Thoughtful Machines

Cooperative robots who prevent human error

Designing equipment properly can prevent human error. Robots whose movements and cooperative behavior are close to human levels are also thoughtful in another sense. They can teach us how human beings make mistakes.

Error correction starts from the premise of error

A warning from the sink

Don't move your hands. Try working through it mentally. To turn on a faucet or to increase the flow, you turn the faucet knob to the left, that is, counterclockwise. But to turn up the volume of sound from a radio or stereo system, you turn knobs to the right, in a clockwise direction.

Now, when you want to turn up the flame on a portable gas stove, which way do you turn the knob?

Our reporter heard about this puzzle while interviewing Assistant Professor Shigeru Haga from the Department of Psychology, College of Art, Rikkyo University, who has written *The Mechanisms of Error: From Forgetfulness to Huge Accidents.*

In this book, Haga offers suggestions drawn from the study of human error on how to prevent mistakes. One approach involves the design of equipment, devices like those with which Haga surrounds himself and to which he points as he explains what has (or has not) been done to prevent those who operate them from making mistakes.

That is where the example of the gas stove came from.

It turns out that you turn the knob to the left to turn up the flame. That's just like the water faucet. Describing this type of pipe and valve system, Haga says, "It takes strength to close a valve tightly, and for right-handed people it is easier to exert strength when turning to the right. These systems are designed for right-handed people." By contrast, in the case of electronic equipment, values on indicator bars increase as they move toward the right, so it's natural to turn knobs to the right when we want to turn up the volume.

This difference in the way handles and knobs that control gas, water and electricity work rarely causes problems because we are so used to it. What bothers Haga, however, is the use of sliding levers to control gas stoves. Sometimes you have to push to the right to turn up the flame, at other times to the left; it's a jumble.

That is why, returning to where we started, when we put the gas-stove question to other members of our staff, they answered, "Now, if it's a gas stove . . . . hmmmm?" The correct answer didn't come instantly to mind. When we reported this result to Haga, we thought it was just a good laugh. But he said, "That's actually very interesting, you know." You cannot assume that because it is gas, you have to turn it to the left. But when you stand in front of a stove, your hand tends to move automatically. That can be dangerous. "It is precisely because in this kind of situation we tend to act unconsciously on the pattern we have learned that the motion should be standardized."

According to Haga, the errors that cause huge accidents and little bloopers in everyday life have basically the same character. That is why taking a close second look at everyday things can provide precious pointers for preventing serious mishaps.

"When I am talking to students about design, one example that always fascinates them is why people pull vertical bars on doors to open them but push on horizontal bars. If you want people to pull a door open, you should place the bar vertically. If you want them to push, you should place the bar horizontally. If you do it the other way around, you will need a big "Push" or "Pull" sign to tell people what to do. This is a good example of how design and human nature interact."

Speaking of standardization, let's look at sinks with levers. Instead of turning a faucet knob, you raise and lower the lever to adjust the water flow. The first manufacturer to produce and market a lever-operated faucet in Japan started with a lever designed so that pulling down the lever turned on the water and you had to lift the lever to turn the water off. When you moved the lever down, water came out the spout. In human engineering terms this combination of perception and action shows a high degree of compatibility. It is a highly rational design.

When other manufacturers entered the market, however, they adopted the

Shigeru Haga, Ph.D.

An Assistant Professor in the Department of Psychology, College of Art, Rikkyo University, Haga is a specialist in industrial and transportation psychology and human engineering. Born in 1953, he received his master's degree in psychology from the Department of Psychology, Graduate School of Letters, Kyoto University. After working as a researcher at the Railway Technical Research Institute, he was an Assistant Professor at Tohwa University before moving to his current position in 1998.

Error-preventing design

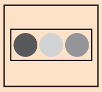
Refined and frequently employed by NASA, for example, the results of this theory have been incorporated in many familiar forms of transportation and in household products.

Compatibility

Making operations and displays consistent with what seems natural to human beings.

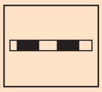

Pulling back on an aircraft's stick causes the nose of the aircraft to move upward.

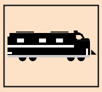

The cursor follows the motions of the mouse.


Red signals hot or dangerous.
Green signals cool or safe.

Fail-safe

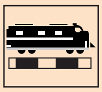
Designs that ensure the safe action in case of breakdowns or other abnormalities.


A red light appears when a circuit is broken. The level crossing stays closed.


A buzzer rings when no action has been taken for a certain length of time. If the buzzer is not reset within five seconds, the emergency brake is applied. (Anticipating accidents caused by railway drivers.)

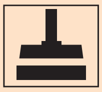
Security systems

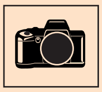
Danger-detection systems.
They don't work by turning off the system when danger is detected. They permit operation only when safety has been confirmed, thus ensuring safety following system malfunctions.

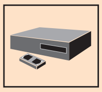

When an infrared beam is interrupted for more than five seconds, this level-crossing damage detection device turns on an emergency warning signal.

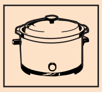
Fool-proof

Design that makes it impossible to operate a device incorrectly.


Presses that won't operate unless left and right buttons are pushed simultaneously (prevents getting hands caught in press).

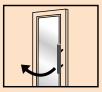

Cameras with shutters that won't operate as long as the lens cap is on.

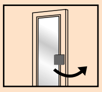

Video decks that won't allow users to preset recording times unless a cassette has been inserted.


Electric rice cookers that won't turn on if they're empty.

Affordance

A theory proposed by psychologist of perception James J. Gibson. It explains why certain types of human engineering or manufacturing designs automatically elicit certain actions from human beings.

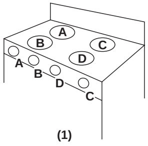

A vertical bar on a door signals people to pull a door toward them.


A flat plate or horizontal bar signals people to push it instead.

Gas burners and knob positions

(M.S.Sanders & E.J.McCormick, Human Factors in Engineering and Design, 1987, p.237)

This example always appears in ergonomics textbooks. For Americans, design number (1) ensures the fewest mistakes.



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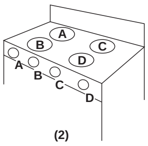

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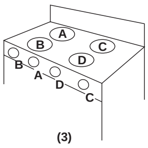

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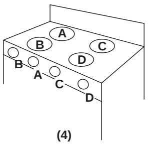

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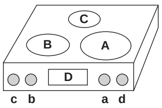
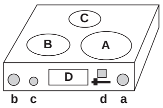
Professor Haga's suggestions for improving knob positions



In existing products, knobs a, b, and c control burners A, B, and C, while knob d controls the grill D.



In the improved design, knob c, which controls the smaller burner C, would be made smaller than other knobs and knob d would be replaced with a push button to light the grill and a slide to control it, located immediately beside the grill. This arrangement is more consistent with how the controls should be used.

* These illustrations are taken with permission from Shigeru Haga, The *Mechanisms of Error: From Forgetfulness* to Huge Accidents, Tokyo: Nihon Shuppan Service.

global pattern in which lifting the lever releases the water and pushing the lever down turns it off. That is why we find both types used on Japanese sinks–and why there are always people who think that they are turning off a faucet and are startled when the water rushes out instead.

If you are washing your hands and the front of your pants gets splashed, it is only a little embarrassing. But, as Haga points out in his book, in other situations the result of acting automatically can be catastrophic. It's important not to assume that actions are innocent simply because they're familiar.

But, what about those late-entrant manufacturers? What was the virtue in having a faucet where lifting the lever releases the water and pushing it down turns it off? If, for example, something falls on the lever, the water (scalding hot water, perhaps) is turned off. That's safer than the other way around. (Even if your cat leaps on the lever, all is well). This is what human engineers call a "fail-safe" system. It is consistent with the idea that mechanisms should be designed for safe operation in unusual circumstances.

That is why, in the wake of the Kobe Earthquake, support shifted to the down-is-off type, which in April, 2000, became a Japan Industrial Standards (JIS) rule.

You have probably already grasped that Haga disagrees with those who say, "If people are careful, mistakes won't happen." He prefers the concept of "compatibility," designing to ensure that humans acting spontaneously do not make mistakes. He also assigns great importance to fail-safe designs that ensure that a glitch does not cause a catastrophe.

"When a medical accident occurs, the head of the hospital bows his head and says, 'It was an inconceivable mistake.' But simply saying that an inconceivable mistake occurred doesn't explain anything. What is important is thorough research that enables us to predict as far as possible what kinds of mistakes people are likely to make in what situations. Then, working on the assumption that misses will occur, steps should be taken to minimize their frequency, to ensure that when mistakes occur they don't turn into catastrophes, and that, in the unlikely event that a serious accident does occur, the damage it causes will be minimized."

IT era human error
How safety can cause errors

Will taking every possible step in designing equipment or systems sharply reduce accidents? Unfortunately, that is not always true. "There are often no guardrails on high scaffolding at construction sites in developing countries. But installing guardrails might not help to reduce the number of falls. People who now walk carefully because there are no rails may feel free to run if the rails are there. That is why there are risk-assessment standards, to show at what level of risk is acceptable, even if some accidents still do occur. In the case of that construction site, if the workers' own standard for acceptable risk is high, their behavior may offset efforts to make the construction site a safer place to work.

Even if safety precautions reduce the frequency of risk, unless the relevant human standard for acceptable risk is lowered, the frequency of accidents is likely to return to its original level. This "risk homeostasis" theory is based on ideas about human inertia and the tendency of human systems to return to their original state–an unfortunate form of homeostasis, indeed.

"In the case of Intelligent Transport Systems (ITS), a warning sounds and the brakes are applied automatically when the distance between vehicles falls below a certain level. This automatic response is said to increase safety. It may turn out, however, that driver behavior will change if these features are introduced, and that issue has not been thoroughly studied. Nobody can deny that developing this kind of technology is important, but if we don't consider how human behavior could cancel out its benefits, we may find that the technology is not as effective as we'd hoped."

Suppose, for example, that drivers believe that their cars will absolutely never collide with another vehicle. How can we expect them to behave? It may, in fact, be safer to leave at least a small element of risk. "Allowing the possibility of error is a difficult proposition to sell, but it wouldn't be an altogether bad thing to allow the possibility of minor mistakes that couldn't lead to major accidents, just to keep drivers on their toes."

The more that technology advances, the more it becomes essential to consider error prevention from unconventional perspectives, because human beings will always make mistakes. "Flying airplanes has been automated to a truly amazing extent. After entering commands in the computer, the pilot has nothing to do but drink coffee until it is time to land. It's a fact that introducing these systems has sharply reduced the frequency of accidents due to human error. But, now we are seeing a new type of error emergence. A Royal Thai Airline pilot taking off from Katmandu was turning the little knob that sets the direction in which the plane would fly. He slipped up and instead of setting it to a 180°turn, he turned it to 360°. As a result, instead of flying south as he had intended to, he flew north and crashed into a mountain near Katmandu. Back when he would have been turning the stick to turn the plane, he would never have turned a full instead of a half circle. New technologies create the possibility of new types of accidents. Careful study of such possibilities is bound to become more and more important."

It is perfectly reasonable to mobilize studies of human error when new products, technologies, or methods of operation are introduced in large transport equipment, cars or products for the home.

"I am often asked by engineers to consult on the mental workload or, in other words, psychological burden imposed by new work processes. There still aren't many cases, however, in which a psychologist's opinions have directly influenced a manufacturing process. This is, of course, something that psychologists also need to ask themselves about. Up until now, Japanese psychologists haven't paid much attention to matters so closely linked to everyday life. In Japan, as in America, we ought to be producing more researchers who work at the boundary between psychology, human engineering, and the study of work processes. Then it will be possible for industry to make more use of 'specialists in human nature'."

Coordinated transport using clustered robots

The mathematics of communication

A series of distinctive buildings, separated by ample space, sit on a site through which a monorail circulates. The scene looks like a life-sized version of a model monorail kit the author saw as a child. Here, in a corner of Tokyo Waterfront City, is the location of the Digital Human Laboratory where Natsuki Miyata works. The setting is almost too perfect for hearing her talk about robots.

I had known about Miyata's research on clustered robots and had sent my request for an interview to the Mechanical Engineering Laboratory of the National Institute of Advanced Industrial Science and Technology, AIST where she used to work. I thought that the research and experiments by which she was trying to get multiple robots to work together in a coordinated manner might tell us something about human nature.

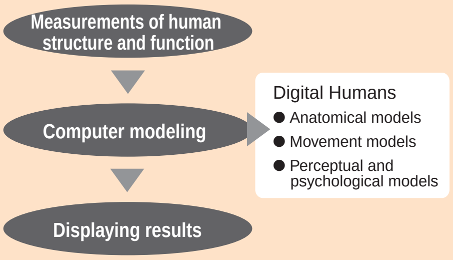
Then I discovered that, starting in July, Miyata had moved to AIST's new Digital Human Laboratory. The words "Human Laboratory" raised my expectations and led to my visiting her at this laboratory, where, for some reason, we see rows of manikins. "Humanity provides, after all, the basic framework for research on clustered robots. Think, for example, of a very simple task that humans perform together–straightening up a room. How do humans work

Natsuki Miyata, Ph.D.

Currently a researcher at the Digital Human Laboratory of the National Institute of Advanced Industrial Science and Technology (AIST), Miyata was born in 1972. She began her graduate studies following her graduation from the Precision Engineering Department of the Faculty of Engineering at the University of Tokyo. In April, 2000, she began working at AIST's Mechanical Engineering Laboratory. She moved to her current position in April, 2001. She recalls that while growing up she loved the machines in the comic Mobile Suit Gundam. Speaking of them now from a researcher's point of view, she says, "To be able to move at will with that many degrees of freedom, the interface would have to be amazing. The best system ever, because it was so simple, was Tetsujin (Iron Man) No. 28."

Digital Human Laboratory

The laboratory's aim is to reproduce the structure and functions of the human body in computer simulations. These "digital humans" will be used not only to understand better how humans behave but also in a wide variety of practical applications in ergonomic product design, for practicing medical procedures, testing human interfaces, and entertainment applications.



Measurements of human structure and function

Computer modeling

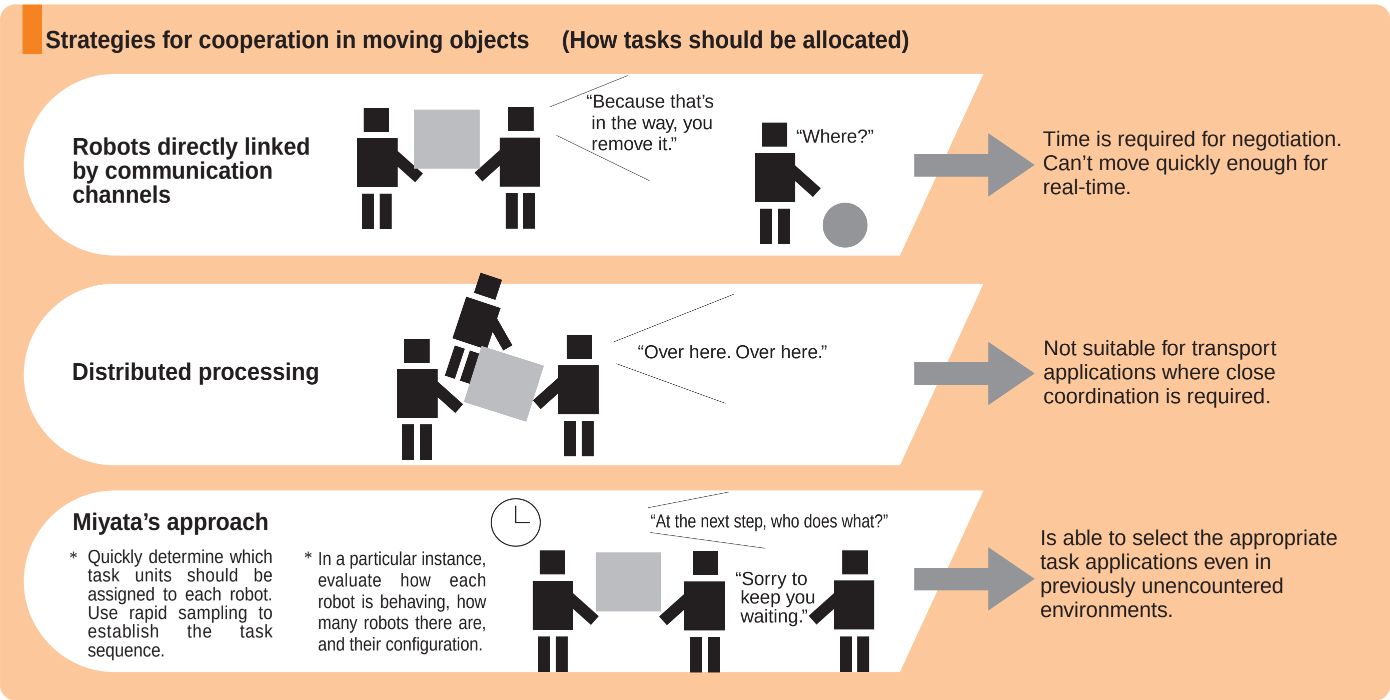
Displaying results

Digital Humans
- Anatomical models
- Movement models
- Perceptual and psychological models

Based on technology for modeling the human body, the lab already has tie-ups with corporations involved in developing shoes with better fit for particular individuals, manikins that more faithfully reproduce actual human forms, and eyeglass frames that don't pinch or weigh on the wearer.

A digital human created by Natsuki Miyata

Miyata says, "Besides the laboratory, there is a common room where other researchers measure experimental subjects to determine forms for their computer modeling. There are robot makers actively involved in creating humanoid robots and physical therapists. It's a lot of fun to be here. Interacting with people from so many different fields stimulates my own research by showing me the goals toward which I should be aiming."



Strategies for cooperation in moving objects (How tasks should be allocated)

Robots directly linked by communication channels

Time is required for negotiation. Can’t move quickly enough for real-time.

Distributed processing

Not suitable for transport applications where close coordination is required.

Miyata’s approach

* Quickly determine which task units should be assigned to each robot. Use rapid sampling to establish the task sequence.

* In a particular instance, evaluate how each robot is behaving, how many robots there are, and their configuration.

Is able to select the appropriate task applications even in previously unencountered environments.

together? One can say, ‘Move that chair over there.’ The chair gets moved. Even if the instructions aren’t very precise, people cooperate so that the room gets properly straightened up. How do they do that? I wondered how difficult the problem really was? Couldn’t we get robots to do that?”

The task that Miyata has set her cluster of robots is to cooperate in moving target objects to specified destinations. As the robots move, they have to survey the surrounding environment and, if they discover an obstacle in their path, remove it. That is what “straightening up” means here.

The first solution that is likely to come to mind involves close interaction between the robots and a clear division of labor. “In the case of human beings, ‘Move it over there’ is good enough. We know that if someone notices that putting it there would meant that it would be in the way later, he will say, ‘No, more over this way.’ But this kind of detailed negotiation involves a huge amount of data. The robots can’t do it in real time.”

Another approach involves distributed processing. Each robot creates its own action plan based on highly local information. The robots are free to move around at will. As a result of repeated trial and error, an efficient division of labor quickly appears.

“Using this technique, there is no need to provide a lot of information before the fact. That has the important benefit of keeping the system from becoming too complex. However, it seemed to me that if we demand the kind of close cooperation that a clustered transport system requires, it was going to be difficult to use a totally distributed system. When we actually set the robots in motion, we would always begin to encounter errors as soon as a robot moved just ten centimeters. When four robots were all trying to move things simultaneously, each moving based solely on its own judgment of the situation, the results were horrific, with many of the things they were carrying broken.”

That led to considering a third approach, “Job-shop Scheduling.” Using this technique, tasks are sequenced in advance and done in a certain, specific order. But that didn’t allow the robots to handle changes in the environment.

“As an approach, this was very close to what I had in mind. However, what I proposed was to have the robots repeatedly sample the environment using short sampling periods, consolidate the information the robots collected, then use it to adjust the sequence of tasks to be done during the next period. This gave the robots some freedom of action.”

This process, in which tasks are sequenced for a short period and information is gathered and fed back, has the flexibility to adapt to changing environments. Also, in the case of rapidly multiplying tasks or tasks with a highly likelihood of occurrence, it is possible to make a tentative calculation omitting a currently scheduled task, leaving a final decision for later. Tasks can then be assigned to individual robots on a one-to-one basis, radically simplifying the choices each has to make.

“It is basic knowledge among robot makers that success lies in using existing techniques. In this case, we needed to find a way to use a fast mathematical technique to develop optimized solutions to a variety of task-allocation problems.”

While the robots would be assigned which objects to pick up in which sequence, the most difficult point was how to assign priorities to tasks. This is where finding a simple, mathematical solution to the allocation problem became significant. “This solution involves a two-step process. The first step is to determine the constants. This requires knowing which tasks must be performed, before others can be performed before the tasks are assigned. The second involves setting parameters, numbers that vary by robot, depending on the time required for a task and which robots are available, allowing us to switch the order of tasks dynamically.”

Aren’t you imagining a robot receiving an order, putting it off, and then long afterward remembering that the task has to be performed?

“Yes, exactly. Changing the temporal priority is exactly that sort of issue. In the case of transport robots, the closer a robot gets to an obstacle, the higher the priority assigned to removing it becomes. At the same time, there are situations in which a task must be done but not enough hands are available to do it. Then, other jobs move ahead of it in the list.”

When the algorithm based on these ideas was tested, using computer simulation, a deeply interesting finding emerged.

When a robot approached an obstacle and was not able to remove it, it would wait until other robots had gathered. Only then would they move it together. Also, when task processing couldn’t keep up and the supervision became sloppy, the robots moved in a controlled manner. They acted cautiously, as if not panicking.

Using a simple mathematical formula produced what appeared to be

cooperative behavior with one robot, in effect, calling to another. The robots that stopped and waited at obstacles seemed particularly human.

“We had had no idea that we could improve the situation by having the robots simply do nothing. This phenomenon probably has something to do with how far it is possible to predict what will happen. At the control level, to minimize risk, the robots can’t see very far ahead and aren’t allowed to move arbitrarily. It appears that robots need a clearly perceived objective. Without it they minimize risk by not moving at all.”

Toward an age of robots and software

Humanoid senses

Following the computer simulation, the next step was an experiment using actual robots. Miyata wanted a physical demonstration that her theory was, in fact valid. The same pattern of behavior appeared.

Now she works at the Digital Human Laboratory. She is in charge of using computer graphics to simulate human motion. She has moved from actual robots to using computer graphics.

I asked her, what is the aim of using computer graphics?

“Historically, the key point in computer graphics has been how well they display natural motion. But I want to do more than create graphics that seem to move naturally. I want to use anatomical knowledge and dynamic calculations to simulate how human beings actually move. It is a problem that requires processing multiple variables. It is as if each joint is a separate robot. Based on the movements of all of the joints, we calculate the movement of the body as a whole. This is the issue with which I am now grappling; it’s an extension of my cluster robot research.”

If cluster robots cannot cooperate, they cannot work smoothly together. “Joints must stay within certain distances of each other. This sets limits to movement, and becomes the controlling condition within which they cooperate.”

What is the goal of reproducing the way people move?

“The immediate objective is to allow computerized manikins to move in more complex ways. For example, when planning an automobile, we could insert a computerized manikin in a car at the CAD design stage. It could get into the car and test its performance and ease of operation. At this point, the manikins used can only extend their arms. If they were able to do what humans do in everyday life and extend their arms while standing up, we would then be able to calculate how much strain movements of differing intensities place on their waists. From observing the how much extra force and reaction is involved, we could calculate more closely effects of the body striking a lever.”

Imagine that today we could call up a manikin with a 20 year-old body and have it move into a Honda StepWagon. “What’s this? This bit that sticks out is in the way.” Getting to that kind of evaluation won’t achieving happen overnight.

“The ultimate goal is to incorporate the results of research on perception and psychology into the factors affecting movements. Then we could explore how people react to buttons of different shapes and colors. Or, if we could model the behavior that occurs when people become impatient or irritated, we could broaden the range of our evaluations. Conversely, by observing the responses of the computerized manikin, we may come to better understand how environmental factors affect perception and psychology. We could look for things like this.”

But computer graphics can only produce robots without real bodies. Once the theory has been refined, Miyata still wants to test it, as she started to do in college, by using actual robots. Her desire to conduct a material test of her ideas has not diminished.

“I used to be involved in a five-year project using the software we developed to control Honda’s P3 Humanoid robot. But when the P3 kicked out its leg at maximum speed, it moved so rapidly and with so much force that I kept quaking and clutching the emergency turn-off switch,” she laughs. “At this lab there are other former participants in the Humanoid robot project. There has been some talk of us working together.”

Progress on humanoid robots has been truly amazing. As a researcher in charge of developing algorithms, she feels like “It’s coming! It’s coming!”

“That’s just it,” she says. “Now that we have such outstanding hardware, we really should use it as a platform in developing new software. That’s how I feel now.”

If robots are to move more like human beings, what algorithms will be needed? This is the problem on which Miyata is now focusing her energies. (Nobody wants to be kicked by a robot!) Robots, too, are becoming more involved in the era of software. “I’d like to see my humanoids flip a table over,” she says.

“Are you trying to recreate the character Hoshi Ittetsu from the comic Star of the Giants?”

“Yes, yes, that’s it exactly. If I succeed, you will have to come and see them.”

“But you will be able to make them mad enough to flip over a table, not just program them to do it? ”

“I’ll make them mad. But first we will do it in the computer. We’ll have them shout, ‘Damn!’”

The age of the gentle robots may start with a cranky father figure.