Knowledge-Based Systems

Concepts, Techniques, Examples

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This course will discuss the key concepts and techniques behind the *Knowledge-Based Systems* that are the focus of such wide interest today. These systems are at the applied edge of research in *Artificial Intelligence*. To put them in perspective this course will take a short historical tour through the AI field and its related subtopics. This tour will focus on underlying themes, with examples drawn from representative systems.

The key factors that underly knowledge-based systems are knowledge acquisition, knowledge representation, and the application of large bodies of knowledge to the particular problem domain in which the knowledge-based system operates. Dr. Smith will discuss a number of formalisms for knowledge representation and inference that have been developed to aid in this process. Once again, this will be illustrated with examples drawn from existing systems.

The course will conclude with a discussion of the pragmatics of actually building a knowledge-based system. This will include: (1) suggestions for selecting problems that are amenable to the knowledge-based system approach, and (2) a description of the characteristics of software tools and high-level programming environments that are useful, and for most purposes necessary, for the construction of a practical knowledge-based system.

Reid G. Smith is the program leader for Expert Geology Systems at Schlumberger-Doll Research, Ridgefield, Connecticut, where he has been since 1982. His current research is on expert systems which explain failures and develop justifications for the information in their knowledge bases. He has been involved in the Dipmeter Advisor project and in the development of tools for expert system construction. He has also worked in knowledge-based systems for passive sonar interpretation for the Canadian Defense Research Establishment Atlantic. Dr. Smith received his B. Eng. and M. Eng. in electrical engineering at Carleton University before doing a Ph.D. at Stanford. He is the author of “A Framework for Distributed Problem Solving” (UMI Press).

PROSPECTUS

Artificial Intelligence
Underlying Themes

Knowledge-Based Systems
Underlying Themes
Example: MYCIN
Example: DIPMETER ADVISOR
Assessment and Outlook

<break>

Representation and Reasoning
Rules / Chaining
Structured Objects / Inheritance
Procedural Attachment

Pragmatics

Perspective

Artificial Intelligence

Goals:

To construct computer programs that perform at high levels of competence in cognitive tasks

Knowledge-Based Systems

To understand and develop computational models of human intelligence

Cognitive Science

As Experimental Computer Science: Side Effects

Time-sharing

Sophisticated Programming Environments

Exploratory Programming

Personal Machines

Local Area Network Processing

FOUR AREAS OF COMPUTING

Type of Processing	Type of Information: NUMERIC	Type of Information: SYMBOLIC
ALGORITHMIC	traditional scientific calculations	data processing
HEURISTIC	computation-intensive application with heuristic control (manipulators)	Artificial Intelligence

WHAT IS A KNOWLEDGE-BASED SYSTEM?

Symbolic: It incorporates knowledge that is symbolic [as well as numeric].

Heuristic: It reasons with judgmental, imprecise, and qualitative knowledge as well as with formal knowledge of established theories.

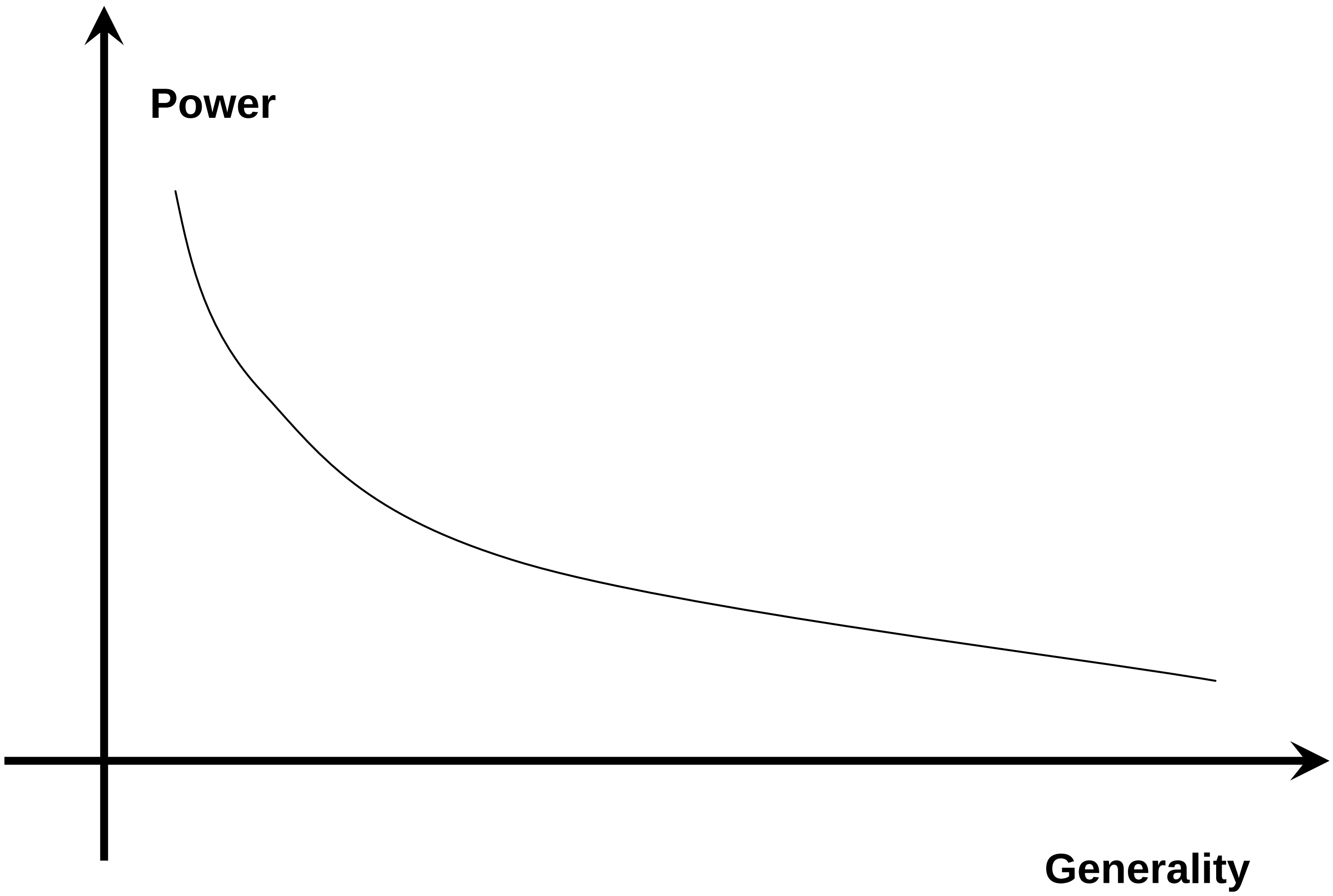
Transparent: Its knowledge is simply and explicitly represented in terms familiar to specialists, and is *separate from its inference procedures*. It provides explanations of its line of reasoning and answers to queries about its knowledge.

Flexible: It is incrementally *refinable* and *extensible*. More details can be specified to refine its performance; more concepts and links among concepts can be specified to broaden its range of applicability.

It is an *expert system* if it provides expert-level solutions.

The power lies in task-specific knowledge.

Generality and Power



AI Paradigm Shift: circa 1970-72

SOME BASIC PRESCRIPTIONS

Don't tell the program what to **do,**
tell it what to **know.**

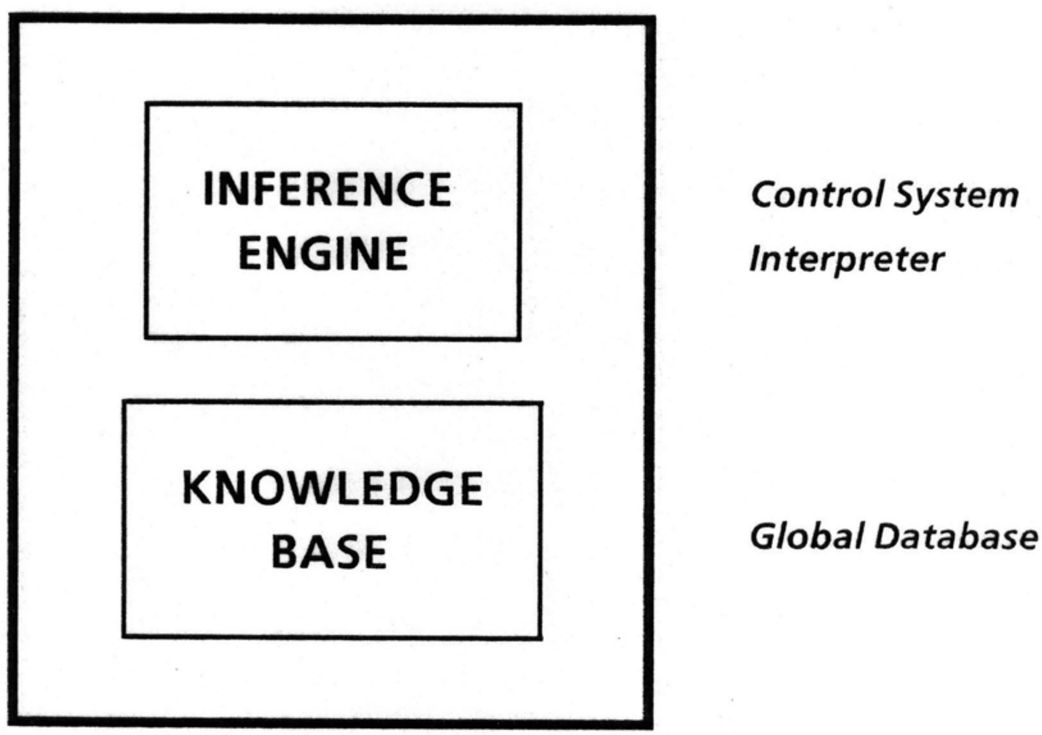
Keep the knowledge in the knowledge base.

Choose a representation that is as
high-level
transparent as possible.

The task is elucidating and debugging knowledge,
not writing and debugging a program.

… Knowledge Programming

Basic
Knowledge-Based System
Architecture



Major Architectural Lesson

EXAMPLE: MYCIN

MAIN ISSUES

IN THE KNOWLEDGE LIES THE POWER

HOW TO DEAL WITH INCOMPLETE, INEXACT DATA

HOW TO DEAL WITH INEXACT INFERENCE

THE UTILITY AND POWER OF SIMPLE MECHANISMS

THE IMPORTANCE OF SYSTEMS THAT ACCOMMODATE THE USER

--------PATIENT-248--------

1) Patient's name: (first-last)
** C.R.
2) Sex:
** MALE
3) Age:
** 52
4) Have you been able to obtain positive microbiological information about a possible infection of C.R.?
** YES

--------INFECTION-1--------

5) What is the infection?
** ENDARTERITIS

The first significant organism from this blood culture (CULTURE-1) will be referred to as:

--------ORGANISM-1--------

9) Enter the identity of ORGANISM-1:
** UNKNOWN
10) Is ORGANISM-1 a rod or coccus (etc.)?:
** ROD
11) The gram stain of ORGANISM-1:
** GRAMNEG
12) Have there been POSITIVE cultures yielding organisms about which you will NOT be seeking advice?
** YES

14) Is the patient's illness with ORGANISM-1
    a hospital-acquired infection?
** WHY

[i.e., WHY is it important to determine whether or not the infection with ORGANISM-1 was acquired while the patient was hospitalized?]

[2.0] This will aid in determining the identity of
    ORGANISM-1. It has already been established that
    [2.1] the morphology of ORGANISM-1 is rod
    [2.2] the gram stain of ORGANISM-1 is
        gramneg
    [2.3] the aerobicity of ORGANISM-1 is facul

Therefore, if
    [2.4] the infection with ORGANISM-1 was
        acquired while the patient was
        hospitalized
then
    there is weakly suggestive evidence (.2) that
    the identity of ORGANISM-1 is pseudomonas
        [RULE050]

15) Enter the identity of ORGANISM-2:
**   SALMONELLA (.4) E.COLI (.3)

INFECTION-1 is ENDARTERITIS with BACTEREMIA

<item 1> E.COLI [ORGANISM-1]
<item 2> SALMONELLA (species unknown) [ORGANISM-1]
<item 3> KLEBSIELLA-PNEUMONIAE [ORGANISM-1]
<item 4> PSEUDOMONAS-AERUGINOSA [ORGANISM-1]
<item 5> ENTEROBACTER [ORGANISM-1]
<item 6> PROTEUS-NON-MIRABILIS [ORGANISM-1]

[Rec 1] My preferred therapy recommendation is as follows:

In order to cover for Items <1 3 4 5 6>:

Give: GENTAMICIN
Dose: 128 mg (1.7mg/kg) q8h IV (or IM) for 10 days
Comments: Modify dose in renal failure

In order to cover for Item <2>:

Give: CHLORAMPHENICOL
Dose: 563 mg (7.5 mg/kg) q6h for 14 days
Comments: Monitor patient's white count

Do you wish to see the next choice therapy?
** NO

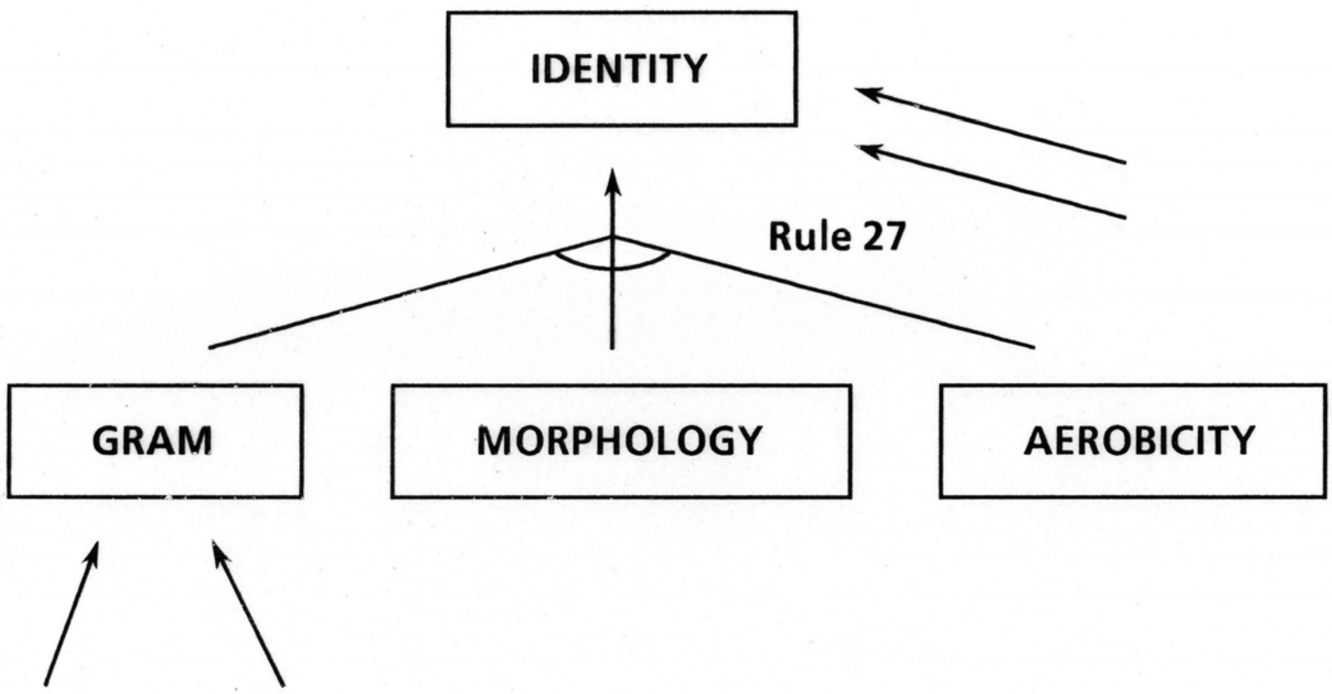
Rule 27:

If 1) the gram stain of the organism is gram negative, and

2) the morphology of the organism is rod, and

3) the aerobicity of the organism is anaerobic,

Then: There is suggestive evidence (7) that the identity of the organism is Bacteroides


IDENTITY
Rule 27
GRAM
MORPHOLOGY
AEROBICITY

INEXACT INFERENCE DESIDERATA

COMMUTATIVE

ASYMPTOTIC

BALANCING OF + AND – EVIDENCE

CF range: {-1 ... 0 ... 1}

$$CF_n = \begin{cases} CF_p + CF(1 - CF_p) & CF_p,\ CF > 0 \\ CF_p + CF(1 + CF_p) & CF_p,\ CF < 0 \\ (CF_p + CF) / (1 - \min\{|CF_p|, |CF|\}) & CF_p CF < 0 \end{cases}$$

** WHAT WAS THE IDENTITY OF ORGAISM-1 ?
= ORGANISM-1
The identity of ORGANISM-1 is e.coli (.51), salmonella (.45), klebsiella (.4), pseudomonas (.22), enterobacter (.21), proteus (.19), pseudomonas-aeruginosa (.08), serratia (.02)

** HOW DID YOU DECIDE THAT ORGANISM-1 WAS AN E.COLI?

I used rule084 to conclude that the identity of ORGANISM-1 is e.coli. This gave a cumulative c.f. of (.51).

I used rule003 to conclude that the identity of ORGANISM-1 is e.coli. This gave a cumulative c.f. of (.43).

** WHY DIDN'T YOU THINK THAT ORGANISM-1 WAS NEISSERIA?

The following rules could have been used to determine that the identity of ORGANISM-1 is neisseria: 9 However, none of these succeeded in the context of ORGANISM-1. If you would like an explanation for why any of these rules failed, please enter their numbers:
** 9

Clause 2 of rule009 ["the morphology of the organism is coccus"] was already known to be false for ORGANISM-1, so the rule was never tried.

LESSONS: MYCIN

FLEXIBILITY [Refinement, Extension]

- Inference Engine - Knowledge Base Separation
- Simplicity
- Modularity

USER ACCOMODATION

- Consultant Role
- Transparency
- Interface

EXAMPLE:
DIPMETER ADVISOR

MAIN ISSUES

DEALING WITH SIGNALS

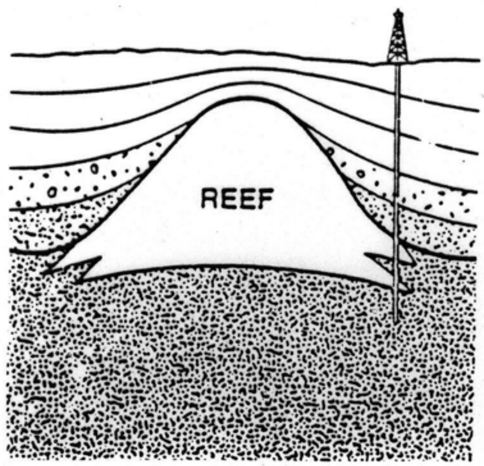
HOW TO COMBINE METHODS AND APPROACHES

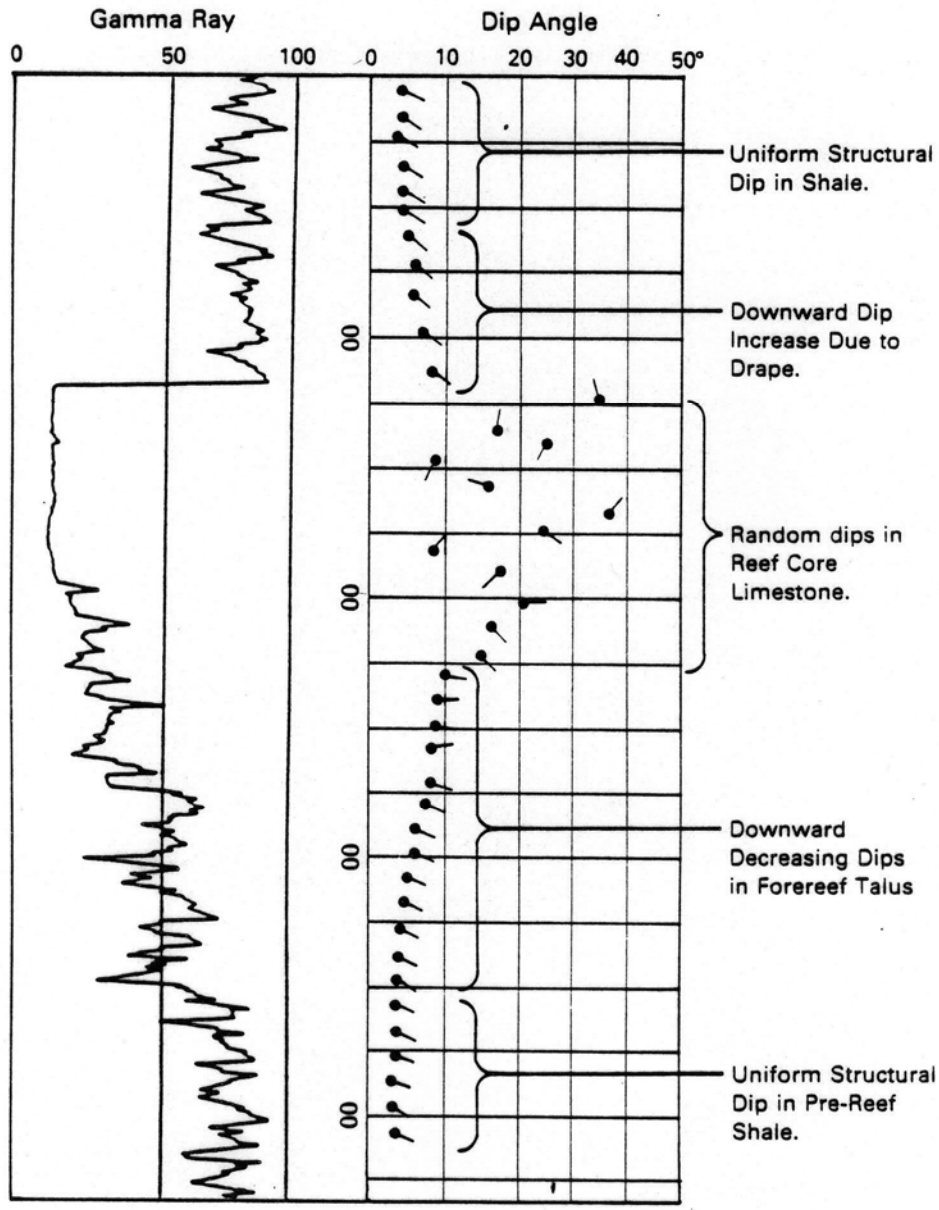
INTEGRATION OF KBS INTO AN OVERALL SYSTEM

THE UTILITY AND POWER OF SIMPLE MECHANISMS

THE IMPORTANCE OF SYSTEMS THAT ACCOMMODATE THE USER

SOLVING THE PROBLEM, GOING COMMERCIAL


REEF


Gamma Ray
0
50
100
Dip Angle
0
10
20
30
40
50°
00
00
00
00
Uniform Structural Dip in Shale.
Downward Dip Increase Due to Drape.
Random dips in Reef Core Limestone.
Downward Decreasing Dips in Forereef Talus
Uniform Structural Dip in Pre-Reef Shale.

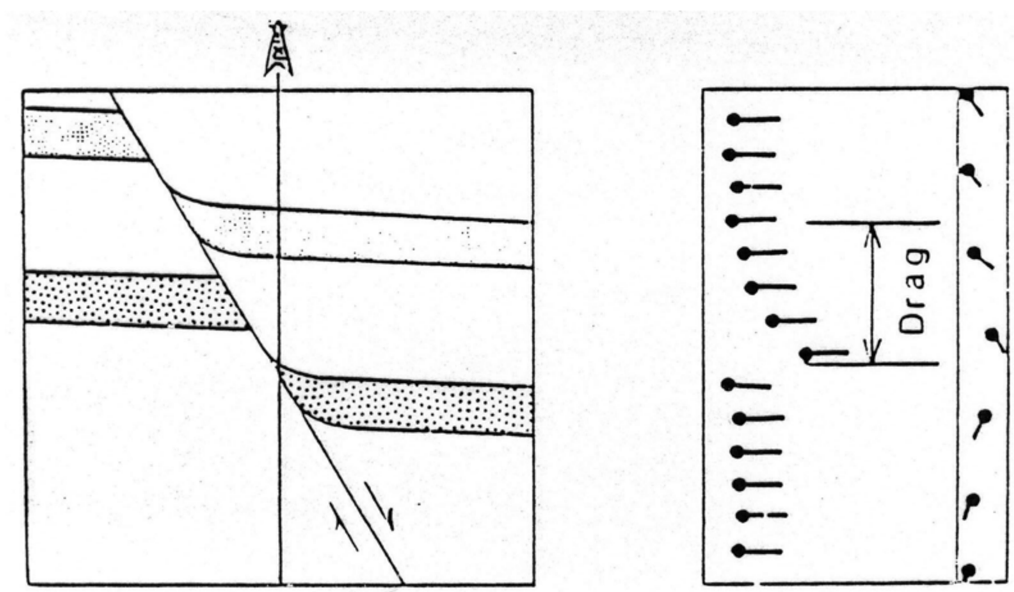
DIPMETER ADVISOR SYSTEM: SAMPLE RULE

IF

there exists a normal fault with class unknown, and
there exists a red pattern
with length < 50 ft.,
with bottom above the top of the fault,
with azimuth perpendicular to the fault strike

THEN

the fault is a late fault
with direction to downthrown block
equal to the azimuth of the red pattern



DIPMETER ADVISOR SYSTEM: PHASES

- **GENERAL:**

  Initial Examination

  Validity Analysis

  Lithology Analysis

- **STRUCTURAL DIP DETERMINATION & REMOVAL:**

  Green Patterns

  Structural Dip Analysis & Removal

- **STRUCTURAL (TECTONIC) FEATURE ANALYSIS:**

  Preliminary Structural Analysis

  Structural Patterns

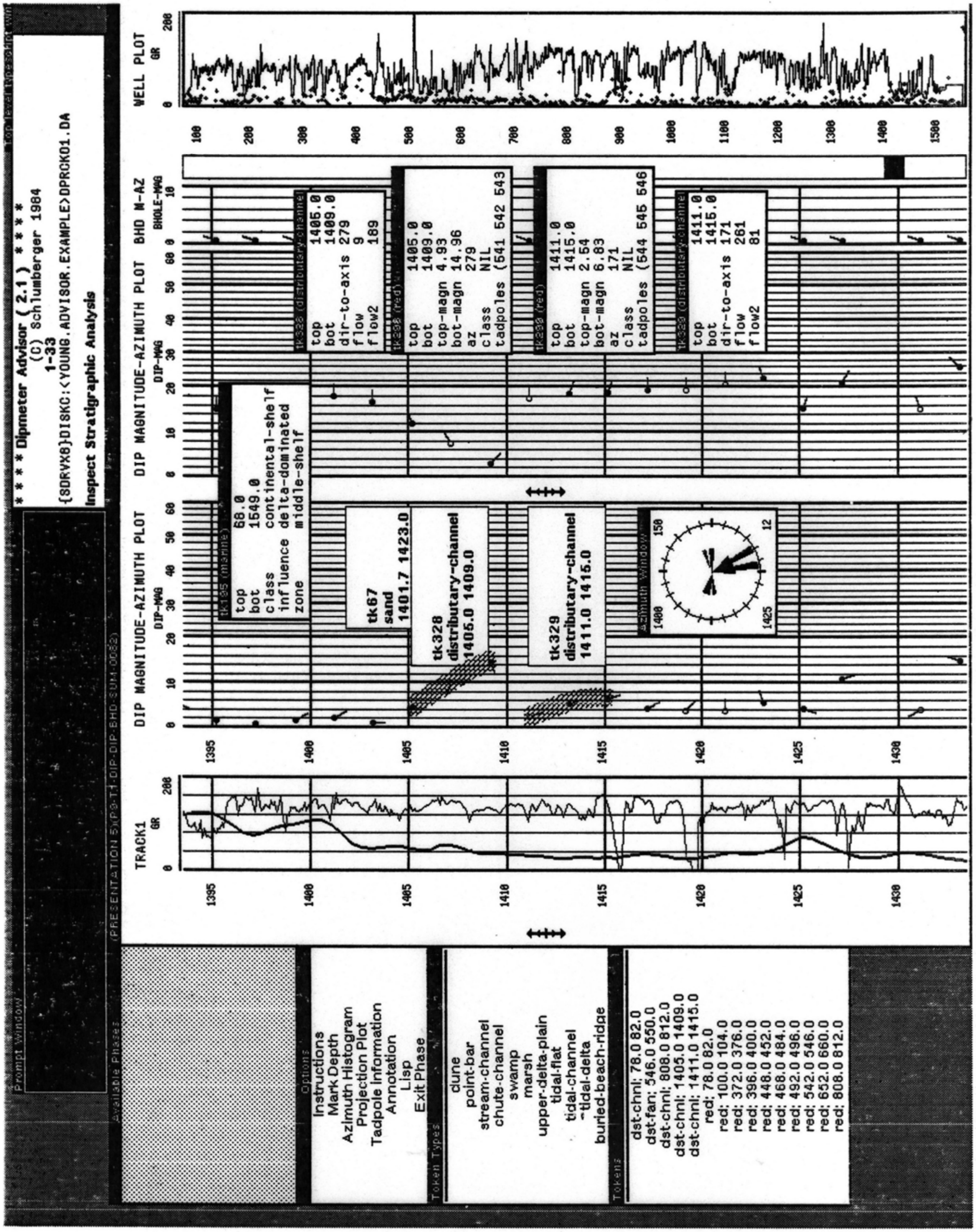
  Final Structural Analysis

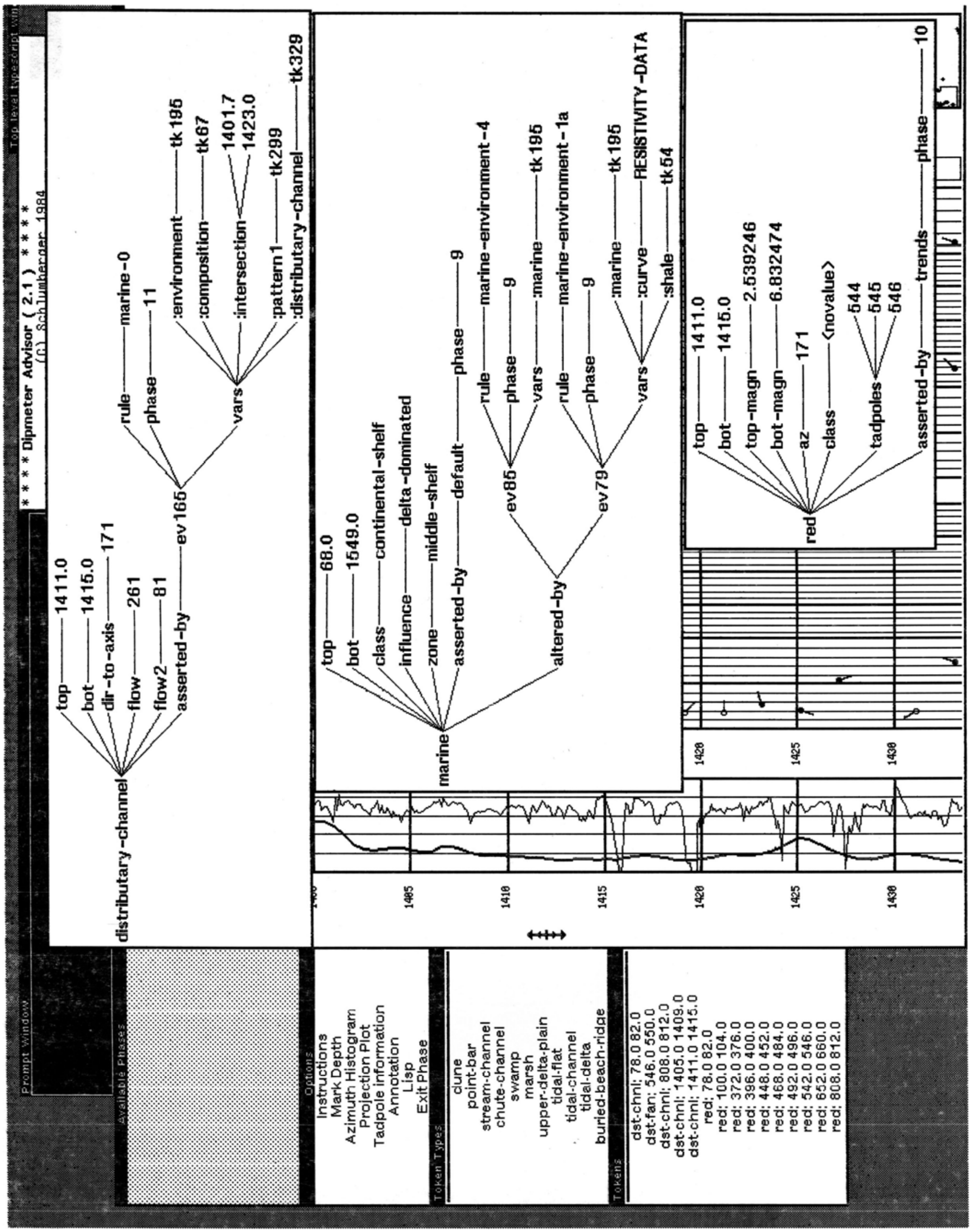
- **STRATIGRAPHIC FEATURE ANALYSIS:**

  Depositional Environment Analysis

  Stratigraphic Patterns

  Stratigraphic Analysis


* * * * Dipmeter Advisor (2.1) * * * *
(C) Schlumberger 1984
1-33
{SDRVX8}DISKC:<YOUNG.ADVISOR.EXAMPLE>DPRCK01.DA
Inspect Stratigraphic Analysis
Prompt Window
Available Phases
TRACK1
DIP MAGNITUDE-AZIMUTH PLOT
DIP MAGNITUDE-AZIMUTH PLOT
BHD N-AZ
WELL PLOT
tk67
sand
1401.7 1423.0
tk328
distributary-channel
1405.0 1409.0
tk329
distributary-channel
1411.0 1415.0
Azimuth Window
Options
Instructions
Mark Depth
Azimuth Histogram
Projection Plot
Tadpole Information
Annotation
Lisp
Exit Phase
Token Types
dune
point-bar
stream-channel
chute-channel
swamp
marsh
upper-delta-plain
tidal-flat
tidal-channel
~tidal-delta
buried-beach-ridge
Tokens
dst-chnl: 78.0 82.0
dst-fan: 546.0 550.0
dst-chnl: 808.0 812.0
dst-chnl: 1405.0 1409.0
dst-chnl: 1411.0 1415.0
red: 78.0 82.0
red: 100.0 104.0
red: 372.0 376.0
red: 396.0 400.0
red: 448.0 452.0
red: 468.0 484.0
red: 492.0 496.0
red: 542.0 546.0
red: 652.0 660.0
red: 808.0 812.0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Prompt Window
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red: 372.0 376.0
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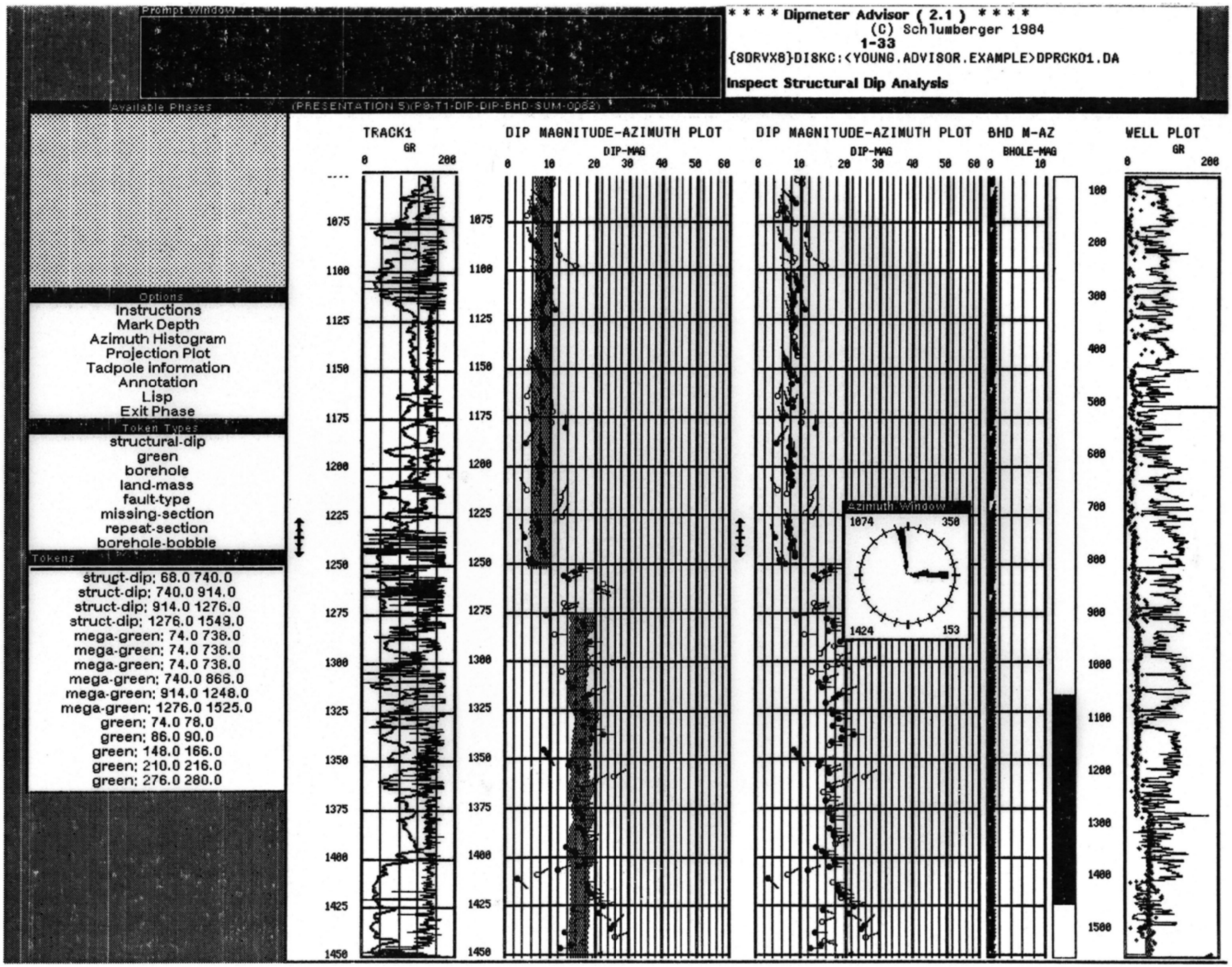
red: 448.0 452.0
red: 468.0 484.0
red: 492.0 496.0
red: 542.0 546.0
red: 652.0 660.0
red: 808.0 812.0
distributary-channel
top 1411.0
bot 1415.0
dir-to-axis 171
flow 261
flow2 81
asserted-by ev165
rule marine-0
phase 11
vars
:environment tk195
:composition tk67
:intersection 1401.7 1423.0
:pattern1 tk299
:distributary-channel tk329
marine
top 68.0
bot 1549.0
class continental-shelf
influence delta-dominated
zone middle-shelf
asserted-by default phase 9
altered-by
ev85
rule marine-environment-4
phase 9
vars :marine tk195
ev79
rule marine-environment-1a
phase 9
vars
:marine tk195
:curve RESISTIVITY-DATA
:shale tk54
red
top 1411.0
bot 1415.0
top-magn 2.539246
bot-magn 6.832474
az 171
class <novalue>
tadpoles 544 545 546
asserted-by trends phase 10
Top level typescript win


* * * * Dipmeter Advisor (2.1) * * * *
(C) Schlumberger 1984
1-33
{SDRVX8}DISKC:<YOUNG.ADVISOR.EXAMPLE>DPRCK01.DA
Inspect Structural Dip Analysis
Prompt Window
Available Phases
(PRESENTATION 5)(P9-T1-DIP-DIP-BHD-SUM-0062)
Options
Instructions
Mark Depth
Azimuth Histogram
Projection Plot
Tadpole information
Annotation
Lisp
Exit Phase
Token Types
structural-dip
green
borehole
land-mass
fault-type
missing-section
repeat-section
borehole-bobble
Tokens
struct-dip; 68.0 740.0
struct-dip; 740.0 914.0
struct-dip; 914.0 1276.0
struct-dip; 1276.0 1549.0
mega-green; 74.0 738.0
mega-green; 74.0 738.0
mega-green; 74.0 738.0
mega-green; 740.0 866.0
mega-green; 914.0 1248.0
mega-green; 1276.0 1525.0
green; 74.0 78.0
green; 86.0 90.0
green; 148.0 166.0
green; 210.0 216.0
green; 276.0 280.0
TRACK1
GR
DIP MAGNITUDE-AZIMUTH PLOT
DIP-MAG
DIP MAGNITUDE-AZIMUTH PLOT
DIP-MAG
BHD M-AZ
BHOLE-MAG
WELL PLOT
GR
Azimuth Window
1074
350
1424
153

LESSONS: DIPMETER ADVISOR

SYSTEM INTEGRATION: EMBEDDING

Much more than IE + KB

SMOOTH AUGMENTATION OF HUMAN ABILITIES

The Intelligent Assistant

Interactive Control of Inference

RULESETS AND INDEXING BY TASK

Understanding a Ruleset as a Unit

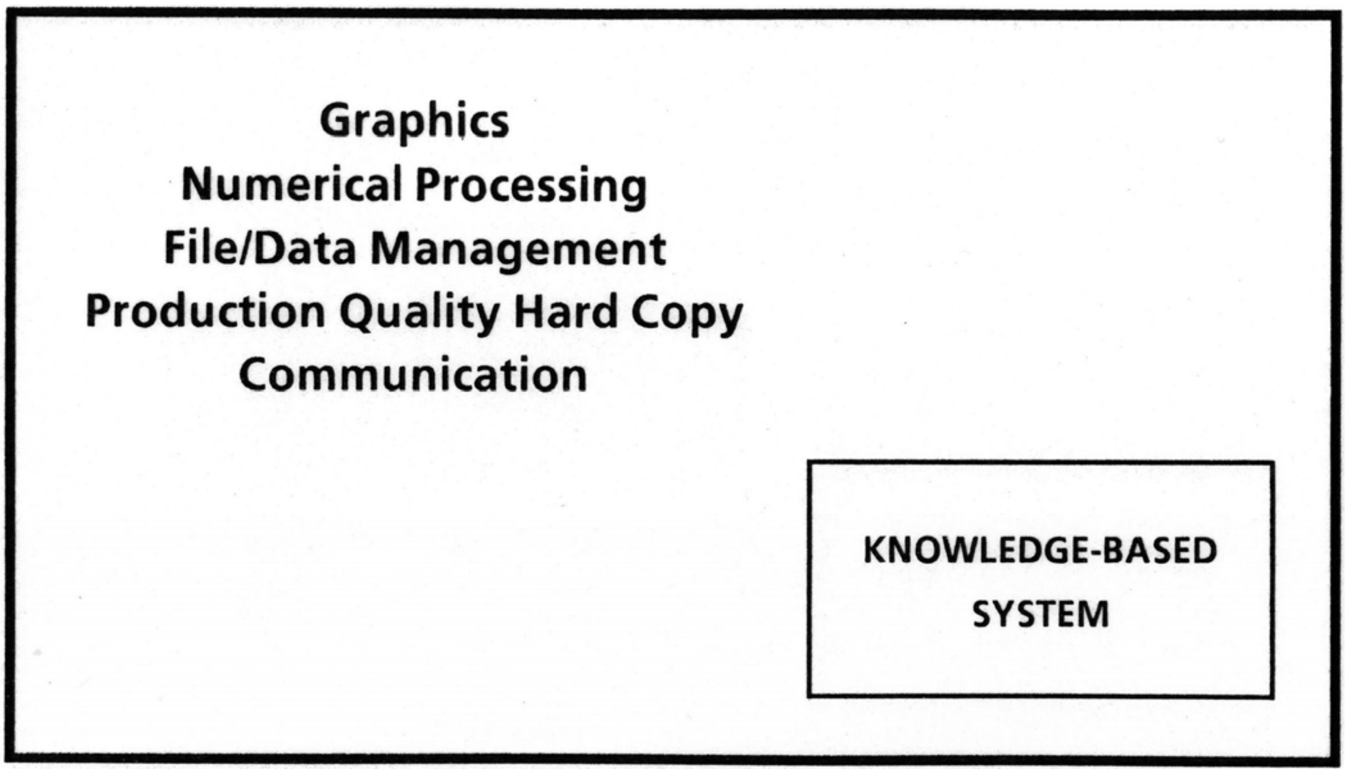
SIGNAL PROCESSING / SYMBOLIC PROCESSING

SOLVING THE PROBLEM

TECHNOLOGY TRANSFER

Impact on the Way Computing Is Viewed and Practiced

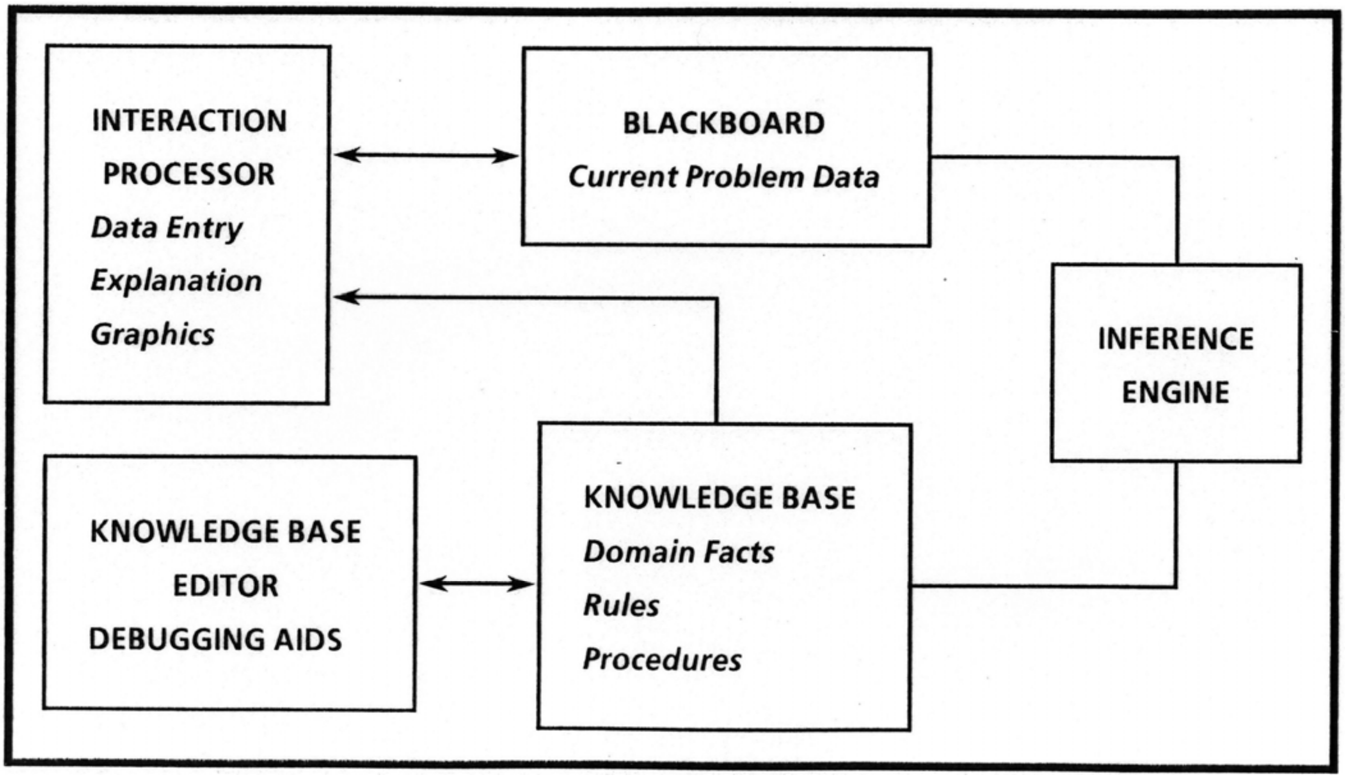
Embedding a Knowledge-Based System: An Intelligent Assistant



A user gets a number of advantages from using the system – one of which is symbolic inference.

In watching the system operate, an observer might never realize that any intelligence is involved.

Detailed Knowledge-Based System Architecture



WHY BUILD A KNOWLEDGE-BASED SYSTEM?

To Decrease Cost or Increase Quality of Goods and Services

Magnify Availability of Expertise

provide expertise to less experienced personnel

avoid delays when expertise is needed

provide expertise in locations where it is not available

Fuse Different Sources of Knowledge

Encode Corporate Knowledge

provide consistency and availability over time

Automate Some Routine Decision-Making or Bookkeeping Tasks

Keep Records of Decisions and Actions

provide a reliable database for later analysis

What's a potential application like?

Is there no known algorithmic solution, or is the algorithmic solution too costly?

Is the domain well-bounded, tractable, non-trivial?

Does the domain require little common sense reasoning?

Are there non-trivial, useful subproblems or "easy" versions of the problem?

Are there recognized experts in the domain?

Does the task have a high payoff?

Does the task normally take less than a few hours (days)?

Does the task have a combinatorial nature?

Can the expertise be incrementally acquired?

Are data and case studies readily available?

Are domain experts readily available?

WHAT MAKES FOR A GOOD APPLICATION?

there are recognized experts

the experts are provably better than amateurs

there is general agreement about the knowledge

the commitment of an expert can be obtained

the task has a high payoff

the task takes an expert a few minutes to a few hours

the knowledge is primarily symbolic

the task has a combinatorial nature

the skill is (routinely) taught to neophytes

data and test cases are available

incremental progress is possible

the task requires no common sense

WHAT IS THE STATE OF THE ART?

Expert-level performance on narrow problems

Sufficient knowledge to solve important problems

Understandable, but limited explanation of line of reasoning

Natural human interface, both graphical and text, but with stylized language and limited vocabulary

Flexible knowledge bases

Requirement for an experienced "knowledge engineer"

Limited to **one** expert as the "knowledge czar"

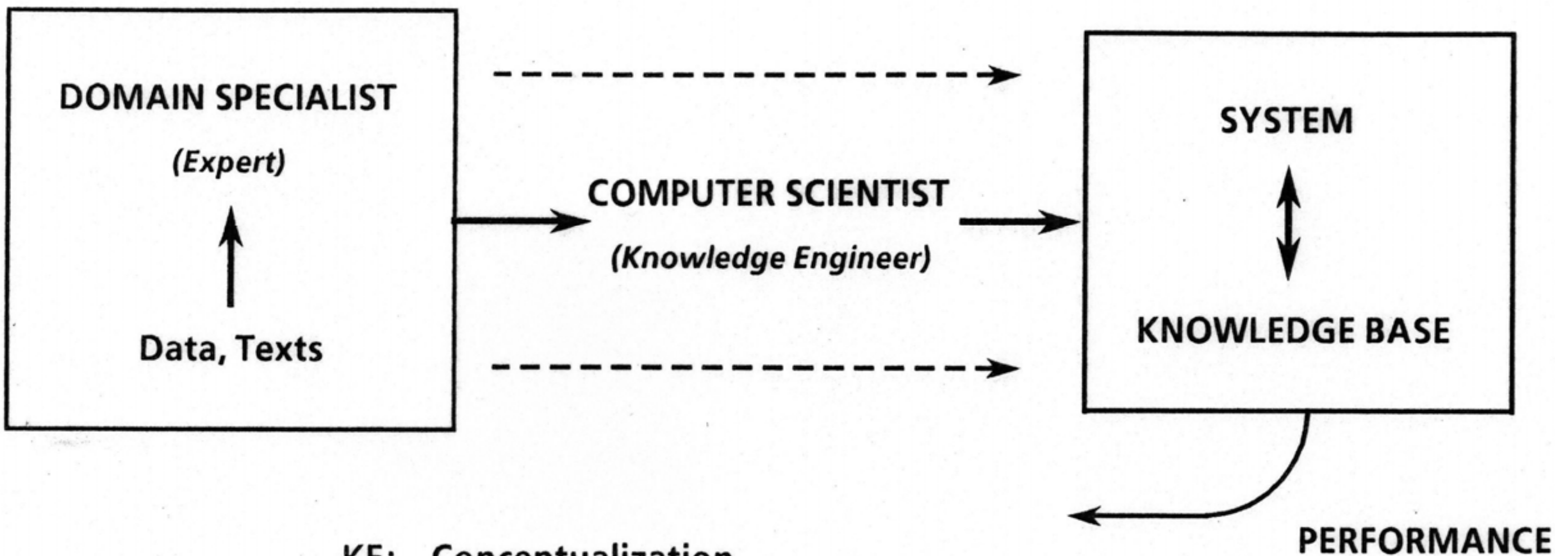
IN THE KNOWLEDGE LIES THE POWER

BUT HOW DO WE GET THE KNOWLEDGE?

KNOWLEDGE BASE CONSTRUCTION

MACHINE LEARNING

Knowledge Acquisition



KE: Conceptualization
Construction
Refinement

KE: Using the framework
vs
Designing the framework

REPRESENTATION AND REASONING

How to conceptualize and encode the knowledge

How to use the knowledge

DESIDERATA FOR GOOD REPRESENTATIONS

Good representations make the important things explicit.

They expose natural constraints, facilitating some class of computations

They are complete. We can say all that needs to be said.

They are concise. We can say things efficiently.

They are transparent to us. We can understand what has been said.

They allow for incremental refinement and extension of the knowledge.

They facilitate computation. We can store and retrieve information quickly.

They suppress detail. We can keep rarely used information out of sight, but we can still get to it when necessary.

They are computable by an existing procedure.

Theoretical Equivalence Is Different From Practical Equivalence

Representation	Typical Inferencing Technique
Rules	Chaining
Structured Objects (Frames)	Inheritance Procedural Attachment

THEME: Explicitly capture an increasing degree of structure in the domain knowledge.

RULES

Thinking in Rules

(Forward) Chaining

A Rule Interpreter

Backward Chaining (Subgoaling)

Adding New Rules

Conclusion: Rules are fine if you either cannot identify more specific knowledge structure in the domain, or *if you do not need to in order to solve the problem at hand.*

THINKING IN RULES

Situation / **Action**

if temp > 300C **then** turn off boiler.

Premise / **Conclusion**

if stain is grampos **then** organism is strep.

Antecedent / Consequent

if x is a dog **then** x is an animal.

FORWARD CHAINING

if stain is grampos **then** organism is strep.

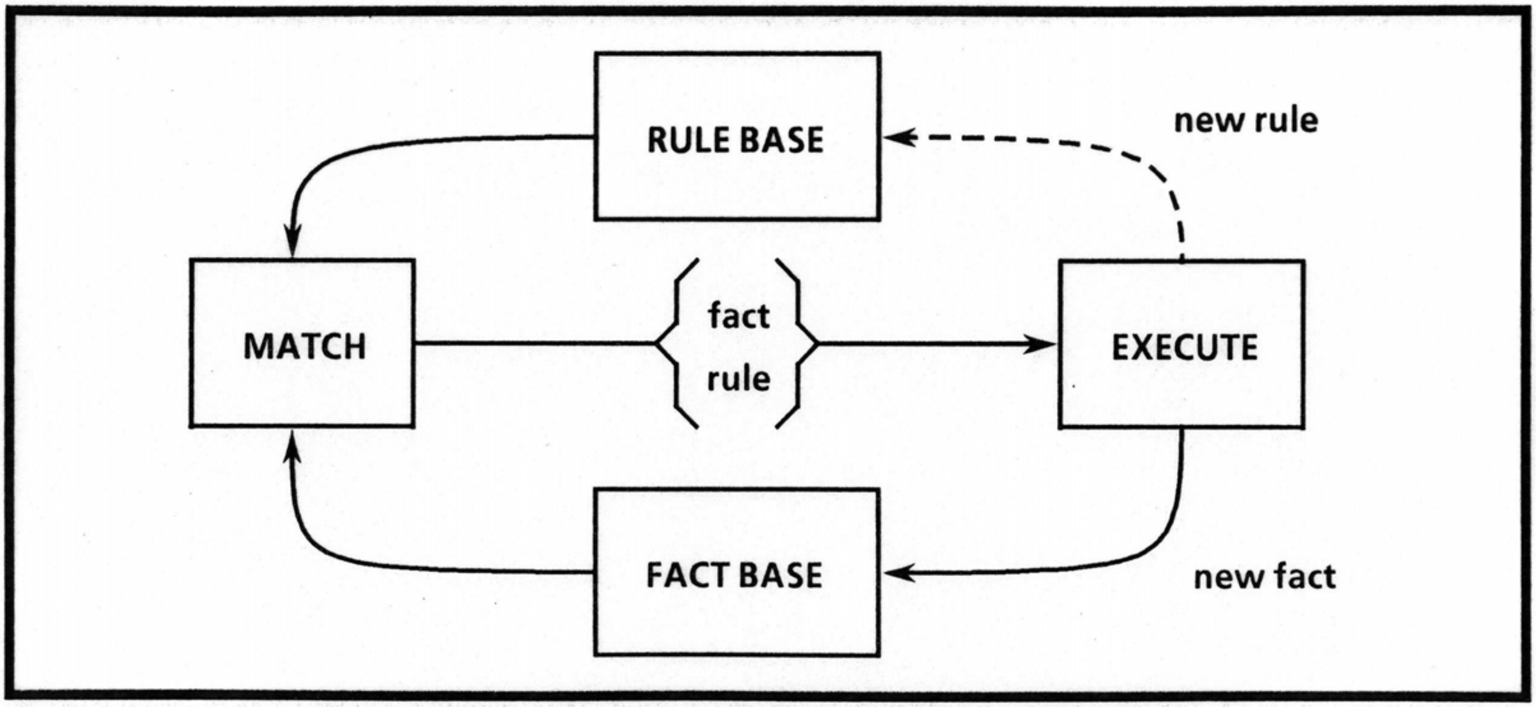
if stain is gramneg **then** organism is e.coli.

if organism is strep **or** bacteroides **then** penicillin is indicated.

if a drug is indicated **and** don't know whether allergic to the drug **then ask** whether allergic to the drug.

if a drug is indicated **and not** allergic to the drug **then** prescribe the drug.

A Rule Interpreter



R1: A rule-based program that configures VAX and PDP-11 computer systems. [3300 rules; used for 20,000 orders (Jan 84)]

If the most current activity context is distributing massbus devices, and
there is a single-port disk drive that has not been assigned to a massbus, and
there are no unassigned dual-port disk drives, and
the number of devices that each massbus should support is known, and
there is a massbus that has been assigned at least one disk drive and that should support additional disk drives, and
the type of cable needed to connect the disk drive to the previous device on the massbus is known

then assign the disk drive to the massbus

BACKWARD CHAINING
(SubGoaling)

Q: What about prescribing penicillin?

if stain is grampos **then** organism is strep.

if stain is gramneg **then** organism is e.coli.

if organism is strep **or** bacteroides **then** penicillin is indicated.

if a drug is indicated **and** don't know whether allergic to the drug **then ask** whether allergic to the drug.

if a drug is indicated **and not** allergic to the drug **then** prescribe the drug.

A: Prescribe penicillin if the stain is grampos and patient is not allergic to penicillin.

ADDING NEW RULES

Myth: "You just add more rules."

Reality:

No Chaining

Infinite Chaining

Introducing Contradictions

Modifying Existing Rules

Rulesets and Structure

Conclusions:

It's still programming

KBS design requires careful choice of abstraction levels in the task domain and rules to move between levels

INTRODUCING CONTRADICTIONS

New Rule:

N) **if** stain is gramneg and shape is rod **then** organism is pseudomonas.

Existing Rules:

1) **if** organism is pseudomonas **then** organism is **not** e.coli.

2) **if** stain is gramneg **then** organism is e.coli **or** bacteroides.

3) **if** shape is rod **then** organism is **not** bacteroides.

Contradiction:

gram(neg)
shape(rod)

N id(pseudomonas)
2 id(e.coli) **or** id(bacteroides)
1 **not** id(e.coli) !!!
3 **not** id(bacteroides)

STRUCTURED OBJECTS

(Frames)

Thinking in Objects

Inheritance

Messages and Procedural Attachment

Event Handlers

Things That Can Go Wrong

Conclusion: Objects are good for capturing static structural knowledge. They are also an excellent organizational paradigm for programming in general.

THINKING IN OBJECTS

An object is an encapsulation of data and procedures relevant to a concept.

From Simulation

In building complex software systems, there is a distinct advantage to constructing a computational world that is an image of the physical world in which the systems operate.

From AI & Cognitive Psychology

A *frame* is a data-structure for representing a stereotyped situation, like being in a certain kind of living room, or going to a child's birthday party. Attached to each frame are several kinds of information. Some of this information is about how to use the frame. Some is about what one can expect to happen next. Some is about what to do if these expectations are not confirmed.

Marvin Minsky (1974)

Capturing Natural Abstractions

Knowledge Acquisition
Knowledge Base Maintenance

GrowthFault1	
Strike	0
TimeOfFault	
Slip	50.0

Slots

PROPERTY INHERITANCE

Taxonomic Hierarchies

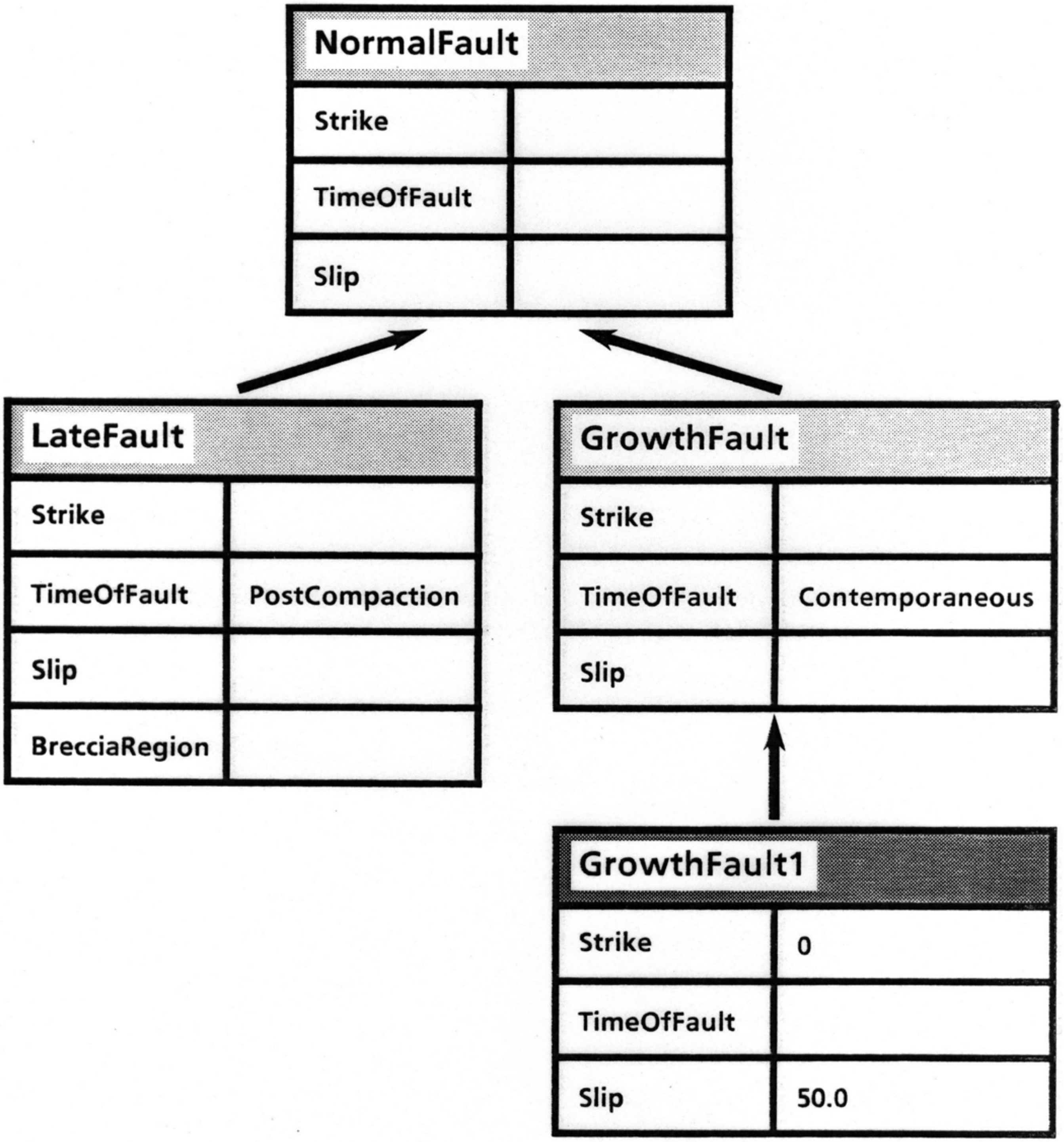
Class & Instance

Factoring

Avoiding Redundancy

Conceptual Clarity

Ease of Extension/Refinement

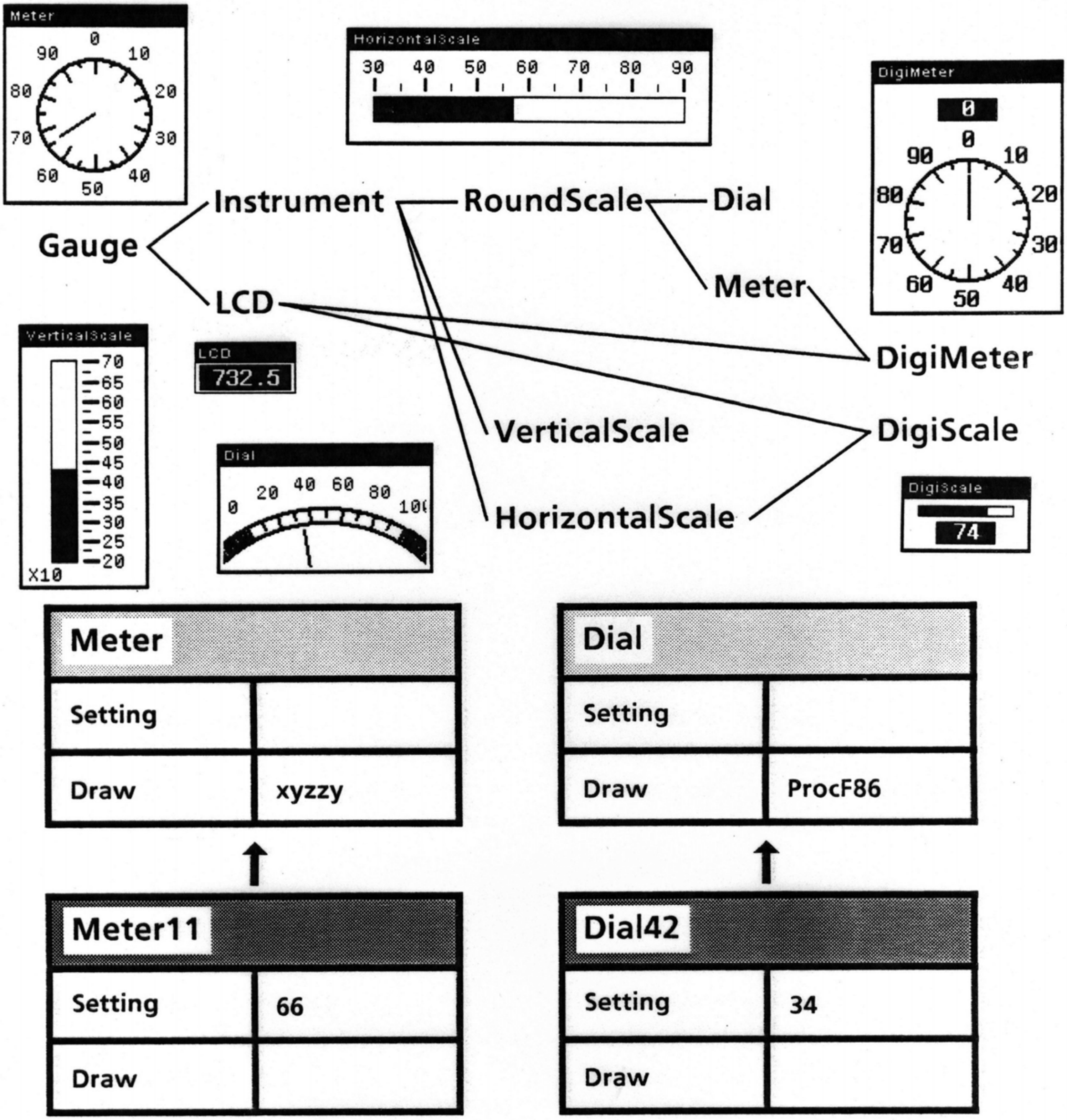

NormalFault
Strike
TimeOfFault
Slip
LateFault
Strike
TimeOfFault
PostCompaction
Slip
BrecciaRegion
GrowthFault
Strike
TimeOfFault
Contemporaneous
Slip
GrowthFault1
Strike
0
TimeOfFault
Slip
50.0

MESSAGES & PROCEDURAL ATTACHMENT

Uniform Invocation Method

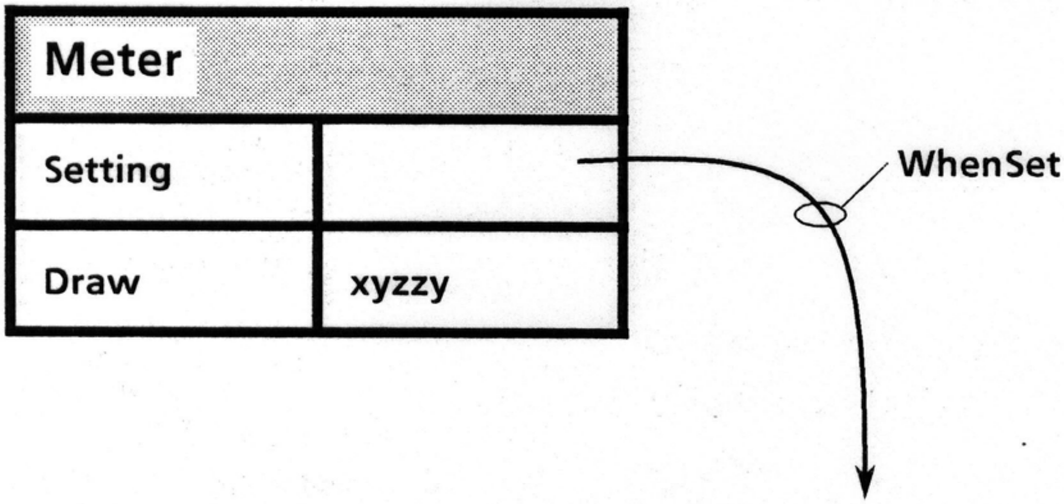
Polymorphism: Increasing Transparency

Modularity: Avoiding Assumptions

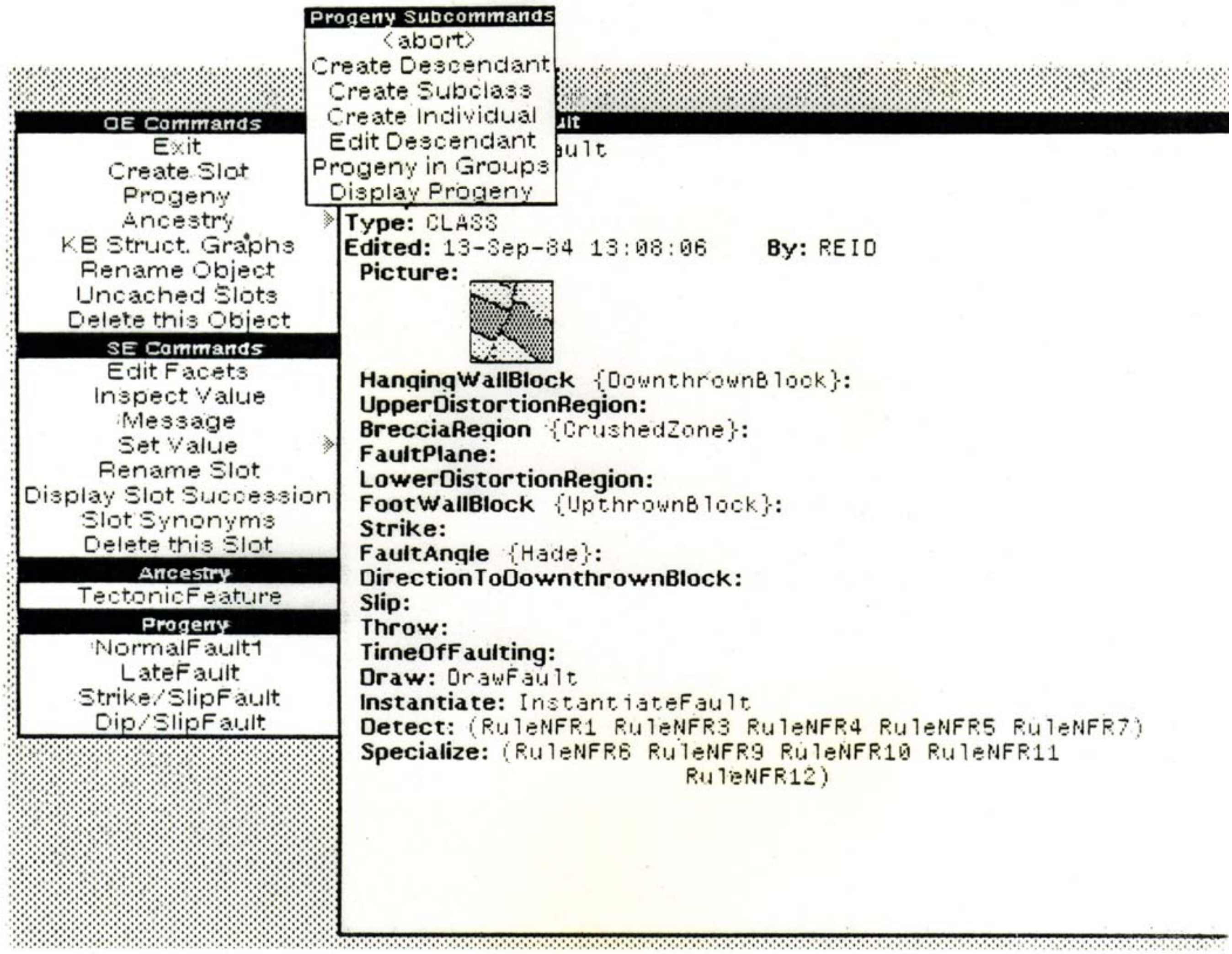


***Loops* Gauges**

EVENT HANDLERS




```
procedure UpdateMeterDisplay (Setting)
   Send(ClearDisplay)
   Send(SetDisplay Setting)
end
```


Progeny Subcommands
<abort>
Create Descendant
Create Subclass
Create Individual
Edit Descendant
Progeny in Groups
Display Progeny
OE Commands
Exit
Create Slot
Progeny
Ancestry
KB Struct. Graphs
Rename Object
Uncached Slots
Delete this Object
SE Commands
Edit Facets
Inspect Value
Message
Set Value
Rename Slot
Display Slot Succession
Slot Synonyms
Delete this Slot
Ancestry
TectonicFeature
Progeny
NormalFault1
LateFault
Strike/SlipFault
Dip/SlipFault
Type: CLASS
Edited: 13-Sep-84 13:08:06 By: REID
Picture:
HangingWallBlock {DownthrownBlock}:
UpperDistortionRegion:
BrecciaRegion {CrushedZone}:
FaultPlane:
LowerDistortionRegion:
FootWallBlock {UpthrownBlock}:
Strike:
FaultAngle {Hade}:
DirectionToDownthrownBlock:
Slip:
Throw:
TimeOfFaulting:
Draw: DrawFault
Instantiate: InstantiateFault
Detect: (RuleNFR1 RuleNFR3 RuleNFR4 RuleNFR5 RuleNFR7)
Specialize: (RuleNFR6 RuleNFR9 RuleNFR10 RuleNFR11 RuleNFR12)

THINGS THAT CAN GO WRONG

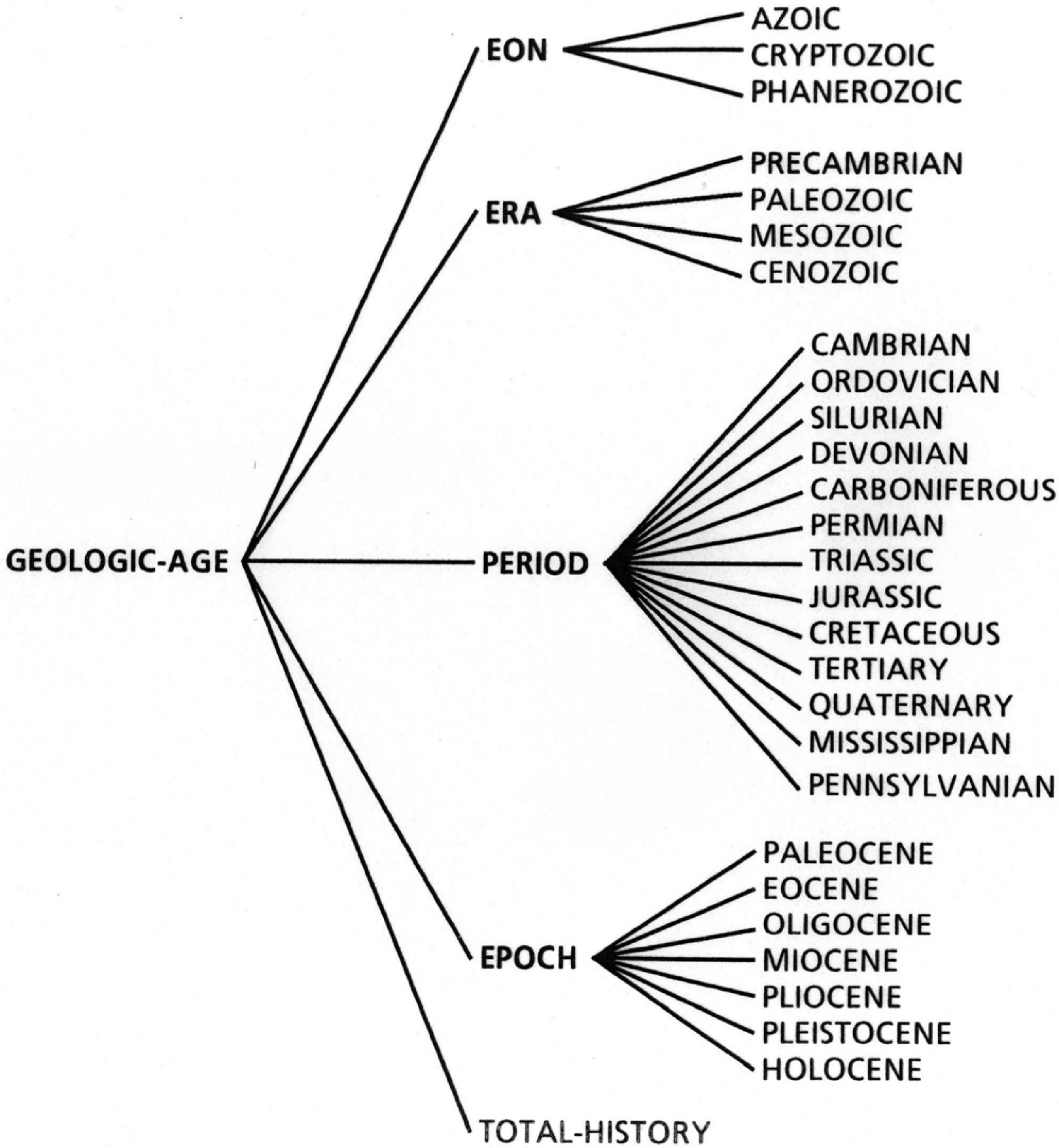
Smashing the semantics

there are many kinds of hierarchies

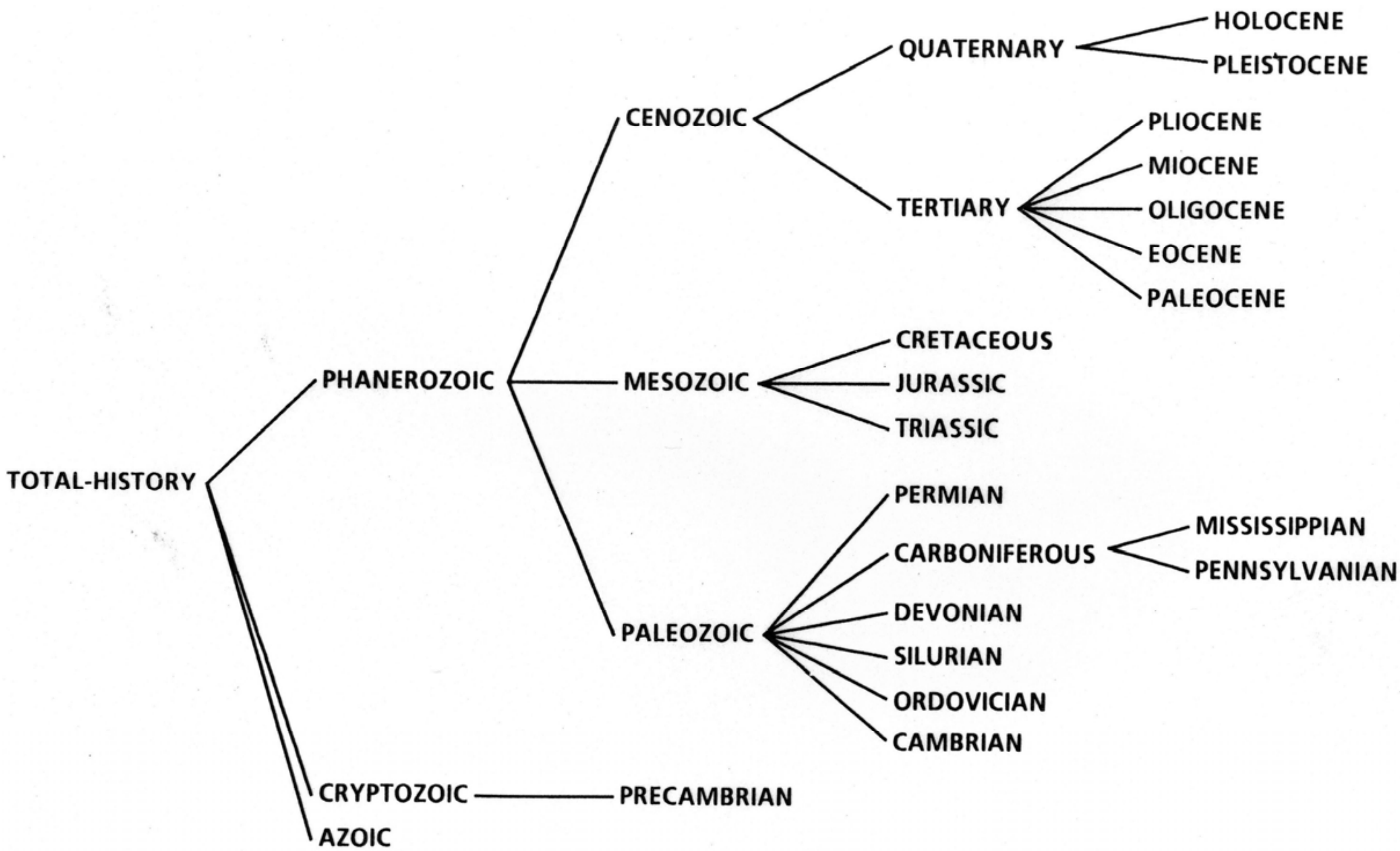
Not using the paradigm uniformly

Efficiency: What is an object?

HIERARCHY OF GEOLOGIC AGE



“PARTS” OF GEOLOGIC AGE



Question: Which shall I use ...

Rules?
or Structured Objects?
or Procedures?

[ANALOGY: Cobol or Fortran or Snobol?]

Answer:

Think about the knowledge structures first.
Representations are just a tool.
Any tool can be used badly.

State of the art systems orchestrate a variety of representations.

PRAGMATICS

Methodology

Tools/Computing Environments

Personnel Training

Costs

Pitfalls

- Excessive aspirations
- Inadequate Resources
- Poor Problem
- Technology Transfer and Sociology

Methodology

Identify the problem.

Identify concepts and levels of abstraction in the problem (e.g., parameter, segment, syllable, word, word-sequence, phrase).

What Kind of Knowledge Is Involved?

Identify knowledge sources for traversing links between levels.

How Is The Knowledge Used?

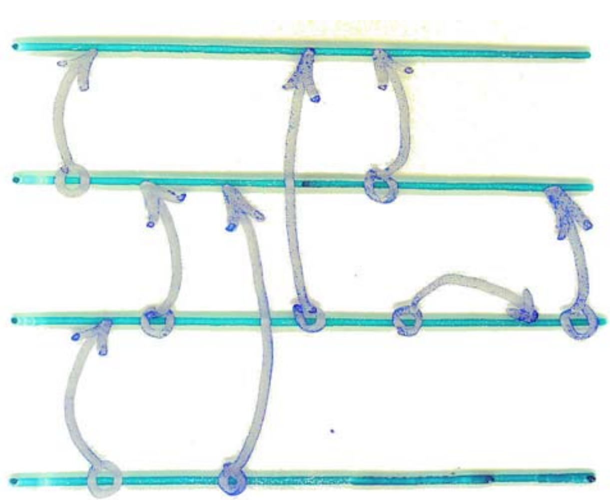
Select or devise an appropriate representation.

How Should The Knowledge Be Represented?

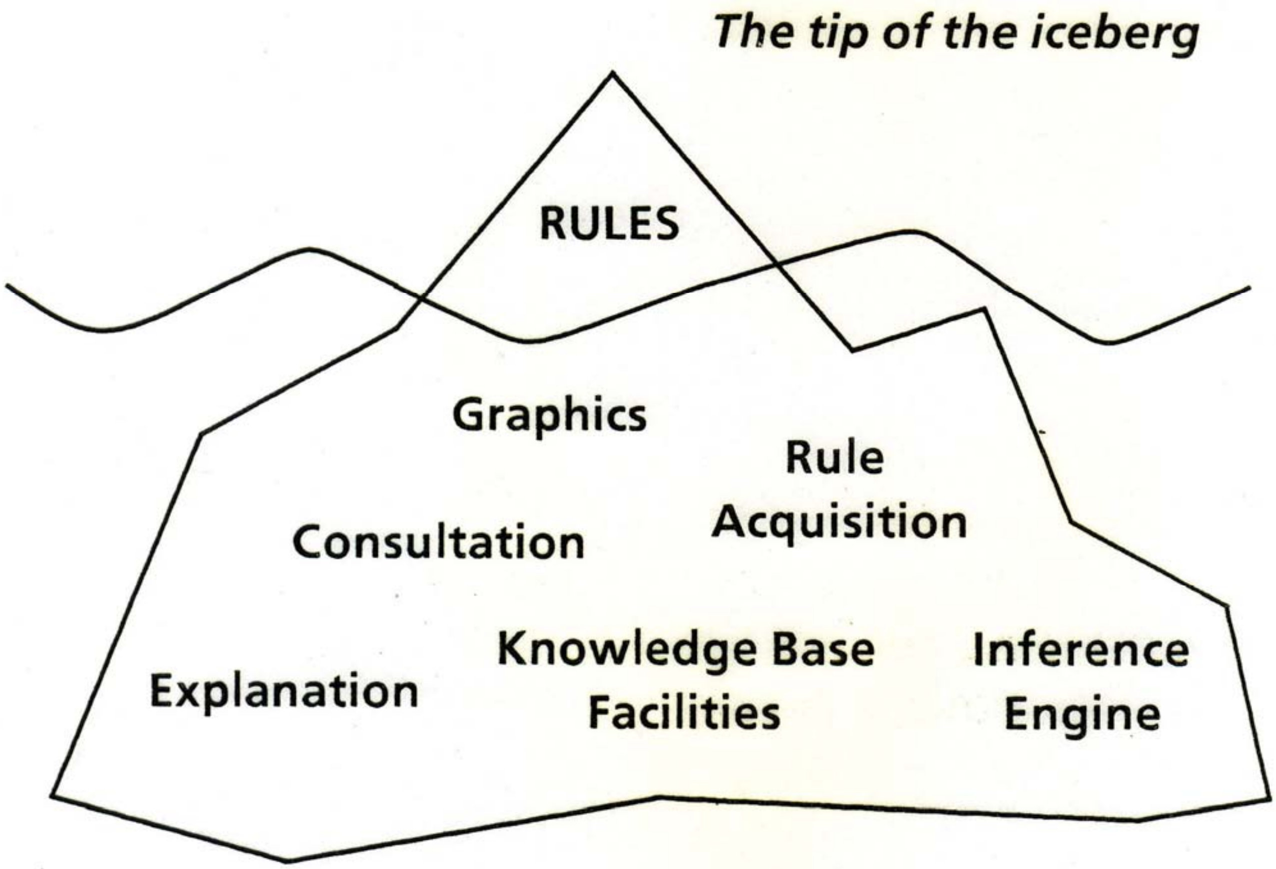
Expose constraints or regularities.

Create particular procedures (for using the constraints, given the representation).

Verify via experiments.



HOW DO SOME SYSTEMS GET BUILT SO QUICKLY?



EXPLORATORY PROGRAMMING

Conscious intertwining of design and implementation for construction of large, complex software systems under uncertain specifications

Uncertain Specifications Arise Because...

we don't understand the problem *a priori* (AI ...)

the design space is too large to explore without extensive experimentation (interactive graphics ...)

How To Deal With This:

Minimize and defer constraints placed on the programmer. Place more of the burden for managing complexity on the programming environment.

Sources of Power

freedom of expression

variety of data types and abstractions

late binding: deferring commitments

automatic storage management

dynamic typing of variables

dynamic binding of procedures

procedures as data

program manipulation subsystems

interpreters for special purpose languages

integrated tools

interpreter and incremental compiler

data inspector

language-sensitive editor

optimizing compiler

static and dynamic analysers

personal workstation

interactive graphics

LAN connections (heterogeneity)

FROM THE LABORATORY TO THE COLD WORLD

Feasibility Demonstration

"this has been implemented"

chewing gum and paper clips

Prototype

experimental users

user interface

change of venue?

Commercial Product

solving enough of the problem to be interesting and useful

integration into an overall system

accuracy of knowledge base

potential of framework for development

efficiency, modularity

user interface, documentation

COSTS OF BUILDING KNOWLEDGE-BASED SYSTEMS

ASSESSMENT
a few days or weeks

PROTOTYPING
1-2 man-years knowledge engineer
0.5 man-years domain specialist

DEVELOPMENT
2-5 man-years knowledge engineer
half-time from domain specialist

FIELDING
software engineering

SOME HARD PROBLEMS

Inexact Reasoning

Knowledge Engineering

Learning by Induction

Default Reasoning

Common-Sense Knowledge

Strategies

Qualitative Reasoning

Huge Knowledge Bases

Self-Awareness

User Modeling

THE CURRENT STATE OF SOME HARD PROBLEMS

	PRACTICE	THEORY
Inexact Reasoning	CF Model	Almost OK
Knowledge Engineering	An Art	Unexplored
Learning by Induction	Hand-Crafted	Over-Developed
Default Reasoning	Inheritance	Emerging
Common-Sense Knowledge	Add Items To KB	Puzzling
Strategies	Meta-Level Knowledge	Not Well Explored

	PRACTICE	THEORY
Qualitative Reasoning	Omit Details	Not Well Explored
Huge Knowledge Bases	Internist AI & DB	Not Well Explored
Self-Awareness	Meta-Level Knowledge	Not Well Explored
User Modeling	Overlay Models	Not Well Explored

AI AS MAGIC

Scenario: We don't know how to solve this problem ...
maybe we should build an expert system ...

Maxim: It's very difficult to build knowledge-based systems without benefit of knowledge, or expert systems without benefit of expertise.

Scenario: Fred isn't doing anything right now, and he wrote a computer program once. Let's have him spend a couple of months and write an expert system. That will enable us to find out whether there's anything more than hype.

Maxim: Acquire or train people.

Physical Symbol Systems

A broad class of systems capable of having and manipulating symbols, yet realizable in the physical universe.

Allen Newell and Herbert Simon

Symbol: A physical pattern.

Symbol Structure: A number of instances (or tokens) of symbols related in some physical way (such as one token being next to another).

Designation: A relation between a symbol and the entities (e.g., operators, symbol structures) it symbolizes.

Interpretation: The act of accepting an input that designates a process and then performing that process.

Physical Symbol System components: input, output, memory, control (that performs interpretation), and a set of operators capable of assigning symbols (creating designations), and copying (creating new symbols and symbol structures), reading (obtaining the symbols that comprise a symbol structure) and writing symbol structures. A Physical Symbol System is a *Universal Machine* that produces through time an evolving collection of symbol structures.

The Physical Symbol System Hypothesis

The necessary and sufficient condition for a physical system to exhibit general intelligent action is that it be a physical symbol system.

Allen Newell and Herbert Simon

> *Necessary* means that any physical system that exhibits general intelligence will be an instance of a physical symbol system.
>
> *Sufficient* means that any physical symbol system can be organized further to exhibit general intelligent action.
>
> *General* intelligent action means the same scope of action seen in human action; that in real situations behavior appropriate to the ends of the system and adaptive to the demands of the environment can occur, within some physical limits.

This hypothesis sets the terms on which we search for a scientific theory of mind. What we seek are the further specifications of physical symbol systems that constitute the human mind or that constitute systems of powerful and efficient intelligence.

The Problem Space Hypothesis

The fundamental organizational unit of all human goal-oriented symbolic activity is the problem space.

Allen Newell

Problem Space: states; operators

Problem: initial states; goal states; path constraints

The only way to solve a problem in a problem space is to search in the space. (Problem-specific knowledge may allow very efficient search.)

PRAGMATICS

- Why Build a Knowledge-Based System?
- What Makes for a Good Application?
- What Is the State of the Art?

- Methodology
- Tools and Computing Environments
- The Development Team
- Costs / War Stories/ Hard Problems

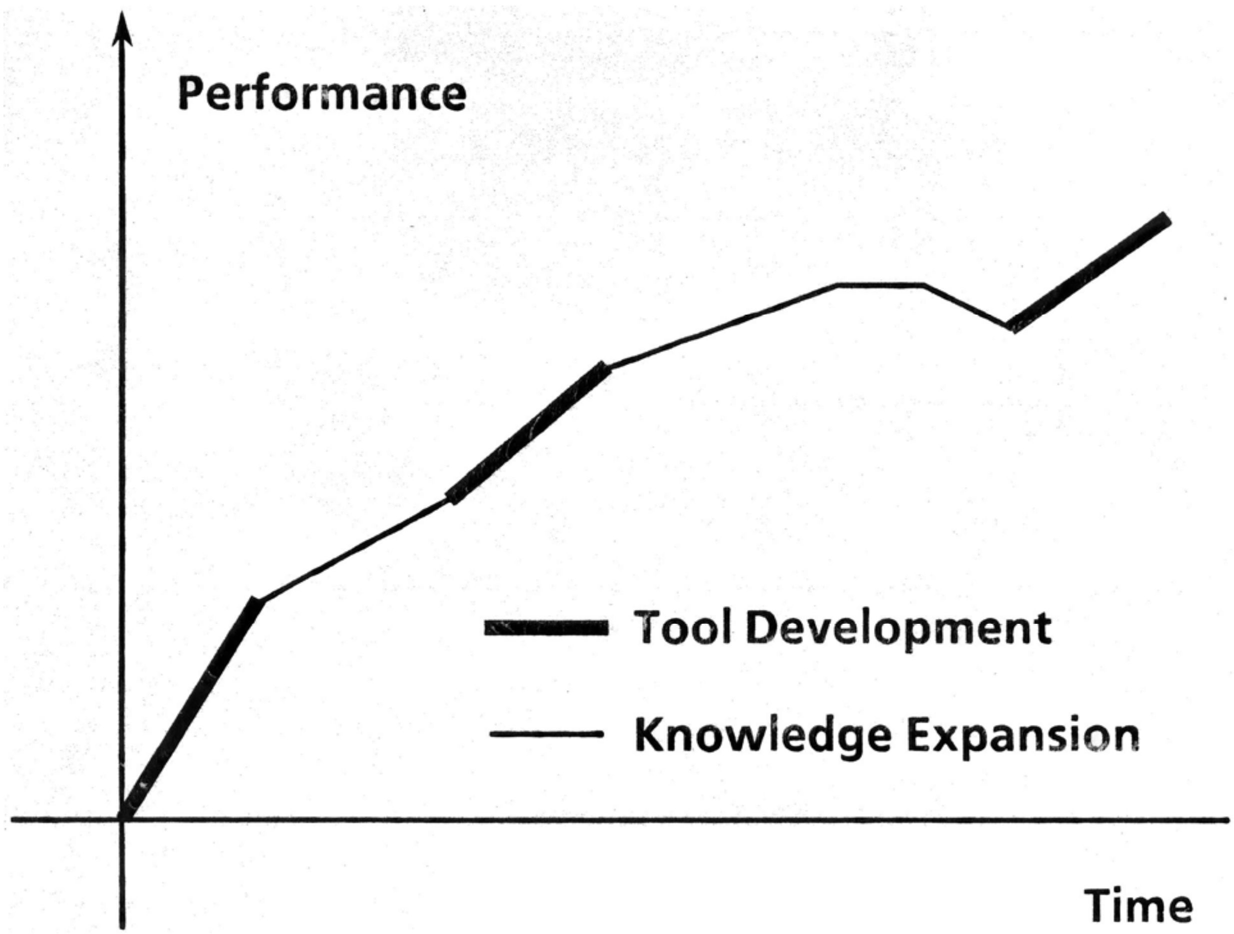
- Pitfalls
  - Excessive Aspirations
  - Inadequate Resources
  - Poor Problem Selection
  - Technology Transfer & Sociology...

THE DEVELOPMENT TEAM

- **DOMAIN EXPERTISE**
- **KBS TOOL DESIGN**
- **KNOWLEDGE ENGINEERING**
- **PROGRAMMING SUPPORT**

- **EXPERIMENTATION**
- **ENGINEERING**

Incremental Development



OBSERVATIONS
ON THE TRADITIONAL WISDOM

- **THROWAWAY CODE vs PROGRESSIVE RELEASE**
- **INCREMENTAL DEVELOPMENT**
  including specialists
- **DIFFICULTY OF CLEAR TASK DEFINITION**
  - **Evolving Performance Changes Definition**
  - **Contingent Definition**
- **EARLY CODING**
- **HUMILITY ABOUT PERSONAL DOMAIN EXPERTISE**
- **FLEXIBLE INTERFACES**
- **DOMAIN SPECIALISTS: SINGLE OR MULTIPLE**
  - **Difficulty of Understanding Multiple Views**
  - **Missing an Important Alternate View**
  - **Observing Interactions - Changes in Strategy**
- **SEDUCTION BY A SIMPLE FORMALISM**
- **STIMULATION OF SPECIALISTS**

TECHNOLOGY TRANSFER

- **The Forward Pass**
- **Prototypes Not Enough**
- **OnSite Engineering & Field Involvement**
- **Domain Expertise and Commitment**
- **Solving a Real Problem**
- **Flexibility**
- **Non-Impact Technology**
  (e.g., WorkStations)
- **Value-Added Systems**
  smooth extension of human capabilities

THEMES

I. **The key to success is Domain Knowledge, not clever programming.**

Corollary: If you have a good handle on the domain knowledge, the right problem organization will follow.

II. Levels of Understanding

EMPIRICAL ASSOCIATIONS

UNDERLYING STRUCTURE AND FUNCTION

Maxim: What you can do depends on what level of understanding you have.

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