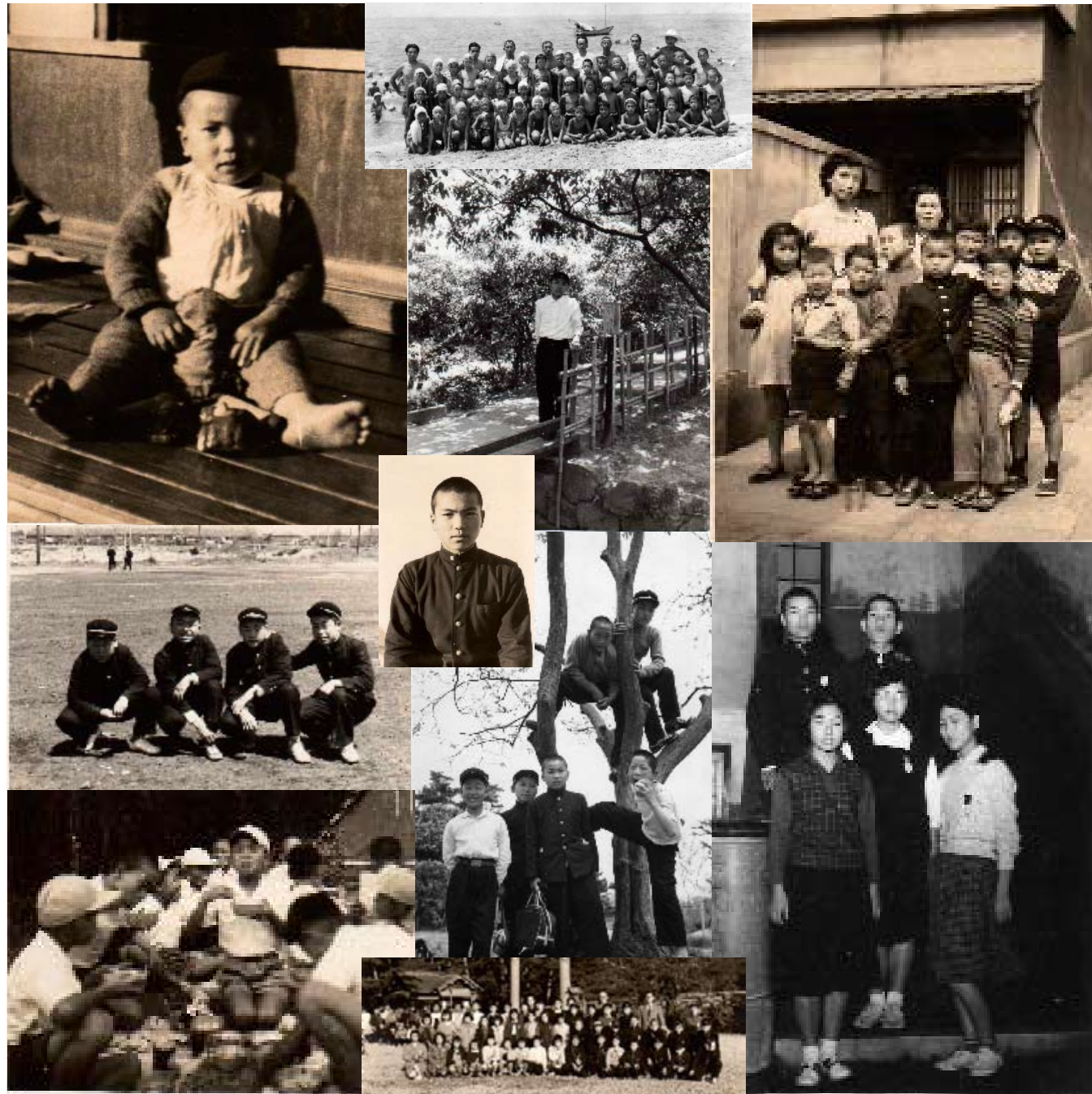




TK60:

Celebrating Kanade's Vision

March 8 & 9 2007 • Carnegie Mellon University • Pittsburgh, Pennsylvania • USA



Welcome to TK60!

Takeo Kanade, the U.A. and Helen Whitaker University Professor, works on a wide range of topics from computer vision to manipulation, from sensors to autonomous systems and from multi-media to medical robotics.

On the occasion of his 60th birthday, Carnegie Mellon University is honoring him with the TK60 Symposium. Its technical program reflects the diversity of Professor Kanade's interest, accomplishments and collaboration with researchers and students from many scientific disciplines.

Thank you for attending.

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Takeo Kanade

***U.A. and Helen Whitaker University Professor of Computer Science and Robotics and
Professor of Electrical and Computer Engineering, Carnegie Mellon University
Director, Quality of Life Technology Engineering Research Center, Pittsburgh, Pennsylvania
Founding Director, Digital Human Research Center, Tokyo, Japan***

From his early efforts in face recognition, through his innovations in computer vision for autonomous vehicles, and continuing on to virtualized reality and intelligent medical systems, Takeo Kanade has expanded the broad reach of computer science. He is a theorist and a systems developer, an educator and an administrator—and a man who imagines things yet to come.

Raised in the port city of Kobe, Japan, the youngest of five children in a poor family, Takeo was a good student with a broad sense of curiosity. He played baseball, built models, raised chickens and became interested in history and languages. He attended Kyoto University where he earned a bachelor's, a master's and a doctoral degree in electrical engineering. After completing his studies, he accepted a faculty position at Kyoto in the Department of Electronics.

Takeo became interested in face recognition at the 1970 World's Expo in Osaka, where a colleague demonstrated an entertaining, yet technically inaccurate, face comparison program. Takeo's 1973 Ph.D. thesis work on "Computer Recognition of Human Faces" is generally considered to be one of the earliest complete automatic face recognition systems. Since then, faces and their

unique features have continued to form a large part of his research. In the mid-1990s, Takeo and his students demonstrated a face detection algorithm with an accuracy rate higher than 95 percent. This feat proved the technical viability of the algorithm and paved the way for the proliferation of face detection technologies in many of today's commercial vision-based products. Takeo is currently part of an interdisciplinary team designing a system to recognize the "micro expressions" of individual facial muscle movements.

Takeo came to Carnegie Mellon University as a visiting researcher in 1977, focusing his efforts on object recognition over the course of his 18-month stay. After many months of struggle, he developed a mathematical theory for 3D shape recovery from a single 2D line drawing. He later published the theory under the title of "Origami World Theory."

Takeo returned to Carnegie Mellon in 1980 and joined the faculty of the Computer Science Department and the newly created Robotics Institute. Using his "science of computer vision" paradigm in which the underlying physical, geometrical, optical and statistical processes were transformed into mathematical and computa-

tional models, he produced a new class of algorithms for color, stereo, motion and texture.

Some of his new computational algorithms revolutionized motion image analysis. The 1981 gradient-based image feature tracking algorithm known as the Lucas-Kanade tracker serves as the basis of almost all of today's motion image analysis programs, including MPEG coders. Most modern vision packages now include the set of algorithms summarized as KLT: the Kanade-Lucas-Tomasi detector and tracker.

With the resources and collective intellectual power of the Robotics Institute close at hand, he began to collaborate at the intersection of vision and robotics. One of his first projects involved a precision robotic manipulator arm with no gears and six degrees of freedom. Takeo and his colleague, Harry Asada, used rare-earth magnets to free the world's first direct-drive arm from the friction and backlash of traditional transmission mechanisms. This technological breakthrough is still the industry standard for high performance control.

Takeo also applied his computer vision theory to several of the Robotics Institute's new autonomous mobile robots. Equipped with 3D vision for terrain mapping and obstacle detection, overall robotic navigation improved dramatically. Two of the most significant projects he initiated with his colleagues and students were the driverless cars known as NavLab and the pilotless helicopter known as Robocopter. Both proved their real-world worthiness by completing difficult tasks with world-class performances. On a driving trip from Pittsburgh to San Diego in 1995, the NavLab-5 system used a video camera and vision algorithms to successfully identify traffic lanes and other cars on the road and autonomously drove the vehicle for 98 percent

of total distance (nearly 3,000 miles). Robocopter won the 1997 Unmanned Ariel Robot Competition and was the first ever to complete the competition's find-pick-and-deliver task. Today, Robocopter is equipped with a complete suite of sensors and is considered one of the most advanced autonomous rotary air platforms in the world.

He also has extended his vision expertise into the field of medical robotics. In 1993, he founded the Medical Robotics and Computer Assisted Surgery group at Carnegie Mellon and has continually fostered the application of robotic and computer technologies within medicine. From computer-assisted hip replacements to repetitive free-hand bone sculpting to the possibility of 3D models constructed from x-ray images, Takeo's research combines the decision-making skills of a physician with the precision of robotic technology. In 2006, Takeo became the founding director of the new Quality of Life Technology Center in Pittsburgh. Funded by a five-year, \$15 million NSF grant, the center is developing new approaches, devices and systems that augment the mind and body functions of human beings and help older adults and people with disability to live independently.

Additionally, Takeo has made unique and pioneering contributions to the field of computational sensors. Along with various colleagues, he developed an analog VLSI chip for 3D range sensing that could accomplish more than 500 frames per second, a sorting image sensor and the world's first video-rate stereo machine.

One of Takeo's favorite projects is something he calls "virtualized reality." It starts by capturing a time-varying event, such as a basketball game or open heart surgery, with a very large number of computer-controlled

robotic cameras. The sequences are then processed and integrated into a complete 4D description in which the viewer can move about in both space and time, freely changing viewpoints or rotating around the activity in "Matrix"-like fashion. In 1995, long before general acceptance of the idea, he built a 51-camera test dome inside one of the buildings on the Carnegie Mellon campus. He and his team have produced a series of theoretical and experimental results leading toward the realization of his vision of virtualized reality. In 2001, a portion of the technology was implemented at Super Bowl XXXV and broadcast throughout the world. This public demonstration contributed immensely to increasing the general awareness of both vision and robotic technologies.

Educating and inspiring future computer scientists and robotics researchers is another facet of Takeo and his vision of things to come. Under his direction, the Robotics Institute established a Ph.D. program in 1989, the first of its kind in the world; Takeo himself has supervised 63 doctoral candidates. He also held the position of director of the Robotics Institute from 1992 to 2001. The Institute doubled its activities during this time and grew into one of the world's most highly regarded robotics research organizations.

In 2001, Takeo founded the Digital Human Research Center in Tokyo. Based on his observation that people are the "weakest link" in many intelligent systems—they represent the most important but least understood component—the center is engaged in measuring human functions, developing computer models for these functions and using the models to design human-centered systems.

Takeo holds more than 20 patents and has authored

over 300 technical papers and reports. In terms of references, he is among the top five computer science professionals in the world. He is the founding and former editor of the International Journal of Computer Vision and has served on numerous government, industry and academic advisory boards.

He is a member of the National Academy of Engineering and the AAAS. He is also a fellow of the IEEE, the ACM, the AAAI and several other professional societies.

The Carnegie Mellon University School of Computer Science is proud and pleased to have Takeo Kanade as part of our faculty and we look forward to many more years of collaboration.

Selected Awards

C&C Prize

C&C Promotion Foundation, 2000

Career Accomplishment Award

The Japan Society of Artificial Intelligence, 2003

Funai Accomplishment Award

Federation of Information Technology, 2004

Allen Newell Award for Research Excellence

Carnegie Mellon University, 2001

Joseph F. Engelberger Award

Robotics Industry Association, 1995

JARA Award for Research and Development

International Federation of Robotics, 1996

Longuet-Higgins Prize for Lasting Contribution in Computer Vision (H A. Rowley, S. Baluja, and T. Kanade)

International Conference on Computer Vision and Pattern Recognition, 2006

Marr Prize (S. K. Nayar, K. Ikeuchi, and T. Kanade)

Third International Conference on Computer Vision, 1990

Yuichiro Anzai

**President
Keio University**

Dr. Anzai received his Ph.D. in engineering from Keio University in 1974. After serving at Keio as an assistant professor until 1985, he joined the faculty of Hokkaido University as an associate professor in behavioral science. He returned to Keio as a professor in electrical engineering in 1988 and became the dean of the Faculty of Science and Technology in 1993. He worked on the reform of the undergraduate departments and graduate programs for more than seven years and launched new educational and research programs with an innovative structure. Since 2001, he has served as president of Keio University, the oldest modern institution of higher learning in Japan; the university will celebrate its 150th anniversary in 2008. He is also a professor in the Department of Information and Computer Science and the School of Open and Environmental Systems.

Professor Anzai was a post-doctoral fellow in the Departments of Psychology and Computer Science at Carnegie Mellon University from 1976 to 1978. He returned to Carnegie Mellon as a



visiting assistant professor in the Department of Psychology in 1981. He was also a visiting professor at the Center for Medical Education at McGill University in 1990.

His fields of research include cognitive science and computer science, particularly cognitive processes in learning and problem solving, and human-robot-computer interaction. He has published about 20 books, single- and co-authored, and more than 120 technical papers. He is currently serving as president of the Information Processing Society of Japan, as president of the Japan Association of Private Universities and Colleges, as a member of the Science Council of Japan and as a member of the Central Council for Education.

Interacting Physically with Robots and Virtually on the Global Digital Campus

The lecture presents two topics: the research on human-robot interaction conducted in the Anzai-Imai laboratory and the activities of the Digital Media and Content Research Institute, both at Keio University.

The first part of the lecture will present a summary of our research on human-robot interaction, embarked upon in 1991 and which is concerned with designing technologies that facilitate the smooth interaction of humans with robots. We initially started by designing software and hardware systems that support human-robot interaction. We then moved forward to designing robots that can smoothly interact with humans. In some cases we conducted behavioral experiments to find out how a human behaves in an interaction with a robot and fed the results back to engineering.

The second part of the lecture will focus on the activities of the Digital Media and Content Research Institute, established in 2004. One of its goals is to use various technologies to extend the reach of our physical campus so that students and faculty members can distribute their academic knowledge to a global audience, interact with people around the world and have convenient access to globally shared knowledge. We have already set up what we call Global Digital Studios in Tokyo, Seoul, Beijing, Cambridge (UK) and San Francisco, with more scheduled to open in New York and other locations. Twenty-four higher learning institutions in 12 Southeast Asian countries are also tied to this network via satellite Internet. The studios and sites can be connected online at any time and are used for many different purposes; the network can be regarded as an early version of Keio University's Global Digital Campus.

Haruhiko Harry Asada

*Ford Professor of Engineering
Massachusetts Institute of Technology (MIT)*

Dr. Asada is the Ford professor of mechanical engineering at MIT. He is also director of the d'Arbeloff Laboratory for Information Systems and Technology and head of the Control, Instrumentation and Robotics Division. He received his Ph.D. in precision engineering from Kyoto University, Japan, in 1979.

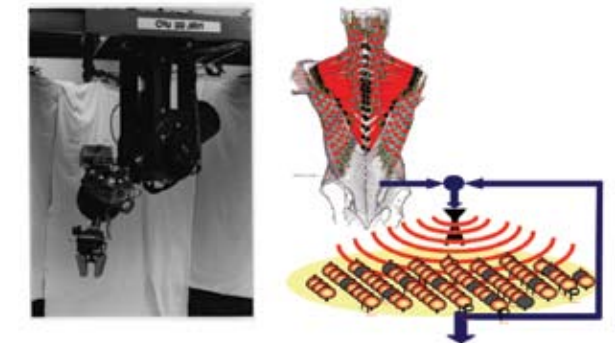
He specializes in robotics, biomedical engineering and system dynamics and control. He has received the O. Hugo Schuck Best Paper Award at the American Control Council, the Outstanding Researcher Award from the ASME Dynamic Systems and Control Division and the Best Paper Award at the IEEE International Conference on Robotics and Automation three times. He has also received best journal paper awards from the Society of Instrument and Control Engineers, the Robotics Society of Japan and the Japanese Associate of Automatic Control Engineers in five separate years. He is a fellow of the ASME.



From Direct Drive to Muscle Actuators

My talk will begin with a collaborative project with Dr. Kanade in 1980. Together, we developed the world premier direct drive robot arm using samarium-cobalt rare-earth magnets. The robot had no gearing; hence it was free from backlash, friction and other problems with gearing. The machine was an ideal test bed for torque and nonlinear dynamic control thanks to its low friction and high stiffness. After the Kanade-Asada project, the quest for advanced robot actuators continued and we have recently developed artificial muscle actuators with cellular architecture. Inspired by skeletal muscles, the new muscle actuator consists of vast numbers of tiny cells made of PZT, SMA and conducting polymers. They are compact, fast and of high energy density and, more importantly, behave like biological muscles; they not only generate force and displacement but also store and dissipate energy. To activate vast numbers of actuator cells, a novel control

and communication methodology called "stochastic recruitment and broadcast feedback" has been developed. This stochastic control allows for amazingly robust and sustainable control: although 40 percent of the actuator cells are dead, it can still track a trajectory. Using a stochastic Lyapunov function, stability and sustainability of the cellular actuator system can be guaranteed. The talk will conclude with discussion on the future of bio-robotics and neuro-muscle control.



CMU DD Arm and artificial muscle actuators with stochastic recruitment and broadcast feedback control

Olivier Faugeras

Research Director, INRIA Sophia-Antipolis
Professor, Computer Science Department, Ecole Normale Supérieure, Paris

Dr. Faugeras received his doctorate in computer science and electrical engineering from the University of Utah in 1976 and his doctorate of science from Paris VI University in 1981. He was an adjunct professor in the Electrical Engineering and Computer Science Department of the Massachusetts Institute of Technology and a member of its AI Lab from 1996 to 2001. Currently, he is research director at INRIA and leads the Odyssee laboratory.

His research interests include the application of mathematics to computer and biological vision, shape representation and recognition and the use of functional imaging (MR, MEG, EEG) for understanding brain activity and, in particular, visual perception.



He has published extensively in archival journals and at international conferences, has co-edited or contributed chapters to many books and is the author of "Artificial 3-D Vision." He has served as associate editor for IEEE PAMI and as co-editor-in-chief of the International Journal of Computer Vision. He is currently the editor-in-chief of the forthcoming Encyclopedia of Computer Vision. He has received two awards from the French Academy of Sciences: the *Institut de France Fondation Fiat* award for his work in vision and robotics and the

France Telecom award for his work on computer vision and geometry. He was one of the founding members of the French Academy of Technology and has been elected as member of the French Academy of Sciences.

A Few Problems Related to the Modeling of Cortical Activity

New methods for observing the brain, such as magnetic resonance imaging (MRI), electro and magneto-encephalography (MEEG) and optical imaging, pose challenging problems to modelers both in terms of analyzing the signals they produce and in terms of how to relate them to the way the brain operates. One of the most striking facts about the way the brain seems to function is that it involves electrical, physical and chemical phenomena at a large variety of spatio-temporal scales which are only partially captured by these measurement modalities. The resulting challenge is to design models and methods of combining several sources of information in such a way that the models can be tested on the data in a statistically significant manner. We illustrate these principles with the combination of functional MRI (fMRI) and MEEG data, through the use of a production model of the BOLD (blood-oxygen-level dependent) signal and with the design of models of assemblies of neurons, such as the cortical column at several scales, that can form the basis of an understanding of the computational properties of parts of the neocortex.

Eric Grimson

*Bernard Gordon Professor of Medical Engineering
Massachusetts Institute of Technology (MIT)*

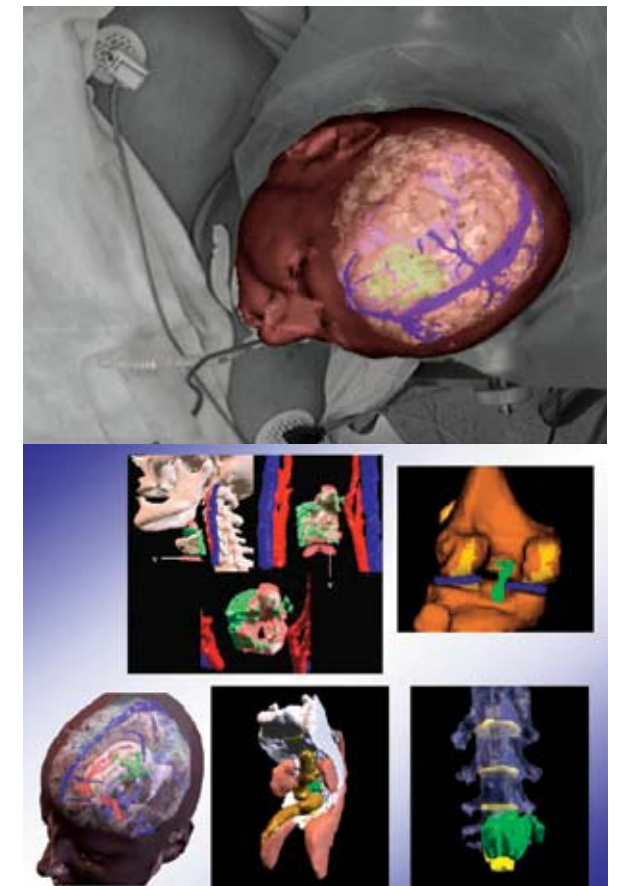
Dr. Grimson is the Bernard Gordon professor of medical engineering and head of the Department of Electrical Engineering and Computer Science at MIT. He is a member of the Computer Science and Artificial Intelligence Laboratory (CSAIL) and head of its Computer Vision Group. He also holds appointments as a lecturer on radiology at Harvard Medical School and at Brigham and Women's Hospital. He received a Ph.D. in Mathematics from MIT in 1980.

His research interests focus on computer vision and medical image analysis. Over the past 30 years, he and his research group have pioneered state of the art methods for activity and behavior recognition, object and person recognition, image database indexing, site modeling, stereo vision and many other areas of computer vision. Since the early 1990s, his group has been applying vision techniques in medicine for image guided surgery, disease analysis and computational anatomy. He is a fellow of the IEEE and of the AAAI.



Image Guided Surgery and Computational Anatomy

The current trend towards minimally invasive procedures raises an interesting challenge for surgeons: how to execute precise surgeries through small openings with limited view of nearby structures. Recent advances in computer vision are solving this challenge. Knowledge-driven segmentation methods provide detailed, patient-specific reconstructions of relevant anatomy. These models allow a surgeon to visualize the site—localizing tumors while highlighting critical structures—and they provide planning tools for optimal approaches to the tumor. Automated registration techniques accurately align the graphical patient reconstruction with actual position in the operating room so that surgeons can see the positions of their instruments relative to critical nearby structures in real-time and allowing a surgeon to execute minimally invasive surgeries as if the anatomy was completely visible. These tools are used regularly in a range of surgical procedures. Moreover, they are applicable to other clinical applications, such as measuring differences in shape of anatomical structures with disease or treatment.



Katsushi Ikeuchi

*Professor, Institute of Industrial Science
University of Tokyo*

Dr. Ikeuchi is a professor at the University of Tokyo. He received his Ph.D. in information engineering from the University of Tokyo in 1978. After working at the Massachusetts Institute of Technology's AI Lab for two years, the Electro-technical Lab in Japan for five years and Carnegie Mellon University for ten years, he returned to the University of Tokyo in 1996.

His research interests span computer vision, robotics and computer graphics. He has received several awards, including the IEEE Robotics and Automation's K. S. Fu Memorial Best Transaction Paper award for the paper "Toward Automatic Robot Instruction from Perception." He is a distinguished speaker of the IEEE computer science society and a fellow of the IEEE.



Learning From Observation: From Assembly Plan Through Dancing Humanoid

We have been developing the paradigm referred to as "programming by demonstration." The method involves simple observation of what a human is doing and generation of robot programs to mimic the same operations. The first half of this talk presents the history of what we have done so far under this paradigm. We will emphasize the top-down approach to utilize pre-defined, mathematically derived task-and-skill models for observing and mimicking human operations. We will show several examples of task-and-skill models applicable in different domains. The second half of the talk will focus on our newest effort to make a humanoid robot perform Japanese folk dances using the same paradigm. Human dance motions are recorded using optical or magnetic motion-capture systems. These captured motions are segmented into tasks using motion analysis, music information and task-and-skill models. We can characterize



personal differences of dance using task-and-skill models. Then, we can map these motion models onto robot motions by considering dynamic and structural differences between human and robot bodies. As a demonstration of our system, I will show a video in which a humanoid robot performs two Japanese folk dances, Jongara-bushi and Aizu-bandaisan-odori.

Shree K. Nayar

*T.C. Chang Professor of Computer Science
Columbia University*

Dr. Nayar is currently the T.C. Chang professor of computer science at Columbia University and co-director of the Vision and Graphics Center. He also heads the Columbia Computer Vision Laboratory (CAVE), which is dedicated to the development of advanced computer vision systems. He received his Ph.D. in electrical and computer engineering from Carnegie Mellon University in 1990.

His research is focused on three areas: the creation of novel cameras, the design of physics-based models for vision and the development of algorithms for scene understanding.

He is a two-time recipient of the David Marr Prize, as well as the recipient of the David and Lucile Packard Fellowship, the National Young Investigator Award and the NTT Distinguished Scientific Achievement Award. He has published over 100 scientific papers and has been awarded several patents for inventions related to vision and robotics. He has received a best paper award at ICPR, twice at ICCV and four times at CVPR.



Computational Cameras: Redefining the Image

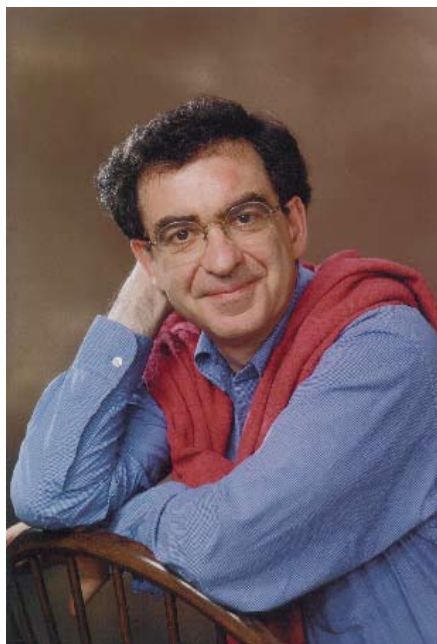
In this talk, we will first present the concept of a computational camera. It is a device that embodies the convergence of the camera and the computer. It uses new optics to select rays from the scene in unusual ways and an appropriate algorithm to process the selected rays. This ability to manipulate images before they are recorded and process the recorded images before they are presented is a powerful one. It enables us to experience our visual world in rich and compelling ways. We will show computational cameras that can capture wide angle, high dynamic range, multispectral and depth images. Finally, we will explore the use of a programmable light source as a more sophisticated camera flash. We will show how the use of such a flash enables a camera to produce images that reveal the complex interactions of light within objects as well as between them.



Tomaso A. Poggio

*Eugene McDermott Professor, Department of Brain and Cognitive Sciences
Massachusetts Institute of Technology (MIT)*

Dr. Poggio is the Eugene McDermott professor at the Department of Brain and Cognitive Sciences at MIT. He is also co-director of the MIT Center for Biological and Computational Learning, a 25-year member of the Computer Science and Artificial Intelligence Laboratory (CSAIL) and a member of the faculty of the McGovern Institute for Brain Research. He received his doctorate in theoretical physics from the University of Genoa in 1970 and held a tenured research position at the Max Planck Institute from 1971 to 1981.



and the neuroscience of learning, particularly how the brain learns to recognize objects in higher areas of the visual cortex. He is an honorary member of the Neuroscience Research Program, a member of the American Academy of Arts and Sciences and a founding fellow of the AAAI. He belongs to the editorial board of several scientific journals. Among the awards he has received are the Otto-Hahn-Medaille Award of the Max Planck Society, the Max Planck Research Award (with M. Fahle) from the Alexander von Humboldt Foundation, the MIT 50K Entrepreneurship

In addition to the application of engineering techniques to computer vision, bioinformatics and computer graphics, his current research is focused on the mathematics of learning theory

Competition Award, the *Laurea Honoris Causa in Ingegneria Informatica* for the *Bicentenario dell'Invenzione della Pila* from the University of Pavia and the 2003 Gabor Award.

Learning: Theory, Engineering Applications and Neuroscience

The problem of learning is one of the main gateways to making intelligent machines and to understanding how the brain works. In this talk I will briefly show a few examples of our efforts in developing machines that learn. I will focus on a new theory of the ventral stream of the visual cortex in primates, describing how the brain may learn to recognize objects, and show that the resulting model is capable of performing recognition on datasets of complex images at the level of human performance in rapid categorization tasks. The model performs surprisingly well when compared with state-of-art computer vision systems in categorization of complex images.

Harry Shum

*Managing Director
Microsoft Research Asia (Beijing)*

Dr. Shum is a distinguished engineer of Microsoft Corporation. He received his Ph.D. in robotics from the School of Computer Science at Carnegie Mellon University. After graduation, he worked as a researcher at Microsoft Research Redmond. In 1999, he moved to Microsoft Research Asia (Beijing) where he is currently the managing director.

His research interests include computer vision, graphics, human computer interaction, statistical learning and robotics. He is on the editorial boards of the IEEE Transactions on Pattern Analysis and Machine Intelligence (PAMI) and the International Journal of Computer Vision (IJCV). He is the program co-chair of the Eleventh International Conference on Computer Vision (ICCV 2007 Brazil). He is a fellow of the IEEE and the ACM.



Prior, Context and Interactive Computer Vision

For many years, computer vision researchers have worked hard chasing the illusive goals such as “can the robot find a boy in the scene” or “can your vision system automatically segment the cat from the background.” These tasks require a lot of prior knowledge and contextual information. How to incorporate prior knowledge and contextual information into vision systems, however, is very challenging. In this talk, we propose that many difficult vision tasks can only be solved with interactive vision systems, by combining powerful and real-time vision techniques with intuitive and clever user interfaces. I will show two interactive vision systems we developed recently, Lazy Snapping (Siggraph 2004) and Image Completion (Siggraph 2005), where Lazy Snapping cuts out an object with solid boundary using graph cut, while Image Completion recovers unknown region with belief propagation. A key element in designing such interactive sys-

tems is how we model the user’s intention using conditional probability (context) and likelihood associated with user interactions. Given how ill-posed most image understanding problems are, I am convinced that interactive computer vision is the paradigm we should focus today’s vision research on.

Russell H. Taylor

*Professor of Computer Science
Johns Hopkins University*

Dr. Taylor received his Ph.D. in computer science from Stanford in 1976. He joined IBM Research in 1976, where he developed the AML robot language. Following a two-year assignment in Boca Raton, he managed robotics and automation technology research activities at IBM Research from 1982 until returning to full time technical work in late 1988. From March 1990 to September 1995, he was manager of Computer Assisted Surgery. In September 1995, Dr. Taylor moved to Johns Hopkins University as a professor of computer science, with joint appointments in radiology, surgery and mechanical engineering. He is also director of the NSF Engineering Research Center for Computer-Integrated Surgical Systems and Technology.

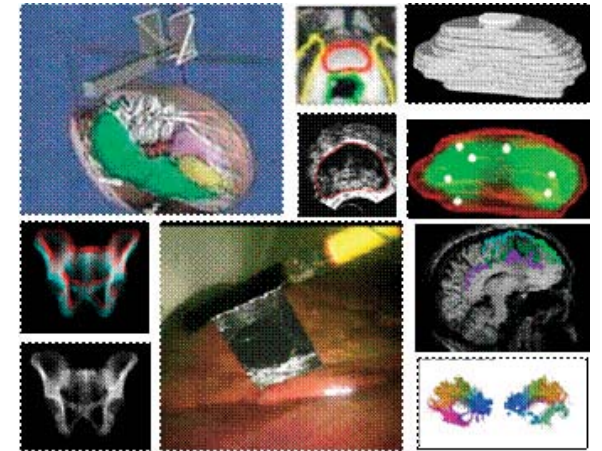
He has a long history of research in computer-integrated surgery and related fields. He led the team that developed the first prototype for the Robodoc© system for robotic hip replacement surgery and he developed novel systems



for computer-assisted craniofacial surgery. He is currently a member of various honorary societies, panels, editorial boards and program committees, including the scientific advisory board of Integrated Surgical Systems. He is editor emeritus of the IEEE Transactions on Robotics and Automation, has received the Maurice Müller award for excellence in computer-assisted orthopaedic surgery and is a fellow of the IEEE and the AIMBE.

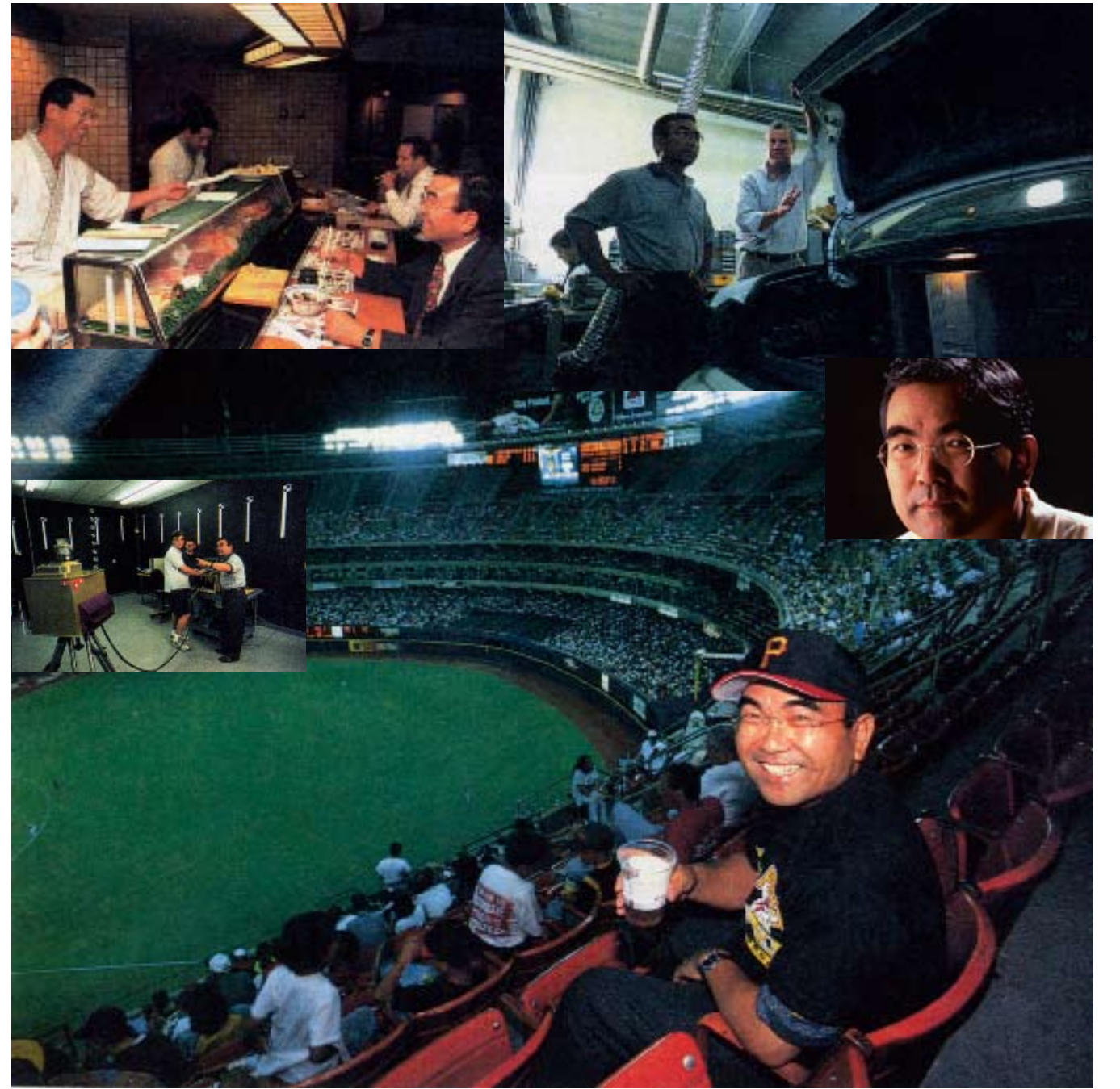
Medical Robotics and Computer-Integrated Surgery

The impact of computer-integrated surgery (CIS) on medicine in the next 20 years will be as great as that of computer-integrated manufacturing on industrial production over the past 20 years. A novel partnership between human surgeons and machines, made possible by advances in computing and engineering technology, will overcome many of the limitations of traditional surgery. By extending human surgeons' ability to plan and carry out surgical interventions more accurately and less invasively, CIS systems will address a vital national need to greatly reduce costs, improve clinical outcomes and improve the efficiency of health care delivery. As CIS systems evolve, we expect to see the emergence of two dominant and complementary paradigms: surgical CAD/CAM systems will integrate accurate patient-specific models, surgical plan optimization and a variety of execution environments, permitting the plans to be carried out accurately, safely and with minimal invasiveness. Surgical assistant systems will work cooperatively with human surgeons in carrying out precise and minimally invasive surgical procedures. Over time, these will merge into a

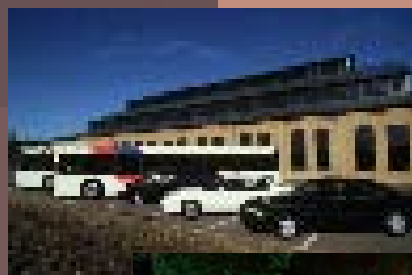


broader family of systems that couple information to action in interventional medicine.

CIS research inherently involves three synergistic areas: modeling and analysis of patients and surgical procedures, interface technology, including robots and sensors, and systems science to develop improved techniques for ensuring the safety and reliability of systems. This talk will explore these themes with examples drawn from our own research and elsewhere.



AUTONOMOUS VEHICLES



Takeo Kanade and Carnegie Mellon were made for each other. His early success in his research in pattern and face recognition naturally made for a great fit with the artificial intelligence pioneers working here in the late 1970s. Takeo found that Carnegie Mellon's collaborative and hands-on approach was just the right one for his own evolution as a scientist.

And what an evolution it has been! His brilliant work on computer vision continues to push the field ahead and it has been the foundation for an ever widening range of applications and new research directions. Ever engaged in the next problem, Takeo's recent interest in quality of life technologies has potential for huge positive impact on health care and more independent living for the aging and the disabled.

We at Carnegie Mellon also know him as a gifted and tireless administrator, taking on time-consuming leadership roles with grace and extraordinary effectiveness—all the while continuing his own research at the usual pace.

Most of all, we value him as a teacher, one whose celebrated scientific accomplishments have attracted superb students to study at Carnegie Mellon. Takeo's generous spirit and incisive mind helps his students to find their way to the right questions. His more than 60 graduate students are spreading his legacy around the world and far into the future.

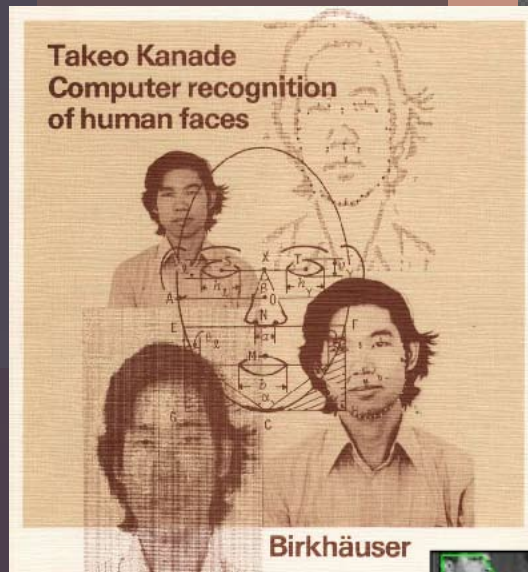
Takeo Kanade is one of Carnegie Mellon's treasures. We are so fortunate that he has chosen to make this university his intellectual home and we are profoundly grateful that he has given so much of himself to further Carnegie Mellon's growth and success.

We wish him all the best on his 60th birthday with hopes for many more productive years ahead.

Happy Birthday, Takeo!

Jared L. Cohon
President
Carnegie Mellon University

FACEWORK



When Takeo Kanade first started to think about what might be involved in making a computer that could see, it must have seemed like the most bizarre science fiction to most people. Given the capacity of the computer in the early 1970s, when Takeo was in graduate school, computer vision would have been dismissed as total fantasy.

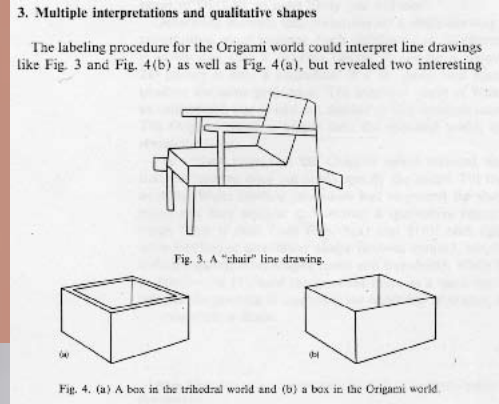
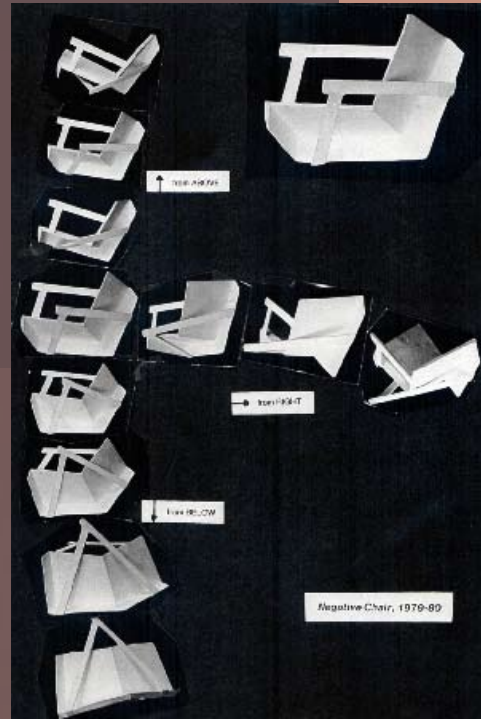
But Takeo Kanade came to Carnegie Mellon, where there was a group of scientists and scholars who shared his enthusiasm and natural curiosity about artificial intelligence. Takeo helped to define this expansive approach to computing, an approach that is now part of the culture of the School of Computer Science and of all of Carnegie Mellon.

It has been an eventful 27 years since he joined the faculty, with many projects undertaken, many technical problems solved and many students educated along the way, but today, machine facial recognition is a powerful, usable technology. While Takeo would be the first to say that he did not do this alone, his intellectual contributions are legendary and his preminent influence in this field is undisputed.

We wish Takeo all the best on his 60th birthday: we celebrate his many, many accomplishments and we hope that for years to come he will inspire his students—and all of us—to continue to make fantastic ideas real.

Mark S. Kamlet
Senior Vice President and Provost
Carnegie Mellon University

ORIGAMI WORLD



Takeo Kanade has been a visionary in computer science ever since his student days at Kyoto University in the 1970s when he developed the first complete system for face recognition by computer as his doctoral thesis.

While he was a visitor at Carnegie Mellon in 1977-78, he developed a mathematical theory for 3D shape recovery from a single 2D line drawing, which he later published as the "Origami World Theory." For many years it was one of the 10 most frequently cited papers in the Journal of Artificial Intelligence.

Takeo joined our faculty in 1980 as an expert in computer vision, but his first project after arriving was to develop the Direct Drive Arm. By eliminating gears or other transmission devices from its mechanisms, a direct-drive manipulator is freed of friction enabling it to move faster and more precisely. The technology and its high-performance control is now standard practice today.

In the ensuing 27 years, Takeo has produced a continuous stream of breakthroughs in a variety of areas. His work in virtualized reality gave the world an eyeful when CBS-TV displayed his EyeVision playback system at Super Bowl XXXV. The Raymond James Stadium in Tampa, Fla. was ringed with more than 33 robotically controlled cameras and software could then reconstruct a view of the action from any vantage point.

I'm not a big football fan. I watch the Super Bowl mostly to see the advertisements, but I remember well a particular instant replay with a virtualized view that clearly showed one of the players still had control of the ball as he ran past the goal line. I remember thinking "this really shows how intelligent technology can make a difference."

Takeo has been a cornerstone of the Robotics Institute from its earliest days. He created the world's first doctoral program in robotics and headed the Institute from 1992-2001, never slacking the pace of his own research.

Now he is leading us in new directions where computer science and robotic technologies will benefit a broader swath of society. In July 2006, Carnegie Mellon and the University of Pittsburgh celebrated the establishment of their newest National Science Foundation research center, which focuses on quality of life technologies. Takeo, whose vision and effort were instrumental in helping us to receive the \$15 million award, is the co-principal investigator. Under his guidance and pioneering spirit, researchers in the Quality of Life Technology Engineering Research Center will develop ways to help older adults and people with disabilities live independently and productively and improve long-term health care for everyone. If this current vision is fulfilled as well as those he has fulfilled in the past, Takeo may be giving all of us the gift of many more happy birthdays. Happy 60th Takeo. May you succeed in all your endeavors.

Randal E. Bryant
Dean, School of Computer Science
Carnegie Mellon University

VIDEO SURVEILLANCE & MONITORING



Takeo is a leader in every sense. He makes deep contributions to the foundations of robotics. He organizes and energizes new subdisciplines. He envisions the future of robotics, and applies his amazing talents and energies to bring that future about.

Takeo's work also serves as a model that inspires all of us. In fact, if you tabulate the different types of careers, I calculate that Takeo provides us with eight different career models. I arrived at this number by considering the different career choices that one might make.

One choice is whether you want to push the envelope in known directions or strike out in new ones. Some of us choose to refine and hone the technology, while others have a broader perspective and the ability to create whole new areas of research.

But Takeo never made that choice. He energetically attends to the nitty gritty of robotics, refining our techniques and continually expanding our understanding. At the same time, he has envisioned new possibilities and put new research areas on the map.

The second choice is whether to spend a career exploring a single area or to move from topic to topic. Takeo never made this choice either. He is universally respected as a leader in computer vision research. But he also has achieved milestones in manipulation, medical robotics and other areas.

The third choice is whether to focus your entire career on research or whether to contribute by building or leading institutions. Again, Takeo chose not to choose. Without a pause in the stream of his research results, he has built or led several outstanding institutions: the Vision and Autonomous Systems Center, the Digital Human Research Center, the Quality of Life Technology Engineering Research Center, the Medical Robotics and Computer-Assisted Surgery center, and, of course, his enormous contributions to the Robotics Institute. Congratulations, Takeo, on eight outstanding careers.

Matthew Mason
Director, Robotics Institute
Carnegie Mellon University

EYEVISION



I heard about Takeo from my very first days as a graduate student back in 1980. He was a legend before he ever joined our faculty and when he did show up, he lived up to everything we had heard about him. He invented computer vision before there was such a field.

He came to Carnegie Mellon as a vision expert, but the first thing he did was to develop the Direct Drive Arm. He was always doing 10 things at once and he had to be good at all 10 of them. His work ethic is legendary. When you make an appointment with Takeo, you have to ask “does it mean 2 a.m or 2 p.m.?”

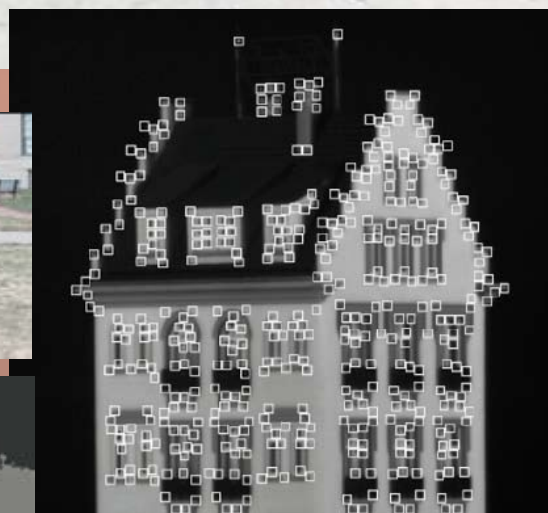
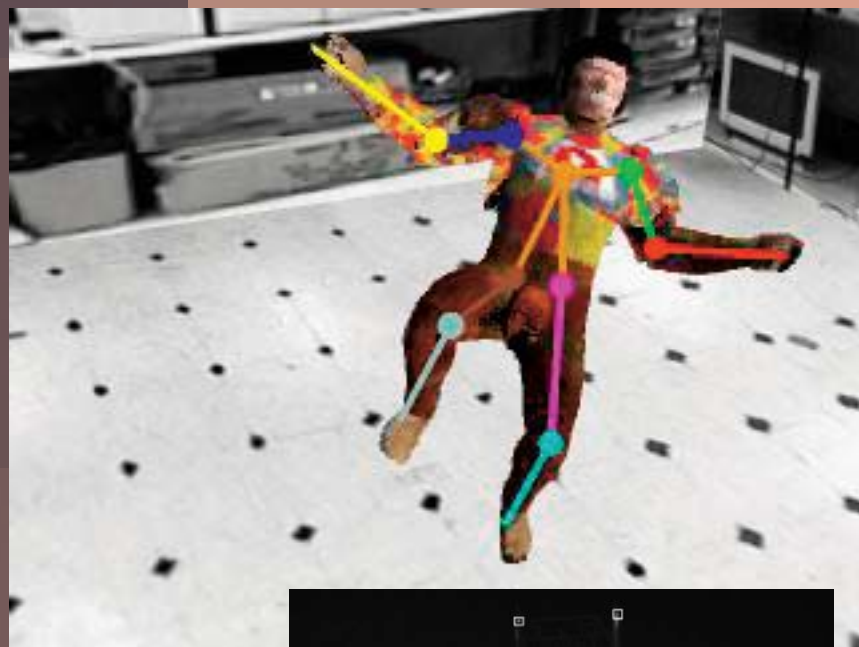
Takeo has built special purpose computers and sensors. He has done theoretical work, created virtualized reality and is pushing developments in the field of medical robotics. Through it all, he has stayed interested in mobile robots. He was the PI on the first NavLab project. We put his stereo vision machine on NavLab-I to make it see. All I can say is that it was a good thing we had a big robot. He kept on top of the breakthroughs—like Dean Pomerleau’s work with RALPH and autonomous driving and Tony Stentz’s work in planning.

He always made time for the big occasions. He flew to Hollywood for the grand finale of No Hands Across America in 1995 and had his picture taken with Jay Leno in front of NavLab-5. He also was on hand for the U.S. Department of Transportation’s 1997 National Automated Highway Systems Consortium demo when a fleet of NavLabs, including two Houston Transit Authority buses, drove themselves autonomously down the HOV lanes of Interstate 5 near San Diego.

Takeo’s management style is to promote the people under him and pass the glory around. He said the only thing better than being famous was to be the boss of all these famous people.

Chuck Thorpe
Dean, Qatar Campus
Carnegie Mellon University

MOTION IMAGE ANALYSIS



Carnegie Mellon University is fortunate to have had the presence of Professor Takeo Kanade for the past 30 years.

We invited Takeo to the university as a visitor in 1977 after meeting him at a vision presentation in Japan. He was working on the same project as my graduate student and he did a much better thesis! When it was time to invite someone as vision faculty, I thought Takeo would make a strong faculty member.

His arrival at the university marked the beginning of the establishment of Carnegie Mellon as the major research center in computer vision. His contributions to the field are numerous.

The factorization method for recovering shape and motion from an image sequence and the multi-baseline stereo method for creating a depth map of an actual scene (with his student Carlo Tomasi) is now used worldwide. CBS Television used a subset of this technology called EyeVision in Super Bowl XXXV for creating a multi-viewpoint instant replay. This accomplishment is unparalleled in the history of any university. The extension of his early work on face recognition, optical flow computation for motion image analysis, computer vision for eye tracking and integrating image sensing and computation on a single chip represent a continuous stream of advances by Professor Kanade and his teams.

In the area of Robotics, Takeo is responsible for designing the prototype of the first direct-drive manipulator with Dr. Asada. His work on vision-based autonomous helicopters, resulting in a highly maneuverable, unmanned helicopter in hazardous environments for search and rescue (with his student Omead Amidi), is a landmark in autonomous aerial systems.

The unique characteristic of all of his work is that it's based on firm theoretical foundations and that he is able to transform the theories into innovative working systems.

Happy 60th Birthday, Takeo. And many more to come!

Raj Reddy
Mozah Bint Nasser University Professor of Computer Science and Robotics
Carnegie Mellon University

VIRTUALIZED REALITY



I met Takeo when he joined Carnegie Mellon in 1980 when the Robotics Institute was one year old. Because of my close association with the institute from the beginning, I got to know him very well. We considered him a rising star at the time, but almost instantly he became a pioneer and proceeded to make seminal contributions year after year.

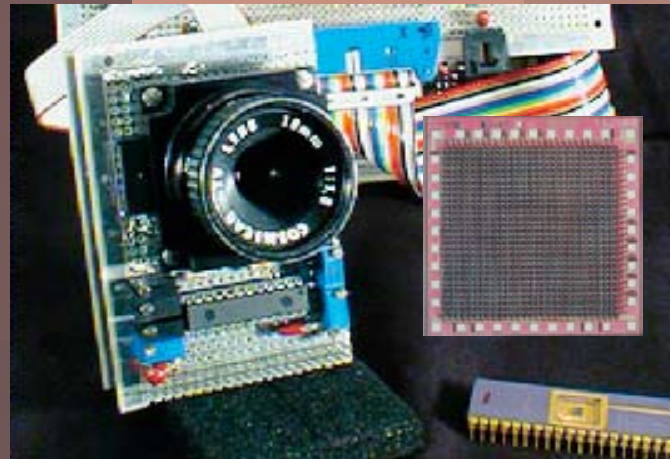
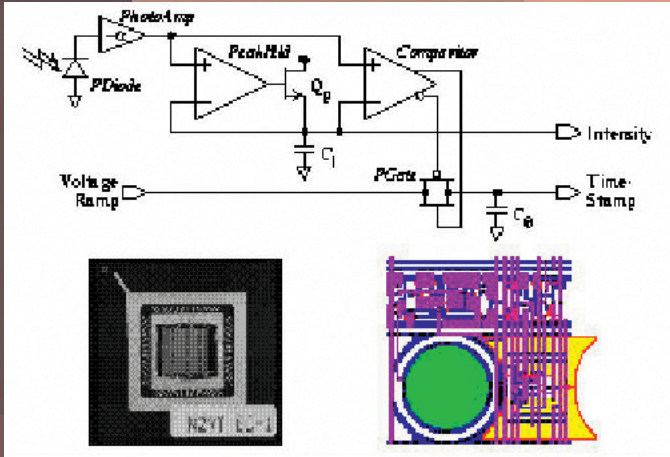
I remember well when a handful of Carnegie Mellon people visited Japan when the Robotics Institute was very young. For all practical purposes Takeo was our host because of his connections with illustrious researchers in Japan.

Over the years he has been tempted to go back to his country. We have been fortunate to retain him at Carnegie Mellon where he has nurtured many roboticists, provided technical and scientific leadership and helped make our Robotics Institute the renowned institution it is today. What is remarkable about Takeo is not only his outstanding publication record but the variety of fields where he has made an impact. He is truly interdisciplinary.

When Takeo became director of the institute, he reported to me as Provost. At that time, space at Carnegie Mellon was at a premium. Many of our encounters were consumed dealing with space issues, but we still had enough time to talk about the research agenda of the institute. I have been privileged to have recommended Takeo several times for prestigious awards, particularly membership in the National Academy of Engineering. It was really easy to make these recommendations. Takeo is a giant not only in robotics but also in many fields of computer science.

Angel Jordan
University Professor of Electrical and Computer Engineering and Robotics Emeritus
and Provost Emeritus, Carnegie Mellon University

SENSORS



Visionary, creative, intense and dedicated are words that come to mind when I think of Takeo Kanade. The vignettes below describe what I mean.

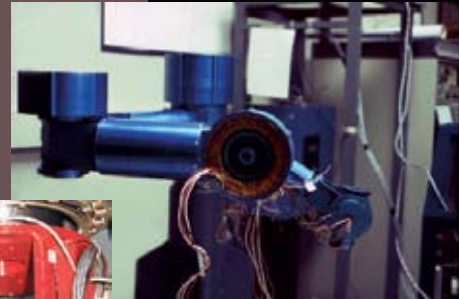
Creative Visionary: While deploying wearable computers for aircraft and computer maintenance in the mid-1990s, the wearable computer team explored the possibility of augmented reality, where information on a head-mounted see-through display appears overlaid on a physical object and remains stationary as the user's head moves. Describing what we perceived as a novel application, we learned that Takeo already had the technology, which he called "Magic Eye." Within a few days, using his group's array processors, the highest performance computing on campus at the time, Takeo's group demonstrated real time labeling for the power supply, disk drive and motherboard while disassembling a personal computer from different viewing angles.

Intense and Dedicated: After a long day spent on an NSF site visit for the Quality of Life Technology Engineering Research Center, and an even longer evening generating responses to the site visit team's questions, our working group was content after the third rehearsal of our responses. But Takeo sensed that we had not adequately answered the questions. He encouraged the team and then led a reformulation of our thinking that greatly improved the quality of our answers.

I enjoy working with Takeo. I know that the visionary creativity resulting from our interactions will change the way future researchers will approach a problem. In addition, Takeo's leading-by-example inspires all of us to perform at ever higher levels.

Dan Siewiorek
Director, Human-Computer Interaction Institute
Buhl University Professor of Electrical and Computer Engineering and Computer Science
Carnegie Mellon University

DIRECT DRIVE ARM



I first got to know Takeo in the summer of 1983 when I was looking for a Ph.D. advisor and he agreed to take me on as a student. Since then he has been my advisor, my colleague and a great mentor. During these years, I earned my Ph.D., joined the Carnegie Mellon faculty, co-founded a company with Takeo and forged a professional and personal relationship that has become stronger and deeper over the years. I don't know of any student-advisor relationship that has lasted so long and grown so deep, especially when a student stayed as a faculty member at the same place as the advisor.

Winston Churchill said it best: "We make a living by what we get, we make a life by what we give." Takeo didn't just make a living at Carnegie Mellon; he made a life and he has made several other people's lives here, including mine.

I have had many memorable moments with Takeo. The ones I remember most fondly, and are most typically Takeo, are our research meetings when I was working on my Ph.D. What follows is typical, give or take an hour or so.

It's 8 p.m. on a Friday evening and I make plans to go out with my girlfriend, Thespine (my wife today), at 10 p.m. because I have a meeting with Takeo at 8:30 p.m. I assume it will last an hour and a half, at most. The meeting typically begins 10-15 minutes late and, after a few minutes of general updates, we start talking about technical stuff and new ideas. Around 9:45 p.m. Takeo gets a call. He says something in Japanese and hangs up. He says his wife is coming to pick him up and that he has to leave around 10 p.m. I say fine because I also have to leave. We continue our technical conversation. After a short while, there's a knock on the door. It's Takeo's wife with their toddler daughter in tow. He says something in Japanese while I take the opportunity to look at my watch. To my horror, it's 11 p.m. As Takeo's wife walks away and he tries to shut the door, I tell him that somebody is waiting for me and I need to tell her that I am running late. I step out to find Thespine sitting on the concrete floor outside Takeo's office. She doesn't look very happy. Fortunately, Eat 'N Park has a midnight buffet so we can still have dinner together as soon as I finish talking with Takeo. I go back to his office and we agree that we will wrap up our conversation soon, but only because we misjudged the duration of the meeting and we both have someone waiting to pick us up.

These meetings clearly showed me how much Takeo loves research. While I have been spared the "excitement" of these research meetings during the past decade or more, I know from other people that he is still the same to this day.

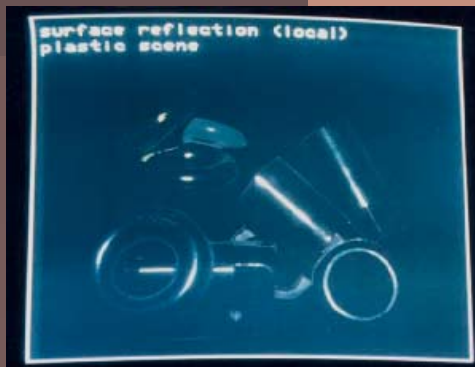
As I fulfill my duties as dean of the College of Engineering, Takeo periodically tells me "you are my boss." It is only when I remind him that a student-teacher relationship (especially in the Hindu culture) never changes and that he will always be my teacher and, hence my boss, does he become at ease. This issue would have been put to rest a long time ago were it not for other people who ask him every so often, "Is Pradeep really your boss?" So whatever you decide to say to Takeo, please never ask him this question!

As I look back, I realize how fortunate I was to have Takeo as my advisor and how fortunate I am to have him as a colleague and friend. I think it would be fair to say that if it were not for Takeo's mentoring, his love of the quest for new knowledge and love of research, I would not be where I am today. Not only did he guide me through the Ph.D. process and beyond, but also he has inspired me to think bigger-- to think of all the possibilities that the world holds for us personally and for Carnegie Mellon. Regardless of how much I accomplish, I know that he will always be better than I am and all I can do is to strive to be as good as he is in all that he thinks and does.

I know that I am his boss but I also know that I will never be his boss!

Pradeep Khosla
Dean, Carnegie Institute of Technology
Carnegie Mellon University

PHYSICS-BASED VISION



The Vision and Autonomous Systems Center (VASC), which Takeo created, had one of its more-or-less-annual retreats and they decided for the first time to have a Karaoke party. About 40 of us were there, a few faculty but mostly students. Everyone was looking at the books that list all the songs, but no one was brave enough to fill out a slip to have one played. It was pretty funny to look around the room and see the hopeful yet nervous looks on everyone's face as they looked through the books and saw some songs they might enjoy singing. But, no one dared. Finally, after almost an hour of the party, Takeo filled out a slip and marched up to have it played: "Yesterday" by the Beatles. Takeo took the microphone and announced to the group this was the only song he knew in the whole book. The music started and within the first phrase it became clear he had absolutely no idea what this song was, what the words were, or how the tune went. He struggled to read it fast enough to say a word or two out of each line of music, straining the whole time, and everyone in the room was first giggling, then laughing out loud. When it was over, he put down the microphone with an apologetic smile and rejoined the room. Everyone started streaming up with their requests for songs and the party was on! Takeo meanwhile approached a faculty group and someone asked him, "If you didn't know that song, why did you choose it?" He said, "I am the leader. I knew if everyone could see me make a fool of myself, then they would know they could do better." How true! And how typical of Takeo's wisdom! Takeo, we all love you and for good reason!!

Steve Shafer
Senior Researcher
Microsoft Corporation



