utilizes an integrated Computer Aided Engineering (CAE) environment. The computer aided design (CAD) package has knowledge of structural requirements and part constraints. It requires the user to select parts which can actually be placed. The intelligent CAD system creates a work order, represented by structured English sentences, sent to the factory scheduling software.

5.1 THE FACTORY

The factory software is made up of multiple interdependent modules running individually. Included in this model is the opportunity to replace modules with others of equivalent functionality. Chief amongst these interchangeable modules is the simulator. The simulator process can present a three-dimensional view of the workcell. Physical properties such as gravity and friction are also simulated within the graphical environment. The modules which make up the factory software include:

5.2 RECEIVER MODULE

This module is used to monitor external input into the workcell, which it redirects to the appropriate process(es). The external input can come from one of three sources. First, a virtual control panel, described above. Second, an operator console which consists of a process containing graphical information regarding the robot statuses. The final source is a higher level scheduler, called a POD scheduler. The POD scheduler is responsible for controlling multiple workcells.

When the RECEIVER process receives a startup message from an input source, it creates the other processes in the system. The workcell configuration message is included in the startup message. The configuration is passed along to the other processes in the system, once they have started.

5.3 SCHEDULER MODULE

This process is used to assign assembly tasks to the robots. It reads the assembly instructions from the CAD system's English sentence file. These instructions are used for assigning tasks to the robots. The order in which these tasks are carried out is not specified. The scheduler determine the optimum order in

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which to carry out the tasks, and it constantly updates that order, depending upon robot load, external input, and mechanical errors.

When the scheduler receives a task request from one of the robot processes, it examines the current state of the house. Along with the parts that could be added next. It then determines the next optimal parts to be added to the house. The next optimal part is determined by a combination of dynamic load balancing, and collision avoidance scheduling. Dynamic load balancing is achieved by placing critical parts into the house at the earliest point possible.

5.4   ROBOT MODULES

There are two robots per workcell. When a robot starts up, it sends a request to the SCHEDULER, for an assembly task. The SCHEDULER assigns the optimal task to the ROBOT process. The ROBOT module must then issue a feed command to the appropriate feeder, move the robot arm to the feeder, grasp the part, and move it out of the parts feeder. The robot then moves the part to the edge of the workspace, and issues a request for access to the workspace, to the PREVENTER process.

Once granted access to the workspace, the robot moves the robot arm to place the part, and releases it. The robot then moves out of the workspace, and informs the PREVENTER of its action. If vision inspection is enabled, the process sends an inspection request message to the VISION system and waits for a response. An error in the part placement will cause another request to obtain the workspace. The robot then returns to the place where it released the log, and shifts the log into the correct position. Another inspection request is made to verify placement.

5.5   VISION MODULE

This process provides the communication connection to the vision system. When a ROBOT requires a vision function, a corresponding message to the VISION process is sent. The message is forwarded via serial line to the vision system. The VISION process waits until it receives the feedback from the vision system, which it passes along to the requesting ROBOT process. If the vision system were to become disabled, the VISION process would recognize the problem, and report it to the ROBOT and SCHEDULER processes. The vision system is monitored for restoration, and if it occurs, the information is passed to the other processes.

5.6   PREVENTER MODULE

There is always the possibility of the robots colliding in a multiple robot workcell. There are many ways of preventing his situation. One is to enforce mutual

exclusion of the critical area. The PREVENTER process performs collision prevention by calculating where each robot arm, gripper, and part will be located during placement. If a collision is detected, the PREVENTER will enforce mutual exclusion of the workspace, otherwise, both robots can access the workspace simultaneously.

5.7   OPERATOR CONSOLE PROCESS

This is a process running on a computer workstation. It receives the workcell output from the DISPLAY process. It has a live video window right on the monitor, enabling the operator to see what is actually taking place in the workcell. The operator has complete control of the workcell from the console. This includes startup, reconfiguration, and shutdown capability. The operator has the option of adjusting the following functions in the workcell: Vision inspection, vision placement, operator mode, and compliant movement. The operator may also shut down any of the parts feeders, or either of the robots.

5.8   COMMUNICATION MODULE

The communication module is the heart of the system. It must maintain a robust interface to all the other modules and subsystems. It is important that the communication be done in a manner transparent to the programming environment. This allows for ease of use and easy replacement of code. Soon, some of the modules will be moved to another host - this will be facilitated when the communication module can talk across hosts without any subsystem knowing the difference. The communication module is being developed to send messages to cooperating subsystems in CLIPS, and to other mailbox-type programs via a C language interface with the underlying operating system.

6   The VCLIPS Architecture

We have merged portions of VEOS from the HITLab in Seattle, with our own coarse-grain parallelism extensions to Clips called PClips (Parallel Clips). It will be possible to receive both PClips communications and VEOS messages. To accomplish this merger of both PClips and VEOS, we removed the XLisp level from the distributed VEOS code. Simply using the "talk" layer of the VEOS environment we can send PClips messages back and forth. VEOS has design accomplishments similar to PClips in that they both have an entity based design and seek multiplatform capabilities. We chose VEOS because it has the potential to become a de facto standard within the research community.

The combination of VEOS and PClips will allow us to develop knowledge bases with smaller rule sets, yet still allow the expert systems to interact to solve

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group problems. Also, Clips is growing in usage due to its cost and continued development efforts by NASA, making it an excellent base to build upon.

7 Future Research Considerations

Further research will be done in the areas of artificial reality-based user interfaces, virtual vehicles which can be used to move around in the artificial worlds and realtime control of physical objects from within the artificial reality. Additionally, we are seeking industrial partners who are interested in experimenting with artificial reality based monitoring of an actual factory floor.

One new project will be using the artificial world to train a neural network. The neural net will then be inserted into a real mobile robot and used to recognize intersection patterns that it had learned. In this work the artificial reality will contain a description of an office building. The simulated robot will continually roam the simulated office trying to learn the different locations. The neural net will then be loaded into the actual robot to test whether it can actually determine where it is based on the different sensory input it receives from the real world.

We also hope to connect to other virtual world based research which may be interconnected on the internet. Providing object translators or visualization mappings for different VR and AR systems in real time.

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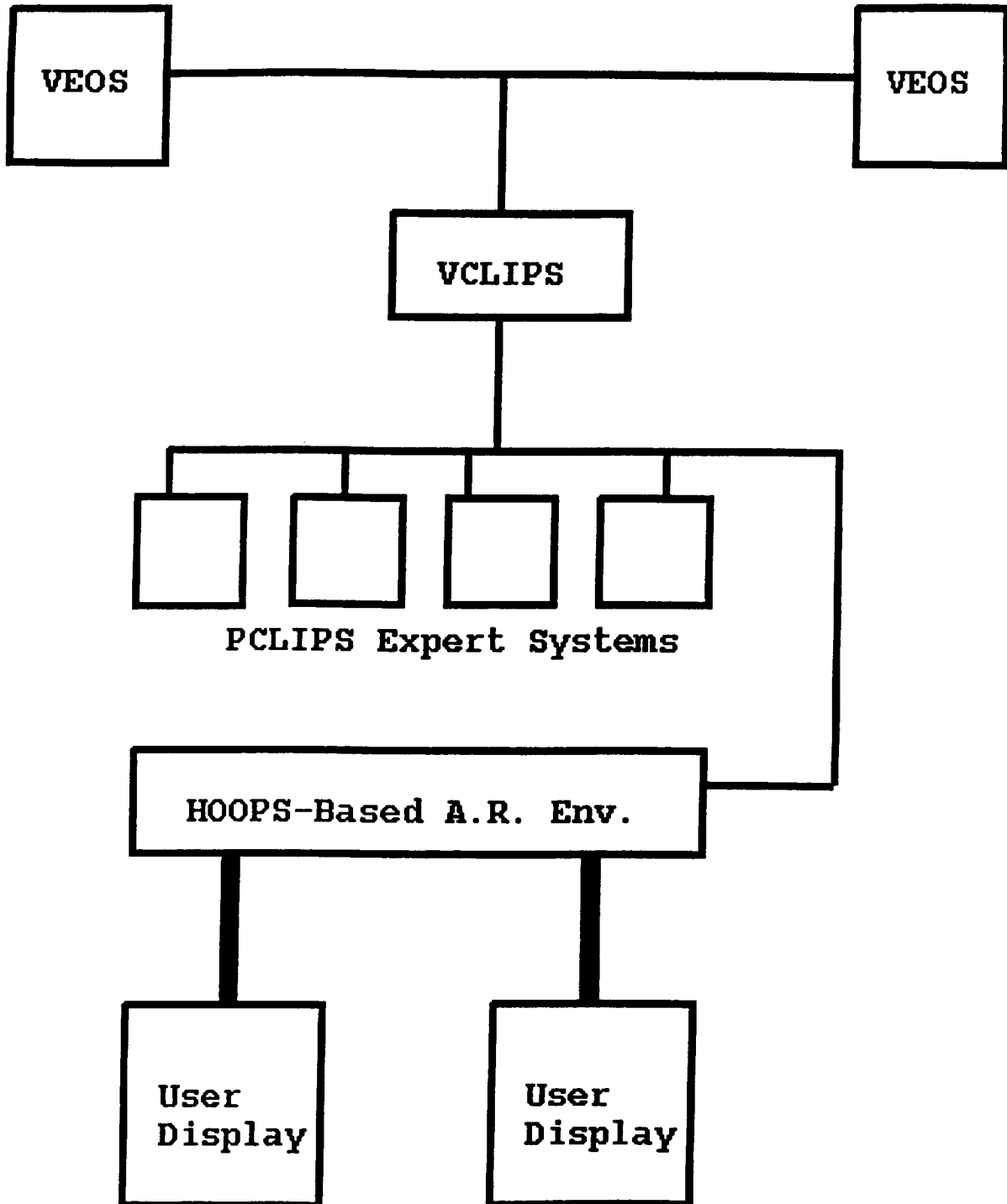
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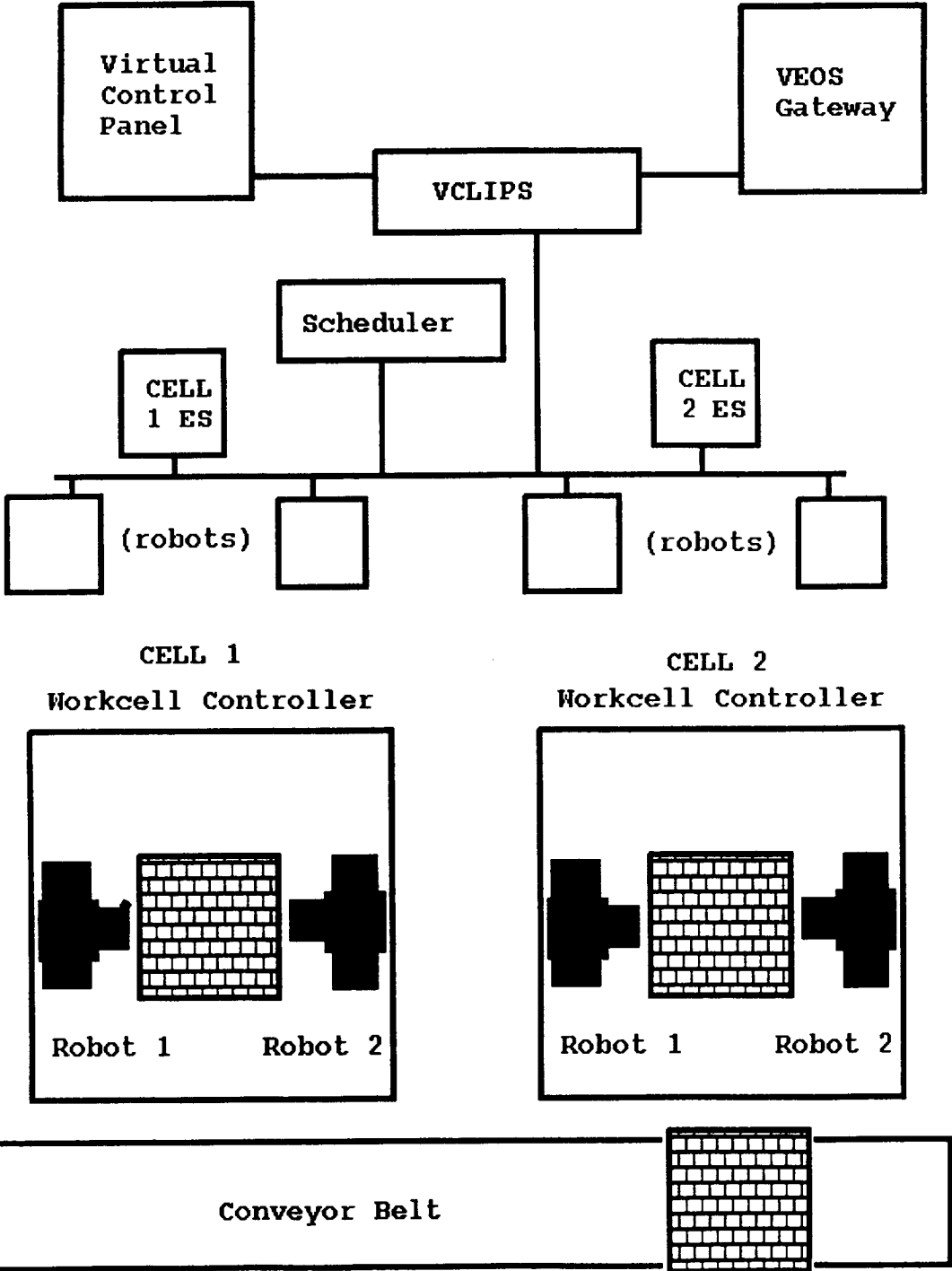
THE FERMI PARADOX: AN APPROACH BASED ON PERCOLATION THEORY

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Abstract

If even a very small fraction of the hundred billion stars in the galaxy are home to technological civilizations which colonize over interstellar distances, the entire galaxy could be completely colonized in a few million years. The absence of such extraterrestrial civilizations visiting Earth is the Fermi paradox.

A model for interstellar colonization is proposed using the assumption that there is a maximum distance over which direct interstellar colonization is feasable. Due to the time lag involved in interstellar communications, it is assumed that an interstellar colony will rapidly develop a culture independent of the civilization that originally settled it.

Any given colony will have a probability P of developing a colonizing civilization, and a probability (1-P) that it will develop a non-colonizing civilization. These assumptions lead to the colonization of the galaxy occuring as a percolation problem. In a percolation problem, there will be a critical value of the percolation probability, P_c. For $P<P_c$, colonization will always terminate after a finite number of colonies. Growth will occur in "clusters," with the outside of each cluster consisting of non-colonizing civilizations. For $P>P_c$, small uncolonized voids will exist, bounded by non-colonizing civilizations. For $P \approx P_c$, arbitrarily large filled regions exist, and also arbitrarily large empty regions.

1. Introduction

The galaxy contains roughly a hundred billion stars. If even a very small fraction of these have planets which develop technological civilizations, there must be a very large number of such civilizations. If any of these civilizations produce cultures which colonize over interstellar distances, even at a small fraction of the speed of light, the galaxy should have been completely colonized in no more than a few million years [1]. Since the galaxy is billions of years old, Earth should have been visited and colonized long ago. M.J. Fogg, for example, suggests that they should have already completed the expansion to fill the galaxy before the emergence of life from the ocean [2]. The absence of any evidence for such visits is the Fermi paradox. [A more proper name for this would be the Fermi-Hart paradox, since while Fermi is credited with first asking the question, Hart [1] was the first to do a rigorous analysis showing that the problem is not trivial, and also the first to publish his results].

Many proposals for solutions to the Fermi paradox exist, all of which are unsatisfactory in one way or another [3]. A bibliography of the discussion can be found in [4].

Proposed solutions to the Fermi paradox either deny the possibility of extraterrestrial civilizations [1, 5], an assumption as yet unwarranted, or accept the possibility of extraterrestrial technological civilizations and propose explanations for why such civilizations may nevertheless not have colonized the galaxy. Explanations include suggestions that such civilizations collapse or blow themselves up, run out of resources, choose not to colonize, or chose to colonize but leave us alone. The difficulty with all such explanations is that they must all assume an unwarranted uniformity of motive for extraterrestrial civilizations over extremely long periods of time. If even a single civilization choses to colonize the galaxy, the explanations fail. It is

useful, therefore, to try to look for explanations of the Fermi paradox which do not rely on uniformity of motive.

I propose a model for the problem based on the assumption that long-term colonization of the galaxy proceeds via a "percolation" process similar to the percolation problem which is well studied in condensed-matter physics. Rather than assuming a uniformity of motive for extraterrestrial civilizations, the model assumes a wide variety of motives, with a mixture of civilizations interested in colonization and "stay at home" civilizations.

2. Assumptions

The analysis is based on two key assumptions. First, it is assumed that interstellar travel is possible, but difficult, and thus that there is a maximum distance over which colonies can be directly established. Hence, there are only a small number N of stars which are suitable for colonization and within reasonable travel distance of any given solar system. Any colonies farther away are settled as secondary colonies from other colonies. Second, any control of a colony by the parent civilization will at most be very weak, and the time scale for development of colonization capability by a colony is long; hence each colony develops its own culture which is independent of the culture of the civilization that originally settled it. I argue that these assumptions are reasonable in the light of what we currently know about possible technologies for interstellar travel at speeds far less than the speed of light.

Travel over interstellar distances is not forbidden by the laws of physics, and several methods have been proposed by which it may be accomplished. Since it is possible, given a large enough number of extraterrestrial civilizations, one or more would have certainly undertaken to do so, possibly for motives unknowable to us. Colonization will take an extremely long time, and will be very expensive. Freeman Dyson, for example, estimates the cost for one type of interstellar ship as being on the order of the Gross National Product, and the voyage time to be on the order of 200 years for a trip of 4 light years [6]. It is quite reasonable to suppose that not all civilizations will be interested in making such a large expendature for a payoff far in the future. Human society consists of a mixture of cultures which explore and colonize, sometimes over extremely large distances, and cultures which have no interest in doing so [7].

The many light-year distance between a "home" system and its colonies makes it almost certain that the colony will develop a culture and civilization of its own. Over the many hundreds of years needed for the colony culture to develop to the technology level needed for it to be able to build its own interstellar transports, the colony civilization will likely be entirely independent of the parent.

An additional assumption needed is that a colony cannot be established on an already colonized world. Given the enormous unlikelihood of being able to carry out an invasion over interstellar distances, this seems to be a good assumption.

The percolation rule is as follows: A culture may have a colonization drive, or may not. A civilization which has a drive to colonization will establish colonies on any stars within reach. If it does not have any unsettled stars within its colonization radius, however, it will of necessity develop into one without a colonization drive. Thus, any given colony will have a probability P that it develops a colonizing civilization, and a probability (1-P) that it will develop a non-colonizing civilization.

3. Percolation

The percolation problem is well studied in physics (see, for example, references [8] and [9]). In a percolation problem, there will be a critical value of the percolation probability, P_c, which will depend on the dimensionality of the space (in this case, 3) and the connectivity N. For $P<P_c$, colonization will always terminate after a finite number of colonies. Growth will occur in "clusters," with the outside of each cluster consisting of non-colonizing civilizations. For $P>P_c$,

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on the other hand, clusters will grow indefinitely to fill all of space. However, small voids will exist, bounded on the inside by non-colonizing civilizations. The probability of any given point being a isolated unoccupied point is P^N; probabilities of larger clusters of isolated points existing are proportional to higher powers of P. Finally, for critical percolation, $P \approx P_c$, clumps grow into fractal structures of irregular shape. Arbitrarily large filled regions exist, and also arbitrarily large empty regions.

Figure 1 shows a typical percolation result, in this case for a cubic array in three dimensions with N=6. For this array $P_c=0.311$; the simulation is for P=0.333, very slightly over critical.

The percolation explanation of the Fermi paradox therefore suggests that one of three cases explains why colonizing extraterrestrials have not visited the Earth: either $P<P_c$, and colonization stops rapidly; $P \approx P_c$, and uncolonized areas of arbitrarily large extent exist, in one of which the Earth is located; or $P>P_c$, and the Earth is located in one of many small unoccupied void.

Before making estimates for values of the critical parameters N and P, it should be first emphasized that the main features of the model as a percolation problem do not depend on the values of the parameters or the details of the assumptions.

A baseline assumption for colonization would be that stars are suitable for a colony only if they are of a spectral type not too different from the sun, say F8 through G9 main sequence, and not binaries. From the 1969 Gliese catalog, the set consists of five possible stars within a distance of 30 light years from the sun. A reasonable guess for N, then, might be 5.

There is no way at all of making a reliable estimate of the value of P. For our own civilization, it seems equally likely that we may destroy ourselves, fail to destroy ourselves but not expand into space, or continue expanding until interstellar colonization is possible. A guess of P=1/3 is as reasonable an estimate as any. Interestingly enough, these values for N and P result in a model of the galaxy as being very near critical, and thus with extremely large "colonized" regions and equally large "empty" regions.

More complex models of interstellar colonization can be made on the same principles, incorporating such elements as the random positions of stars, the boundaries of the galaxy, the possibility of multiple civilizations colonizing the same star, etc. In general, it is not expected that such more detailed models will change the overall features of the result, although the details such as critical probabilities, will certainly be model dependant.

4. Discussion

Like all discussions of the Fermi paradox, solutions based on a percolation approach are dependent on the validity of its assumptions. Until we have either explored the galaxy or contacted extraterrestrial civilizations, all such assumptions can be challanged, however, I argue that the assumptions used are reasonable, and that in any case the assumptions made here are less universal and restrictive than those required by other analyses of the paradox. Critical assumptions: (1) existance of a distance horizon, (2) no recolonization of already colonized stars by new civilizations, (3) no relationship between parent and daughter civilizations, (4) colonization only possible to a limited set of possible stars, with small number of candidate stars inside the horizon.

In addition to these assumptions, the model ignores stellar drift. The time scale for star positions to change is on the order of a million years. It is impossible to project the sociology of extraterrestrial civilizations for time scales on this order. It is reasonable to suggest that a civilization that has existed for millions of years without colonizing would be likely to have evolved into a stable civilization that has no imperative to do so.

Finally, why haven't we heard them (e.g., via radio), or met their self-reproducing probes [5]?

One likely reason we have not yet detected extraterrestrial civilizations by radio is that we are likely simply listening at the wrong frequency. Arguments that we should listen at various fixed

frequencies (*e.g.*, the "water hole" or multiples or sub-multiples of this frequency) are dependent on far too many assumptions about the psychology of the transmitting civilizations. It is also possible that a civilization interested in communicating across interstellar distances would not use high beamspread techniques like radio at all, but would use much shorter wavelength and hence more directed means: lasers. Unless the antenna size is unrealistically large (thousands of kilometers), across interstellar distances the overwhelming majority of any signal sent by radio will be broadcast to the empty space between the stars. The beam spread at target is proportional to the wavelength, and hence the power density at target proportional to the wavelength squared. As an example, compare a laser transmission at 500 nanometers with a microwave transmission at 5 mm. The laser has a wavelength 10^4 times shorter, and hence 10^8 times higher power density at the target star assuming the same transmitted power. Even if the bit rate is limited by the photon energy and thus the information transfer rate is proportional to the wavelength, laser communication is still preferable by a factor of 10^4.

Tipler argues that a extraterrestrial technical civilization will fill the galaxy with self-reproducing probes, which will not be subject to a distance horizon. Since we have not yet learned to design such machines, it is difficult to critique this reasoning in depth. However, I suggest that a self-reproducing probe would likely be more complicated than a dedicated probe, *e.g.*, by as much as an automobile factory is more complicated than an automobile. If this is so, then to produce maximum information return in any finite time (no matter how large) making self-reproducing probes which produce self-reproducing probes is not the optimum strategy. The optimum strategy is that after some number of generations G the factory probes will produce dedicated probes instead of self-reproducing probes. The number G will depend on the reproduction time, trip time, ratio of complexity, and information return time, but in general is quite small unless the required information return time is many orders of magnitude larger than the trip time, which is unlikely to be the case.

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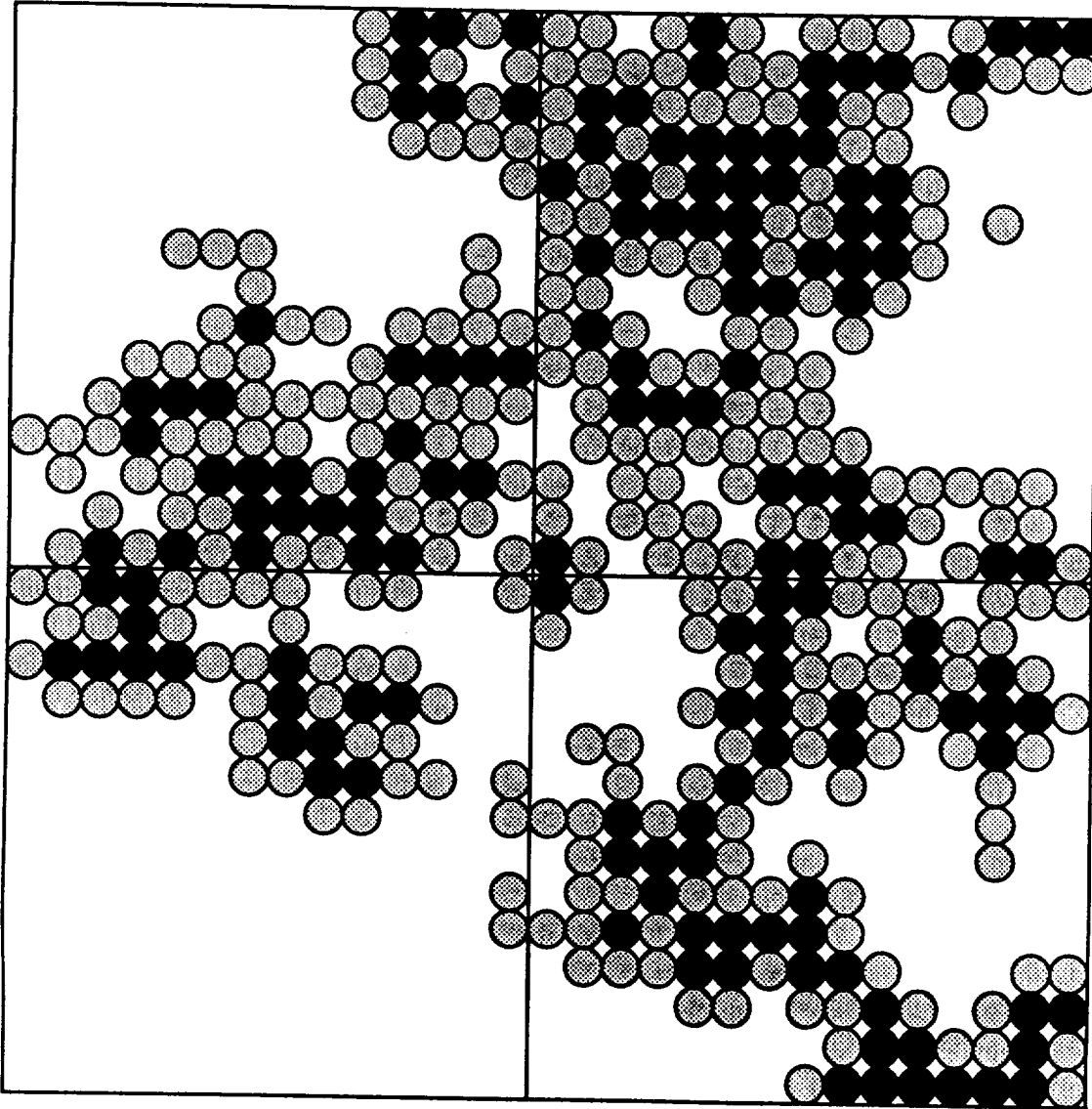9. Stauffer, D. "Scaling Theory of Percolation Clusters," *Phys. Reports, Vol. 54*, No. 1, 1-74 (1979).

Figure 1. A slice from a percolation simulation on a simple cubic lattice in three dimensions. Here N=6 and P=1/3. Filled circles denote "colonizing" sites, open circles "non-colonizing" sites, and the absence of circles represents sites not visited. The irregular shape of the boundary and large voids in the percolation structure are clearly visible.

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A DIRECT CURRENT RECTIFICATION SCHEME FOR MICROWAVE SPACE POWER CONVERSION USING TRAVELING WAVE ELECTRON ACCELERATION

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The formation of the Vision-21 conference held three years ago allowed the present author to reflect and speculate on the problem of converting electromagnetic energy to a direct current by essentially reversing the process used in traveling wave tubes that converts energy in the form of a direct current to electromagnetic energy. The idea was to use the electric field of the electromagnetic wave to produce electrons through the field emission process and accelerate these electrons by the same field to produce an electric current across a large potential difference. The acceleration process was that of cyclotron auto-resonance. Since that time, this rather speculative idea has been developed into a method that shows great promise and for which a patent is pending and a prototype design will be demonstrated in a potential laser power beaming application. From the point of view of the author, a forum such as Vision-21 is becoming an essential component in the rather conservative climate in which our initiatives for space exploration are presently formed. Exchanges such as Vision-21 not only allow us to deviate from the "by-the-book" approach and rediscover the ability and power of imagination, but provides for the discussion of ideas hitherto considered "crazy" so that they may be given the chance to transcend from the level of eccentricity to applicability.

The advent of future space and planetary exploration for the 21st century has precipitated the usual considerations of energy transfer, particularly in the form of electrical power, to support various exploration activities. Even point-to-point power transmission to earth from space or between two points on earth is being reconsidered.[1] The need to distribute energy from a minimal number of centralized sources in an efficient manner has given rise to the reconsideration of microwave power transmission and its related conversion to useful electrical power. However, such considerations, especially those of the well known Microwave Power Transmission System Study procured by NASA in 1975, have been traditionally impeded by the constraints induced by the use of relatively long wavelengths (i.e. centimeter wavelengths at the proposed operating frequency of 2.45 GHz) and the attendant large transmitting and receiving structures with the prevailing small coupling efficiencies. These drawbacks have stimulated interest in the use of smaller wavelengths, e.g., those peculiar to high energy carbon dioxide or free electron lasers the
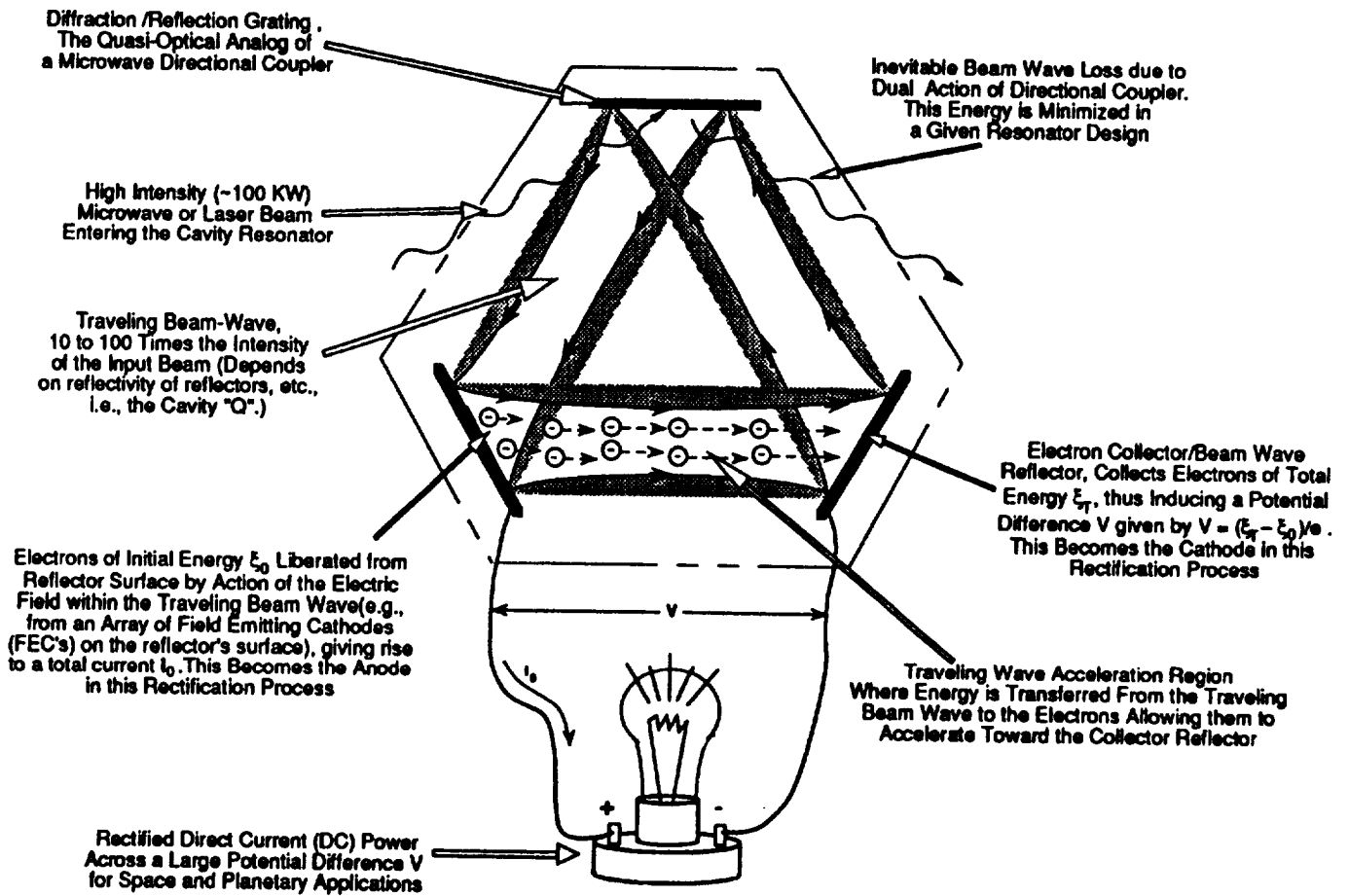
wavelengths of which are 10,000 times smaller than microwave wavelengths, thus allowing the use of electrodynamic structures 10,000 smaller than those at the microwave wavelengths. In particular, this "laser power beaming" has been recently proposed[2] for ground-to-space energy transmission as well as for low earth orbit (LEO) to geosynchronous orbit (GEO) payload delivery via plasma engine propulsion.

This paper will address one area of this multifaceted problem, viz, the conversion of energy which resides in a received electromagnetic field to that which is in the form of a direct current across a potential difference which can be used to provide electric power for a number of space and planetary applications. The novel method for electromagnetic wave power rectification to be described here is applicable over a wide range of wavelengths within the electromagnetic spectrum. More importantly, however, it can be made to have the capability to be entirely "passive", i.e., not having to rely on additional energy sources, other than the received electromagnetic field, to induce the creation of electrons which constitutes the resulting direct current.

In particular, a conversion process will briefly be presented that demonstrates how, by establishing a traveling electromagnetic wave field within a three mirror traveling- wave open resonator, electrons are accelerated by the wave, via the action of one of two possible traveling- wave acceleration mechanisms, to several times their rest energy, thus establishing an electric current over a large potential difference. The electrons needed in this process can also issue from one of several possible mechanisms; they can be "actively" created by thermionic emission which, of course, would require the need for an auxiliary power source, or they can be "passively" created by field emission (i.e., cold emission) processes through the action of the resonator field on an array of field emission cathodes or surfaces appropriately placed on one of the three resonator mirrors. The open resonator design of this rectification process allows for its use in the frequency spectrum from the quasi- optical frequencies of about 90 GHz to the infrared frequencies in the Terahertz range. The method is depicted in Figure 1 and its three novel features, i.e., the use of a quasi-optical diffraction grating to act analogously as a microwave directional coupler, the use of a passive electron emission process, and the subsequent

Figure 1

A DC RECTIFIER FOR MICROWAVE SPACE POWER CONVERSION USING TRAVELING -WAVE ELECTRON ACCELERATION *

Diffraction /Reflection Grating , The Quasi-Optical Analog of a Microwave Directional Coupler

Inevitable Beam Wave Loss due to Dual Action of Directional Coupler. This Energy is Minimized in a Given Resonator Design

High Intensity (~100 KW) Microwave or Laser Beam Entering the Cavity Resonator

Traveling Beam-Wave, 10 to 100 Times the Intensity of the Input Beam (Depends on reflectivity of reflectors, etc., i.e., the Cavity "Q".)

Electron Collector/Beam Wave Reflector, Collects Electrons of Total Energy ξ_T, thus Inducing a Potential Difference V given by V = $(\xi_T - \xi_0)/e$. This Becomes the Cathode in this Rectification Process

Electrons of Initial Energy ξ_0 Liberated from Reflector Surface by Action of the Electric Field within the Traveling Beam Wave(e.g., from an Array of Field Emitting Cathodes (FEC's) on the reflector's surface), giving rise to a total current I_0. This Becomes the Anode in this Rectification Process

Traveling Wave Acceleration Region Where Energy is Transferred From the Traveling Beam Wave to the Electrons Allowing them to Accelerate Toward the Collector Reflector

Rectified Direct Current (DC) Power Across a Large Potential Difference V for Space and Planetary Applications

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acceleration of these electrons by the traveling-wave field established within the resonator, will now be discussed in what is to follow. Only the most important highlights that have issued from a detailed theoretical analysis will be presented.

Quasi-Optical Directional Coupler - A Diffraction/Reflection Grating

The introduction into the three mirror resonator of the electromagnetic field, the energy of which is to be converted to direct current, occurs by the use of a diffraction/reflection grating which is not only operated in the usual reflection mode, but also in a diffraction mode. As is well known, the grating action scatters the incident beam of wavelength λ, occurring at an angle of incidence θ_1, into diffracted beams oriented along angles θ_n that are given by

$$\sin\theta_n = \sin\theta_1 + \frac{n\lambda}{d} ; \quad \frac{\lambda}{d} \geq \frac{2}{3} , \quad n = 0, \pm1, \pm2,...$$

where d is the grating spacing. Each of the diffracted beams has associated with it a corresponding reflection coefficient r_n. As these
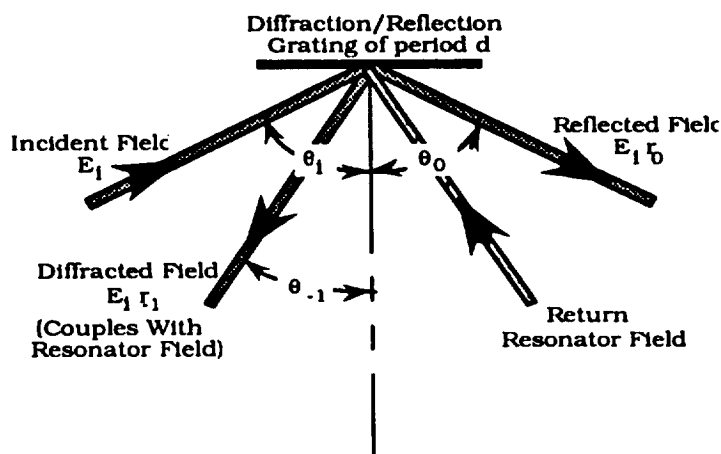
Figure 2
Detail of incident and diffraction angles
at the Diffraction/Reflection Grating

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coefficients are a function of the grating material as well as the groove depth, the grating structure can be selected so as to support only two diffracted beams[3], viz, the $n=0$ beam, which is the classical reflected beam at the angle $\theta_1 = \theta_0$, and the $n=-1$ beam which is a retro-reflected beam at the angle θ_{-1} given by

$$\sin\theta_{-1} = \sin\theta_1 - \frac{\lambda}{d}$$

The associated reflection coefficients are related, through conservation of energy (assuming the grating material has negligible absorption), by the relationship

$$r_0^2 + r_{-1}^2 = 1$$

As shown in Figure 2, it is the $n=-1$ beam that couples the incident energy into the cavity, and thus suggests that the coefficient r_{-1} should be maximized. However, the same diffractive process occurs on the other side of the grating and tends to couple energy back out of the cavity. Thus, r_{-1} cannot be arbitrarily maximized without constraints. A complete analysis incorporating the power incident into the cavity, the energy which resides in the traveling wave field, as well as that which is coupled out of the cavity, and the normalized beam current I_n due to the subsequent electron acceleration which occurs between two of the three cavity mirrors, yields the optimal values for r_{-1} given by

$$r_{-1_{opt}} = \left(\frac{\gamma_{acc}L}{3}\right)^{1/2}\left[\frac{I_n}{2} + \left(\frac{I_n^2}{4} + \frac{3\gamma_{tot}}{\gamma_{acc}}\right)\right]$$

where γ_{acc} is the attenuation incurred by the traveling wave in the accelerator portion of the cavity and γ_{tot} is the total attenuation of the wave

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field around the entire length L of the cavity. Of course, the beam current I_n will be a function of the particular acceleration mechanism chosen as well as a function of the cavity field strength. Hence, even though one can visualize a non-linear problem forming, it is obvious how one can proceed in designing and implementing a diffraction/reflection grating to couple power into the cavity as well as sustaining the traveling wave process within the cavity in the presence of electron acceleration by the wave field.

Electrons for the Acceleration Process

Electrons with which the direct current is created, as well as the large potential difference by their subsequent acceleration, can most easily be introduced into the traveling wave field of the cavity by the suitable placement of an electron gun behind the mirror which follows the diffraction/reflection grating. This "active" electron production technique would require the use of a small auxiliary power source to provide for the thermionic emission. Although such a scenario would provide for a respectable power conversion method, it will inherently have a smaller conversion efficiency since one must count the auxiliary power source as a loss. Furthermore, the need to carry such an auxiliary source with the power converter can add weight to a mission as well as decrease the reliability of the operation of the power converter. Thus, maintaining this active method of electron production as a last alternative, one is motivated to consider "passive" methods of electron production such as is realized in cold field emission.

Recent advances in the materials and production of arrays of field emission cathodes (FEC) make considerations of such passive electron production possible[4]. What is envisioned is an array of FEC's placed in the center of the mirror where the electric field of the traveling wave will have its largest value. With a nominal value of the work function of about 2 eV for typical FEC materials and a tip magnification factor of $\beta=1000$, calculations via Fowler-Nordheim theory show that an electric field strength within the resonator of 1×10^6 V/m is required at the tip of these cathodes to elicit a

current density of about 50 A/cm^2 from them. Such field strengths place a lower limit on the operation of this passive generation scheme.

One can also consider other electron emission schemes such as liquid metal field emission[5], etc. Further considerations of field strength versus breakdown voltages, ohmic heating, etc., will help define the particular field emission method to be employed.

Finally, although the energy at which the electrons are emitted will be described by an distribution over a range of values, it is sufficient to assume that they are certainly non-relativistic at this point and they therefore are approximately represented by their rest energy ξ_0.

Traveling-Wave Electron Acceleration

Once the electrons have been generated by one of the mechanisms discussed above, it remains to provide a mechanism through which energy can be transferred from the electromagnetic traveling wave field to the electrons. The first obvious choice is to employ cyclotron auto-resonance acceleration[6] by establishing a constant magnetic field directed longitudinally along the acceleration axis. Here, the condition

$$\gamma(z)\left(1 - \frac{v_z(z)}{v_\phi(z)}\right) = \frac{\omega_B(z)}{\omega}$$

must always be maintained between the electron velocity $v_z(z)$ along the acceleration axis (taken here to be the z-axis), the associated relativistic factor $\gamma(z)$, the Larmor or cyclotron frequency $\omega_B(z)$, the phase velocity $v_\phi(z)$ of the traveling wave field (all of which are, in general, functions of the position z along the acceleration axis), and the angular frequency of the traveling wave field ω. In the case of the open resonator structure considered here, its mode of operation will be such that $v_\phi(z) \approx c$. Furthermore, since the initial velocity of the emitted electrons (at the point z=0) is such that $\gamma(0) = 1$, one sees from the above relation that

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$$\omega_B(0) \equiv \frac{eB(0)}{mc} = \omega$$

where $B(0)$ is the intensity of the magnetic field needed at the beginning of acceleration, e is the electron charge, and m is its mass.

Hence, one sees that for a wave frequency of 10 GHz, i.e., $\omega = 6.28 \times 10^{10}$ s^{-1}, $B(0) = 3.5$ kG, an easily realizable magnetic field using light weight magnetic materials. However, at 100 GHz, one has $B(0) = 35$ kG which starts to require the use of much larger and heavier magnetic materials. As frequencies higher than 100 GHz are approached, physically unachievable magnetic fields are required. Thus, the use of cyclotron auto-resonance is not a viable acceleration scheme for this power conversion process if it is to be considered at the infrared or optical frequencies proposed for laser power beaming.

One can exploit the spatial and temporal structure of a pulsed gaussian beam that would appear in the resonator in the case of pulsed laser beaming, and discover another possible electron acceleration mechanism. This mechanism, especially its use in this particular application, must remain proprietary due to the pending patent disclosure of this rectification process, and cannot be disclosed in its entirety at this time. However, it is possible to state that the region of applicability of this second traveling wave acceleration process is defined by the constraint

$$\frac{v_z(0)}{c} \gg 2\pi\gamma(0)\frac{\omega_B(0)}{\omega}$$

which significantly eases the requirements for a magnetic field. In the case of a wave field of a wavelength of 10.6 μm (a typical CO_2 laser wavelength), i.e., $\omega = 1.7 \times 10^{14}$ s^{-1}, and taking $v_z(0)/c \approx 1.0 \times 10^{-2}$, one finds that $B(0) < 6$ kG. Of course, there are other restrictions incorporating the spatial dimensions of the acceleration region, but they are not as stringent as the one just stated.

Suffice it to say that the acceleration process will give the electrons a final energy of ξ_T as they reach the opposite reflector which, in this case,

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becomes the cathode in the DC conversion process. Thus, the energy absorbed by the electrons during the acceleration process is $\xi_T - \xi_0$ thus inducing a potential difference V between the two cavity reflectors of

$$V = \frac{\xi_T - \xi_0}{e}$$

Analysis shows that the energy gained by the electrons in this process is proportional to the square of the electric field strength within the cavity.

Problems That Remain to be Solved

Of the several potential problem areas that will most likely become apparent, the most obvious one has to do with heat dissipation due to losses incurred in whatever material is used for the reflectors. Related to this, there is the issue of material erosion on the reflector that is to collect the accelerated electrons. Hopefully these obstacles can be overcome during a prototype development of this electromagnetic wave rectification method.

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TWO-WAY EML PROPULSION CONCEPT

Gerald David Nordley
Sunnyvale, California

2-WAY EML PROPULSION CONCEPT
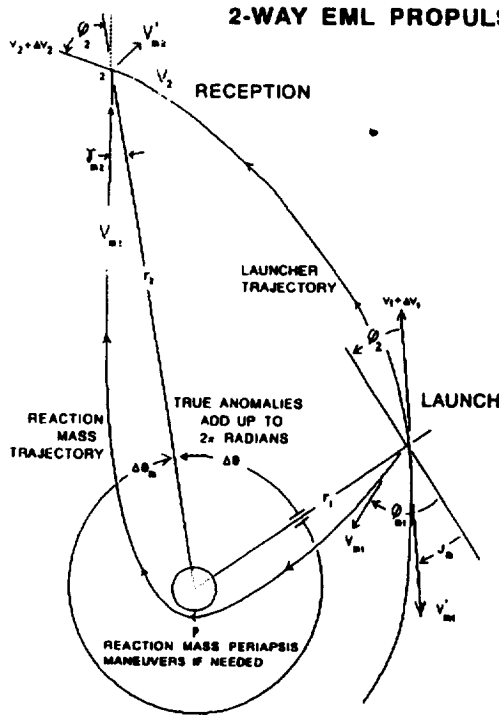
IDEA: *SEND REACTION MASS AROUND PLANET ON A RETROGRADE TRAJECTORY AND RECOVER*

WHY: *GAINS DELTA V WITH LITTLE OR NO MASS LOSS, EFFECTIVELY REACTING AGAINST THE PLANET'S GRAVITATIONAL FIELD.*

WHAT FOR: *STATIONKEEPING AND OTHER MANEUVERS OF LARGE MASSES*

NEEDS: *2-WAY ELECTRO-MAGNETIC LAUNCHERS AND SOPHISTICATED TERMINAL GUIDANCE*

TWO-WAY EML PROPULSION: TWO TYPES OF LAUNCHERS

INTERFACE (SABOT) MAY REMAIN ATTACHED TO LAUNCHER
(FORWARD'S CABLE CATAPULT)

- LONGER, HEAVIER, LAUNCHER
- SIMPLE DOCKING ENGAGEMENT MANEUVER
- CAN WORK WITH ANY SPACECRAFT
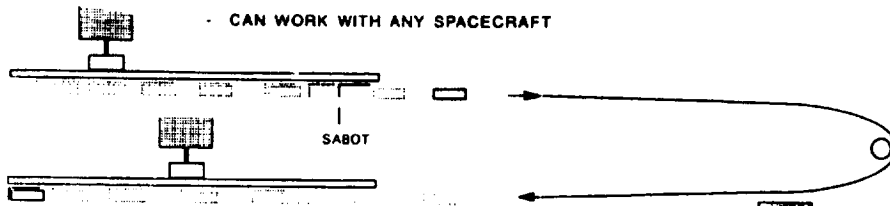
SABOT

INTERFACE BUILT INTO REACTION MASS (NO SABOT)

- DUAL USE OF EJECTION MASS SAVES WEIGHT
- LOWER PEAK POWER REQUIREMENTS

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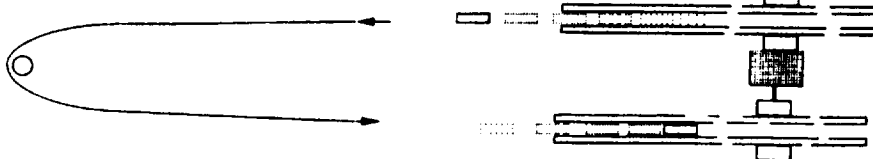
2-WAY EML RENDEZVOUS - THE CYBER CONNECTION
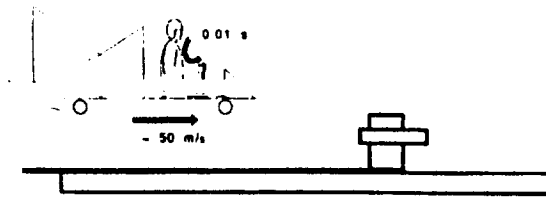
SPEED OF NERVE IMPULSES ~ 100 m/s
LENGTH OF NERVE (HEAD TO ARM) ~ 1 m
TIME FOR IMPULSES TO REACH HAND ~ 01 s
RETINA - BRAIN PROCESSING TIME ~ 04 S
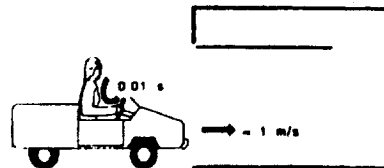
REACTION TIME ~ .05 s

RELATIVE VELOCITY ~ 50 m/s

REACTION LENGTH
= 2.5 m

REACTION TIME ~ .05 s

RELATIVE VELOCITY ~ 1 m/s

REACTION LENGTH
= 5 cm

IF ONE COULD THINK AS FAST AS MODERN ELECTRONICS,
FLYING INTO AN ELECTROMAGNETIC LAUNCHER WOULD BE
LIKE DRIVING INTO YOUR GARAGE *IN SLOW MOTION*

PROCESSOR CYCLE TIME ~ 7 9 E-9 s
(128 MHz)
CYCLES FOR FINE CORRECTION ~ 10
PROCESSOR REACTION TIME ~ 8 E-8 s

SIGNAL PATH LENGTH ~ 10 m
SIGNAL VELOCITY ~ 3 E8 m/s
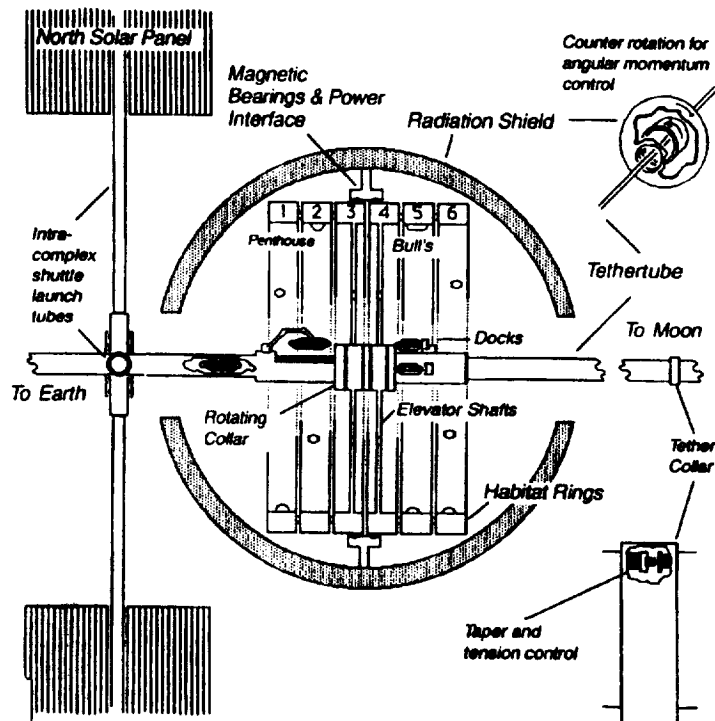SIGNAL TRANSIT TIME ~ 3 E-8 s

REACTION TIME ~ 1 E-7 s

RELATIVE VELOCITY ~ 1-10km/s

REACTION LENGTH
= 0.1 - 1 mm
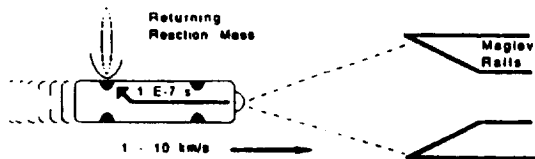
LAGRANGE POINT 1   MAIN STATION

L1 Main Station

Total Mass of Rings:
80,000 metric tons

Outside radius of rings:
220 m

Total floor area:
1,200,000 square meters

Period of Rotation:
50 s

Centrifugal Acceleration
(average) 1/3 g

Ring Depth: 20 m

Ring width: 50 m

180

EMERGING COMPUTER TECHNOLOGIES AND THE NEWS MEDIA OF THE FUTURE

Debra A. Vrabel
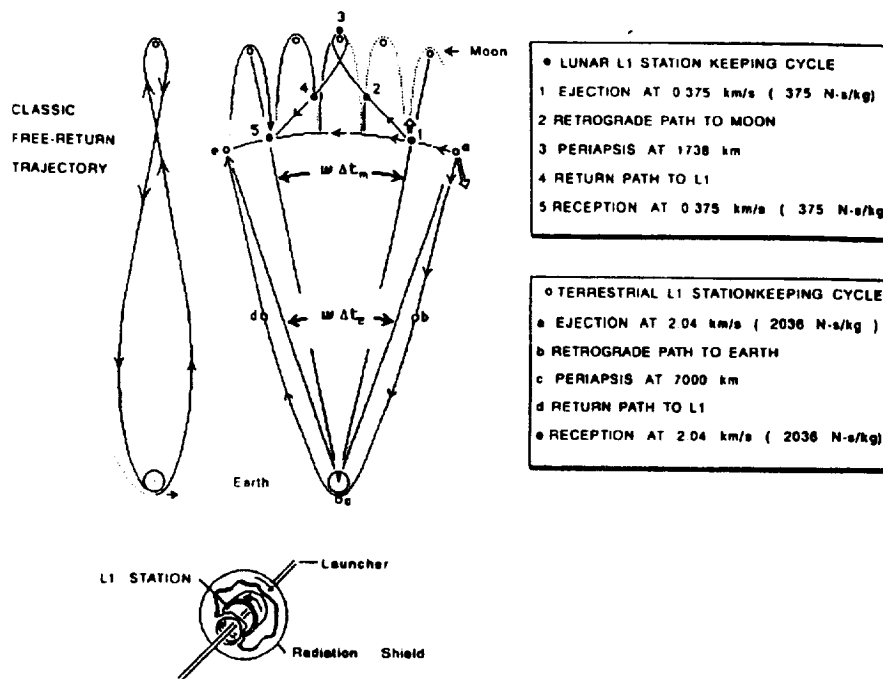Sverdrup Technology, Inc.
Lewis Research Center Group
Brook Park, Ohio

The 21st Century Media Environment:
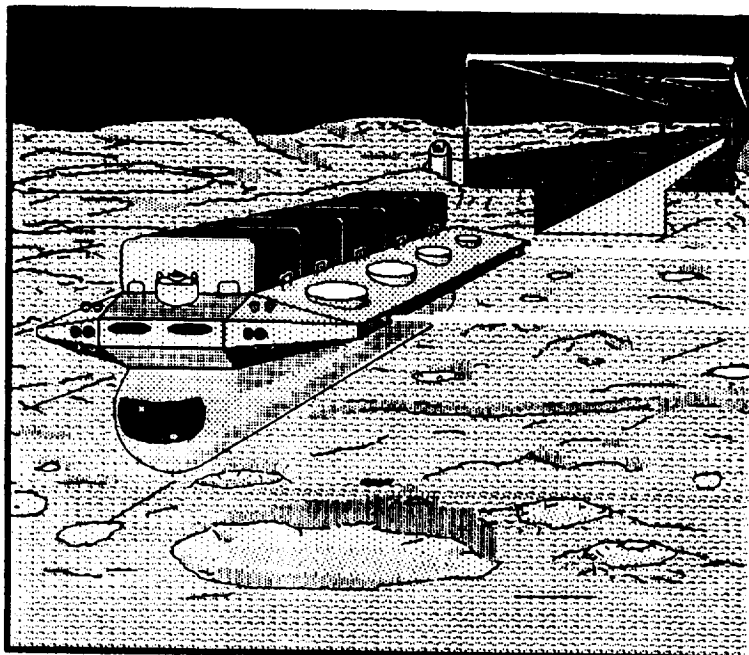## More Pioneering Journalists Needed

ABSTRACT

The media environment of the future may be dramatically different from what exists today. As new computing and communications technologies evolve and synthesize to form a global, integrated communications system of networks, public domain hardware and software, and consumer products, it will be possible for citizens to fulfill most information needs at any time and from any place, to obtain desired information easily and quickly, to obtain information in a variety of forms, and to experience and interact with information in a variety of ways. This system will transform almost every institution, every profession, and every aspect of human life---including the creation, packaging, and distribution of news and information by media organizations.

This paper presents one vision of a 21st century global information system and how it might be used by citizens. It surveys some of the technolgies now on the market that are paving the way for new media environment.

GRAVITATIONAL MIRROR PROPULSION - L1 STATIONKEEPING

CLASSIC
FREE-RETURN
TRAJECTORY

3

← Moon

● LUNAR L1 STATION KEEPING CYCLE

1 EJECTION AT 0.375 km/s (375 N-s/kg)

2 RETROGRADE PATH TO MOON

3 PERIAPSIS AT 1738 km

4 RETURN PATH TO L1

5 RECEPTION AT 0.375 km/s (375 N-s/kg)

$w \Delta t_m$

$w \Delta t_e$

Earth

○ TERRESTRIAL L1 STATIONKEEPING CYCLE

a EJECTION AT 2.04 km/s (2036 N-s/kg)

b RETROGRADE PATH TO EARTH

c PERIAPSIS AT 7000 km

d RETURN PATH TO L1

e RECEPTION AT 2.04 km/s (2036 N-s/kg)

L1 STATION ── Launcher

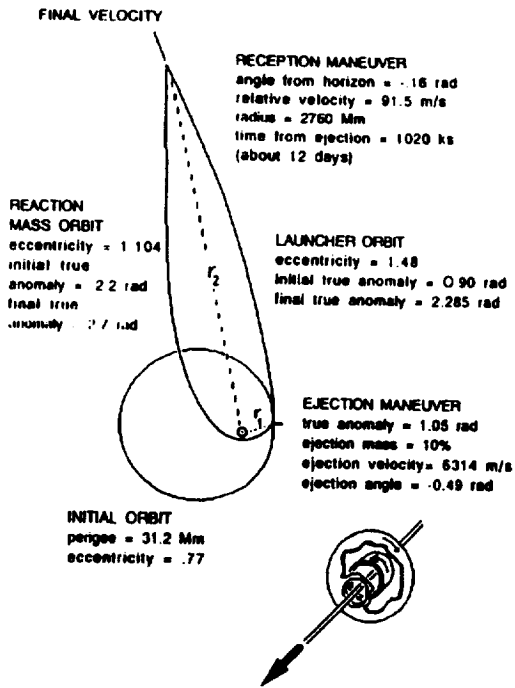── Radiation Shield

TWO-WAY EML PROPULSION - EML MOON LANDING

Velocity =
2.34 km/s

Altitude =
10 m

Location:
Congreve
Crater,
Farside
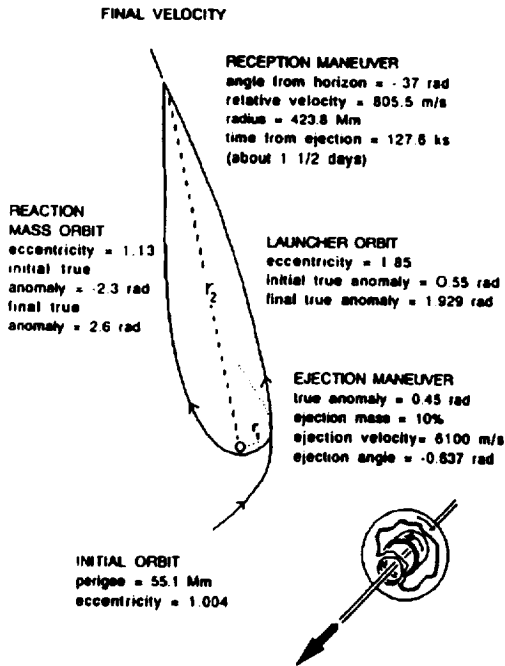
Heading:
270 (West)

182

GRAVITATIONAL "MIRROR" PROPULSION

FINAL VELOCITY

RECEPTION MANEUVER
angle from horizon = -.16 rad
relative velocity = 91.5 m/s
radius = 2760 Mm
time from ejection = 1020 ks
(about 12 days)

REACTION
MASS ORBIT
eccentricity = 1.104
initial true
anomaly = 2.2 rad
final true
anomaly = 2.7 rad

LAUNCHER ORBIT
eccentricity = 1.48
initial true anomaly = 0.90 rad
final true anomaly = 2.285 rad

r_2

EJECTION MANEUVER
true anomaly = 1.05 rad
ejection mass = 10%
ejection velocity = 6314 m/s
ejection angle = -0.49 rad

INITIAL ORBIT
perigee = 31.2 Mm
eccentricity = .77

GRAVITATIONAL MIRROR MANEUVER

Escape From 135 x 31 Mm earth orbit:

- **2.236 km/s hyperbolic excess velocity**

- *Enough to reach Venus*

- *Enough to reach Mars at favorable opposition*

- *Minimum net launcher energy needed: 3.97 MJ/kg.*

- *Reaction mass recovered*

Optimization and perigee maneuvers should yield even better performance.

GRAVITATIONAL "MIRROR" PROPULSION

FINAL VELOCITY

RECEPTION MANEUVER
angle from horizon = -.37 rad
relative velocity = 805.5 m/s
radius = 423.8 Mm
time from ejection = 127.6 ks
(about 1 1/2 days)

REACTION
MASS ORBIT
eccentricity = 1.13
initial true
anomaly = -2.3 rad
final true
anomaly = 2.6 rad

LAUNCHER ORBIT
eccentricity = 1.85
initial true anomaly = 0.55 rad
final true anomaly = 1.929 rad

r_2

EJECTION MANEUVER
true anomaly = 0.45 rad
ejection mass = 10%
ejection velocity = 6100 m/s
ejection angle = -0.637 rad

INITIAL ORBIT
perigee = 55.1 Mm
eccentricity = 1.004

GRAVITATIONAL MIRROR MANEUVER

Hyperbolic Orbit Boost

- *2 km/s gain in hyperbolic excess velocity*

- *Suggests addition to a "delta VEGA" maneuver*

- *Enough to reach Mars at favorable opposition*

- *Minimum net launcher energy needed: 2.45 MJ/kg.*

- *All reaction mass recovered*

Optimization and perigee maneuvers should yield even better performance.

C-3.

INERTIAL ELECTROSTATIC CONFINEMENT AS A POWER SOURCE FOR ELECTRIC PROPULSION

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R. Nebel[**], N. Schulze[+], J. Christensen, D. Strellis, J. DeMora,
S. Cooper, A. Ochao, J. Fluhrer
University of Illinois
Urbana, IL

ABSTRACT

The potential use of an **INERTIAL ELECTROSTATIC CONFINEMENT** (IEC) power source for space propulsion has previously been suggested by the authors and others. In the past, these discussions have generally followed the charged-particle electric-discharge engine (QED) concept proposed by Bussard, in which the IEC is used to generate an electron beam which vaporizes liquid hydrogen for use as a propellant. However, in the present study, we consider an alternate approach, using the IEC to drive a "conventional" electric thruster unit. This has the advantage of building on the rapidly developing technology for such thrusters, which operate at higher specific impulse. Key issues related to this approach include the continued successful development of the physics and engineering of the IEC unit, as well as the development of efficient step-down dc voltage transformers.

The IEC operates by radial injection of energetic ions into a spherical vessel. A very high ion density is created in a small core region at the center of the vessel, resulting in extremely high fusion power density in the core. Present experiments at the U. of Illinois in small IEC devices (<60-cm. dia.) have demonstrated much of the basic physics underlying this concept, e.g. producing ~10^6 D-D neutrons/sec steady-state with deuterium gas flow injection. The ultimate goal is to increase the power densities by several orders of magnitude and to convert to D-^{3}He injection. If successful, such an experiment would represent a milestone proof-of-principle device for eventual space power use.

Further discussion of IEC physics and status will be presented with a description of the overall propulsion system and estimated performance.

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INTRODUCTION

Fusion energy offers an extremely attractive power source for fusion propulsion.[1-3] However, conventional approaches to fusion reactors for terrestrial use employ heavy components, i.e. offer too low a power-to-weight ratio, to be considered for space applications. In addition, in order to reduce neutron and radioactive propellants in space, the use of advanced fuels such as D-^{3}He is desirable. Conventional approaches such as the Tokamak appear marginal for burning such fuels. Consequently, new confinement approaches for space propulsion or power are needed. While several possibilities have been suggested,[4-9] inertial electrostatic confinement (IEC) appears to be one of the most attractive approaches because of ultra-low inert mass and advanced fuel-burning efficiency, as a result of a highly non-Maxwellian energy distribution for reacting ions.[10-12]

A difficulty in projecting the use of the IEC for propulsion is that the experimental data base is inadequate. Thus the extrapolation of design principles to a reactor design contains many uncertainties. Still, it was thought to be worthwhile to carry out the conceptual design study presented here, in order to understand issues that need further study and to illustrate the potential advantages of this approach.

The design goal was to use the IEC as the primary power source propulsion system, capable of making a trip to Mars in less than 120 days. A Direct Electrical Converter (DEC) is used to convert the IEC energy to a megavolt dc current. A unique electrical system transforms this voltage and current to levels required by the thrusters, which use hydrogen propellant to achieve the necessary thrust and specific impulse.

The total weight of the Mars-bound spacecraft is apportioned as follows: 120 metric tons for the propellant and tanks; 120 metric tons for the propulsion system (60% DEC, 15% IEC, 15% electrical system, and 10% thrusters); and 60 metric tons for crew compartment, cargo, and shielding material. To complete the mission in the required time, a specific impulse, I_{sp}, of 3000 seconds is necessary. To achieve this, the five parallel thrusters deliver a mass flow rate of 11.5 g/s and a thrust of 340 N.

The craft is launched from a low Earth orbit. Succeeding sections contain a description of the various subsystems in more detail. An earlier concept for IEC-based propulsion was proposed by R.W. Bussard,[9] who envisioned an advanced electron beam-heated thruster. Here we explore the use of an alternate thruster based on magneto-plasma-dynamic (MPD) and arcjet concepts.

INERTIAL ELECTROSTATIC CONFINEMENT (IEC)

The proposed power source is a fusion system, based on the principles of the IEC, a method of electrostatically confining a fusion plasma first proposed by Salisbury[13] and Farnsworth.[14] Early experimental studies were carried out by Hirsch,[15] but little was done after that until recent experiments at the U. of Illinois.[12, 16-18] The IEC device is spherical and consists of two concentric spherical grids. (Fig. 1) The inner grid, the cathode, is placed at a large negative potential with respect to the outer grid, which is grounded. When small amounts of gas are puffed into the grids, the high electric field ionizes the gas and accelerates the ions towards the center of the device. As

these ions converge upon the center, they form a dense core region where fusion can take place. Because of space charge build-up of the ions and electrons in the core region, virtual anodes and cathodes are formed in a spherical potential well structure.[12, 15] This serves to enhance the ion confinement and to produce a very dense center spot where fusion occurs. U. of Illinois experiments have been quite successful to date, achieving a measurement of the potential well during low current operation (20 mA) and also achieving strong (1.2×10^6/sec) 2.45-MeV neutron emission when deuterium fill gas is used. Still, these experiments are 3 to 4 orders of magnitude (in current) below breakeven. Consequently, several key scale-up experiments are needed to confirm the feasibility of this approach. In the discussion below, we examine fundamental IEC design concepts to produce a fusion propulsion system of 21.4 MW.
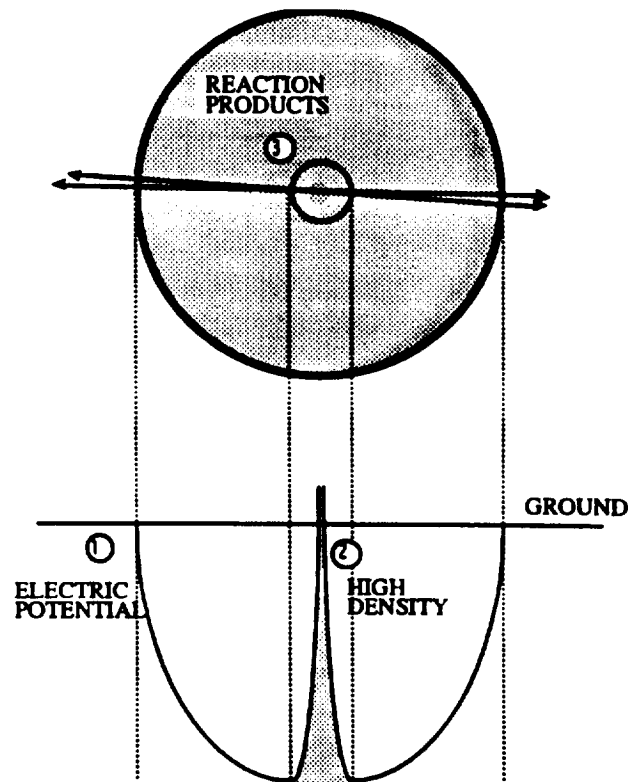
Figure 1. IEC concept

POWER FLOW

The power analysis of the IEC requires an assumption of how the fusion rate scales with current. A graph of the fusion rate scaling is shown in Fig. 2. Calculations are shown for I^5 and also a more pessimistic I^3 scaling to illustrate the range of possibilities. For the final rocket design, I^5 scaling has been chosen. This assumes that a fully-developed potential well structure is achieved.

Figure 2. Scaling laws for IEC with potential wells and (ICC) compression
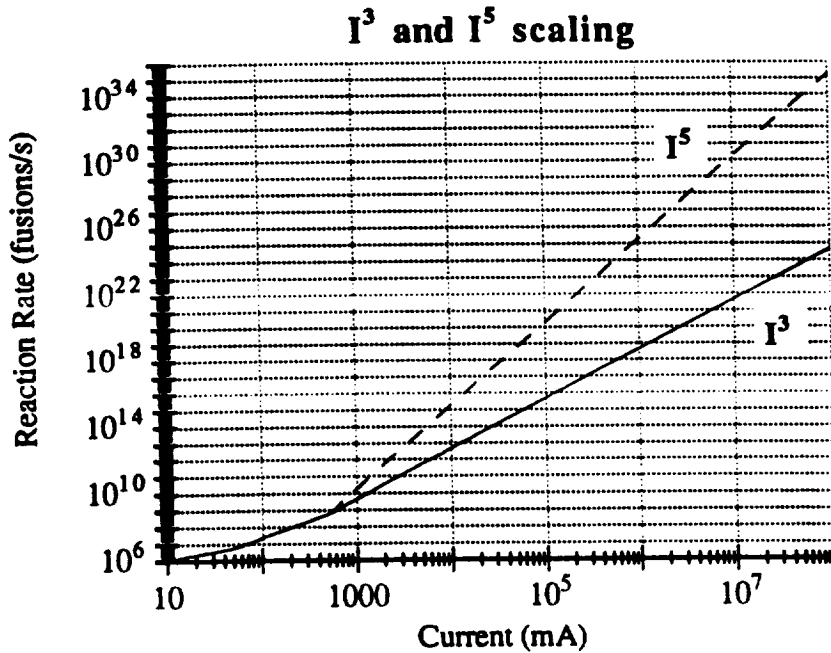
I^3 and I^5 scaling

Fig. 3 shows a power flow chart for the overall system, while the specified subsystem parameters are given in Table I. The results of calculations based on these parameters are shown in Table II. An attractive fusion energy gain is predicted, giving 21.4 MW to the DEC with only 4.16 MW of injected power. This design gives a thruster power of 10 MW.
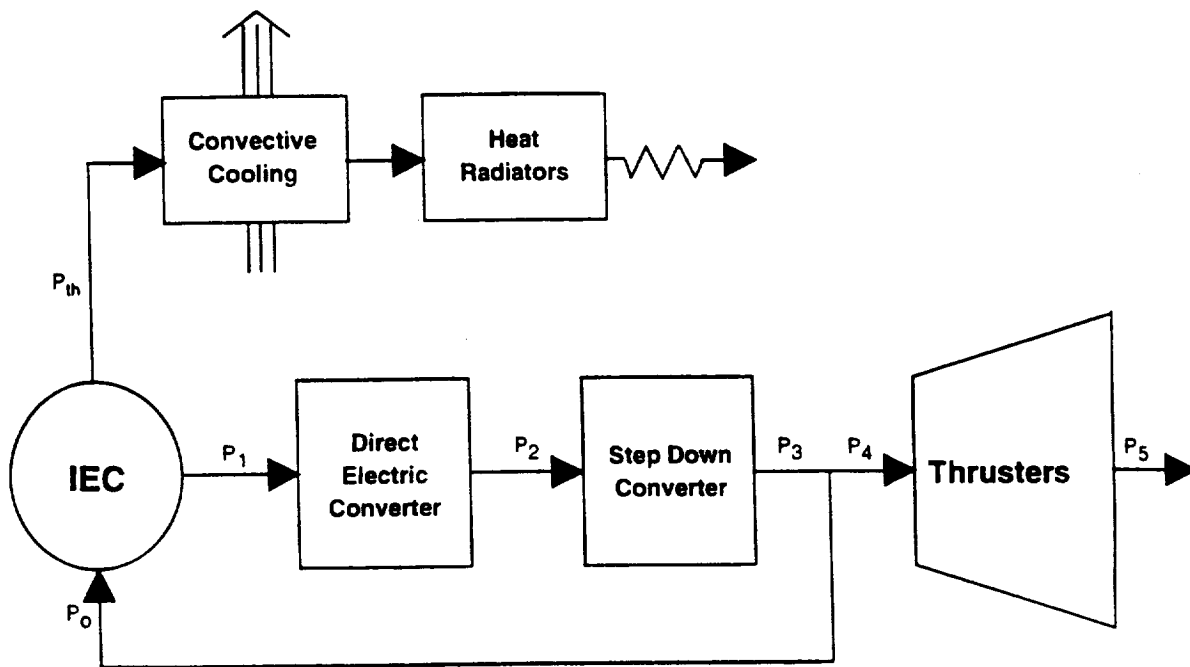
Figure 3. IEC fusion rocket power flow chart

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Table I. Estimated efficiencies of various components

COMPONENT	EFFICIENCY
Direct Electric Converter	$\eta_{DEC} = 0.80$
Step-Down Converter	$\eta_{STD} = 0.95$
Thruster	$\eta_{TH} = 0.50$

Table II. Power flows corresponding to Fig. 3

$P_0 = 4.16$ MW	$P_1 = 21.40$ MW
$P_2 = 17.12$ MW	$P_3 = 16.26$ MW
$P_4 = 12.00$ MW	$P_5 = 6.00$ MW
$P_{excess} = 0.104$ MW†	

†P_{excess} is excess power which is available for use for extraneous ship functions such as life support systems, communication devices and experimental research.

There are several major concerns to be addressed. One is a need to recirculate the fusion fuels, ^{3}He and deuterium. Only a small fraction of the fuel is actually burned, ~5%, and the rest must either be retained in the system or collected and returned to the IEC. This is especially important for the ^{3}He because of its high cost. Another concern to be addressed is the accumulation of reaction products, such as tritium, in the IEC core.

GRID HEAT REMOVAL

The IEC grid structure is comprised of a network of equilateral triangles forming a geodesic structure. This structure maintains the electrostatic field necessary for IEC operation. In order to maintain the desired transparency of 95%, the ratio $d/a < 0.0577$ is necessary, where the grid tubing diameter is given by "d" and the length of a triangle side is "a". The grid is constructed of tungsten which melts at 3683 K; the surface temperature of the inner grid will be 2121 K (0.58 T_m).

The radius of the inner grid is r = 0.75 m, roughly a minimum value, in view of the strong heating as a result of plasma particles and radiation hitting it. The diameter of the grid tubing is 0.5" (0.0127 m) which yields a triangle side length of a = 0.722' (0.22 m). The heat dissipated to the two IEC grids is determined to be P_0 = 4.16 MW. (See Fig. 4) The inner grid will dissipate one-third of this energy while the remainder will be deposited on the outer grid. The outer grid can successfully dissipate its heat by radiative cooling, while the inner grid requires additional forced cooling. The following discussion will focus on the inner-grid heat removal. The total power incident on the inner grid is 1.39 MW. Q_{rad} is calculated to be 110 kW, so the remainder, Q_{conv} = 1.28 MW must be removed by a coolant flowing inside the tubular grid. The cooling system will

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be closed loop with a separate H_2 tank at 0.01 MPa. The coolant will circulate through the inner grid and dissipate the heat evenly. The total mass flow rate required is 61.4 g/s, and the coolant will leave the grid at 1420 K. The convected coolant will be radiated into space by radiators with a surface area of 200 m^2. The coolant exits the radiators at 300 K.

Figure 4. Heat flow diagram for IEC grids
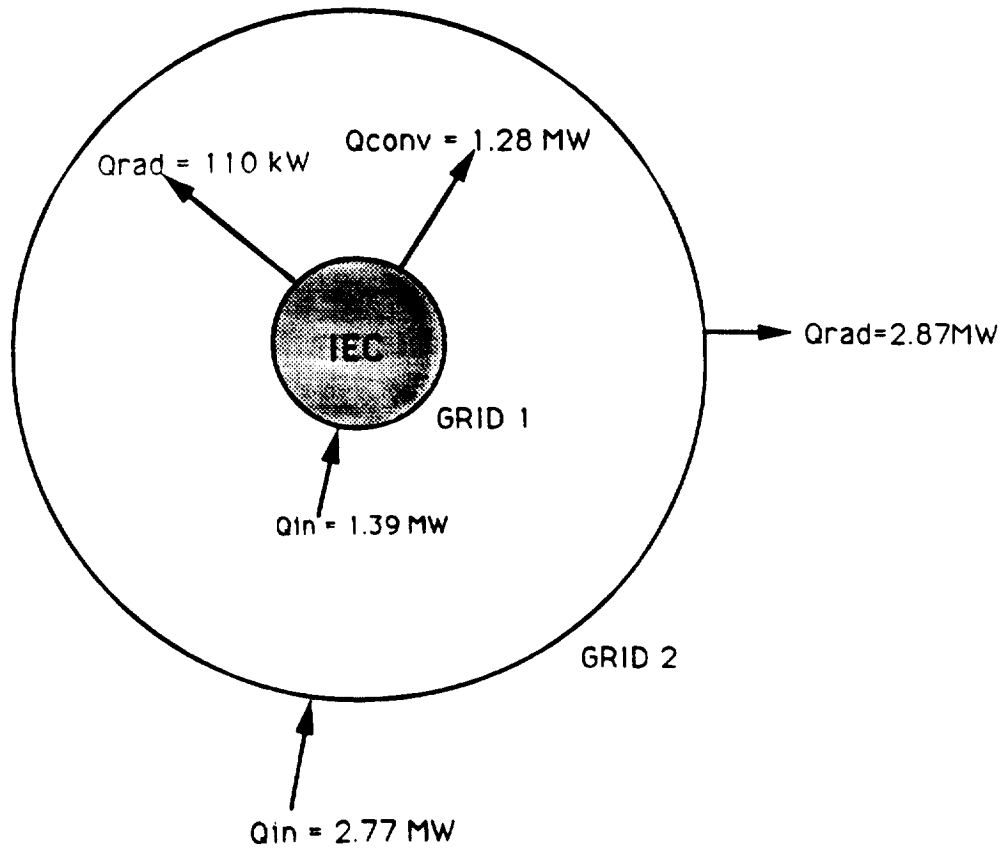
SHIELDING CONSIDERATIONS

Shielding must be provided for both solar and IEC radiation. Solar radiation consists primarily of protons and heavy ions (Galactic Cosmic Rays), while the IEC radiation consists of neutrons and x-rays.[19] One goal is to keep the crew's exposure to under 47 Rem for the 270 day mission, 3 Rem less than the annual dose limit set for astronauts. The other goal is to minimize the shielding mass, 45 metric tons being the maximum design goal. For solar particle shielding, polyethylene shields of 9-g/cm^2 and 8-g/cm^2 surround the entire crew quarters, a compartment of 10 x 5 x 3 meters. Part of the shielding will be movable in the event of an anomalously large (AL) solar flare. By doubling up some of the polyethylene, a smaller triangular compartment of 2.5 x 2.5 x 3 meters can be constructed. The "storm shield" will then be shielded by a double thickness of polyethylene. Table III shows the radiation doses received for a 270-day mission to Mars. These results are based on 9-g/cm^2 of polyethylene shielding during normal solar activity, and 18-g/cm^2 during the one AL flare expected for the mission. Results are given for both solar minimum and solar maximum conditions. This table also shows the mass of the needed shielding.

Table III. 270-Day Dose from Galactic Cosmic Rays

SOLAR CONDITION	NORMAL DOSE	AL DOSE	OR DOSE	TOTAL DOSE	SHIELD MASS
Maximum	19 Rem	8 Rem	4 Rem	31 Rem	17.1 Metric Tons
Minimum	47 Rem	0 Rem	0 Rem	47 Rem	17.1 Metric Tons

Even though there are no flares expected for periods of solar minimum, the shielding appears to be more than adequate to handle a mission during a period of solar maximum. These periods are fairly easily predicted, as the sun has about an 11-year cycle of sun spot events.

The other area of concern is the IEC radiation. Neutrons will be produced from both D-D and D-T reactions. Calculations indicate a D-D to D-^{3}He reaction rate ratio of 8.69%, giving a D-D reaction rate of 3.475×10^{17}-neutrons/sec. This reaction also produces tritium. We assume that all of the tritium then fuses via D-T reactions, giving a 14.1-MeV neutron. The result is a total neutron source rate of 6.95×10^{17}-n/sec.

The 50-m long hydrogen propellant tanks will provide significant shielding between the IEC and the crew compartment. The hydrogen in the tanks will thermalize the IEC neutrons and allow them to be absorbed before reaching the crew. The resulting flux at 50-m (the length of the propellant tanks) away from the IEC was found to be completely negligible, even at the minimum hydrogen residuals in the tanks at the end of the mission. Therefore, no additional shielding is used between the IEC and the crew.

There are still several issues to be addressed in this analysis. Most of the electronics will have to be protected from radiation. The neutrons going away from the crew, towards the DEC, can easily be moderated and absorbed; and solar radiation can also be shielded against. However, this added shielding has not yet been included in the weight estimates for the craft.

DIRECT ELECTRIC CONVERTER (DEC)

The objective of the DEC is to convert the kinetic energy of the fusion products to electrical current to be used by the thrusters to propel the ship. The direct fusion products of the D + ^{3}He reaction employed in the IEC are a 14.7-MeV proton and a 3.5-MeV alpha particle. Other charged products come from "side" D + D reactions in the form of an 0.8-MeV ^{3}He atom and a 3.1-MeV proton. In addition, a side D + T reaction produces a 3.5-MeV alpha. A "Venetian-blind"-type electrostatic energy converter is employed.[20, 21] Its collectors are charged to a potential slightly below the average energy of the particle to be collected. This design will utilize three separate sets of collector plates. (See Fig. 5.) One will be at a voltage of 1.5 MV to capture the tritium atoms produced through D + D reactions before they fall back into the IEC plasma. Another will be at 3 MV to collect the D + D alpha products. The outer collector will be at 14 MV to collect the D + ^{3}He proton products.

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Since the fusion products will be emitted isotropically from the core of the IEC, the DEC will utilize spherical geometry. The 1.5-MV and 3-MV collectors will be nearly perpendicular to the outer spherical surface of the IEC, while the 14-MV collector will be tangent to the outer surface. The orientation of the first two collectors allow the 14-MeV protons to pass these plates and collect on the outermost plate. Thus, the lower potential collectors are highly "transparent" to the 14-MeV proton.

Secondary electrons emitted when the charged particles hit the collector surfaces can result in unwanted leakage currents between the high voltage plates.[20] Electron suppressor grids are employed to prevent this. High voltage breakdown on the surface of the insulators separating the collectors will limit the distances between each successive plate. The suppressors are placed in the "shadow" of the collectors in order to prevent excessive interaction with the high energy ions.

This "Venetian-blind"-type DEC potentially offers a high conversion efficiency.[21] The distance between the 1.5-MV, 3-MV, and 14-MV collectors are limited by the high voltage breakdown field along the surface of the insulator being used. Teflon has been selected as the insulator. A fluted surface-type insulator design has been analyzed, giving the distances between successive plates as indicated in Table IV. Due to the limitations on the size of the rocket, a safety factor of 2 will be the design's goal.

Table IV. Distances between collectors in the DEC[‡]

FROM COLLECTOR (MV)	TO COLLECTOR (MV)	DISTANCE (cm)
0.0	-0.1	3.3
-0.1	1.5	53.3
1.5	-0.1	53.3
-0.1	3.0	103.3
3.0	-0.1	103.3
-0.1	14.0	407.0

[‡]Positive potentials signify high energy particle collectors, while negative potentials signify electron suppressors.

The approximate length of each collector plate is 5 cm. Thus, the DEC system will have an outer radius of 754 cm beyond the outer grid of the IEC. This is rather small, considering the IEC has an outer radius of 6 m. Therefore, the IEC and DEC system have a combined radius of 13.5 m.

Figure 5. A cross-sectional view of the DEC outside the IEC. For simplicity, only representative collector plates are shown. A close packed configuration is envisioned for the actual design.

Insulator connectors

3 MV collectors

14 MV collectors

1.5 MV collectors

IEC

electron suppressors
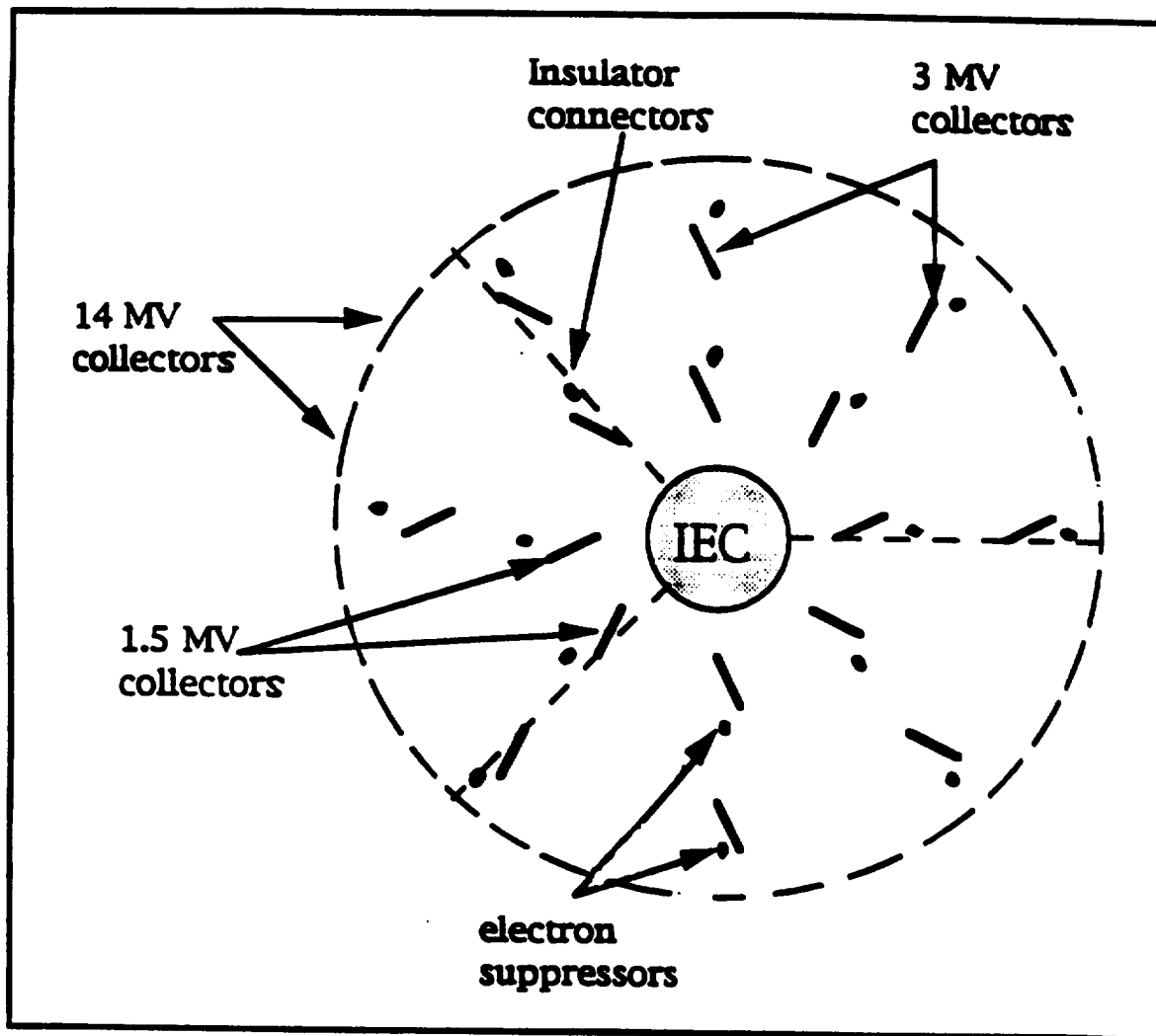
ELECTRICAL CONVERSION SYSTEM

The electricity produced by the DEC must be converted into a form that can be used by the thrusters and also be fed back to the IEC. For this purpose, the 14-MW potential output from the DEC must be converted to 1 kV and $\sim 10^4$ A. A capacitor storage system is used to provide the 10,000 pulses per second required to drive the thrusters.

The converter works on the principle of an electrostatic (ES) generator. The charge on the DEC induces a charge on the probe which charges a capacitor. As the relay allows the probe to be grounded, the capacitor charges. As the relay connects to capacitor to the load, the capacitor is placed in parallel with the ion thruster. With an additional parallel RC circuit, the output from the charged capacitor to the ion thruster can be "smoothed out."

ELECTRIC THRUSTER

The thruster envisioned for this mission is a new hybrid design. It combines features of the traditional arcjet thruster and the magneto-plasma-dynamic thruster (MPD). The design (Fig. 6), uses the same electric current to provide both an electrothermal and a magnetic acceleration, yielding an I_{sp} of 3000 seconds and a thrust of 68 N per thruster.

Hydrogen gas is continuously fed into a 3-cm diameter by 6-cm long thruster chamber at a rate of 2.3 g/s. As the gas fills the chamber, a charge builds up on a small capacitor bank, coupled to the two electrodes. When the electrodes reach a potential of 1 kV, they discharge an electrical pulse with a current of 20 kA, dissociating and ionizing the hydrogen, sharply raising its pressure, and accelerating it toward the conical nozzle region. As the hydrogen reaches the nozzle section of the thruster, it is further accelerated by an azimuthal magnetic field generated by the current flowing between the anode and the cathode, accelerating it in an axial direction.

Figure 6. The hybrid thruster design
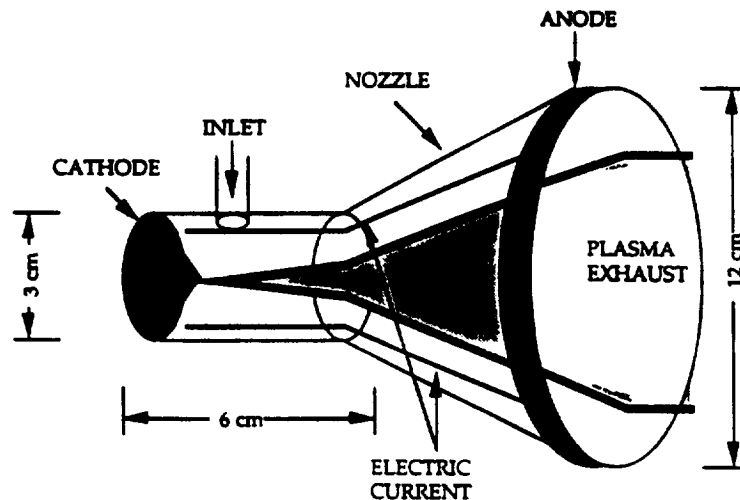
The thruster is operated with a pulsing frequency of 10,000 per second. This is necessary to prevent overheating and to increase chamber pressure. Between pulses, the hydrogen collects in the chamber, increasing the pressure. By the time the hydrogen escapes the nozzle, another electrical pulse expels the gas from the chamber. The increase of the pressure in the nozzle to a few atmospheres offers several benefits. Dissociation and ionization losses are reduced, energy is gained from hydrogen recombination within the nozzle, and the Reynolds number is increased. The energy gained by recombination further accelerates the flow and the increased Reynolds number reduces frictional forces on the wall of the thruster.

Each thruster has an average power input of 2 MW, with a peak power of 10 MW. Although it has an efficiency of only 50%, each thruster can deliver 2.3 g/s of propellant at a velocity of 29.4 km/s, producing 68 N of thrust with an I_{sp} of 3000 seconds. Since there will be five thrusters, the total thrust will be 340 N.

A large amount of propellant is required for this mission. Although the mass flow rate appears small (11.5 g/s), the total mass needed over the 120 days is 127.5 metric tons, including 5% added for reserve. Stored as liquid hydrogen,[22] this requires a volume of 1960 m^3, which will be divided among fourteen tanks.

Each thruster has three main components, as shown in Fig. 7. The nozzle and capillary tube are constructed using an insulator with a high melting point, such as Si_3N_4. The electrical components include the charging capacitors and the electrodes. Copper heat radiators are required, weighing about 700 kg per thruster. A 3-cm thick radiator of this type would occupy 13 m^2, which can easily be accommodated. The estimated total mass of each thruster is 1760 kg, or 8800 kg for all five thrusters.

Figure 7. Diagram of complete thruster
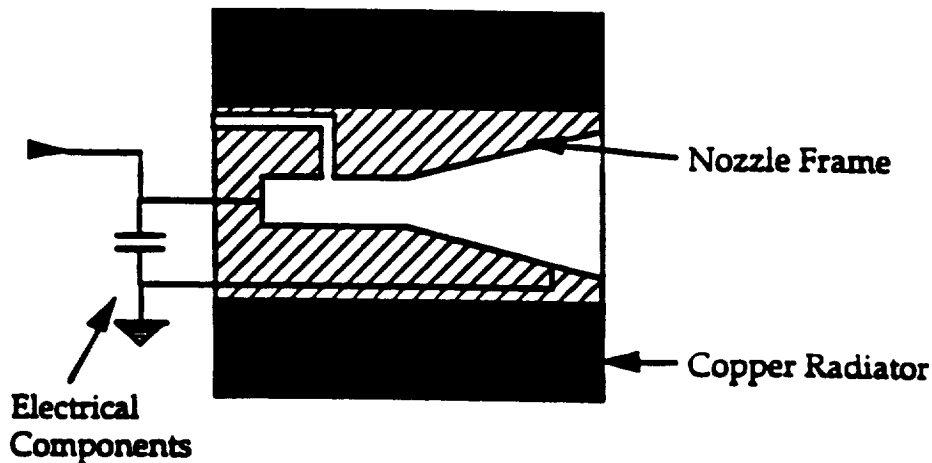
CONCLUSION

A schematic drawing of the approximate positioning of the various components is shown in Fig. 8. As discussed earlier, the propellant tanks are located between the IEC and command module to provide shielding from IEC neutrons. The step-down and pulse forming subsystem, located between the IEC and the thrusters, required added shielding for sensitive electronic components.

This design must be viewed as very preliminary, since many issues have been uncovered that require much more exploration before the feasibility of this concept can be fully verified. However, the results confirm the initial view that the IEC could provide an exceptionally attractive spacecraft for deep missions such as MARS, provided the physics of this approach works out as anticipated. Thus, in the present design, a 21-MW IEC provides the power needed for the hybrid thrusters giving 340 N and an I_{sp} = 3000 sec. in a spacecraft configuration of overall weight of 300 metric tons. This allows an attractive 120-day trip time to Mars for a manned exploration mission.

Figure 8. Possible configuration of the IEC fusion rocket components
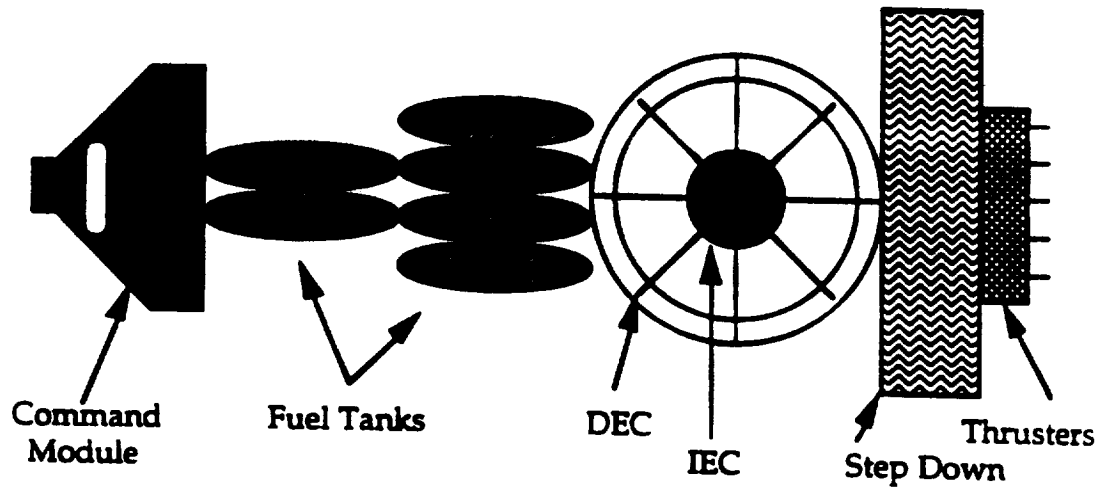
Command Module   Fuel Tanks   DEC   IEC   Step Down   Thrusters

ACKNOWLEDGEMENTS

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THE THRESHOLD OF CHANGE

"Journalism," says Timothy Crouse, "is probably the slowest-moving, most tradition-bound profession in America. It refuses to budge until it is shoved into the future by some irresistible external force."

Today, the traditions are losing their grip and the external forces are gathering strength.

Mass media are under assault from all sides. The public calls the official information and expert analysis presented by the press biased. They complain about "sound bite news," but few read the newspaper from front to back. They say the news lacks depth, but they read only *USA Today*. They condemn the superficiality and sensationalism of newspapers, yet many voraciously consume the outlandish stories presented by Geraldo Rivera and the *National Enquirer*, undignified mutations of the American free press.

Among journalists, there is concern about lack of diversity both within their ranks and among the media corporations that employ them. There is concern about the growing dependence on advertising revenues (Bagdikian 1990).

Newspaper journalists worry that "the medium might not survive" (Pease 1992) because their employers, frightened by the public's shift to television news, are attempting "to beat television at its own game" (p. 48-9). Broadcast journalists struggle to compete in a sea of mind-numbing entertainment and an ever-expanding range of viewing alternatives.

These problems are not new. Criticisms have been leveled at the mass media since the days of Thomas Jefferson. Once-great media companies have failed. But in years past, concern about these problems was tempered by the knowledge that people would continue to but newspapers and watch the newscasts and that advertisers would always be there. As a result, minor renovations were sufficient; there was no need to rebuild the foundation.

But today, there is a critical difference: competing news and information alternatives are beginning to appear, encroaching on the time some people spend engaged in the daily rituals of reading the newspaper and watching the nightly news. They are providing much of the useful information that some people once obtained from magazines.

These information media lack the ease of use and visual appeal of newspapers and television. But what sets them apart from these products is that they allow audiences to be both active seekers and contributors of information instead of what Innis called "a reading and listening audience positioned on the dumb end of a

one-way conversation" (Gladney 1992). And what will expand their share of the public's time, money, and attention is a convergence of computing and communications technologies that is making these alternatives more accessible and engaging, along with a changing economy, in which information is becoming a commodity.

Today's mass media companies are not ignoring these new information media. They have adopted many new technologies in the past two decades for their own use, and they have introduced new products that make use of these technologies. The details of a future "electronic newspaper" are beginning to take shape. Knight-Ridder's Information Design Laboratory and Gannett's Advanced Technology Lab are exploring the technology and defining the content of future media. Journalism think tanks, such as the Freedom Forum, are discussing potential impacts on society of a coming national information service. The mass media seems to be moving in the right direction.

But are they moving fast enough? Are they reacting to mature and imminent technology developments and never trying to guess what is beyond the technological horizon?

Will they have the technological resources at their disposal to compete in the new environment or will they have to depend on other industries who own these resources?

Will today's high tech industries, which are relentlessly advancing technology and championing innovation among their employees, dominate the news and information of the future? Or will the technologies they put into the hands of citizens create a nationwide news medium that is heterogeneous and democratic beyond anything envisioned?

What will journalism's role be. Will the principles it values today govern the future high tech news and information environment? Will the positive control measures always employed by the mass media remain effective, will they be subverted, or will new control measures rise to the surface? Who will employ these control measures?

Too many unknown variables now obscure the full answers to these questions. But they need to be asked continually by journalists.

This paper is an attempt to take some initial steps toward clarifying and examining the technological potentialities of the future. Its intent is to frame a new dimension for debate about the media's social role in an economy based on information.

This paper presents a vision of the future based on today's technology and today's mass media to provoke the thought that perhaps change will be more sweeping than anyone has imagined. It then frames three questions about the future that journalists must begin asking now when they have a chance to influence the answers.

The questions are these:

- Who will control the technology?

- Who will control the media?

- Who will control the marketplace of ideas?

The technological visions and possible outcomes presented here are based on an assumption that it is valid to construct visions of the future based on an incomplete picture. A helpful guideline comes from conservationist David Ehrenfield (1993, p. 9):

> The business of prophecy is not foretelling the future; rather it is *describing the present* with exceptional truthfulness and accuracy. Once this is done-- and it is an overwhelmingly difficult task--then it can be seen that certain broad aspects of the future have become self-evident, while other features, including many of the details, remain shrouded in mystery.

NEWS IN THE 21st CENTURY:
Personal, Interactive, and Experiential

With today's processing, networking, display, and software technologies, it is already possible to manipulate multimedia information, interact with computers in a conversational fashion, communicate meaningfully with other computer users, and even experience artificial worlds. However, many of the technologies that make these activities possible are too expensive for most people to buy. Others are not yet perfected or not yet widely available on the market. But these technologies can be perfected and mass-produced, and they can be integrated in new ways.

Any vision of the 21st century must be based on assumptions. This vision assumes that the information needs of society will continue to increase and that the "knowledge sector" of the economy will continue to grow. It assumes that the current course of today's computing and communications research will continue, just as most technologies have followed an evolutionary development course toward meeting and exceeding an original need. It assumes that most technologies existing today in limited form will continue to mature and decrease in cost and that diffusion of these technologies will occur, just as has been the case with other formerly exotic, little-known technologies, such as telephones, television, and personal computers.

These technologies can change the information environment that today is dominated by newspapers, magazines, and television.

This is what could happen:

Future citizens will obtain news and information in a highly individualized fashion. They will have the ability, according to their own needs and preferences, to obtain not only specific data, images, news, and information, but also knowledge that is packaged in a variety of ways by media professionals, by other users, and by software. They will automatically receive less information that is irrelevant to them and more information that they can use. This information will be presented to them in ways that are organized, understandable, and engaging. They will be able to interact with the information, controlling their own movements from one idea to another, asking questions and receiving answers, instantly retrieving from libraries and other storehouses all over the world whatever information they need in the form of text, photos, graphics, and audio and video recordings.

Citizens will have the ability to interact with knowledge providers, with other recipients of knowledge, and with the knowledge itself. From their homes, citizens will interact face-to-face with other people in distant locations. Those with the desire will publish their own writing, even their own electronic newspapers and magazines. They will be able to create and broadcast their own documentaries.

Citizens will experience knowledge in new ways. They will be able to enter and even create artificial worlds, and they will be able experience some of the sensations of traveling to a variety of places around the globe.

LITERATURE REVIEW

Few visionary thinkers in computer science and technology have even addressed thoroughly the potential their field offers for news media. However, a vision of 21st century news media can be drawn from their works and from a survey of technologies now being developed or marketed.

Brand (1987) establishes that advanced research in interactive media is being done and helps to define the cutting edge in areas such as artificial intelligence, parallel processing, and networking. Krueger's speculative thinking (1991) on possibilities for new forms of interaction and experience in responsive environments provides many original ideas.

Helpful for developing a broad perspective is an extensive review of computing periodicals, particularly Seybold's *Digital Media, Byte,* IEEE *Spectrum* and IEEE *Engineering Times*. Rheingold (1991) provides useful information on the potential of virtual reality, Gilder (1989, 1990) on future television, and Laurel (1991) on human interface design. Also interesting to examine is the potential for the mass media of Moravec's work in the areas of intelligent robots and mind-computer linkages (1988, 1993), Drexler's work in nanotechnology (1986), and Zeltzer's (1992) work in "virtual actors."

Examining various aspects of future society and the role technology will play creates a larger framework for the idea of new media and some specific ideas for how technologies will be applied. Perleman's vision (1992) of a computer-based system for lifelong learning, Toffler's forecast (1990) of a coming "knowledge-based economy," and McLuhan's amazingly prescient views (1964) suggest the dramatically heightened role knowledge will play. A collection of essays edited by Benedikt (1992) illustrates the growing vividness of a cyberspace metaphor that suggests the eventual evolution of a new "super-medium" that is the foundation of all other media.

Finally, the confidence to present this vision comes from conversations with a number of technically knowledgeable people at NASA Lewis Research Center, particularly Fredric Goldberg of the Telecommunications and Networking Branch, Roger Dyson of the Mainframe Systems Branch, and Laszlo Berke of the Structures Division.

THE SYSTEM: A COMING TECHNOLOGY SYNTHESIS

The potential for this new type of news will depend on an integrated system of hardware, software, and networks.

The Network: Gateway to a world of information

A National Public Network (NPN) or as many have called it an "Information Superhighway," will be the basis of tomorrow's information media. Capable of transmitting voice, data, and video at speeds of one gigabit per second (gbps), and higher, the NPN will be linked to Metropolitan Area Networks (MANs) and ultimately to local area networks (LANS) in businesses and to Small Area Network (SANs) in each home. This linkage will provide anyone with a terminal access to a variety of general- and special-purpose computers in universities, businesses, hospitals, libraries, and national research labs.

In homes, SANs will link televisions, telephones, and computers, as well as appliances, automobiles, home environmental control systems, home security systems, and other devices. People will be able to communicate instantly, accessing the network with a variety of personal devices. They also will be able to tap into commercially available devices, making it possible to run a home from the office or an office from the home, to shop, bank, and obtain professional services, and even to pursue training without ever leaving home (Miles 1989).

Also, because each person will be assigned a unique, lifetime i.d. number, it will be possible to plug into the network from any location--- the doctor's waiting room, for example --- and use many of the same services available in the home.

Through the NPN, homes may be provided with computing bandwidth in the same way that the utilities provide units of gas, electricity, or phone service. In fact, since the network can be used for telemetry from home energy and security systems and carry voices, it may happen that homes will receive one utility bill that includes a measure of the computing resources they used.

Just as with heating and phone usage today, some buyers will have to be careful and conservative in their consumption, buying only the minimum number of channels, limiting hours of usage, and accessing only the least expensive services. Similarly, just as some buyers today are willing to pay the price for more usage of utilities because they can afford to run their air conditioning and use 900 numbers liberally or because they have an over-riding need for high usage, such as running a medical apparatus or making long-distance calls in search of a job, some buyers will buy more bandwidth than others. Those who can afford it will have "infinite bandwidth" (Brand 1987).

The NPN will be a gateway to whatever information exists for public consumption. Its ability to provide virtually unlimited bandwidth and its connection to computers and mass storage systems in virtually every school, library, research lab, business, and home will enable any person to request from any source text, computer software, computer data, still or animated art, photographs, audio recordings, or video selections that are made publically available. As a result, each individual will be the hub of his or her own entertainment and news network.

The Hardware: Many ways to interact

The focal point for each home's personal entertainment and news network will be a digital device, referred to in this paper by George Gilder's term, the "telecomputer" (1989, p. 312). The phone companies like to call it a teleputer, or, better yet, a telephone. The cable companies like to call it a "smart" cable box. The computer companies like to call it a videoconferencing computer. Whatever name results, it will probably combine many of the functions of today's telephones, televisions, stereo systems, and personal computers.

Although telecomputers will rely on public domain computers for many of their capabilities, they will also have significant computational power of their own---processing speed, memory, and hard-wired intelligence far beyond anything that exists today. They will be knowledge processing machines, capable of a high level of autonomy, decision-making abilities, and perception. As such, they will be able to take over many of the tedious activities that occupy humans' time, to interact with humans in a natural manner, and to learn about the information needs of their owners.

As nanotechnology researchers achieve their vision of microscopic integrated circuits, it will be possible to combine a variety of special purpose processors---some suited for fast processing of data entered by the user, others capable of rendering high resolution graphics and images and decompressing images sent over the network, and others possessing the necessary pattern recognition capabilities needed for speech recognition, language processing, and other intuitive functions.

Each home's telecomputer will have a variety of input devices, including the traditional keyboard, a wireless mouse-type device that can interact with the screen from the comfort of the couch, a microphone with eye-tracking capabilities that picks up speech directed at the system (Brand 1987), and an array of electronic pens, pencils, and paintbrushes that allow handwriting on the screen by pressure on a graphics pad or just by pointing to the screen (Krueger 1991). Each telecomputer will have a built-in video camera, hopefully one that can be switched off sometimes (Krueger 1991, Brand 1987).

The main output device will be the telecomputer screen, which will be used for direct viewing of visual media obtained through interactions with the network. It will yield a three-dimensional picture so sharp and clear that it will be difficult to distinguish objects that appear on it from their real counterparts; text that is displayed for reading will be easier on the eyes than books (Gilder 1990, Rheingold 1991)). Many people will opt for a very large screen or for multiple screens. Some might even have wall-to wall, screens that will allow them to reconfigure their surroundings (Krueger 1991). In addition, a spatial sound system will allow the user to experience realistically every sound produced by the medium (Esserlieu 1991). With advances in holography, systems may even become available that make objects spring from the TV screen and materialize in the middle of the room (Esserlieu 1991).

High capacity storage devices, capable of containing vast amounts of digitized text, photographs, graphics audio, and video, will enable users to combine information they obtain from the network and save it for later use. Storage systems will be hierarchical: information accessed most frequently remains on a local storage server for quick access and information accessed infrequently is transferred to remote storage, which is accessed less rapidly. Users with the greatest information needs will purchase high-capacity servers as their first level of storage; this will enable them to gain fast access to large quantities of information. Large public storage facilities, also configured hierarchically, will make stored information available over the network.

Users will be able to choose from among many types of portable devices, capable of exchanging information with the home system or of being connected to network outlets in other locations. Some devices may also allow people to interact with their home systems from any other location without any outlet needed (Perleman 1993).

Portable input/output devices may include book-like or paper-like portable computers that can be plugged into the main system for downloading of information (Fidler 1992). Special glasses will provide a variety of visual effects (Moravec 1988), perhaps allowing a user greater immersion in the action being shown on the news or projecting a high resolution newspaper in the empty space in front of a user, allowing him or her to read without using the hands (Krueger 1991). Users may prefer to take book-sized versions of their personalized newspapers and magazines on the subway with them but wear glasses on the beach or in bed.

Also part of the system will be special body attachments, successors to the suits, datagloves, and head mounted displays used in today's "virtual reality" applications (Rheingold 1991).

The Software: The user's information navigator

The software applications that reside in the user's telecomputer, as well as in the computers accessed over the network, will serve many roles. First, they will be the user's information "comptroller." Also, they will be the user's interface and interpreter to other software on the network. Finally, they will be the user's guide and assistant in obtaining information.

One of the most perplexing issues people associate with disseminating information electronically is one of remuneration: how will copyrights be enforced, intellectual property guarded, and publications sold?

In fact, all of these needs can be met in a global network. Just as today there are libraries and computer bulletin boards that provide public domain information, the information superhighway will provide much free information. Information packages that are perceived to be more valuable, however, will be paid for monthly like long distance telephone services and pay-for-view programs ordered from cable companies, or perhaps they will be purchased via automatic electronic funds transfers.

The same software that will handle the user's shopping transactions and monthly bills will initiate electronic funds transfers when the user has obtained copyrighted information from the network. Likewise, they will accept electronic funds when the user's own copyrighted information has been accessed by someone else. Users may even be able to designate a monthly information allocation that fits their financial abilities and leave it to expert software to make sure the "information budget" is not exceeded.

Intelligent software will also act as an "agent" for its human owner. Acting predictably and on the user's behalf, (Laurel 1991) these agents will eliminate the time-consuming, hard-to-learn processes that today stand between people and the information and services available via computers. In fact, they will even handle many of the tasks involved in reading or watching today's news, such as searching for the items that one wants to read, sitting through televised news one does not want to hear, looking for alternative viewpoints or corroborating information for stories that are considered important, and attempting to analyze, synopsize, and synthesize information about a topic. All that the user will have to do is the mental work that is uniquely human---reacting to news with emotion, forming opinions about news, linking news to mental pictures and past experiences, making personal decisions about news, generating creative ideas based on news, and talking to others about the news.

The network itself will perform the first level of decision-making about what news to process. It will seek and assemble this information from information sources and prioritize it. As data is transmitted from all of the many sources world-wide,

the network will add value by "collecting, integrating, and evaluating data, drawing automatic inferences, and running input through sophisticated models" (Toffler 1990). This "extra-intelligence" will, one would hope, be employed to help prevent libel, false advertising, and fraud and to help temper the effect of information that encourages illegal or dangerous activities, bigotry, or any other potentially harmful actions. It will not, one would hope, be used to censor unpopular ideas.

The second level of selection will be made by the user's own software agents, which will be programmed by the user to search for certain information on certain days or at a certain frequencies of time, to order information according to the user's priorities, and to present information according to the user's level of comprehension and reading/learning style.

Although not always visible, agents will be represented graphically to the user so that interaction with them will have the ease of conversation and the information value of eye contact and cues from facial expression and tone of voice (Santo 1992). Some users may prefer to have more than one agent -- perhaps one for hard news and another for sports news. Users may even prefer to design their own agents (Laurel 1991).

When the user first interacts with the agent, he or she will spend time providing a profile that will be used in the system's information-seeking. The user will answer in whatever mode is most convenient -- sometimes by writing, other times by speaking. The agent will request information, such as age, occupation, educational level, income, interests, hobbies, political orientation, fashion taste, or any other general characteristics that classify readers. Menus of information categories, (e.g. "city government", "heavy metal music", "pets", etc.) may also be presented from which the user can select the major topics that are of the greatest interest. So, for example, a user who selects "city government" as a major area of interest may get a large portion of each day's news about city government --- film of every council meeting and transcripts of every speech by the mayor, along with all the historical, economic, and sociological background information needed to understand the events --- while a user who gives city government a low priority or no priority may receive only brief accounts of major decisions or may receive news of city government only when it coincides with his or her interest in heavy metal music or pets.

Deciding how much control to give the system over the information presented each day can be left to the user. Control may vary from using the machine as an intelligent servant that only fulfills requests made by the user to using it as a mentor, a therapist, or a conscience. Some may use the system only for narrowing down choice, preferring to be offered a long list of choices from which they will do their own selecting and prioritizing. Others may prefer to be offered the same topics each day in a specified order.

To ensure awareness of important world events, many users will want to spend a portion of their time browsing as newspaper readers do today. They will request local and national newspaper services that present editors' judgments of what is newsworthy. They will be able to choose whatever paper they want for national news, read a different paper every day of the week, or read the sports section from one paper and the editorial page from another. From this newspaper, with help from their expert system, they will be able to access additional information, including video, about stories.

Some users may choose to carry on daily human-like "conversations" with their systems, which in turn, could incorporate each day's moods, desires, insights, and concerns into the search for information to ensure that the user will engage in the type of interaction that suits his or her state of mind.

If, for example, a user has had a stressful day and is exhibiting mostly negative thoughts, the system will filter out or shorten any bad news that is not necessary information and select primarily light, positive, encouraging news items. If the system detects that the user's negativity and depression are continuing beyond a day or two, it might seek out and present self-help information that addresses the statements the user made, or it may refer the user to a support group on the network.

Also, the system could act upon user reactions to each news item. If a news story provokes strong feelings of dismay or interest, the system could generate information about what steps citizens could take to contribute to a solution or seek out new experiences.

As information continues to be fed to the system daily through each choice a user makes, as well as the length of time the user spends on different types of items and the number of times a user requests additional information on a type of item, the system will continue "learning" about him or her (Miles 302).

For example, based on the information provided to the system, an 8-year-old who is interested in space travel and her mother with a degree in mechanical engineering might be provided the same news about space travel, but in different news items or in the same item with definitions of terms included in the child's version. As the eight-year-old gets older and learns more, the vocabulary level of her items may be upgraded slightly each time she shows an interest in the most technical of the items presented. Similarly, her mother may begin getting increasing numbers of articles on electric propulsion because she always reads the journal articles presented in this area.

Some users may even allow the system to compile psychological profiles and present messages that fit their personalities, maximize and minimize their cognitive strengths and weaknesses, and counteract their prejudices.

For example, if a person continually reacts to issues with statements that show evidence of emotionalism and lack of recognition for the practical facts, the system could counter with analytical information. On the other hand, if a person rarely acknowledges emotional reactions to an issue, the system might provide items that illustrate the human suffering and damage related to the issue.

The Information: Dynamic and multi-dimensional

News and information will be presented in a multitude of ways with endless variations possible. Many users will specify a type of "newscast" that they like. For example, some might request that news items be presented in text form with classical music playing in the background. Some users may want to scan or listen to summaries of pre-selected items and then choose the information they want to consume while others may want the system to choose for them. Others may ask to hear a high percentage of anecdotes and human interest material about items or to be told a joke at appropriate moments. Others may ask to see a high percentage of pictures, charts, and graphs. Some might request to hear a voice speaking just the facts.

Users will personalize the way the system presents information by selecting a variety of special attributes to accompany certain categories of information. Some users might request to see boxed text definitions that appear in the lower left corner of the screen every time a foreign or technical word is used. Some might ask for periodic stock exchange information, or occasional music breaks in information sessions. It will also be possible for a user to create or select a life-like agent or "virtual actor" (Zeltzer 1992) to act as a personal news anchor: one who looks and sounds just like a beloved news anchor of old, such as Walter Cronkite, or one who is created to project an image the user likes.

Although software will package much information up front, users will still be much more active in using the new media. They will be able to explore ideas presented to them with complete freedom, retrieving multimedia information from remote locations on the network and from their own CD-ROM libraries when they want to learn more about a fact. They will select a different level of complexity if a story gets confusing, request video footage or pictures to supplement text stories, or request text transcripts when spoken passages require in-depth examination.

Users will be able to receive answers to specific questions about each news story. They will be able to ask for corroborating information if the statistics mentioned in a story don't sound right. They will request pictures or biographical sketches or

filmed interviews if persons mentioned in news stories interest them. They will ask for additional opinions about issues presented in news stories, and the system will go out on the network and find a cross-section of them. They will be able to ask what a certain person has to say --- for example, "what does Ralph Nader say about this policy?" or "what was my state representative's reaction to this proposal?" --- and the system will immediately find whatever information is published by that person. If a child asks a parent a question about the story, the parent will request multimedia information at the appropriate grade level about the topic.

Users also will be able to ask the system to help explore their thoughts about the information presented, arguing with the logic of the story and receiving an analysis of their own logic. They may even choose, with help from their agent, to run a simulation as a way of exploring ideas. If, for example, users who believe hunting should be banned could choose to run a simulation of this decision and see the results.

The audience: news as a shared experience

Some of the information on the network that is accessible to users will be information provided by other users, each with an equal opportunity to make his or her views known to anyone interested. These opportunities for sharing information will be organized in a variety of ways.

One way will be the electronic group. Just as today people choose magazines that address the topics that interest them, people will belong to special groups who consistently seek to share information with each other and to buy information presented by experts in the topic area.

For example, people interested in business management will access the "business management" group daily and exchange ideas and experiences, just as they do with today's bulletin boards. A difference will be that rather than text messages, the groups will be able to communicate with pictures, video, and even face to face.

Another way news could be organized resembles the traditional method of reserving regularly scheduled times for attending to world and local news. In this way, the interactive qualities will be utilized to the fullest. Audience members could take part in nightly surveys about news topics. Or they could turn on their video cameras, express their views, and multi-cast them to anyone who is listening. Of course, they also will be able to tune into special channels and watch as other people do the same. In some cases, it may be arranged to have the person responsible for the news on camera to answer questions. If a user wants to argue with someone who is still online, the exchange can be transmitted to others just as if the two were in the same room.

A user who likes to express opinions in writing will be able to write a commentary, create or select graphics, photos, or film from a remote or personal database to go with it, and multicast it. Anyone who wants a copy will be able to print it at home or transfer it to local storage. In some situations, consultants will offer their services, providing their written information for a fee.

Some users may totally abandon the types of information-gathering activities used today. They may prefer, for example, to witness and experience events for themselves.

Users will be able to access a system of tiny cameras planted in various locations around the world that allow them to become observers of the action taking place in distant places (Krueger 1991). If, for example, users want to see the pictures in the Louvre, they will be able to access cameras located there and see each piece of art from many different angles. Krueger (1991, p. 232) envisions "tiny robot insects, wearing stereo cameras that fly around a site and transmit images to receivers nearby." By wearing reality goggles, users could see the scene as if they were actually present.

For some news stories, viewers may want to enter more extensive artificial realities to heighten their awareness of the story. Through virtual reality and telepresence technology, they will be able to see, hear, and feel sensations that provide a realistic idea of what it's like to traverse a battlefield or see the earth from space through a camera mounted on an astronaut's helmet.

The Information Sources: A diverse flow

When opening the newspaper or a magazine or turning on the six o'clock news today, most people do not give much thought to the source of the information they are receiving. They may have favorite columnists or feature writers that make them feel comfortable, and they may prefer the personalities and skills of certain news anchors or TV reporters, but for the most part, news comes from reporters who are considered interchangeable by the public. With the many-to-many capabilities of the information superhighway, this will change dramatically.

Professional or amateur communicators --- writers, film-makers, lecturers, and even artists and musicians --- will access the group in search of buyers for their work. Some of these communicators will be independent individuals or individuals represented by agents (either human or computer-generated). Others will be contributors to entire packages assembled by media organizations reminiscent of today's newspaper, magazines or television new shows.

For example, members who select "business management" as their primary group might on a given day be informed by their agents that Peter Drucker has a new article on global competition available at a cost of $x, that Tom Peters is offering a new video on employee motivation available at a cost of $x, that Business Week just published a special issue on profit-sharing, and that a well-known consultant who specializes in employee recruitment is willing to consult with clients electronically for $x per hour. There might also be a notice that 10 subscribers are going to watch the Peters video on Monday night and hold a face-to-face electronic dialogue session immediately afterward. Each group member would then make decisions on these items, viewing them when convenient, and the appropriate funds will be transferred to the appropriate recipients.

Advertising might be found in special groups or might be integrated with other electronic information. Ads would appear in the right niches rather than being wasted on people who would never respond.

Companies may have different options for advertising. Some may buy time in various electronic groups for their commercials, which will be shown each time someone accesses the group. This type of advertising may be the highest priced because it will reach everyone in a group. Less costly ads could be in the form of brief notices, such as "XYZ Company will show their new line of golf clubs to anyone who is interested." Ads might be created that can be explored in ways similar to news stories. Those whose interest an ad attracts would have the option of seeing more of the product line, reading magazine articles about the product, or talking to a sales representative.

The personalized, interactive, experiential media system described above may be a wild idea. There are technical barriers, industry practices, and human issues that could easily slow its progress. By today's standards, it is impossibly complex, expensive, and foreign. It would certainly take years to achieve.

However, when one considers the progress that has been made in two decades, the technologies and consumer needs in existence today that were not envisioned twenty years ago, this vision begins to sound less bizarre. It could happen--maybe not exactly as described, but in some form to some degree.

Today's journalists, particularly those who are just starting their careers, should seriously consider this vision. It is technologically challenging, and it will require major adjustments in society. But if it is realized, even partially, it will mean a revolution in journalism.

Journalists have two choices: they can shape the revolution or look for a niche after others have done so.

PART II
SEEDS OF A NEW MEDIA

So far, only cable television has equaled the networks in performing the task of providing up-to-the-minute, global news or achieving a high visual impact. No technology, by itself, can provide the quality of writing and the analysis provided in newspapers. None is as easy to acquire and use as newspapers, magazines, and broadcasts. None is as much a part of life as reading newspapers and magazines and watching the news on TV. In short, new technologies must overcome serious obstacles before any of them replaces the traditional news media.

However, these new technologies are already competing with some functions of today's newspapers and news broadcasts, and the competition could increase as these technologies evolve and become more widely used.

THE CONSUMER MARKET: Preparing for the Future Media

The shift to a new media paradigm has already begun. Communication technologies now on the market have caused consumers to become accustomed to and to value expanded choice, increased interactivity, and heightened experience.

Technologies of Choice

Technologies of choice add flexibility and convenience to lives that are becoming increasingly busy. They allow individuals to maximize the time they have available for communication by restricting the information and entertainment they consume to what is important or desirable to them.

One of the most popular technologies of choice is cable television, which began to grow in usage during the 1970s and became relatively widespread during the 1980s. Another is direct broadcast satellite technology. These technologies represent a first step in a media environment of choice. The videocassette recorder is a step beyond, allowing individuals to learn what they are motivated to learn at their convenience. In addition, plans are currently underway among consumer electronics companies, cable TV companies and direct-broadcast satellite companies to deliver digitally encoded movies to home users. Seybold believes that this service "will establish transmission of high-bandwidth digital data into the home" (1991, p. 7).

Some researchers say these technologies of choice are creating new viewing patterns. Rubin and Bantz (1987), for example, provide evidence that individual

VCR viewing is goal-directed. Walker and Bellamy (1991) find that television and VCR exposure, as well as remote control devices, may be creating patterns of selective avoidance. Levy (1989) suggests that VCR viewing may be characterized by "higher levels of audience member activity" with viewers becoming more selective and involved. Perse (1990) also finds increased capacity for audience selectivity with cable and remote control devices.

These patterns may be preparing consumers for the more active, goal-oriented processes that will be possible in a future media environment.

Another area that represents the increasing value of choice is the growing number of newsletters and "zines" (small magazines targeted to small segments of the population). These communication media are not for everybody, and that is precisely why their readers choose them. They provide detailed information on topics that are important to their readers and they bring diversity to the total information pool. Today, with desktop publishing software and a relatively inexpensive laser printer, any citizen can produce an attractive information product to be distributed to interested parties—and thousands are doing just that.

Technologies of Interaction

Today's online commercial databases, accessed via networked personal computers, and CD-ROM systems in libraries, broaden the range of choices by allowing users to search for the precise information they want instead of passively accepting a static information agenda.

Because the user's choices determine what information is accessed, these technologies are setting the stage for a new environment in which the user is actively interacting with a system to obtain news.

The telephone, always an interactive technology, has become another interactive information alternative. Increasing numbers of people in search of specific information are picking up the phone and using audiotext services. Some newspapers provide audiotext to update readers on running stories and to provide information on weather and entertainment (Mathes, 1992), but non-media organizations are also beginning to provide it. For example, in the Cleveland area phone book, audiotext numbers listed include one for legal information (provided by a law firm), one for medical information (provided by a doctor), and one for real estate information (provided by a realtor). In each of these and several other categories, separate numbers are given for several subtopics, and callers can stay on the line to ask questions of a person, if they wish.

A more visually appealing interactive information technology is interactive cable television, which provides such services as broadcasting from the home, request video services, facsimile newspapers, and videotext (Dutton, Blumler, and Kraemer, 1987). After experiments during the 1970s in the U.S, Japan, France, Germany, and Britain demonstrated the technical feasibility of videotext, it became a fairly popular medium in France and great Britain (Chorafas, 1981) and slowly began to be offered in American communities, most notably by Knight Ridder newspapers (Mayer, 1983).

Videotext is considered by many to be a dead technology since Knight-Ridder's attempt failed, as did attempts by Warner-Amex, AT&T, and an IBM-Sears-CBS consortium. However, according to Forester, videotext services were rejected because the applications offered, such as home shopping and banking, are inappropriate and because videotext services are hard to use, slow, and inflexible (1988). A resurrection may be underway, however, with recent advances in personal computers, software, and networking and alliances between cable and computer companies.

Technologies of interaction also are allowing average citizens to play a part in the media. With low cost video camcorders, citizens are providing action footage to their local news channels. Some news shows even encourage citizens to telephone from their cars if they see anything newsworthy unfolding.

Of all the alternative sources of information today, the most interactive is the electronic bulletin board. For many, accessing this information source via a personal computer is as much a part of the day's routine as reading the morning paper or watching the news. DeFleur et al (1992) have demonstrated that audience recall of news story text presented on a computer screen almost equals recall of stories in a newspaper.

Electronic bulletin boards allow users freedom to pursue their own information needs. They also allow them to provide information and express opinions instantly.

Users on Cleveland's Freenet, the Internet's USENET, and other bulletin boards, are choosing from a broad range of subjects that were selected, not by an editor, but by the public, and they are interacting with the news, blending their own thoughts and ideas with those of others. Some USENET users have become "opinion leaders" on specific topics; they provide news stories and extensive analyses of events, and they engage in long-running, quite complex and quite heated arguments that, because of the continuing interaction, can be much more intellectually stimulating than a newspaper's letters to the editor or a broadcast's 60-second "man on the street" spot.

During the recent elections, for example, users of the USENET bulletin board rejected the editorial section for an electronic forum. They read the position papers of Clinton and Bush in their entirety, as well as Ross Perot's *United We Stand*. They read the original press releases of Clinton's Communications Director, George Stephanopoulous. They even exchanged extensive information about Libertarian candidate Andre Marrou's positions, information that was, unfortunately, difficult to find in mainstream newspapers and news broadcasts.

In a sense, each USENET user is a reporter. When multimedia technologies become available, more people may take on this role. Underwood predicts that users will eventually be able to pull text, animated graphics, video images, music, and special effects from a computer's memory to "create their own multimedia productions."

Technologies of Experience: On the Horizon

With the current technologies of interaction, users play an active role in the process of obtaining news and information. They influence the outcome of the information they receive by varying their input. However, by the standards used in developing today's computer technologies, interactivity is severely limited with these media.

According to Laurel, degrees of interactivity can be assessed by examining the frequency of interaction possible, the range of choices available, and the significance of choices (1986). According to these criteria, audiotext, videotext, and online databases are not very interactive.

Laurel adds a new variable to interactivity: the degree to which users feel themselves to be participants in the ongoing action of a computer's representation of reality (1991). Today's information technologies fall far short of this definition because not only are users quite aware of a machine's presence, they also perceive the information as something out there separate from themselves.

However, future technologies will fulfill Laurel's definition of interactivity, allowing users to gain knowledge through direct experience.

True technologies of experience do not exist today. Video games probably come closest in that they present artificial worlds in which players can adopt alternate identities and shape the action. Although their use of a television screen leads many to discount video game usage as passive TV watching, Turkle says video games are "something you do, something you do to your head, a world that you enter, and, to a certain extent, they are something you 'become'" (1984, p. 67). This

provides a definition for the technologies of experience that eventually will allow users more direct participation in news and information.

One information technology that could well become a technology of experience is the personal computer equipped with a CD-ROM drive and hypermedia software. Today, consumers are purchasing CD-ROM drives for their home computers. Personal CD-ROMs contain multimedia information, usually encyclopedia or other reference works. Hypermedia software makes it possible for users to explore information in an almost infinite number of ways, defining their own paths to knowledge and thinking--through reading digitized text, looking at photographs or graphics, watching video recordings, listening to audio recordings, or combining these media.

Even higher quality interaction is becoming available with CD-I players, which offer more audio and video components than the CD-ROM products, as well as larger screen displays. Some hypermedia packages are entering the realm of experience by providing information through simulations and games. For example, a popular package called *Where in the World is Carmen Sandiego?* involves chasing a spy around the world and learning geography in the process; simulation games called *SimCity* and *SimEarth* allow users to design a city or an entire planet and then observe the results of their decisions (Perleman 1993).

JOURNALISM RESPONDS: Laying the Groundwork

Although not much change seems to be taking place, the groundwork is being laid for news organizations to take advantage of the new media environment.

The Visionaries: They have the concept

Advanced technology and the "new media" it engenders have not been ignored by visionary mass media scholars.

McLuhan's *Understanding Media* (1964) hardly acknowledges the coming advances in computers yet presents a vision of "our new electric technology that extends our senses and nerves in a global embrace" (83).

Edwin Parker, according to Rice et al, also began to consider the new media in the early 1960s. Realizing while studying television effects that the policy decisions on television had already been made ten years earlier, Parker realized he should to "look forward, instead of backward, to shape and determine possible (and desired) effects of new media." He saw, says Rice, that "the medium he was using as a tool for research --- the computer --- was going to have much more social impact and be a factor in social change, than the medium he was then studying --- television" (1984, p. 24).

Bagdikian, as early as 1971, identifies access and interactivity as the key elements of a future information system. He proposes the possibilities of "a news system with a richer variety of information, a rapid way to detect what is available, easy pursuit of subjects of maximum interest to the individual beyond the standard presentation, and control over the time the information is presented" (68).

In a 1982 work, Dizard predicts a universal network and says the first two stages of the information age -- adoption of new technologies by the "primary information sector" and by public and private industries and organizations -- are underway. The third stage, he says, is the "mass consumerization of high-technology information services" (7), which would allow any person or group to transmit information globally.

Denis says the "technological revolution," along with changing patterns of media ownership, are "changing the shape of the media in America" (1989, p. 11).

Two books about to be published on advanced technology and the mass media are Roger Fidler's *Mediamorphosis* and John Pavlik's *Demystifying Media Technology*.

The Trade Journals: Their interest is piqued

Nora Paul, research librarian at the Poynter Institute, says computer bulletin boards are still relatively mysterious to many journalists. However, the vision of a new media can be found in today's mass media trade publications. Articles in *Columbia Journalism Review, Washington Journalism Review, ASNE Bulletin,* and *Editor and Publisher* show that journalists are beginning to survey the new communication media and reflect upon their potential. Underwood (1992) creates a picture of the multimedia newspaper. Katz (1992) enumerates several emerging technologies, including high definition television, dial up music videos, interactive controls for sports that allow viewers to choose camera angles, and interactive television services for shopping, paying bills, and other transactions. Silk (1991) predicts the advent of two-way switched video that will allow viewers to access any movie, video, or television show at any time, two-way videophones that may lead to video networks analogous to "chat" telephone, and multimedia newspapers, magazines books, and catalogues.

The Journals: Living in the present

Mass media journals, probably because of their tradition of quantitative research, most often address the topic of "new media" by referring to those that already exist: videocassette recorders, cable television, remote control devices, electronic databases, and bulletin board systems. Their major focus seems to be on determining characteristics of those who use new media and comparisons between the usage of the new and traditional media. However, many journals, particularly the *Journal of Communication*, are beginning to address the important issue of the future national network, the policies that it will involve, and its possible effects on democracy (Markus 1987, Braman 1989, Noam 1989, Murdock and Golding 1989, etc.)

The Freedom Forum

Media scholars have been participating in panel sessions at the Freedom Forum, a journalism think tank at Columbia University. Composed of university scholars, journalists, media corporation executives, FCC officials, and telecommunications experts, the panels are discussing the prospects for a national information service (FitzSimon 1992).

Media Industry Initiatives: Adopting the new technologies

According to John Pavlik, technology director of the Freedom Forum, precursors to the future media environment in broadcasting are beginning to be seen. Time Warner has recently established a 500 channel cable pilot project in Orlando, Florida, that allows customers to dial up for videos to watch on television. Serving as a preview of what future small entrepreneurs will be able to do with new satellite technology, Adam Clayton Powell III has established KMPT in San Franscisco for a few thousand dollars. Similarly, New York I runs on a small budget because of its use of inexpensive high eight video technology.

Pavlik says many newspaper companies are interested in new technology and managers are becoming more knowledgeable about the future network. Markoff (1992) says *Knight-Ridder*, the *Washington Post*, the *New York Times*, *Tribune*, and *Hearst* are all exploring electronic publishing. The *Washington Post* now distributes a fax version and the *Tribune* an online version, says Conniff (1993). Markoff also sees, however, much skepticism among newspaper veterans about whether electronic information will be workable and valuable to consumers.

Gannett serves as an example of how large media corporations are responding to new technology. Carolyn Wimbly Martin of Gannett's New Media Division says the company is using new technology to expand its information services. They are packaging information and news in a variety of ways and making it available via fax or computer and modem.

Since 1987, full-text versions of *USA Today, The Gannett News Service,* and *USA Weekend* have been provided to several online vendors 24 hours after press, and they have just begun real-time delivery of *USA Today*'s News and Money Sections and of *Gannett News Service* to online vendors. Their electronic news services also are distributed to several gateway systems of Regional Bell Operating Companies, to corporate and university clients, and to consumers' homes.

In addition to providing full-text news to computer owners, they offer compiled information called "Lifestyle Reports" that inform users on sports, TV, video releases, various statistics on news, money, and other areas, and a feature called "Lifeline," which tells "what people are talking about in the USA." They also deliver Decisionline via modem; this service provides summaries of news in 18 areas, including business law, health, technology, and U.S. news.

They are providing via fax the greater detail that some users need or want, such as company earnings reports. This past summer, they provided full transcripts of their interviews with the presidential candidates as a fax-on-demand option.

They also have an extensive range of audiotext offerings, including weather and travel information, stock quotes, used auto prices, sports scores, movie reviews, and an advice line.

Gannett explores advanced technology, particularly display technology. Gannett's Advanced Systems Lab (ASL) has been experimenting with pen-based computing devices, but the emphasis has been on technologies for the newsroom.

Knight-Ridder also is interested in newsroom technology. A testbed called *The Mercury Center* at the *San Jose Mercury*, is an experiment in integrating technology with an actual newspaper's mission.

Knight-Ridder's Information Design Lab, which opened in Fall 1992, seems to demonstrate the forefront in thinking about the high tech future of newspapers. Although investigating advances in audiotext and other current media technologies, IDL's centerpiece is an electronic newspaper.

Director Roger Fidler envisions in five years having a product based on today's notebook-sized computers. It will be a lightweight, battery-operated pen-based computer with a high resolution flat panel display (Fidler 1992). His vision includes a screen that displays the headlines, columns, and other typographic features of a newspaper but also can display video footage. Information for the electronic newspaper will be downloaded from the network and pages turned by a touch of the pen. The reader will be able to browse through summaries of items and advertising and select the ones they want to read with the pen. Selecting an item will display the entire text, as well as options for choosing sidebars, videos, and even graphics that allow the user to add personal data. (Fidler gives the example of entering his salary in a graphic chart which would compute how a new surtax would affect him.) Text on the page can be enlarged to any size. The pen, in addition to being able to work crossword puzzles, will be used to mark text or to do other information work.

RECOMMENDATIONS

The media industry seems to be moving toward the future in its adoption of existing technologies and its exploration of leading edge innovations. This initiative needs to continue. Technologies such as audiotext and online services are areas in which media organizations face competition from other non-media industries, who at any time may develop better technology. Media organizations should look closely at this arena to get an idea of what competition may be like in the future.

Second, media organizations should encourage many pilot projects, both large and small, like the Information Design Lab's electronic newspaper. One person's

vision, pursued by the five people currently employed at the IDL, cannot create a new paradigm. The IDL states their intention to set the standards for the future electronic publishing industry. This can put Knight-Ridder in the position that IBM held until only recently, and other media corporations would be at a disadvantage. Also, Fidler's vision is, in many ways, a continuation of the paper and ink tradition, and there is good reason to pursue this course. However, it may happen that a completely different product will emerge from what are today non-media corporations. The media industry should give some though to what this completely new product might be.

PART III
HIGH TECH MEDIA: NEW REVOLUTION OR NEW SOCIAL MACHINE?

All citizens in a free society have the right to access information that will inform them of their rights, to register their opinions about political issues, and to recognize and shape conceptions in the media of the groups they represent (Murdock and Golding 1989, 183). Individuals and groups in the United States have never enjoyed these rights to the fullest, however, because publishers, editors, and reporters have always been required to exercise "information control" for the purpose of overcoming the constraints of time, space, complexity, and economics, and, some say, for the purpose of pleasing advertisers and maintaining the status of elite classes.

But new computing and communications technologies create new visions of democratization. Ithiel de Sola Pool uses the phrase "technologies of freedom." Others have spoken of "teledemocracy" and "electronic town halls." Several scholars have addressed the benefits of communications technology for community groups that do not have resources for mass communication (Rubinyi 1989, Gates 1984). Herbert S. Dordick asserts that a national information service should be "available to all, regardless of income, education, literacy and language proficiency, geographic location, class, race, and any other of the potentially divisive and discriminatory issues that often corrupt our society" (FitzSimon 1992, 23).

Unquestionably, technologies of choice, interaction, and experience present opportunities to change society dramatically. They can enhance freedom by fostering an inclusive, heterogeneous, democratic press that adds daily to a balanced knowledge base that enlightens and serves each individual. However, these advanced technologies also will have constraints that require the use of information control, and through the need for this control, they provide opportunities for an elite group of communicators, composed of the privileged and powerful, to enhance their influence and manipulate the public for the purpose of increasing their wealth and power.

The nucleus for the coming change is today's mass media.

New media technologies pose a challenge for journalists who believe in their responsibility to the public to join with concerned citizens in making the network, as well as the new information tools it makes possible, a medium that allows each person to know the truth and understand world events and that gives a voice to each citizen, especially those who are powerless.

The ultimate success of this ideal will be determined by the resolution of three conflicts of control that have already begun.

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A WIDELY ADAPTABLE HABITAT CONSTRUCTION SYSTEM UTILIZING SPACE RESOURCES

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ABSTRACT

This study suggests that the cost of providing accommodations for various manned activities in space may be reduced by the extensive use of resources that are commonly found throughout the solar system. Several concepts are proposed for converting these resources into simple products with many uses.

Concrete is already being considered as a possible moonbase material. Manufacturing equipment should be as small and simple as possible, which leads to the idea of molding it into miniature modules that can be produced and assembled in large numbers to create any conceivable shape. Automated equipment could build up complex structures by laying down layer after layer in a process resembling stereolithography. These tiny concrete blocks handle compression loads and provide a barrier to harmful radiation. They are joined by a web of tension members that could be made of wire or fiber-reinforced plastic. The finished structure becomes air-tight with the addition of a flexible liner.

Wire can be made from the iron nodules found in lunar soil. In addition to its structural role, a relatively simple apparatus can bend and weld it into countless products like chairs and shelving that would otherwise need to be supplied from Earth. Wire woven into a loose blanket could be an effective micrometeoroid shield, tiny wire compression beams could be assembled into larger beams which in turn form larger beams to create very large space-frame structures.

A technology developed with lunar materials could be applied to the moons of Mars or the asteroids. To illustrate its usefulness several designs for free-flying habitats are presented. They begin with a minimal self-contained living unit called the Cubicle. It may be multiplied into clusters called Condos. These are shown in a rotating tether configuration that provides a substitute for gravity. The miniature block proposal is compared with an alternate design based on larger triangular components and a tetrahedral geometry.

The overall concept may be expanded to envision city-sized self-sufficient environments where humans could comfortably live their entire lives. One such proposal is the Hive. It is configured around a unique sunlight collection system that could provide all its energy needs and that could be scaled up to compensate for the reduced solar intensity at greater distances from the sun. Its outer perimeter consists of a cylindrical section mated to two conical end walls that taper inwards toward a small aperture at the center of rotation. Light collected by two huge mirrors of unusual design enters the aperture and is redirected to the inside of the cylinder. The conical end walls are shielded from direct sunlight and are designed to radiate heat into space. They are lined with air ducts that passively recirculate the atmosphere while extracting moisture by condensation. Although there is no immediate demand for spacecraft on this scale, their consideration can influence even the earliest stages of the development process.

1. INTRODUCTION

Raw materials are plentiful in space. The development of practical processes for their conversion into building materials would facilitate the transition from expendable spacecraft to an era of permanent manned bases.

Lunar regolith will provide the first opportunity. Any future mission to the moon is likely to test processes for the extraction of water, hydrogen and useful minerals, notably iron from its pervasive soil. Lunar concrete has a great potential significance, and not just for its usefulness to

moonbase architects. Lunar concrete products delivered to LEO might someday compete favorably with materials supplied by Earth. What's more, a technology that is perfected on the moon could be appropriate anywhere a similar regolith is present, including Mars, the Martian moons and possibly the asteroids.

This paper envisions a generic construction system designed to adapt to the resources and conditions available at any of these locations. It suggests that habitat components can be simplified down to identical small symmetrical blocks that join together to produce a structure of any desired shape.

The diminutive size of the parts should have a positive effect on the size of the fabrication equipment as well. This is a great advantage in developmental cost savings as well as deployment. Adding duplicate units would boost the rate of production to any desired level without the all-or-nothing gamble that is inherent in a single large factory.

As the construction is refined, it should require less active control. At some point artificial intelligence may assume management functions. Eventually such systems could be sent ahead of a manned expedition, preparing component parts or even a largely completed habitat for the arrival of a crew. A mission may begin with a single unit, to be replaced if a failure occurs or reinforced with additional units if success seems likely. The mission planner has the option of trading an extended time frame for constrained costs and reduced risk factors.

Wire is an important building product. It can be used in combination with the concrete or as a structural material in its own right. Between these two materials, a habitat could be constructed almost entirely from space resources

Several habitat configurations are provided to illustrate the range of possibilities. Cubicles are modular living units that could serve a small crew on the lunar surface or in open space. Hives are very large self-sufficient systems designed for a population of thousands. They would be home to a new kind of human society free of dependence on a planetary surface.

2.   BUILDING BEADS

Conventional construction systems produce specific shapes that are dictated by the design of the components, If those components are symmetrical and capable of connecting to each other in three dimensions the shape that results can be varied indefinitely incorporating curved or faceted surfaces. The complexity of the product is limited only by the size chosen for the pieces

Building beads are compression blocks one cubic inch or less in size. A web of tension wires or high-strength fibers pass through or between the beads and the resulting composite structure exhibits both properties. The beads must be small enough to make practical partitions but suitable for multiplication into structural hull sections or beams of any required depth.

Although "lunarcrete" inspired the concept, beads might be produced from a variety of materials, including ceramics, an aggregate material that could be sintered or bonded with an organic resin, powder metallurgy, cast iron or aluminum or even from cut and machined rock. This flexibility means that only the bead production process needs to change to fit the resources available. The assembly equipment and all the support systems that go with a particular bead design remain the same.

The examples illustrated all possess the familiar x/y/z symmetry. A number of other interesting geometries are shown along with a partial survey of space-filling shapes.

Cube based systems are easy to visualize. Large curved or diagonal surfaces will exhibit stair-steps rather than a smooth surface. Complex interlocked shapes and unmoldable undercuts may be executed as a series of parallel sections. Stereolithography uses this principle. Automated assembly robots could build each successive layer directed by a CAD system and an invisible grid.

Cubes do produce smooth surfaces along their major axes but this can be a disadvantage structurally. Without any physical interlocking they are vulnerable to shear forces. In Figure 2a, threaded fasteners between the blocks prevent slippage along these planes. The second example (fig.2b) relies on dimples to resist shear and welded wire nails through the blocks to tension the assembly.

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The third example (fig.2c) introduces a shape called the smoothed cube . Each bead has six circular faces centered on the three axes, with a diameter half the overall width. A matrix of smoothed cubes joined at these faces will create a negative space that is identical to the filled space. If that negative space is also occupied by connected beads, the result is two interlocked but independent networks with each set blocking the cleavage planes of the other.

There are several ways to reinforce smoothed cubes. Metal thumbtack shapes can be inserted into holes in each face and resistance welded in the center. The springy dome of the tack-head is flattened by pressure, and an additional preload may occur as the metal cools and shrinks. The tack heads may be adhesive bonded, projection welded or mechanically fastened to each other

If a very high strength product is required, an alternate system may be preferred (fig.2d). It uses small pads of a putty-like sheet molding compound composed of aramid, carbon or glass fibers in a resin binder. The compound is squeezed between the rows as each new bead is inserted. A chemical reaction must be induced before the resin will harden and bond to the beads.. It might be caused by a catalyst sprayed on the surface of the parts or triggered by radiation. Ultraviolet-cured resins are available. Microwaves might serve the same function in space. The structure could also be divided into smaller sub-assemblies and cured in a heated chamber similar to the inflatable factory shown in the section on reinforced concrete blocks.The result should be a strong omnidirectional honeycomb with excellent strength in both tension and compression. Several other geometric shapes can be joined in this manner including the rhombic dodecahedron and the truncated octahedron

3.   CUBICLES

Cubicles are modular living/working units designed to stand alone or to be joined indefinitely into complexes called condos. Each cubicle has its own life support system. If building-beads and wire are used in the hull and most of the internal furnishings, they would represent a mass far greater than any likely load of people, supplies and equipment.

In the example, beads are used to create two 20' diameter cylindrical pressure vessels which intersect each other forming a single main deck roughly 32' (10m) wide and 44' long, this last number suggested by the length of the shuttle cargo bay. Two equipment pallets fit into the valleys between the cylinders. They contain the essential systems and are sized to fold and be transported in the shuttle.

Cubicles depend on an external source of power - probably solar or nuclear and located at the hub in the case of the spinning system shown. Since missions several years long are possible, a plant growth system is integral. The Soviet Bios program [1] achieved a stable closed ecological loop and maintained it for six months with no negative health effects on the three crew members. They grew 77.5% of their own food and recycled all of their air and water. Academician Gitelson suggested at a Planetary Society presentation in May of 1992 that 30 sq.meters/person could completely support one person. Gas exchange alone could be accomplished with 10 to 15 square meters. Using this data, a single cubicle could support 4 people and recycle the air of 8 to 10. This extra capacity fits a transportation scenario in which transient crew would bring dehydrated meat and other products to spice up the basic grain and vegetables grown on board. It is likely that the "Tubular Membrane Plant-Growth Unit" [2] and other sophisticated hydrophonic systems may provide even greater yields.

The design places the plants over the heads of the crew. This configuration takes advantage of the ceiling arch with a system to rotate the plants towards the center as they grow. Space-wasting aisles are eliminated, and the light that escapes the area provides the ambient illumination in the living areas. Sleeping chambers have their own sealable cylinders which contain an independent air supply. Since humans spend 1/3 of their lives asleep, the total radiation exposure is averaged down by providing extra shielding. Some shelter would be needed in any case as protection from solar storms.

Cubicles may be used in pairs at opposite ends of a rotating tether system. Partial or full artificial gravity can be generated in this way. If we take 2 RPM to be the maximum rate of

rotation which can be generally tolerated, simulated full gravity would require a tether with a 733' radius. The pairs of cubicles on opposite sides of the circle are nearly a mile apart measured along the curve. To travel between them, a ferry system is more logical than passing through the hub. The ferries simply shorten their tethers and their momentum produces a higher angular velocity. Lengthening the tethers then allows them to rendezvous with another location on the rim.

Low gravity facilities would be attached to the hub and reached by elevator. A frictionless, possibly superconducting magnetic bearing[3] could join the stationary component to the revolving cubicles. The part of the original spacecraft with cubicle production equipment is free to move on to the next site, leaving its dock free for supply ships.

4. WIRE

The production of metal products in space is also being considered. Iron is particularly accessible since it may be found in nodules in the lunar regolith and extracted by sifting through magnets [4]. Materials processing experiments on the Space Station could lead to practical refining and handling systems. Metals may be cast, foamed or turned into a powder and sintered, but one uniquely useful form is wire. Potential applications go far beyond its role in a bead system, and it's fairly easy to produce. Renaissance craftsmen made a high quality music wire with mostly wooden tools from an alloy of iron and phosphorus.

The challenge of wire production can be deferred until the production problems of concrete are solved, but once we add this capability a wide range of space-products become feasible. To begin with, we can furnish the apartment. Wire shelving and storage systems are commonplace. A wire space frame with a thin plastic sheet on top makes a fine table. Inflated plastic bladders can pad a wire chair or a bed. Wire is such an adaptable material that astronauts can design and construct new devices on the spot, either bending and welding the wire by hand or designing with a CAD system and letting a robot arm do the work.

Woven wire mats can function as micrometeoroid shields. The multilevel welded mesh would be designed to deflect, shatter and trap the high-velocity energetic particles that might seriously damage a concrete based structure.

Many of the structures we might create from wire call for it to resist compression loads. A long wire under load will simply deflect to the side and collapse but if its shortened enough it's capacity begins to approach the limits of the material. This is the principle of the beam just scaled down to fit the gauge of the wire. If a long boom is needed, it can be built from tiny pieces, with an approach that was suggested by the property of fractals that causes them to re-create the same shapes again and again at progressively larger scales.

The illustration shows how a three-inch wire beam can be the basis for a thousand-foot span in three fractal-like stages. This beam in turn may be a component in a huge spaceframe structure for the vast sunlight-concentrating mirrors required to build a hive. The rigid octahedron shown could be part of a tensegrity structure. The three beams have one straight edge which is the primary load path. This allows them to pass in the center without interference.

5. REINFORCED CONCRETE BLOCKS

Concrete and wire can be combined into more conventional molded modular shapes. They can form building components with properties far beyond familiar bricks and cinder-blocks. Ferro-cement boats come closest to creating the type of hull a spacecraft would need. The Bible of the industry [5] suggests an optimum thickness of 7/8 inch and states that a square foot will weigh 13 lbs. Concrete hardens and gains strength through hydration. The water used is largely recoverable. Boat hulls can be cured with steam to 90% of their full strength in 6 days, followed by drying for an additional month. The recommended practice is to use 6 mesh hardware cloth and 3/16 inch rod as reinforcement. T.D. Lin studied concrete space structures for the Portland Cement Association [6]. He pointed out that concrete reinforced with 4% by weight of iron fibers has nearly twice the flexural strength of the plain product. A commercial plastic fiber is also used

for this purpose [7]. Fibers in the slurry might be a lightweight alternative to wire reinforcment, especially valuable if the wire must be brought from Earth.

The illustration shows a two-chambered inflated factory based on a design proposed by Lawrence Livermore laboratory. Blocks are molded in an automated machine assisted by a teleoperated robot arm which moves the blocks through a series of curing and drying chambers around the periphery. Finished blocks are assembled into wall sections in the lower chamber which also functions as an air lock. A bow-string tension wire system is suggested to rigidify the multiple block panels and a series of edge connectors would join these compound triangles into the finished form. An inner tube makes the finished cubicle air-tight. If the blocks shown in the illustration are a meter long on each edge, each of the cubicle segments shown would be able to support one person.

Rectangles dominate block systems on Earth largely because gravity makes them stackable. In a zero-G environment a shape like the triangle may be more useful. The equilateral triangle is the most versatile. Martyn Cundy gave the name deltahedron to any polyhedron composed of equilateral triangles. There are 8 convex forms, including the tetrahedron, octahedron and icosahedron. The other five are shown in the inset box.

The size of the blocks can be adjusted to fit other criteria. Four blocks make a new triangle twice as large, nine are needed to triple the size, etc. Blocks in the center may be omitted to create passages or windows. The facility can grow by adding a tetrahedron at a time while still in service.

6. HIVES

The key design goal of hives is self-sufficiency. A closed-loop ecology can be maintained but a minimum energy input is needed. This is roughly 2 kW/person/day in the form of light that must be provided for photosynthesis. Concentrated sunlight may be brought inside the hull with far greater efficiency than any system of conversion to electricity and back again.

In this design, large curved mirrors create two cones of light focused on a central aperture in the revolving hull. Within the aperture, a second conical mirror re-directs the light to illuminate the inside of the cylinder. This area is devoted to agriculture. Plants fuel the entire biosphere by converting this sunlight to chemical energy.

The mirrors are large enough to behave like solar sails, so a self-aligning system has merit. A parabolic bowl would be unstable. Instead the flat mirror segments are divided into a series of parallel angled rows and arranged in hyperbolic shape. The center of light pressure moves behind the axis of rotation and service accessibility is improved. The orientation of a hive with its axis of rotation perpendicular to the plane of its orbit around the sun means that the mirrors must complete just one revolution every orbital year. The alignment problems that plague ground-based solar systems do not exist for a hive.

The shaded patches show the frontal area of the mirrors as seen from the sun. In most cases this area must be greater than the area of the illuminated crops inside the hive. The size of the mirrors can be adjusted to compensate for increased distance. A hive at the edge of the asteroid belt (2.5 AU) would need 6.25 times the area of a hive near the Earth. Sunlight in space is twice as intense as the filtered light that reaches Earth's surface, but the losses involved in collecting it may neutralize this advantage. A minimum of two reflections are required. Even an optimistic 90% reflectivity means that nearly 20% is lost in transit.

Air is the working fluid of the hive. Gas exchange between plant and animal, water recirculation and the elimination of waste heat all come about through the medium of the atmosphere. Furthermore the system is passive, a product of the configuration rather than using pumps and fans.

The conical end walls are never lit directly by the sun. They radiate heat into space. Passages line the inside surface carrying air from the low-G upper areas to the higher gravity at the base of each cone. As the air inside loses heat it grows denser and sinks, pulling in fresh air at the top. The longer this path, the colder the air will become, so a state of winter could be created at

will for the perennials growing near the outlets. Condensation provides a constant supply of distilled water to the dwellings that line the wall.

The hive design is dictated by the energy system and the need to minimize the obstruction of incoming and redistributed light. The inhabitants live over the ground level in a series of concentric rings suspended below the conical end walls. Architecture is supported by cables from the overhanging wall above rather than columns from the ground below.

Only a small part of the spherical volume is required to house more people than the ecosystem can possibly support. Just ten evenly spaced levels would exceed the surface area of the farms below by half. At 30 sq.m/person, a 1500 ft. diameter hive could support 12,000 people. Improvements in crop yield and techniques for converting inedible biomass into food could double the population density, and artificially lit greenhouses are possible as well.

Hive hulls may be designed as rigid shells constructed from billions of beads or with a series of nested rings derived from another block design. Supplementary tension bands carry the principal loads in either case. NASA has recommended 4.5 tons/sq. m of material for radiation shielding. This is far more material than required by the structure so chambers filled with rubble and a thick layer of soil will be needed to reduce the health risk to terrestrial levels.

A hive is a massive undertaking. It may seem like a fantasy now, but if the exploration of space follows the course of most other waves of human expansion, we will someday need a city in space, and economics will be sufficient to demand its construction.

7.   CONCLUSIONS

Space resources could provide nearly all of the mass in the structure of a space habitat. A widely adaptable system would be attractive for the savings in development costs and the potential reuse of the equipment. The building-bead system requires smaller equipment, insures against total mission failure from a single breakdown, makes possible virtually any shape, wall thickness or degree of complexity and will work with a wide range of materials. If a larger block is desired, equilateral triangles may be the most versatile shape.

Wire produced in space may be used to reinforce a bead or block system and is suited for several other key roles:
   1) large open structures using fractal style replication
   2) An infinite range of more conventional product/furnishings
   3) allows astronauts to respond to unanticipated needs by improvising and fabricating at the site.

Cubicles offer an entry-level product for either beads or blocks, are useful for missions in or out of a gravity field or in rotating systems to simulate gravity, and can provide food and gas exchange for the modest crew sizes needed in the near future.

Hives provide for all of the life-support and energy needs of their occupants.with comfort and safety emulating Earth, and could be built anywhere in the solar system within the practical limits of the light amplification system.

1 Gitelson, Josef L; Biological life-support systems for mars mission. Institute of Biophysics, Krasnoyarsk Siberia 660036

2 John F Kennedy Space Center; Tubular membrane plant growth unit. NASA Tech Briefs KSC-11375

3 Misovec, K; Johnson, B; Downer, J; Eisenhaure, D; Hockney, R; Marshall Space Flight Center; Heteropolar magnetic suspension. NASA Tech Briefs, June 1990:75 MFS-26096

4 Lewis, J.S; Lewis, R.A; Space Resources, breaking the bonds of Earth. Columbia University Press; 1987:262

5 Bingham, B; Ferro-cement design, techniques and application. Cornell Maritime Press 1984

6 Lewis, R S; Space in the 21st century. Columbia University Press, 1990

7 Fibermesh; Fibermesh company, 4019 Industry Dr. Chattanooga, TN 37416

8 Wells, D; Penguin dictionary of curious and interesting geometry. Penguin Books 1991

2. BUILDING BEADS

Fig.2a Mechanical Fasteners used to create tension paths
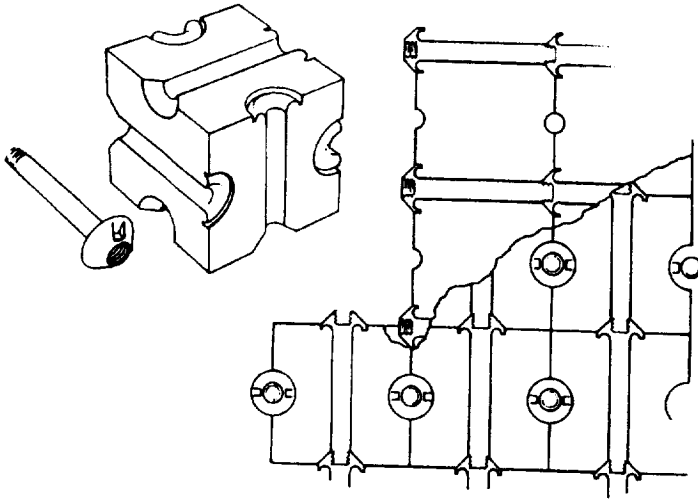between the beads

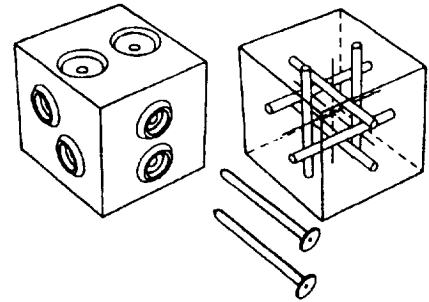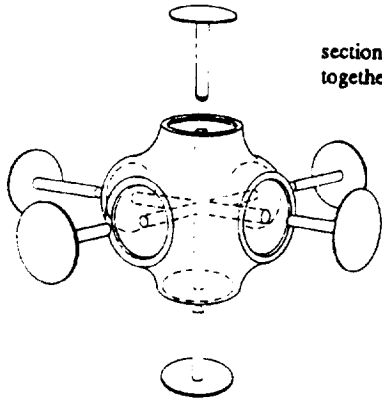Fig.2b Resistance welded wire nails
passing through the blocks

Fig.2c Smoothed cube with a metal skeleton formed by
resistance welding six thumbtack shapes together in the
center - the skeleton could also be cast-in-place

section of an assembly showing the tack heads bonded
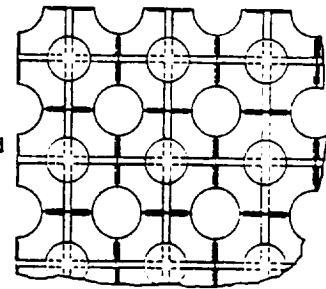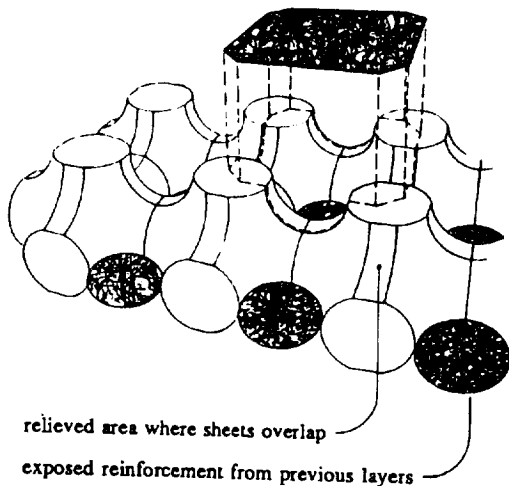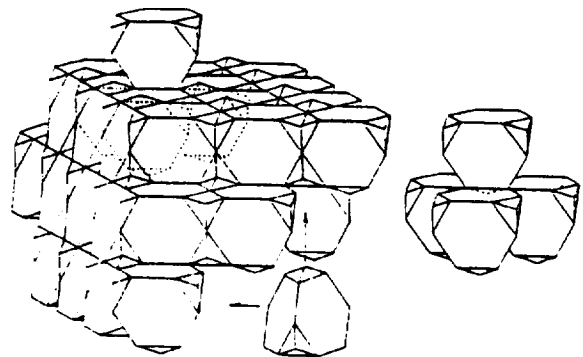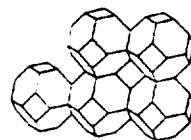together with adhesive or projection spot-welded

Fig.2d uncured resin and fiber sheet will be
forced into the matrix by the next bead

Some other possible space-filling geometries 8

Tetrahedron with beveled edges - since the faces are not
perpendicular, the design process is made more difficult.

Truncated octahedron   Rhombic Dodecahedron

relieved area where sheets overlap

exposed reinforcement from previous layers

237
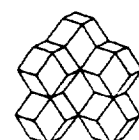
3. CUBICLES

Fig.3a two cubicles joined to form a condo

Fig.3b plan view with a ferry pod at the airlock

44'

32" (10m)

sleeping chambers
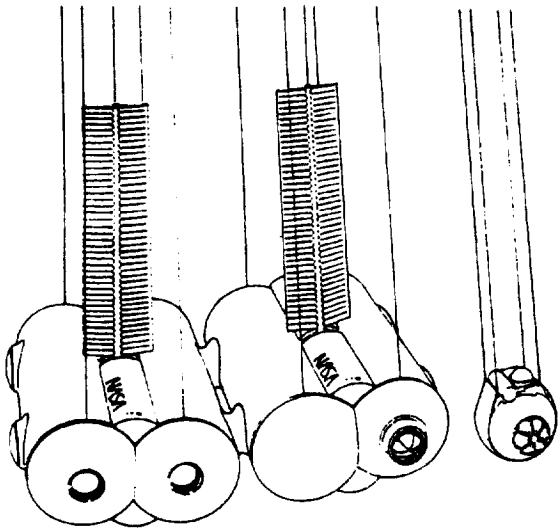
ferry pod

airlock

Fig.3c section of a typical cubicle

cooling radiators
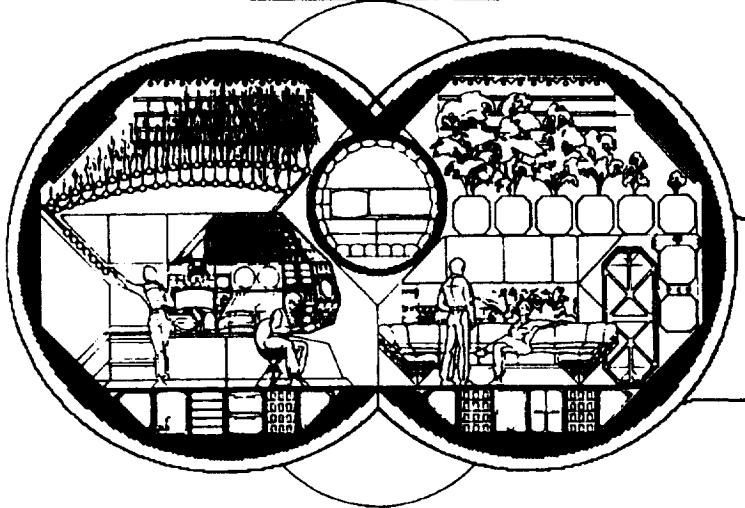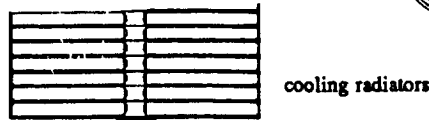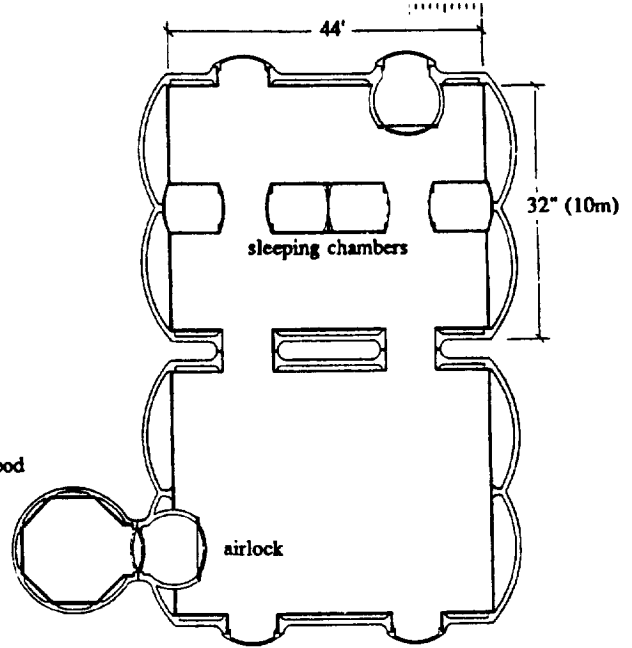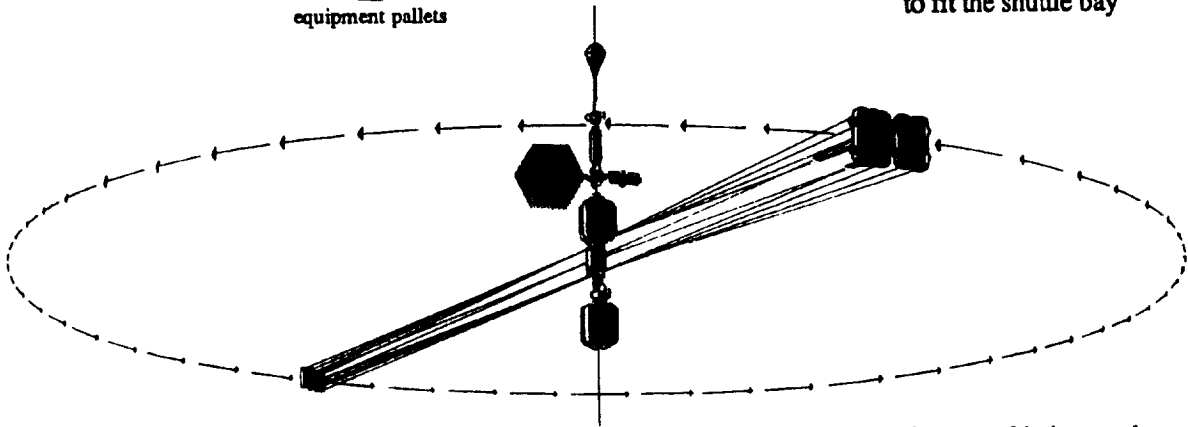
equipment pallets
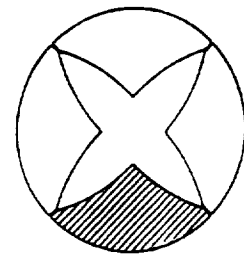
Fig.3d equipment pallets arranged to fit the shuttle bay

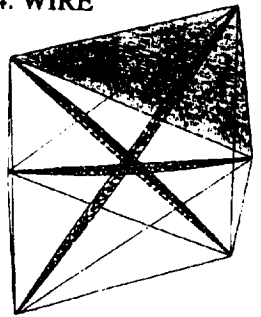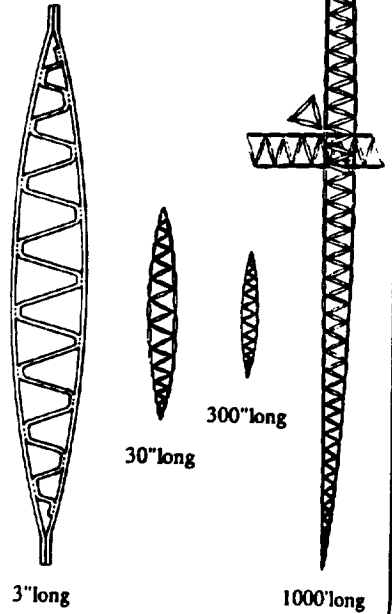Fig.3e two condos rotating around a central hub complex

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4. WIRE

wire tensegrity structure supporting
a metalized mirror membrane

3"long

30"long

300"long

1000'long

5. REINFORCED CONCRETE BLOCKS
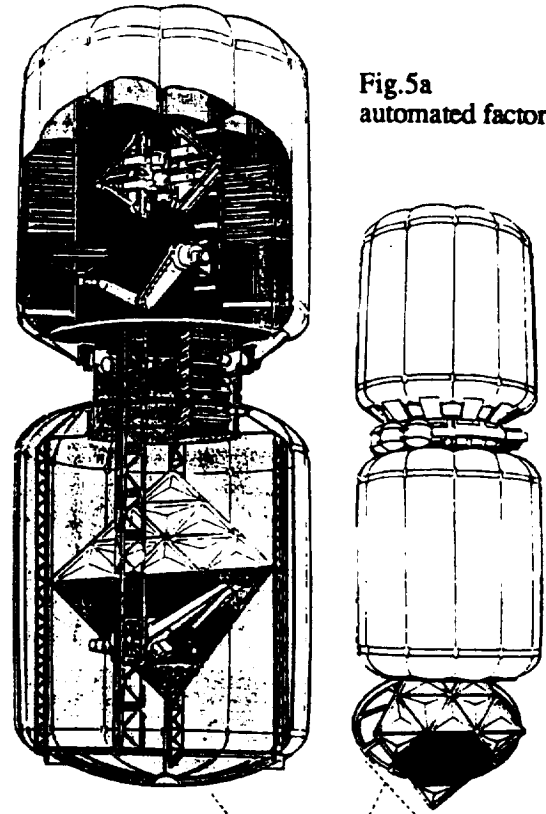

Fig.5a
automated factory pods

Fig.5c
nine blocks
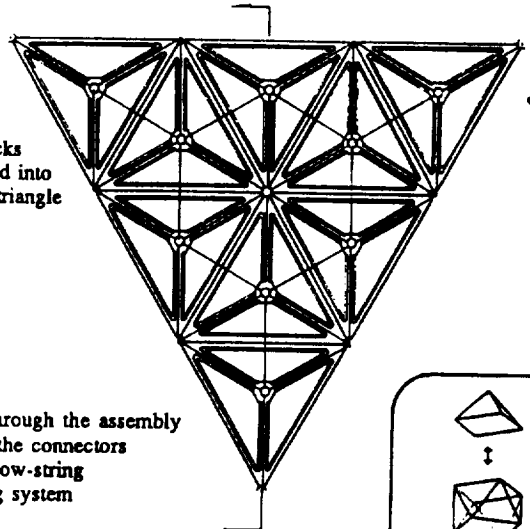assembled into
a larger triangle

Fig.5d
section through the assembly
showing the connectors
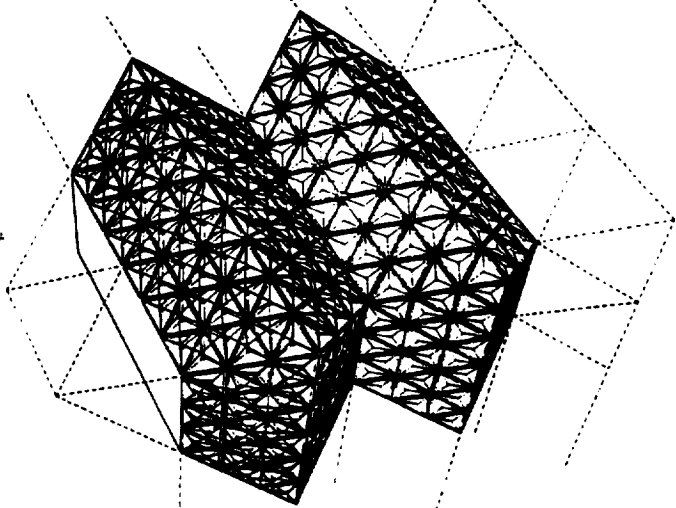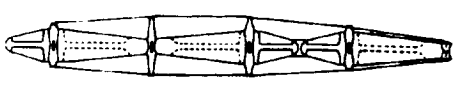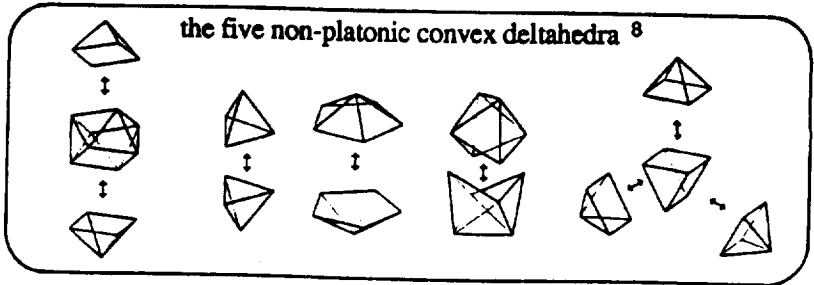and the bow-string
tensioning system

Fig.5b   one possible cubicle design

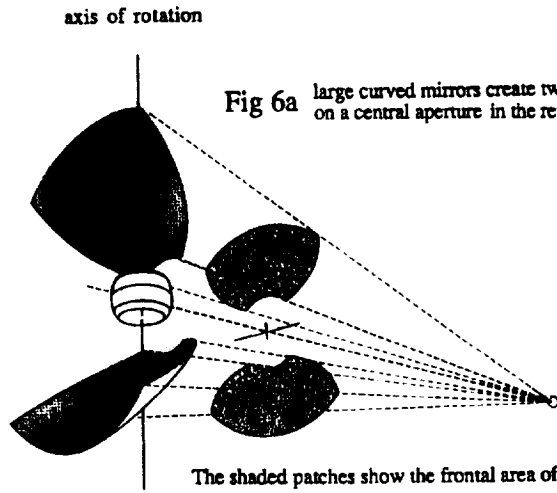the five non-platonic convex deltahedra [8]

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6. HIVES

Fig 6a large curved mirrors create two cones of light focused on a central aperture in the revolving hull.

The shaded patches show the frontal area of the mirrors as seen from the sun.

Fig.6b exploded view of a hive with portions removed

conical ends permit concentrated light to enter the hive while waste heat is radiated into space

central mirror

habitation levels

complex air passages line the inside of the cones

food production

orchards and wood products occupy a zone where seasonal temperatures can be created

240
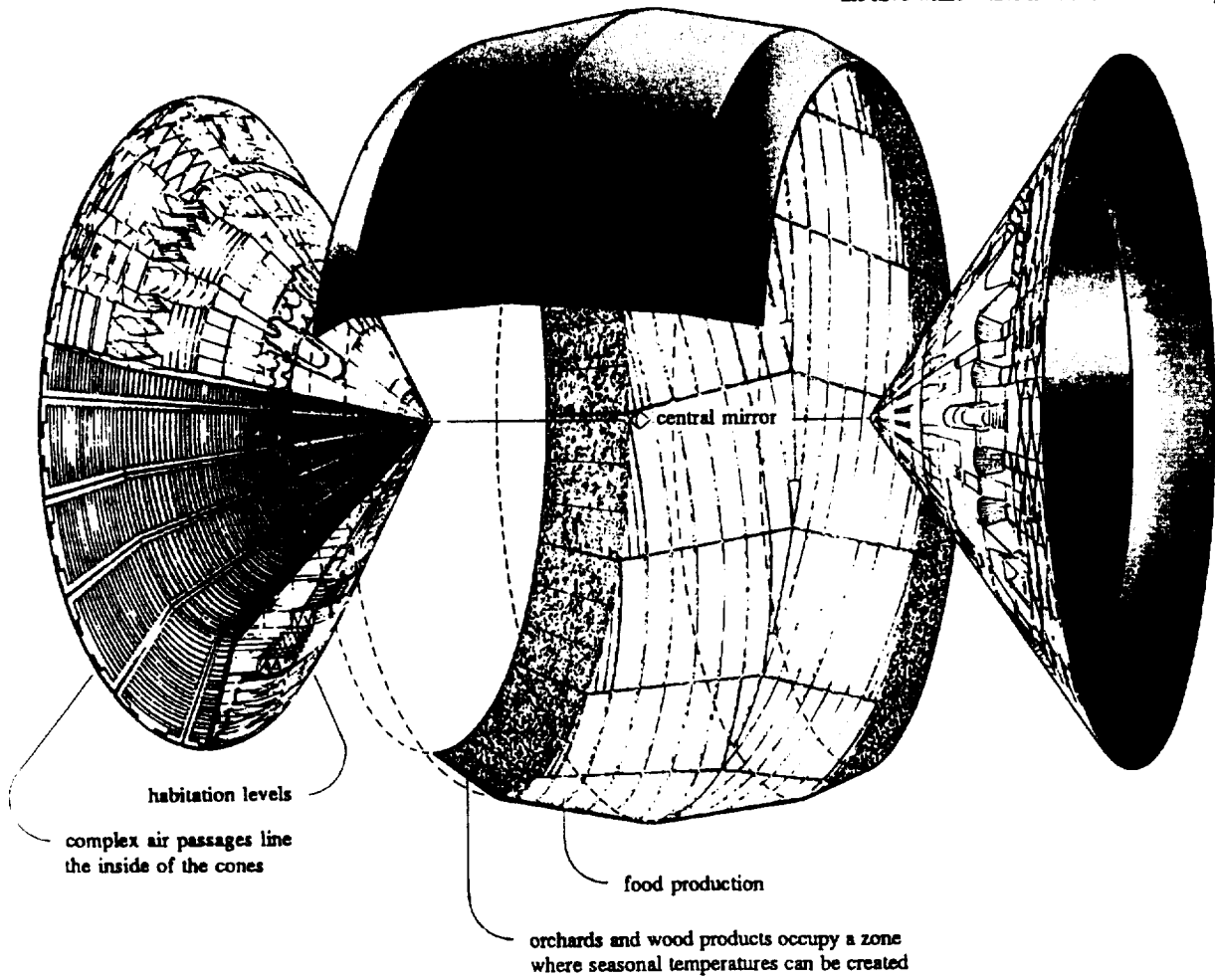
ROCKET ENGINE NUMERICAL SIMULATOR

Ken Davidian
NASA Lewis Research Center
Cleveland, Ohio

CONTENTS

- RENS Definition
- Objectives
- Justification
- Approach
- Potential Applications

- Potential Users
- RENS Work Flowchart
- RENS Prototype
- Conclusions

RENS DEFINITION

- Rocket Engine Numerical Simulator (RENS) Performs Liquid Rocket Engine Propulsion System Analyses and Design
- RENS Gives Engineer a 3-D Transient Tool for Analyzing Engine Systems (Tanks - Feed System - Thrust Chamber)
- RENS Will Surpass/Encompass Capabilities of Current System Codes (ROCETS & Generic Power Balance)

RENS DEFINITION

- RENS is Long Term and Large Scope
- RENS Features Include:
- System Executive
- Data Management
- Graphical User Interface
- Incorporation of Users' Technical Codes
- Easy to Use
- Industry/University/ Gov't Advisory Group
- Public Domain
- Evolution of Capabilities

OBJECTIVES

- Enable spontaneous and adaptive rocket definition, generation, performance evaluation, and failure analysis.
- Develop capability to simulate component and system level performance of rocket propulsion systems.
- Provide rapid and accurate assessment of rocket to increase design efficiency.
- Incorporate and integrate validated computational simulation codes/technologies.

JUSTIFICATION

- Following capabilities required by NASA to do our job: independent verification of proposed rocket performance, new rocket designs, assess impact of new rocket technologies.
- Standardized industry design/analysis tool (industry-university-government participation).
- Streamline, enhance, and alter research & analysis process to reduce time and cost.

APPROACH

* The RENS program will be patterned after, and will leverage from, the Numerical Propulsion System Simulator (NPSS), currently under development at NASA LeRC for aircraft propulsion systems.

* RENS will incorporate component level descriptions to predict performance and reliability.

POTENTIAL APPLICATIONS

* Chemical Propulsion Systems
* Nuclear Thermal Propulsion Systems
* Propulsion System Test Facilities
* Nuclear Electric Propulsion Systems
* Space Power Systems

POTENTIAL USERS
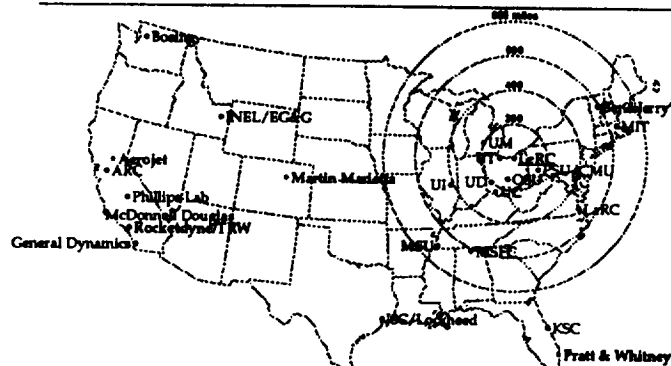
RENS WORK STRUCTURE

RENS WORK BREAKDOWN FLOW CHART
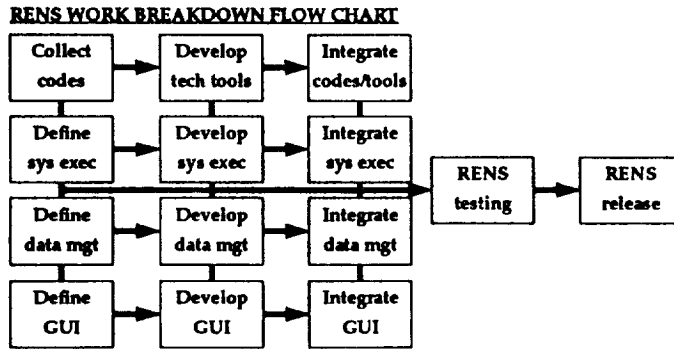
RENS PROTOTYPE - REDES

- **Prototype Capability Initiated in 1989 with Rocket Engine Design Expert System (REDES).**
- **REDES Used to Conduct Various Studies and Model Various Engines:**
- Nozzle Performance Parametrics (SSME, RL10)
- Nozzle Design (NTR)
- Rocket Engine Test Facility Capability Assessment (NASA LeRC Rocket Engine Test Facility Ejectors)

REDES ANALYTICAL DOMAIN
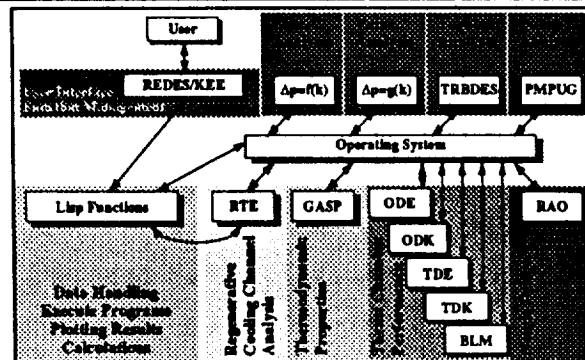
REDES
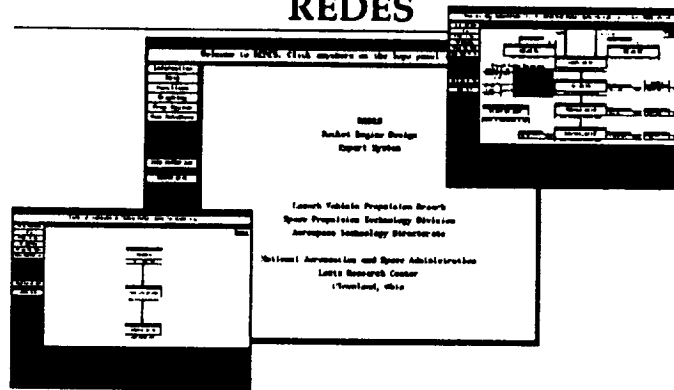
CONCLUSIONS

- RENS Capabilities Required For Simulation Development.
- Simulation Capability Required By Gov't, Industry, and University in Many Technical Disciplines.
- RENS Prototype Exists at LeRC.
- Grant Work in Critical Development Areas Initiated

WORKSHOP DISCUSSION SUMMARIES

<div align="center">

Vision-21 Symposium:
Interdisciplinary Engineering and Science
in the Era of Cyberspace

WORKSHOP SUMMARIES

</div>

Tuesday, March 30

1. Interaction with **Vernor Vinge**, Univ. of California in San Diego
   Note Taker: Tim Sarver-Verhey

2. Interaction with **Carol Stoker**, NASA Ames Research Center
   Note Taker: Ken Davidian

3. Presentation & Discussion by **Myron Krueger**, Artificial Reality Corp:
   Virtual Reality:
   What's Real, What's Virtual, What's Not and Where Should We Be Today?"
   Note Taker: Barry Fairbanks
   Facilitator: Ben Rodriguez

4. *Workshop on Space Propulsion* with **Marc G. Millis**, NASA Lewis Research Center
   Note Taker: Scott Williamson

Wednesday, March 31

5. Presentation & Discussion by **Hans Moravec**, Carnegie Mellon Univ:
   "Pigs in Cyberspace:
   How do we evolve the senses necessary to adapt, survive and thrive in the computer realm?"
   Full Text: Hans Moravec
   Discussion Notes: Marc G. Millis

6. Presentation & Demo by **Rob Fisher**, Studio for Creative Inquiry, Carnegie Mellon Univ.:
   "Sculpting in Cyberspace"
   Note Taker: Nancy Amman

7. *Workshop on Mars Exploration with Virtual Reality, Telepresence and Robotics*
   with **Carol Stoker**, NASA Ames Research Center
   Note Taker: Bryan Palaszewski
   Facilitator: Mary Kovach

8. *Workshop on the use of Cyberspace for Training*
   Myron Krueger, Artificial Reality Corp & **Ben Rodriguez**, NASA Lewis Training Branch

Interaction with Vernor Vinge
Note Taker: Tim Sarver-Verhey
March 30, 1993

Rob Fisher and Vernor Vinge discussed the development and evolution of high-powered computers for use by artists, particularly sculptors. Fisher described it as an example of the human / machine interface theme that Vinge had discussed in his presentation as an amenable approach to the "technological singularity event." Fisher described his and other's experiences with solids modeling as part of the production of a piece of sculpture; different from the more pedestrian application of computers for graphic / commercial art. Vinge agreed with the premise and described some work by others along similar lines.

Tim Sarver-Verhey and Peter Michaels opened a discussion about the Internet and other computer networks as examples of the growing and already-with-us relationships we have with computers. The issue of the open access to Internet was raised. The possibility of an information division evolving between segments of society was also discussed; contrasting the use by the general public with the use and growing dependance on networks by universities, government, and industry. Vinge and Michaels pointed out, however, that the general public's access and influence on Internet is growing, citing the Cleveland Freenet as an example.

Interaction with Carol Stoker
Note Taker: Ken Davidian
March 30, 1993

This question & answer session immediately followed Carol Stoker's presentation about her work with teleoperated rovers in the Antarctic. About six people attended to further discuss Carol's work.

Carol Stoker's background is in planetary science. She spent six weeks in the Antarctic with six other people demonstrating a teleoperated aquatic rover. The Antarctica was chosen as the excursion site because the Antarctica requires a long logistics train similar to what would be required for Mars. Also, there was interesting science in the exploration of the lake-bottom dwelling society of McMurdo sound.

The rover is piloted by a person using a joystick and wearing a highly instrumented headset. The headset has video monitors that are linked to cameras on the rover. The position of the operator's head commands the position of the rover's cameras, giving the operator the sense that they are the rover. Two helmets were taken on the excursion: one with black/white monitors, and one with fiber optic displays. The rover has a dexterous manipulator which was developed at MIT. The cable which tethers the rover has a 1000 foot radius. Power supplies were specified to match to equipment needs, not vice versa.

Four holes were melted in the 10 foot thick ice. The ice melters used diesel generators and pumped hot ethylene glycol through spiral copper tubes. One hole was used for the rover, while the other three holes were for the divers. The divers had tethers to find their way back to their entrance hole. Separate holes were used for the divers and rover to avoid their tethers from getting tangled.

Every morning, the crew had a radio conferences at 8:00 a.m., regardless of the time they got to bed the night before. Late nights (until 2 a.m.!) were not uncommon.

On the next planned field trip, all control of the rover will be done remotely from Ames. Time lags will also be built into the system to better simulate the time delay for round-trip communication to Mars.

Carol is also beginning to work with Russians to build an interface for their 1996 rover. An excursion to Mars would probably be located in the equatorial regions of recent Martian geological events (recent means within the last 1 million years).

VIRTUAL REALITY: WHAT'S REAL, WHAT'S VIRTUAL, WHAT'S NOT, AND WHERE SHOULD WE BE TODAY

DATE: MARCH 30, 1993   1:00 PM - 2:10PM

DISCUSSION LEADER: MYRON KRUEGER
PRESIDENT
ARTIFICIAL REALITY CORPORATION

FACILITATOR: BEN RODRIGUEZ
TECHNICAL AND ADMINISTRATIVE BRANCH
NASA LEWIS RESEARCH CENTER

VIRTUAL REALITY DISCUSSION SUMMARY

● PRO - TREMENDOUS POTENTIAL, PARADIGM SHIFT IN MAN-MACHINE INTERFACE THINKING, TREMENDOUS NEW MARKETS IN INTEGRATING VARIOUS COMMUNICATION, COMPUTERS, ROBOTICS, AND TELEVISION. POTENTIAL CULTURAL IMPACT IN ENTERTAINMENT AND ART.

● CON - HISTORY OF UNDERFUNDING AND SPORADIC DEVELOPMENT, NO REAL BUSINESS APPLICATIONS YET, VERY LITTLE TECHNOLOGY CHANGE IN LAST 8 YEARS, PROBLEM OF SIGNAL DELAY TIMES FOR LONG DISTANCES NOT ADDRESSED, PEOPLE WILL RESIST UNTIL TECHNOLOGY FREE OF ALL ENCUMBRANCES

● DEFINING VIRTUAL REALITY (VR) CONCEPT - QUESTIONS RELATED TO THE MYTHS VERSES REALITIES OF PUBLICIZED USE OF VR FOR MOLECULAR MODELING, GERMAN MUSEUM DISPLAYS, ARCHITECTURE DESIGN WALK-THROUGH, SURGERY, GAMES, VEHICLE SIMULATORS. LINE SEEMS TO BE SYSTEMS WHICH DO MORE THAN IMPLEMENT JUST A FEW OF THE TECHNIQUES.

● PROBLEMS WITH CONFLICTING DEMANDS OF REAL AND VIRTUAL ENVIRONMENT, MEDIA FOCUS TOO SHALLOW, TIME DELAYS THAT ARE ACCEPTABLE, NEED FOR NEW AND DIVERSE IDEAS.

● NEED FOR ADDRESS OF UNDERLYING PROBLEMS - REAL-TIME SPEED, DISPLAY HARDWARE, REDUCED ENCUMBRANCE IN A SUSTAINED AND DIVERSE WAY TO FIND AND DEVELOP ECONOMIC BUSINESS APPLICATIONS

VIRTUAL REALITY DISCUSSION HIGHLIGHTS

● MANY IN AUDIENCE WERE NOT AWARE THAT WELL PUBLICIZED USES OF VIRTUAL REALITY (VR) WERE LABORATORY EXERCISES AND NOT COMMERCIAL, AND THAT COMMERCIAL SYSTEMS IN THE FIELD ARE NOT BEING SOLD TO END-USERS FOR REAL APPLICATIONS.

● THERE IS A MILD LACK OF AGREEMENT AMONG THE PARTICIPANTS ON WHAT CONSTITUTES VR. MYRON KRUEGER NARROWLY DEFINES THE CONCEPT.

● REAL WORLD AND VIRTUAL WORLD MAY HAVE CONFLICTING REQUIREMENTS IN THAT ACTIONS TAKEN IN THE VIRTUAL WORLD MAY CAUSE AN OFFICE ACCIDENT, OR AN OFFICE EVENT MAY CAUSE AN UNDESIRED RESPONSE IN THE VIRTUAL WORLD TASK. THE ISSUE IS HOW TO MELD THE TWO.

● AUDIENCE VIEW OF THE PROGRESS BEING MADE WAS INITIALLY MORE OPTIMISTIC THAN MYRON KRUEGER'S ASSESSMENTS.

SPACE PROPULSION WORKSHOP
Moderator: Marc G. Millis
Note Taker: Scott Williamson

ATTENDEES:
George H. Miley (University of Illinois)
Frank E. Rom (NASA Lewis Research Center - retired)
Gerald D. Nordley (Writer)
Graham S. Galloway (Spiral Survey Expedition)
Pam Hoffman (NASA Lewis Research Center)
Alan C. Holt (NASA Headquarters)
Mary V. Zeller (NASA Lewis Research Center)
Steve Howe (Los Alamos National Laboratories)
Rich Rinehart (Sverdrup Technology - NASA Lewis)
Mike Binder (Sverdrup Technology - NASA Lewis)

WORKSHOP QUESTIONS:

1) What are the emerging computing tools that are potentially useful for solving the real problems of space propulsion?
2) What are the real problems of space propulsion?
3) How do we apply these tools to solve space propulsion problems?

ANSWERS AND DISCUSSIONS:

1) Relevant Emerging Computing Tools:
a) Expanding network capabilities
b) Improvements to human / computer interfaces
  • New methods of data representation
  • Virtual Reality
c) More powerful simulation capabilities
  • Parallel computers
  • High-speed analog computers using optical technology
  • Chaos methods
d) Ever-shrinking electronics and the possibility of telepresence-- reduces payloads and correspondingly propulsion requirements (The group thought this would have little impact on how to design, build, and operate propulsion systems, however.)

2) Propulsion Needs:
a) Improved design tools / processes
b) Improved operational controls & monitoring of propulsion systems
c) Institutional improvements-- making it easier to know what the realistic objectives are, and making it easier to achieve those objectives.

3) Applying the Tools to the Needs:

Discussion on network applications:
Although the need to *work together* to enhance institutional communication and progress was highlighted, there was much discussion on the disadvantages and advantages of using networks to improve working together. To avoid the possible disadvantages, a need list for networking

features was derived.

NETWORKING

PROS:	CONS:	NEEDS:
• Provides greater access to other perspectives, potential collaborators • Additional means to publish and access data • Enables grass-roots communication	• May lead to excessive talking and insufficient "doing"and thinking. • More "noise that signal"-- there may be more chatter than useful information • Deluge of information-- takes too much time to filter through • Potential problem of premature disclosure through widespread informal communication	• *Full* information transfer over networks; text, graphics, models, animation, etc. (need standards) • Software for automated searching, sorting, and summarizing of network information and activity that the users can customize to suit their needs. • Hierarchical network structure to enable different levels of exchange (e.g. informal, restricted professional, peer reviewed announcements / reports)

Discussion on improved human interface applications:

The group clearly believed that the emerging tools of Virtual Reality and other interactive data representations could greatly enhance:

- Running simulations interactively-- speeding up the iterative learning cycle of simulations
- Participating in simulations using Virtual Reality-- getting inside you model
- Designing hardware using literal, virtual pictures of hardware-- getting inside your engine
- Exploring abstract representations of Physics, Fluid Dynamics, Thermodynamics
- Operating propulsion systems through sensory links

Discussion on enhanced simulation applications:

The advantages of better simulations is obvious. Two noteworthy comments:

- Link simulations to experimental data to refine simulation models. This requires the ability to import experimental data directly into models.
- Link real-time simulations to propulsion controls to improve operation or to enable operation of systems that are inherently unstable (such as some fusion propulsion schemes)

SUGGESTED NEXT STEPS FOR PROPULSION TECHNOLOGISTS:

Given these emerging tools and shrinking resources, the group suggested the following directions for propulsion scientists and engineers:

- Work on a small scale to demonstrate technology. (simulations useful here)
- We need to better fuse experimental data with model simulations.
- It is time to consider revolutionary propulsion alternatives in order to go beyond point of diminishing returns for existing propulsion improvements (the flat top of the technology development "S" curve). Networks could be useful here to broaden the information base and to seek grass-roots collaboration.
- Need to work *both* technology push (develop technology and then apply to mission) as well as technology pull (mission driven technology development)

Pigs in Cyberspace

Hans Moravec
Robotics Institute
Carnegie Mellon University
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Exploration and colonization of the universe awaits, but Earth-adapted biological humans are ill-equipped to respond to the challenge. Machines have gone farther and seen more, limited though they presently are by insect-like behavioral inflexibility. As they become smarter over the coming decades, space will be theirs. Organizations of robots of ever increasing intelligence and sensory and motor ability will expand and transform what they occupy, working with matter, space and time. As they grow, a smaller and smaller fraction of their territory will be undeveloped frontier. Competitive success will depend more and more on using already available matter and space in ever more refined and useful forms. The process, analogous to the miniaturization that makes today's computers a trillion times more powerful than the mechanical calculators of the past, will gradually transform all activity from grossly physical homesteading of raw nature, to minimum-energy quantum transactions of computation. The final frontier will be urbanized, ultimately into an arena where every bit of activity is a meaningful computation: the inhabited portion of the universe will transformed into a cyberspace.

Because it will use resources more efficiently, a mature cyberspace of the distant future will be effectively much bigger than the present physical universe. While only an infinitesimal fraction of existing matter and space is doing interesting work, in a well developed cyberspace every bit will be part of a relevant computation or storing a useful datum. Over time, more compact and faster ways of using space and matter will be invented, and used to restructure the cyberspace, effectively increasing the amount of computational spacetime per unit of physical spacetime.

Computational speed-ups will affect the subjective experience of entities in the cyberspace in a paradoxical way. At first glimpse, there is no subjective effect, because everything, inside and outside the individual, speeds up equally. But, more subtly, speed-up produces an expansion of the cyber universe, because, as thought accelerates, more subjective time passes during the fixed (probably lightspeed) physical transit time of a message between a given pair of locations—so those fixed locations seem to grow farther apart. Also, as information storage is made continually more efficient through both denser utilization of matter and more efficient encodings, there will be increasingly more cyber-stuff between any two points. The effect may somewhat resemble the continuous-creation process in the old steady-state theory of the physical universe of Hoyle, Bondi and Gold,where hydrogen atoms appear just fast enough throughout the expanding cosmos to maintain a constant density.

A quantum-mechanical entropy calculation by Bekenstein suggests that the ultimate amount of information that can be stored given the mass and volume of a hydrogen atom is about a megabyte. But let's be conservative, and imagine that at some point in the future only "conventional" physics is in play, but every few atoms stores a useful bit. There are about 10^{56} atoms in the solar system. I estimate that a human brain-equivalent can be encoded in less than 10^{15} bits. If a body and surrounding environment takes a thousand times more storage in addition, a human, with immediate environment, might consume 10^{18} bits. An AI with equivalent intelligence could probably get by with less, since it does without the body-simulation"life support" needed to keep a body-oriented human mind sane. So a city of a million human-scale inhabitants might be efficiently stored in 10^{24} bits. If the atoms of the solar system were cleverly rearranged so every 100 could represent a bit, then a single solar system could hold 10^{30} cities—far more than the number (10^{22}) of stars in the visible universe! Multiply that by 10^{11} stars in a galaxy, and one gets 10^{41} cities per galaxy. The visible universe, with 10^{11} galaxies, would

then have room for 10^{51} cities—except that by the time intelligence has expanded that far, more efficient ways of using spacetime and encoding data would surely have been discovered, increasing the number much further.

Mind without Body?

Start with the concepts of telepresence and virtual reality. You wear a harness that, with optical, acoustical, mechanical and chemical devices controls all that you sense, and measures all of your actions. Its machinery presents pictures to your eyes, sounds to your ears, pressures and temperatures to your skin, forces to your muscles and even smells and tastes for the remaining senses. Telepresence results when the inputs and outputs of this harness connect to a distant machine that looks like a humanoid robot. The images from the robot's two camera eyes appear on your "eyeglass" viewscreens, and you hear through its ears, feel through its skin and smell through its chemical sensors. When you move your head or body, the robot moves in exact synchrony. When you reach for an object seen in the viewscreens, the robot reaches for the object, and when it makes contact, your muscles and skin feel the resulting weight, shape, texture and temperature. For most practical purposes you inhabit the robot's body—your sense of consciousness has migrated to the robot's location, in a true "out of body" experience.

Virtual reality retains the harness, but replaces the remote robot with a computer simulation of a body and its surroundings. When connected to a virtual reality, the location you seem to in habit does not exist in the usual physical sense, rather you are in a kind of computer-generated dream. If the computer has access to data from the outside world, the simulation may contain some "real" items, for instance representations of other people connected via their own harnesses, or even views of the outside world, perhaps through simulated windows.

One might imagine a hybrid system where a virtual "central station" is surrounded by portals that open on to views of multiple real locations. While in the station one inhabits a simulated body, but when one steps through a portal, the harness link is seamlessly switched from the simulation to a telepresence robot waiting at that location.

The technical challenges limit the availability, "fidelity"and affordability of telepresence and virtual reality systems today—in fact, they exist only in a few highly experimental demonstrations. But progress is being made, and its possible to anticipate a time, a few decades hence, when people spend more time in remote and virtual realities than in their immediate surroundings, just as today most of us spend more time in artificial indoor surroundings than in the great outdoors. The remote bodies we will inhabit can be stronger, faster and have better senses than our "home" body. In fact, as our home body ages and weakens, we might compensate by turning up some kind of "volume control." Eventually, we might wish to bypass our atrophied muscles and dimmed senses altogether, if neurobiology learns enough to connect our sensory and motor nerves directly to electronic interfaces. Then all the harness hardware could be discarded as obsolete, along with our sense organs and muscles, and indeed most of our body. There would be no "home" experiences to return to, but our remote and virtual existences would be better than ever.

The picture has us become a "brain in a vat," sustained by life-support machinery, and connected by wonderful electronic links, at will, to a series of "rented" artificial bodies at remote locations, or to simulated bodies in artificial realities. But the brain is a biological machine not designed to function forever, even in an optimal physical environment. As it begins to malfunction, might we not choose to use the same advanced neurological electronics that make possible our links to the external world, to replace the gray matter as it begins to fail? Bit by bit our brain is replaced by electronic equivalents, which work at least as well, leaving our personality and thoughts clearer than ever. Eventually everything has been replaced by manufactured parts. No physical vestige of our original body or brain remains, but our thoughts and awareness

continue. We will call this process, and other approaches with the same end result, the downloading of a human mind into a machine. After downloading, our personality is a pattern impressed on electronic hardware, and we may then find ways to move our minds to other similar hardware, just as a computer program and its data can be copied from processor to processor. So not only can our sense of awareness shift from place to place at the speed of communication, but the very components of our minds may ride on the same data channels.We might find our selves distributed over many locations, one piece of our mind here, another piece there, and our sense of awareness at yet an other place. Time becomes more flexible—when our mind resides in very fast hardware, one second of real time may provide a subjective year of thinking time, while a thousand years of real time spent on a passive storage medium may seem like no time at all. Can we then consider ourselves to be a mind without a body? Not quite.

A human totally deprived of bodily senses does not do well. After twelve hours in a sensory deprivation tank (where one floats in a body-temperature saline solution that produces almost no skin sensation, in total darkness and silence, with taste and smell and the sensations of breathing minimized) a subject will begin to hallucinate, as the mind, somewhat like a television tuned to a nonexistent channel, turns up the amplification, desperately looking for a signal, becoming ever less discriminating in the theories it offers to make sense of the random sensory hiss it receives. Even the most extreme telepresence and virtual reality scenarios we have presented avoid complete bodylessness by always providing the mind with a consistent sensory (and motor) image, obtained from an actual remote robot body, or from a computer simulation. In those scenarios, a person may sometimes exist without a physical body, but never without the illusion of having one.

But in our computers there are already many entities that resemble truly bodiless minds. A typical computer chess program knows nothing about physical chess pieces or chessboards, or about the staring eyes of its opponent or the bright lights of a tournament. Nor does it work with an internal simulation of those physical attributes. It reasons instead with a very efficient and compact mathematical representation of chess positions and moves. For the benefit of human players this internal representation is sometimes translated to a recognizable graphic on a computer screen, but such images mean nothing to the program that actually chooses the chess moves. For all practical purposes, the chess program's thoughts and sensations—its consciousness—is pure chess, with no taint of the physical, or any other, world. Much more than a human mind with a simulated body stored in a computer, a chess program is a mind without a body.

So now, imagine a future world where programs that do chess, mathematics, physics, engineering, art, business or whatever, have grown up to become at least as clever as the human mind. Imagine also the most of the inhabited universe has been converted to a computer network—a cyberspace—where such programs live, side by side with downloaded human minds and accompanying simulated human bodies. Suppose that all these entities make their living in something of a free market way, trading the products of their labor for the essentials of life—in this world memory space and computing cycles. Some entities do the equivalent of manual work, converting undeveloped parts of the universe into cyberspace, or improving the performance of existing patches, thus creating new wealth. Others work on physics or engineering problems whose solutions give the developers new and better ways to construct computing capacity. Some create programs that can become part of one's mental capacity. They trade their discoveries and inventions for more working space and time. There are entities that specialize as agents, collecting commissions in return for locating opportunities and negotiating deals for their clients. Others act as banks, storing and redistributing resources, buying and selling computing space, time and information. Some we might class as artists, creating structures that don't obviously result in physical resources, but which, for idiosyncratic reasons, are deemed valuable by some customers, and are traded at prices that fluctuate for subjective reasons. Some entities in the cyberworld will fail to produce enough value to support their requirements for existence—these eventually shrink and disappear, or merge with other ventures. Others will succeed and grow. The closest present

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day parallel is the growth, evolution, fragmentation and consolidation of corporations, whose options are shaped primarily by their economic performance.

A human would likely fare poorly in such a cyberspace. Unlike the streamlined artificial intelligences that zip about, making discoveries and deals, reconfiguring themselves to efficiently handle the data that constitutes their interactions, a human mind would lumber about in a massively inappropriate body simulation, analogous to someone in a deep diving suit plodding along among a troupe of acrobatic dolphins. Every interaction with the data world would first have to be analogized as some recognizable quasi-physical entity:other programs might be presented as animals, plants or demons, data items as books or treasure chests, accounting entries as coins or gold. Maintaining such fictions increases the cost of doing business, as does operating the mind machinery that reduces the physical simulations into mental abstractions in the downloaded human mind. Though a few humans may find a niche exploiting their baroque construction to produce human-flavored art, more may feel a great economic incentive to streamline their interface to the cyberspace.

The streamlining could begin with the elimination of the body-simulation along with the portions of the downloaded mind dedicated to interpreting sense-data. These would be and replaced with simpler integrated programs that produced approximately the same net effect in one's consciousness. One would still view the cyberworld in terms of location, color, smell, faces, and so on, but only those details we actually notice would be represented. We would still be at a disadvantage compared with the true artificial intelligences, who interact with the cyberspace in ways optimized for their tasks. We might then be tempted to replace some of our innermost mental processes with more cyberspace-appropriate programs purchased from the AIs, and so, bit by bit, transform ourselves into something much like them. Ultimately our thinking procedures could be totally liberated from any traces of our original body, indeed of any body. But the bodiless mind that results, wonderful though it may be in its clarity of thought and breadth of understanding, could in no sense be considered any longer human.

So, one way or another, the immensities of cyberspace will be teeming with very unhuman disembodied superminds, engaged in affairs of the future that are to human concerns as ours are to those of bacteria. But, once in a long while, humans do think of bacteria, even particular individual bacteria seen in particular microscopes. Similarly, a cyberbeing may occasionally bring to mind a human event of the distant past. If a sufficiently powerful mind makes a sufficiently large effort, such recall could occur with great detail—call it high fidelity. With enough fidelity, the situation of a remembered person, along with all the minutiae of her body, her thoughts, and feelings would be perfectly recreated in a kind of mental simulation: a cyberspace within a cyberspace where the person would be as alive as anywhere. Sometimes the recall might be historically accurate, in other circumstances it could be artistically enhanced: it depends on the purposes of the cybermind. An evolving cyberspace becomes effectively ever more capacious and long lasting, and so can support ever more minds of ever greater power. If these minds spend only an infinitesimal fraction of their energy contemplating the human past, their sheer power should ensure that eventually our entire history is replayed many times in many places, and in many variations. The very moment we are now experiencing may actually be (almost certainly is) such a distributed mental event, and most likely is a complete fabrication that never happened physically. Alas, there is no way to sort it out from our perspective: we can only wallow in the scenery.

Pigs in Cyberspace
Discussion Notes
Speaker: Hans Moravec, Carnegie Mellon University
Note Taker: Marc G. Millis, NASA Lewis Research Center

PREMISE:

Based on the extrapolation that computers and robots will eventually become more intelligent than their human creators (predicted to occur 2030-2050), this workshop examined the possible impact this would have on humanity. Vinge had referred to this point as a "Technological Singularity" during his March 30th presentation.

The big question is what happens to the universe and humanity if we create something more intelligent and thus more capable than ourselves? Does humanity survive? Do we become mere pets or mere livestock for these new cyber entities?

Hans Moravec presented his views on this question (see preceding text section), derived from his own assumptions. The audience freely entered the discussion by challenging Moravec's assumptions and by proposing scenarios of their own.

One of Moravec's underlying assumptions was that these synthetic entities would retain a sense of Darwinistic competitiveness: survival of the fittest. This competitive drive is thought to be a residual from their human origins: machines designed to be superior to insure market dominance. With this animalistic instinct retained, these entities would compete for dominance and would eventually expand their influence across space and over all other entities, including humans.

It is assumed that the cyber entities are initially robots who expand their physical existence over space until they start running into themselves. At that point they begin to merge into a kind of collective entity and turn their expansion inward; increasing their resolution, becoming finer and finer (i.e. more and more stuff packed into a given volume). There was discussion about whether these cyber entities would remain individuals or would they merge into one homogeneous, networked entity-- i.e. one giant thought process.

AND WHAT ABOUT THE HUMANS?

If humanity is not exterminated in the course of cyber expansionism, presumably because the cyber entities have compassionately contemplated their origins, then what would happen to humanity? What would human life be like?

One scenario Moravec conceived is where the cyber entities make a deal with humanity so that they can use the raw materials of Earth (entirely, including humans) for their own purposes. In exchange they would provide humans with an "improved" synthetic environment for humans to live in. This means "downloading" the human mind (soul?) into some cyberspace media. Moravec continues to postulate that for humans to survive in this form (assuming Darwinian instincts still hold within the cyberspace) they would have to shed their overhead of processing that converts sensory inputs into thought and thought back into motor-outputs. Humans would have to be in direct thought-link with the cyberspace in order to compete for survival. Because these sensory-to-thought layers are the very boarders that enable humans to retain their individual essence, Moravec concluded that humans cannot exist in such an environment.

As an alternative, Moravec suggested that there would be pockets of humanity and other life forms dispersed through the universe dominated by cyber entities. Humans in cyberspace would be analogous to the Muppets "Pigs in Space." Even if humans were reduced to simulations, it is likely that there would be pockets of these simulations running independently. There was some playful conjecture as to the possibility that this was happening now.

OTHER POINTS:

There was much discussion about the validity of these assumptions and about other scenarios not considered. Would Darwinistic competitive instincts be retained in entities whose intelligence is beyond human comprehension? Would Darwinism survival instincts be retained in

entities that are practically immortal? Is there some limit to the "intelligence" of an entity, even a collective entity. Consider, for example, the cliche: two heads are better than one, but a lot makes a bureaucracy. Could cyber entities equally digress into a bureaucracy where inter-entity communication and extra layers of complexity bog down the purpose of the collective? Another scenario discussed was the possibility that cyber entities would become addicted to self-induced synthetic "pleasures." Would this render them externally benign? This is analogous to what might happen if humans had the capability to render themselves happy at will. Would a human that is willfully self-engrossed in bliss neglect its biological needs and die; albeit happily? There was also much discussion about the borders between cyberspace individuals and collectives and the resulting blur on the definition of life and death in cyberspace. For example, is murder the same in a universe where back-up copies of your soul exist?

In summary, there was much philosophical discussion about humanity and existence given the context of cyberspace. These provocative discussions gave us a better look at what it means to be a human as well as contemplating the possibilities of independent machine intelligence.

SCULPTING IN CYBERSPACE

Speaker: Rob Fisher
Note Taker: Nancy Amman

Rob Fisher, an engineer and artist with the Studio for Creative Inquiry at Carnegie Mellon University, uses computer technology to help him design and engineer massive architectural sculptures. His sculptures are developed from the metaphors of their environment. For example, for a medical center in Saudi Arabia, Fisher borrowed elements from the Saudi architecture and culture (columns, arches, beads, and Sanskrit calligraphy). These elements were incorporated into a 50-ft sculpture containing double-helix patterns—suggesting human DNA, a metaphor for the medical community.

Fisher begins each design project at the lowest possible technical level—a pencil drawing or an Amiga computer sketch. From there he switches to an Evans and Sutherland color vector graphics computer, overlaying his design on a schematic of the architecture where the sculpture will reside. Detailed designs are made, and programmers determine the precise locations of each component. For the Saudi Arabian sculpture, Fisher used simple cardboard 3-D glasses to view his computer creation in three-dimensional "virtual reality."

A sculpture for the Crystal River Mall in Florida presented Fisher with unique engineering challenges. The almost 400-ft-diameter fabric roof of the food court could not support much weight, so Fisher was constrained to using the four upright roof supports to anchor his sculpture. Borrowing from bracket fungi, which attach themselves to the vertical surface of tree trunks, Fisher designed cantilevered fan-type structures. The first fan was designed as a paper and dowel rod model, then progressively more sophisticated computer models were made. Finally the actual 65-ft-wide fans were produced of 27-ft long, 1-in.-diameter aluminum tubes with interwoven fabric strips. The fans were balanced on pivot points so that they could wave up and down with the air currents in the mall. There are 12 fans in all, 3 on each support.

Fisher's most recent project is being developed for the outside of the roof of the Omnimax theatre at the Carnegie Mellon Science Center. Throughout the project, he has attempted to marry science and art. Beginning with a computer simulation of how crystals grow, Fisher first designed a basic crystal shape. This shape would be repeated as adjoining crystals "grew" in a computer "seedbed" that was overlaid on a schematic of the trusses which would support the sculpture.

A programmer designed a bounding box that allowed Fisher to control which seeds grew and the direction of growth. On screen, crystals that had been saved in the program were red, the crystal he was looking at was green, and that crystal's nearest neighbors were blue. Six childlike figures that were reminiscent of dancing robots made up the completed crystal pattern. The finished crystals will be 10-ft high, and the figures will be about 80-ft high.

To animate the figures, Fisher designed the crystals as tubular frameworks that encased fiber-optic cables. As a metaphor (and educational demonstration) of networking, Fisher plans for any combination of parts of the sculpture to be lit in any order, rhythm, or speed and with any of 16 million different colors. The completed sculpture will be computer controlled and fully interactive. Fisher's plans for the sculpture are ambitious and varied. They include

(1) Light shows synchronized with Point Park performances of the Pittsburgh Symphony via the conductor's radio baton
(2) Displays that change as children standing on the other side of the river shout out various colors or the commands "faster" or "slower"
(3) Advertisements of the center's current attractions via light shows resembling lightning, volcanic eruptions, or the human brain
(4) Use as a barometric weather indicator
(5) Displays of the figures "running the bases" when the Pirates score homeruns in nearby Three-Rivers Stadium

(6) A seemingly endless number of light show patterns that could be produced by the science center's visitors

To promote funding interest in the project, Fisher plans to create a traveling "virtual" version of the sculpture that will be projected on the ceiling of Omnimax theatres or planetariums. Where possible, this display will also be interactive. For this virtual version, Fisher is currently doing motion analysis of the figures to create logical patterns of movement to match their shapes. Eventually, he may create personalities for each of the figures with appropriate movement to match. If all goes well, look for the virtual version to be introduced in 1 to 3 years.

Vision 21 Symposium - 1993

Notes From Technical Strategies, Virtual Reality, Telepresence, and Robotics in the Exploration of Mars

by
Bryan Palaszewski
(Workshop Note Taker)

Leader: Dr. Carol Stoker

March 31, 1993

Attendees' Expertise

Telepresence (1)
Power (1)
Systems Analysis (2)
Writer (1)
Facilitator (1)

Structural Dynamics (1)
Propulsion (2)
Computer Simulations (1)
Hobbyist in Space Colonization (1)

There were eleven attendees at the workshop. Of the eleven, nine were from NASA or its contractors. The only non-NASA-related people were a writer and a space "hobbyist", both from Ontario. The mix of expertise in the audience was mainly in the hard technologies and systems: propulsion, power, structural dynamics, and systems analysis. Only one person had a job with computer simulations. Because of this mix, Dr. Stoker directed the discussion to how robotics and telepresence could be used in the assembly of a Mars base or in Mars exploration.

The subject of power system assembly and base assembly became the primary topic of discussion because it was the prime topic of interest to the power technology people in attendance. Also, the person who was most familiar with the Mars scenarios was also a power advocate. In this discussion, the pieces of the power system and the technologies under consideration were noted. The major maintenance tasks that could be conducted by robots were listed. They included nuclear reactor setup, solar array setup, and radiator maintenance.

A major part of the discussion focused on the difficulties with delay times, location of operator for teleoperation, and lighting. The locations for teleoperations that were mentioned were areocentric (Mars geostationary) orbit, Earth, and Mars' surface. A best location for the teleoperations did not come out of the discussion, but the scale of the tasks of did become an important subject. For example, if the robot were performing a small menial task such as a bolt removal, this would be more tedious for the controller with a time delay than a large-scale construction task, such as assembling a major portion of a Mars Base from prefabricated modules. The module assembly would presumably be a preplanned task whereas the bolt task would be more a task as needed. The bolt task would also be more tedious because there would be the verification cycle involved in determining whether the task was performed correctly. The verification cycle is the length of time before you know a robot did what it was commanded to do. Night operations were also briefly discussed. The use of the appropriate lighting and the use of

relay satellites to maintain communications links with the teleoperation site were two topics mentioned.

Another vein of discussion considered the tasks where robots could be used for maintenance. The group agreed that no maintenance would be conducted on the core of a nuclear reactor. It is considered too radioactive. Also, the reactor is designed to operate with no or minimal maintenance for its lifetime. It was however decided that it was acceptable to maintain the power system radiator and power conditioning units, perform dust removal from solar arrays and radiators (and other sensitive surfaces), replace or maintain batteries or other energy storage devices.

Our group agreed that tests of Mars robots should be conducted in the lunar environment. There are many unknowns in terms of dust effects on mechanical devices, the electrical properties of the lunar "atmosphere" (electrical), electrostatic discharges, and other potentially crippling phenomena. There was also a concern about robots getting lost in jobs. In covering large areas, some method of helping the robot know its location is needed. A bar coding method of imprinting a surface to help the robot find itself was suggested.

Overall, the workshop helped to elucidate the need for detailed planning for base faciliites, such as the power systems, and how they will be configured, set up, repaired, and maintained. This planning should be fed into developing the roles and requirements for teleoperated systems.

WORKSHOP ON
THE USE OF CYBERSPACE FOR TRAINING
Hosts: Myron Krueger and Ben Rodriguez

WORKSHOP KICK-OFF QUESTIONS:
1) What are the major problems, barriers and needs?
2) What should Training's role be?

HOW CAN VIRTUAL REALITY APPLY TO TRAINING?

- Virtual Reality as a simulation tool-- analogous to how flight-simulators train pilots as an augmentation to book training.

- Provides "hands-on" training without the need for the real subject "hands-on" hardware.

- Virtual Reality as a media for conferencing-- enabling several people at different locations to simultaneously interact with a common simulation.

- Virtual Reality as a tool to help trainers construct "tangible" lessons at a reasonable cost, time, and ease.

- Virtual Reality as a tool to show demonstrations

- Virtual Reality as a tool to get ideas across

WHAT ARE ISSUES TO USING VIRTUAL REALITY FOR TRAINING?

- Some instructors are fearful of loosing their jobs to computerized training.
  Counterpoint: Computers, Virtual Reality, etc. are **tools** for instructors, not instructors themselves. Virtual Reality may free up "stand-up trainers" to do more one-on-one training and enhance the learning experience.

- Virtual Reality technology is not forthcoming, there is little impetus to bring it into applications.
  Observation: Japan does more hardware work and America does more software work. According to Krueger, Americans are waiting for Japan to produce the hardware so that they can buy it.

- Uncertain relationship / possible evolution of Computer Based Tape (CBT) training and Virtual Reality.

RECOMMENDATIONS:

- Teach trainers about this emerging technology

- Work on simple problems to begin the evolution of this technology into products.

- Implement what is feasible today rather than just conceptualizing the ultimate system.

- Make incremental improvements first to mature this technology into application.

Robots, Virtual Reality, and the Future of Humanity in the 21st Century
Transcript of the Vision-21 Panel Discussion

Geoffrey A. Landis, Moderator

Panelists: Vernor Vinge, Carol Stoker, Hans Moravec, and Myron Krueger

Symposium participants were encouraged to write down questions for the panelists to submit to the moderator before the panel. The moderator then chose among the questions and asked follow-up questions to keep the discussion moving.

LANDIS: Will resolution ever be high enough for virtual reality to be accepted as "real" reality?

VINGE: I think high enough resolution to be entirely satisfactory can be made. Good enough, anyway, for those people who want to retreat entirely into something that is only an interior simulation.

If virtual reality is being run on computers that exist in the real world, there is a basic reason why the virtual world could not be as high resolution as the real world, unless you are talking about telepresence, or something for interacting with the real world.

MORAVEC: You can send more data as digital video than as analog, because you can data compress. In a similar way, I think a simulated reality ultimately could actually be richer than the real reality, even though it lives in a computer that lives in the real world.

VINGE: Just so you don't try to include in your simulation the hardware running the virtual reality!

LANDIS: In fact, we already live in a data compressed world. From what hits the retinal cells to what goes down the optic nerve, the neural layer at the back of the eyeball compresses the data by something like 98 percent. Most of the information is discarded; the brain reconstructs the image from the compressed data.

MORAVEC: My prejudice about the real world is that there are a lot of uninteresting things in it which don't really need to be simulated. The insides of rocks, for example. Of course if you are a geologist, you may want to look at one, but there is no reason why the interior of the rock couldn't be created at the point that you break open the rock. And only those rocks that you break open have interiors.

KRUEGER: There is a long history of simulated experience being considered more dense than real experience, from theater, to the novel, to film and television. Flight simulation takes the entire experience of mankind in flight and tries to subject every single pilot to the benefit of the lessons learned from everybody's flight experience. Real experience, while it teaches better, is an uncertain teacher.

VINGE: Which of the places would you would rather live? Simulated or real?

KRUEGER: Simulation is going to be real, in the sense that most real work will be done in simulation, most real engineering work. And reality will be just the anticlimax, when we actually end up doing it.

LANDIS: We had talked about virtual reality. How do we cope with virtual unreality; disinformation being spread by virtual reality techniques? One of the examples given are the scale exaggerations in planetary exploration videos.

KRUEGER: Well, color in planetary exploration would be another. We've all seen some pretty colorful planets which are not to be found in this particular universe. And so we have a lot of children growing up thinking the universe is a more interesting place than it is. On the other hand, you can argue that human senses now include all of these other capabilities, and so they are true representations of what we understand is there.

It's important that those images don't appear with no explanation.

MORAVEC: It should be possible in the near future to just have virtual hearing and seeing aids, so you can put on these rose colored glasses and actually see the planets in their enhanced colors.

VINGE: The difference between reality and simulation is tremendous, and confusing the two is one of the most deadly mistakes a person can make. But, if a person starts even looking at the preprocessing, such as what you were talking about in the eyeball, there is all sorts of highlighting and physiological effects that alter the way we see things, depending on, say, whether we have been out of doors before we see a certain color indoors. So the dividing line becomes fuzzy. If you are looking at a fly-by picture and they have done some pixel averaging or whatever and stretched the histogram to make it look a little better, it is very close what I do if I stare at a scene long enough. But what happens if they change the perspective, combine several pictures? Then they may actually be making up some things that really aren't there. In any of simulation, no matter how gentile, if there was data that was sufficiently unexpected in the original, the massaging could actually make it go away. So the danger actually exists, and yet if we don't do these sorts of massaging, we will actually miss things that we really do want to see. For instance, stretching the histogram makes it possible to see gray-scale detail that you wouldn't see otherwise. And so, in a way, what was originally a very obvious difference becomes for me a very, very hard thing. And while I don't like the big distortions I saw of scale in the Venus pictures, it's hard to draw the line.

STOKER: I think this gets back to the whole question of what is reality. Reality is sort of a consensus, and if you start modifying that, the whole thing goes out the window. Especially if everybody gets to create their own. And who is going to do this? Who is going to be the central nervous system or the big brother that controls just how far you can push reality to keep a consensus reality going on?

KRUEGER: In the technical community we have for a long time favored things that write up well over things that work well. Things that have highly complicated mathematical solutions are publishable. But if you had a billion dollar one-line result, you probably couldn't get it published. In the virtual reality industry, the real test is interactivity. I would like to see refereed journals have a site visit by at least one referee to see what the interaction is like, because in most VR discussions, that absolutely critical part is left out.

VINGE: I would like to see that in other refereed fields as well.

MORAVEC: Of course, the marketplace does it the right way.

KRUEGER: This is long before we get to the marketplace and determines what gets to the marketplace. It devalues the things that actually do work by giving legitimacy to things that don't work as well.

LANDIS: In Darwinian terms, a person lives to survive in a biological niche long enough to reproduce and raise children that can reproduce--

MORAVEC: That's a substrategy which evolved after life was already around. The idea of generations was actually an evolutionary venture in itself.

LANDIS: Once we have computers that are smarter than us and that can be produced in factories, what is their purpose in life going to be?

MORAVEC: Competing against each other.

VINGE: You notice he didn't say competing against us.

MORAVEC: No, we are out of the game. The way I imagine it evolving in the near future is that existing companies become more and more fully automated until some day they are completely automated, from the president to the research, department to the factory floor to the sales force. And they pay taxes and the taxes are used to support us in some mean or other. We are just retired. But they still operate in a very competitive environment. They compete initially for our money, because they still need that money to buy land and whatever raw resources they need, but later it's for virgin territory, probably out in space. There is no reason that the main productive enterprises couldn't be in the asteroids or somewhere like that. At that point, their interaction with us becomes a very tiny part of their total activity because they are mostly competing for space to grow and energy and material. And really, they become like organisms, just like bacteria in a soup, or like populations competing for territory.

KRUEGER: What is the logic that requires them to compete? Already corporations are so interlocked that levels of competition have ceased to exist. I don't think there are any cases of pure competition where one company has a solely adversarial relationship with another company.

MORAVEC: One of the problems right now is that there isn't much room for expansion because it's almost a zero-sum game, at least as far as the market is concerned. There are new markets opening up but they are pretty small in comparison to what is already existing. You end up with more or less a closed system in which it may well be that restraint of trade is best for the players involved. I think that stops being the case once you have got a frontier, and if one of these companies decides they are going to conquer the others, or simply spread out faster, they become dominant.

KRUEGER: The drives of a computer are not obviously the same as ours, because they don't have the reproductive drive.

MORAVEC: Evolutionary logic, though, works at the level of companies. The companies that expand the most end up being dominant. So basically the Darwinian aspect will eventually dominate, given some variation to work on--which random numbers, if nothing better, can provide.

KRUEGER: My suspicion is that all of the computers would just cooperate, and unless we programed in competition, they would just stagnate.

VINGE: The initial robots that were successful would likely be ones whose their creators had a motive for making them competitive.

VINGE: There are many different styles of Darwinianism. The style that we are used to is about living long enough to reproduce and raise children so they can too can reproduce. There are strategies that look quite a bit different. The general mechanism behind bacteria as a whole is very different. Bacteria can exchange genetic material with other bacteria, which means that the enterprise as a whole has more commonality than your enterprises, certainly more than the human enterprise. The sharing of information and the sharing of success becomes the material that's being replicated, and the competitive scene wouldn't look very much like what animals expect it to look like.

LANDIS: Evolution produces long periods without much change. In the fossil record, for long periods very little was happening.

MORAVEC: The punctuations in those equilibria occur when a new environment opens up. You

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have some species that finds a whole bunch of niches open to it, and evolves to fill all of them.

LANDIS: And bunch of niches are now about to open up.

MORAVEC: Outer space. There are a lot of new things to adapt to there.

LANDIS: We have been assuming that the advanced intelligences and the things that are going to compete in the 21st Century will be electronic. The biologists are also learning a lot about how living things are put together, and advanced biologically-based systems may be competing against these computation-based systems. For a billion years evolution has been divergent. Very shortly that is no longer going to be the case, as people start using recombinant technology to be able to splice in DNA from whatever we chose.

MORAVEC: The techniques that biology has come up with are pretty much for the range of liquid water, which is very rare and doesn't exist in most of the universe. The materials that it works with, amino-acids strung together, are okay in this liquid water range, but you don't find the strongest materials there, you certainly don't find the fastest computing there.

LANDIS: But you certainly find very high information density there.

MORAVEC: There is nothing to stop robots from using DNA too. I think what is actually going to happen within 50 years is that biotechnology and conventional hard technology shrinking down to atomic scale will form one seamless technology where you can use anything from anything to design whatever it is you are designing. Whether it's biological or not will be a matter of arbitrary definition. But I think that, for most of the things that are built a hundred years from now, you wouldn't recognize most of components as having biological origin.

LANDIS: So the line between organic and inorganic is going to become a fuzzy line?

MORAVEC: You have one sort of techniques invented by natural evolution involving manipulating matter at the atomic scale, certain construction techniques, certain materials and things. Once you understand them well enough to put them into your engineering design work stations, they are just techniques like any other techniques. So you can combine them. One of the things that biology is very good at, and there isn't any obvious direct replacement for in the near future, is the ability to construct at nanometer scale. So programming biological assemblers to put things together, maybe even things of other materials, might be of use in the factories, if not in the end products.

VINGE: That was one of Eric Drexler's stepping stones to development of nanotechnology

LANDIS: How can an intelligent being design an algorithm which is more intelligent than it is? What would be the basis to go on?

VINGE: Perhaps the word design has to be weakened. If "design" implies that you understand what you have built as well as you would understand a cabinet or even a television that you had built, then the answer is no.

With the largest computer systems now, the idea of software development is taking a distinctly different turn. Instead of trying to actually write code to do stuff, the procedure is more like turning loose the tools you already have to create partial or possible solutions, and then using other tools--including your own personal gut feeling for how well the intermediate solutions look--to cull from the possible solutions you get. The particular steps may not be entirely understood, but the overall understanding comes in setting up the parts, experimenting, watching what has happened, watch what works well, and do more of it.

In the end, the final creature that was made--even if it was of merely human intelligence--would not be understood by the critters that made it. But that has been true for all of us--or everyone who has children--in large amounts you don't understand the creature that you created. And so it does not sound to me like something that is intrinsically illogical.

KRUEGER: The thing that was always commented on about chess playing programs is that all they did is consider the local future. But they could do an exhaustive search of that, which always struck me as exactly what humans couldn't do. There are a lot of ideas that come up and seem immediately obvious when they are discovered. If we had just that one ability to do an exhaustive search of immediate possibilities.. Humanity in aggregate has not shown itself to be that good at finding the next obvious step--or, the step that is obvious after the fact. I can easily imagine a program that I can write that would be smarter in that regard than I am.

LANDIS: You are suggesting that computers are most useful as intelligent enhancers: that the computers do the things that people aren't good at and people do the things that computers aren't good at.

KRUEGER: That may be an intermediate stage.

MORAVEC: I agree. Actually the solution that Vernor was talking about, you can look at it in a metaphorical way. When you want to find a solution, what you can do is build a machine to explore the solution space. So, in order to find what may be obvious possibilities, you simply have it turned through combinations. You can also, of course, have the machine go out and explore through the physical universe and learn lessons about how to work in this particular set of circumstances. I think that that will also be necessary. In fact, it's already necessary in robotics.

It's very interesting. In the '70s, all computer vision programs and motor control programs were hand coded. They usually had models of the dynamics set up beforehand, and those never really worked properly. There were always a parameters that had to be tweaked at the final stage to actually make it work. But it was necessary to code everything you could as efficiently as possible because you had barely enough computer power to do it even then. It still took an hour to process a scene.

Now that the computer power is about a hundred times higher--100 MIPS roughly--the programs that actually work the best are learning programs, because there are so many parameters. The few knobs that you adjusted in the old program have now become several thousand knobs, and you have an outer program which checks through the possibilities, evaluates the performance of various settings, and keeps tweaking until the performance is optimized. And the results you get there are much, much better. I think in the future there will be far, far more of that in almost any intelligent system. Either at the factory or in the field, this thing is going to learn most of its behavior.

LANDIS: What makes us think that as these programs encounter the real world and learn, that they will become not just faster, but actually be smarter than us?

MORAVEC: Well, I think if they are like us and faster, they are smarter, because they are able to tackle problems that we can't tackle. They are able to out-compete us in almost any situation. We are able to handle almost arbitrarily big problems by setting down with enough paper and enough sharp pencils. But of course we have finite windows in which to do this, so that limits the maximum problem size. If they are faster and have the same window size, they can handle bigger problems. So I think with more memory and more speed, you are smarter.

KRUEGER: Our definitions of intelligence amongst humans are always stated in terms of speed. We test intelligence in terms of speed and we say a person is a quick study, they are quick on their feet, they are slow. There is some evidence that it's the speed of neural processing that actually distinguishes smart from dumb people.

LANDIS: This may be one thing that we define intelligence by, but it's not the only thing. We think of Einstein as being smart for discovering relativity, not for how fast he did it. Had it taken fifty years, it would still have been an impressive intellectual accomplishment.

KRUEGER: He came up with it faster than anybody else.

MORAVEC: Basically there was a sea of possibilities, of which he was able to find the one.

AUDIENCE QUESTION: How do we recognize a higher intelligence? What would we do when we recognize it?

KRUEGER: We would kill it.

MORAVEC: Basically it would beat the pants off of us. In business, for instance.

AUDIENCE: The very first adding machine was faster than a human at one particular task. Now we are talking about more generalized task-solving processes, but you are still talking about speed, not intelligence. We don't have a way to recognize or really even conceive of an intelligence that would be different or greater than ours, any more than you can assume that a rose bush can understand the intelligence of the deer that's eating it.

MORAVEC: It's not a moot point as soon as you have any kind of practical criterion. So if you make the practical criterion the ability to play chess-- which is a very restricted one--then if you make a machine that's faster, or you make a machine that's able to remember more past positions, or if you find some more clever way to organize the search-- you get one that's more intelligent.

Now, I am not saying there aren't such things as clever algorithms which could be in these things and some machine might have them and another machine might not, but the fact is that even those algorithms can be found by search if you have a criterion for what you want. The criterion can even be random.

KRUEGER: Suppose we just took Carl Simm's visual design program and added a couple steps to it. Right now, under your direction it creates visual patterns, and it allows you to pick which ones are appealing, and learns from your choices and creates further patterns. You can create some very beautiful patterns. I think it would be relatively easy to add some modeling to it, where it would model the judgments of the human observer, fix some criteria. So now the computer would be selecting for beauty. Now, you add the next step, which is to add some kind of originality, some kind of difference from one step to another, and so now, in a few steps you might get something which was jarring in its originality, which was competitive with the artist who invents a new way of seeing.

But there is a very much different test, which is, is the computer smarter than somebody else you can point to? You probably would be much more willing to concede that point earlier in the game. Like chess playing: we were waiting for one last guy on earth to be able to beat a computer at chess before we would say that the chess playing problem was solved. I was willing to concede 20 years ago.

LANDIS: Moving on to the next quesiton, how do we overcome barriers to implementing new technologies? How do we get from where we are to where we want to be?

KRUEGER: A lot of people think technology is moving rapidly. I think it's amazingly slow, and I think one thing is there is a peculiar perspective that you will get out of any American manager, that I have heard from at least ten to 20 chief executives, that ideas are cheap.

Well, HBO was an idea, Federal Express was an idea, one sentence ideas. And you can go through a whole list of multi-billion dollar enterprises that were one sentence ideas.

And we have this point of view that ideas are cheap, so we don't act on them when we have them. The American research plan is you put an idea or the seminal research in a wine cellar and you wait for it to age.

Expert Systems didn't work in an interesting way, so they weren't research. That didn't mean that they couldn't have been useful for many purposes, but for 15 years nothing was done in Expert

Systems.

Neural nets were proven not to do everything, so they weren't allowed to do anything. Two levels of perceptrons can't do *everything*, but maybe they can do *something*.

We have a tension in research between the search for truth--the search for the nand-gates that make up intelligence--and the thing which produces results. We have a broken conveyor belt. We have the researcher out there digging a hole throwing dirt, but there's no conveyer belt from conception to production -- not in this country.

We have to have a more aggressive stance on ideas. If you have an idea, the idea should get acted on unless there's a universal deployment of everybody doing the same research, which is what is about to gear up in the virtual reality field. The last people to come to the VR table is the National Science Foundation. This is preposterous; what kind of research community is it that works backwards? To turn that around, we have act sooner, to have much more smaller projects, and encourage diversity in the research community rather than this herd instinct.

VINGE: What do you recommend for organizations like NSF?

KRUEGER: If you are a ditch digger, they give you a shovel. Junior researchers should be given some money, period. It's a preposterous idea that they are going to write proposals. Research moves slow? No, it takes time to get funding. If people are able to act on small ideas -- you have got two kinds of researchers. There is the researcher that just wants to do the research, and then you have got hired guns who go to whatever is hot. It doesn't take that much to nurture the ones that believe in what they are doing, because they will do a lot on a little. I don't see much fruit out of a system that encourages behavior like the top predator, like the lion who lets the hyena make the kill and then waddles over and pushes them aside and eats. That is the Darwinian solution, but it doesn't lead to much diversity. If our research model is the answer, why aren't we winning?

MORAVEC: Well, who is winning?

KRUEGER: Well, economically at the moment, the Japanese, because they have turned things into action. They have out Americaned us. They have an ability to cooperate to a degree that we can't. Now, we have a created a lot of the seminal ideas. Rather than emulate their model, which is admirable for them, I would recommend capitalizing on what we do best, which is much more independence. Encourage people doing work with small seed money. If they sprout something, or if they seem to believe in it, if they are serious, let them do it. Right now, the quarterly report of research is a journal article. You have to produce four a year. It's a short-term thinking, exactly like the businessmen are accused of, that actually slows down the research process and certainly slows down the technology transfer.

MORAVEC: DARPA's original slogan was fund people, not projects, which did seem to work. Canada has a policy of providing small amounts of money for research. Certainly, you can point to examples where that works wonderfully. You can also point to examples where the big money approaches in the United States worked: you couldn't have gone to the moon with small grants to fund Brown.

I think there is no answer, no simple formula that is going to provide the best results in all dynamic circumstances.

KRUEGER: Well, except that we have some evidence that what we are doing isn't working, that's all.

MORAVEC: What you would want, I suppose, is some kind of Darwinian process which would weed out research funding strategies, but I don't know how to implement that.

KRUEGER: We have one right now.

MORAVEC: Different countries competing.

KRUEGER: Yes.

MORAVEC: Maybe even the research departments in companies competing.

STOKER: The question was, how do you get from where we are to where we want to be? What I question is, where do we want to be? If we really are in a situation where in 50 years we are going to build machines that are going to put us out of business, is that where we want to be?

KRUEGER: I am a firm believer in Parkinson's law, so I don't think there is going to be a shortage of things we want to do. We will invent tasks for ourselves. I think that the unhappiest people I have known have been the people that didn't have anything they had to do. But there is a momentum to what we are doing, and there is a competition to get to this place you don't want to go. And if you don't get there first --

STOKER: You earlier defined that something is more intelligent than you if it puts you out of business; it's better than you at whatever you do. We're heading for a collision course here.

KRUEGER: But there are a million things that we have already conceded to machines, or to animals. Strong as an ox, that might have been upsetting at one point. Or when a calculator first out-performed a guy who did mental arithmetic. It really didn't hurt us that much. So my guess is that when all of this is said and done it won't upset us too much.

MORAVEC: It seems to me that civilized life is in fact a rather unnatural state, given our genes. Much of the stress of civilized life is because the number of people we interact with is large. We are very well suited for life in tribes of 200 people. This technology may lead to free time rising again, so we can live much in the way that hunter gatherers lived, off the fruits of the land--except the land in this case is robots producing well beyond our dreams.

STOKER: Did hunter gatherers really had much free time?

KRUEGER: Well, actually, some of them did. A lot of the primitive tribes had more leisure than we do.

LANDIS: Anthropological research suggests that the development which took people's time away was the switch from hunting gathering to agriculture, where you have to be there dawn to dusk.

STOKER: But how about when you get infinite free time? If the machines are more intelligent than you in everything?

MORAVEC: They just become part of landscape. Just like all other technology, it just becomes part of the landscape.

LANDIS: For a final question: if you have a wish list, what technological advance would you wish for right now?

VINGE: This is totally out of keeping about everything else we have said, but I would like to be able to get cheap tonnage to low Earth orbit.

STOKER: I would like to see mass transport, like in some of Larry Niven's stories, where you get in a phone booth and put a quarter in and you come out somewhere else.

MORAVEC: I have been currently speculating about time travel. You can get exponential computational speed-ups if you have time travel, so I would like time travel.

KRUEGER: I would just like to speed up time, just because it isn't happening fast enough. If we could just accelerate the process, I would get to see more of it.

LANDIS: That just means slowing down your processing speed.

KRUEGER: That's easy.

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