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Dear Prof. Xie

A Happy CNY to you and your family!

Enclosed is an article on Humanoid Robots for your reading pleasure. Hope you will find it is interesting.

Yours sincerely,

Yihan

# Born to Run

**C**reatures that took human shape without actually being human made their first appearance in recorded human history in Western civilization. These were the beautiful women made of gold described in the *Iliad* (eighth century BCE) by Homer. Much later, in eighteenth-century Europe, automata utilizing clock technologies were constructed.

The word "robot" derives from the Czech *robota* (meaning compulsory labor) and first appears to have been used in playwright Karel Capek's *Rossum's Universal Robots*, in 1920.

Even though studies on humanoid robots are being carried out in the United States, France, and other countries, Western society in general may be accused of lacking in enthusiasm when it comes to building humanoid robots, possibly because of religious or ethical views. Typical of Western representations of robots is the Hollywood film *I, ROBOT* released last year, in which robots are depicted as highly sophisticated machines but with horrible natures.

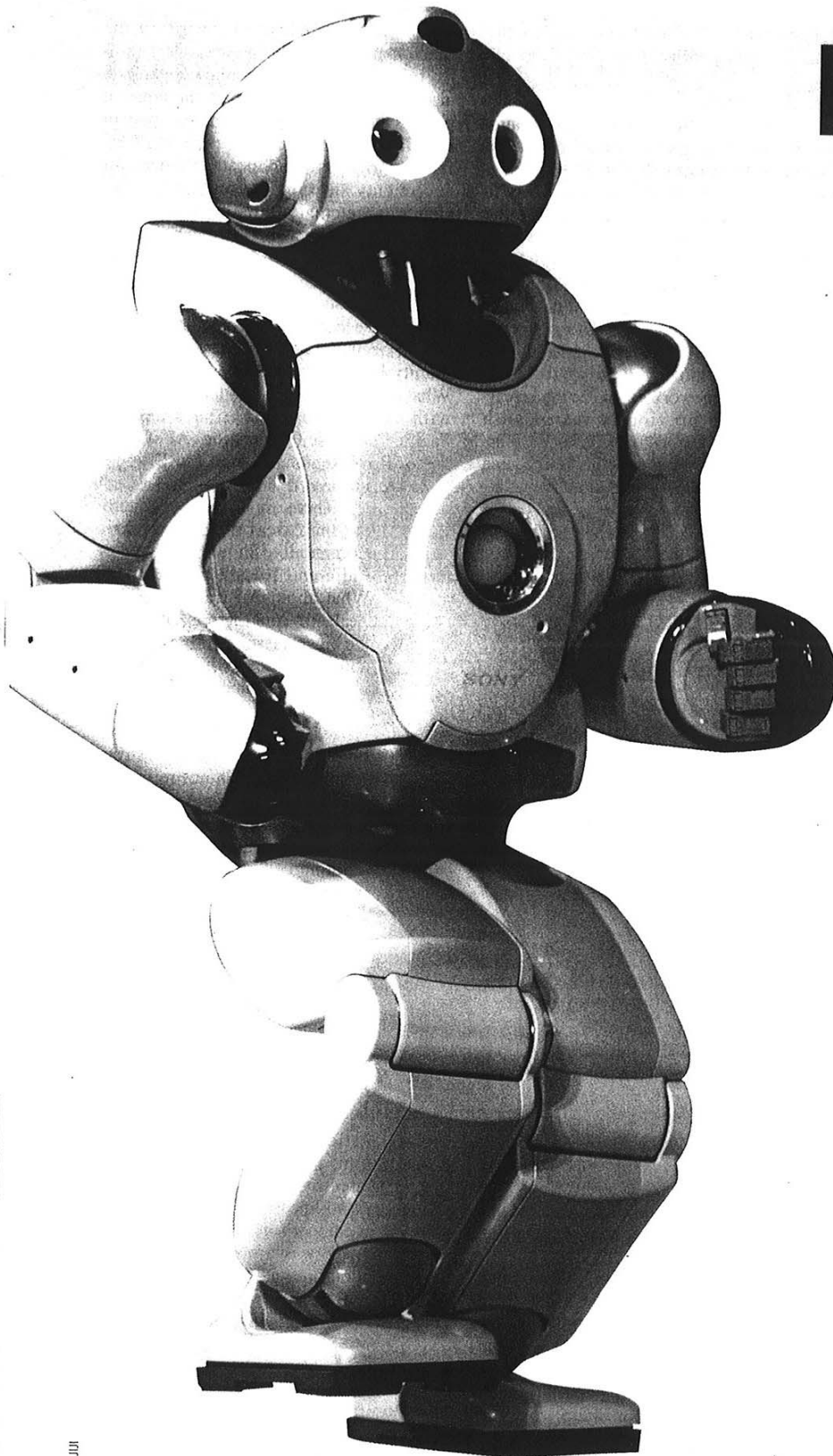
The Russian-born American author Isaac Asimov was more positive in his outlook. He described in his work a relationship based on safety between humans and robots, under the title *Three Laws of Robotics*. These laws stated that first, a robot may not harm a human being, or, through inaction, allow a human being to come to harm. Second, a robot must obey the orders given to it by human beings, except where such orders would conflict with the First Law. And third, a robot must protect its own existence, as long as such protection does not conflict with the First or Second Law.

Asimov also stated in his work *The Caves of Steel*, which dates back to 1954, that robots need to have a human figure so that they can also use the tools people use, without modification.

## Are Friends Electric?

Why are Japanese people so interested in humanoid robots, and what kind of humanoid robots are they looking for?

One underlying factor in the interest in humanoid robots is a fetishism that is universal among people. Cultural factors also play a role. Many people consider human-



Standing 58 centimeters tall and weighing seven kilograms, Sony's Qrio robot offers cheer and healing.

The day is fast approaching when the humanoid robots now entertaining guests at corporate gatherings and the like will move into society proper serving truly useful functions. *The Japan Journal* looks at the background to the initiatives that have driven the development of humanoid robots in Japan since the 1960s, and checks out some of the robots' latest incarnations.

oid robots to be "cute" and "fun," because they resemble humans. People crowd around and cheer humanoid robots when they are put on display.

The release of two robot models that walk on their own two feet—ASIMO by Honda Motor and SDR-3X (QRIO today) by Sony in 2000—marked the arrival of the serious development of humanoid robots. Today, these development efforts are moving in two directions. The first direction is to build an entertainment robot that offers cheer and healing; the second direction is to develop highly practical robots that allow humans to avoid dangerous tasks.

Needless to say, the research and development involved in achieving either objective is difficult. Humans, for example, can walk, converse, and be moved by nature or by cultural and artistic work, without being aware of it. Unless these activities and reactions that come so naturally to people can be clarified scientifically and explained theoretically, functions that are useful for human society cannot be added to humanoid robots. In this respect, humanoid robots are still in their infancy.

Professor emeritus Ishii Takemochi of the University of Tokyo, a doctor of engineering and medicine, has this to say about humanoid robot development.

"The process of growth of a newborn child is a replay of human evolution. When humans began to walk on two feet, their hands were freed for use for other purposes. Respiration, which had formerly synchronized with walking on four feet, also changed, and we became capable of uttering words instead of mere sounds. Walking on two feet is far less stable than walking on four feet, so humans were forced to think about where to step while walking. As a result, they developed the ability to process data at high speed while on the move. These were important elements in human evolution. Yet this concept has not been developed in the research and development efforts for humanoid robots, partly because researchers haven't thought to learn from the evolution of mankind."

Today, one of the major objectives in humanoid robot R&D is to understand humans from a scientific perspective. It might perhaps even be the ultimate objective.



Honda's ASIMO spearheads the company's near-future vision of "one robot for each household." ASIMO is 120 centimeters tall—about the optimum height for household applications—and weighs 43 kilograms.

COURTESY OF HONDA MOTOR

## Karakuri

Looking at cultural factors today, one can be described by the term “*karakuri*” and another by the *Astro Boy* concept.

“Karakuri” (meaning a device, system, or mechanism) is a word coined in the Edo period (1603–1867) for a mechanical setup and skillful mechanism. It refers to technologies and entertainment using dolls and

according to a verse in the *Chronicles of Japan*. Later, in the fifteenth century, *karakuri* became popular as a show. When clocks were brought in from the West in the early Edo period, a technological revolution also took place in *karakuri*. Wooden gears and pulleys, as well as springs made of whale pulp, began to be used to make ingenious mechanisms. These were broadly

Hanzo.” Towards the end of his life, in 1796, he published Japan’s first mechanical engineering book, titled *Kiko zui* (Collection of drawings of mechanical devices). Another popular *karakuri* doll, the “bow-drawing child,” was created in 1850 by Tanaka Hisashige (1799–1881), the founder of corporate giant Toshiba and himself nicknamed “Karakuri Giemon.” The bow-drawing child picks up an arrow by himself and tilts his head before shooting, as if he were aiming at the target, and even misses intentionally at least once every four shots. As can be imagined, the doll incorporates subtle mechanisms.

The parade car *karakuri* that drew crowds achieved the greatest development in Aichi- and adjacent Gifu-ken prefectures, where the skills and a tradition in carving, woodwork, and clothing were also highly developed. The cultural heritage of the land later contributed to the rise of Toyoda Sakichi (1867–1930), who invented the automatic weaving machine, and his son Kiichiro (1894–1952), who founded Toyota Motor Corporation.

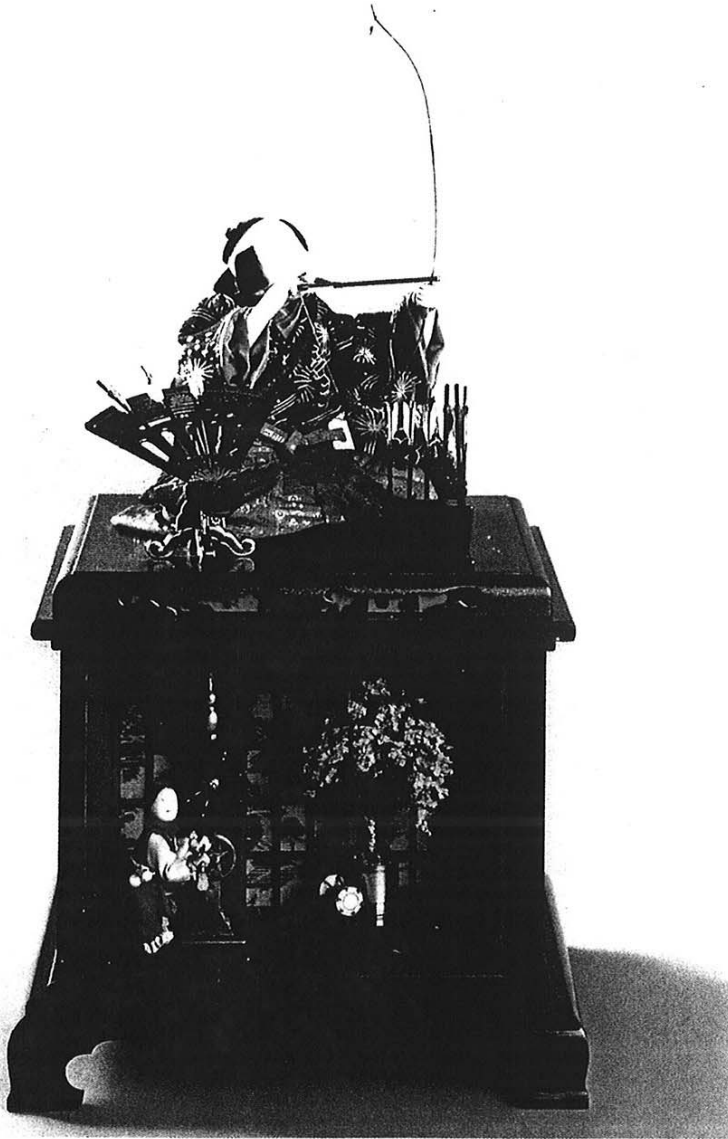
Many researchers working with humanoid robots have shown an interest in sophisticated *karakuri* technologies.

*Karakuri* has certainly influenced the humanoid robots of today. The entertaining aspect of *karakuri* led to the development of Sony’s entertainment robot QRIO, and facial expressions resembling *noh* masks were passed down to the Toyota Partner Robot.

Takagi Soya, general manager of the Manufacturing Technology Development Division at Toyota, was in charge of the Toyota Partner Robot, which was launched in March 2004 and which boasts the ability to play the trumpet with artificial human lips and lung functions. Takagi describes the design concept of the Toyota Partner Robot: “We gave it a facial expression that leaves room for imagination and appears to be laughing or angry depending on the person who sees it, just like *noh* masks.”

## The Astro Boy Generation

Another influence on the many humanoid robot researchers of Japan is the science fiction cartoon serial known as *Astro Boy*, created by Tezuka Osamu (1928–1989) and first appearing in 1952. *Astro Boy* is a humanoid robot depicted as a symbol of peace, capable of understanding the human mind and flying through the sky when he uses his mighty powers to fight for justice. But *Astro Boy* differs somewhat from his Hollywood superhero counterparts. Even though he uses his overwhelming robotic power to defeat evil, he also suffers, as he knows power is not always justice. In addition, he is hurt by society’s prejudice against robots and is saddened at times when he is not understood.



YOMIURI SHIMBUN

Designed by Tanaka Hisashige (1799–1881), this “bow-drawing child” *karakuri* indicates the sophistication of Japanese mechanical playthings 150 years ago.

other devices. In fact, *karakuri* devices have their roots in the seventh century. A craft called a “south-pointing cart,” which is a cart with a mountain hermit figure that pointed to the south no matter in which direction it was pulled, was brought in from China and presented to the Emperor in 658,

categorized into parlor *karakuri* owned by individuals and parade car *karakuri* used in festivals. Both became wildly popular.

Hosokawa Hanzo Naoyori (1741–1796), who created a typical parlor *karakuri* device known as the “tea-serving doll,” was a master craftsman nicknamed “Karakuri



Astro Boy captured the imagination of the American public, but the fictional robot had a far more profound impact in Japan.

This cartoon serial was broadcast throughout the United States by NBC with the title *Astro Boy* from September 1963, and has come to be regarded as one of the outstanding animated picture shows of the 1960s.

"I was influenced by *Astro Boy*. I am among the *Astro Boy* generation. The same is true for many other researchers. *Astro Boy* is like a landmark for humanoid and intelligent robots. In addition, he is a hero trying to preserve justice." So says Hirukawa Hirohisa, who leads the humanoid robot development efforts at the National Institute of Advanced Industrial Science and Technology. A wall in Hirukawa's laboratory features design drawings of *Astro Boy*.

The drawing shows a 135-cm-tall humanoid robot weighing 30 kg. This could be manufactured, but it is impossible to incorporate into the body specifications enabling flight and one-million-horsepower demonstrations. For researchers, *Astro Boy* seems to have been an object for considering scientific reality.

"In one well-known episode," says Hirukawa, "research personnel of Honda were asked by their boss to create *Astro Boy*."

Indeed, actual development of humanoid robots started in 1986 at Honda. The original intention of the project, however, was to develop unique electronic control technologies needed for the automobiles of

the future. But to succeed, Tagami Katsutoshi, who led the project, felt he needed to convey a specific theme to researchers. What came to mind was "Saiyuki," an old Chinese folktale. In the

story, the monkey character Songoku can operate a flying vehicle known as the "Kinto Cloud," and uses a trick to make his alter ego appear.

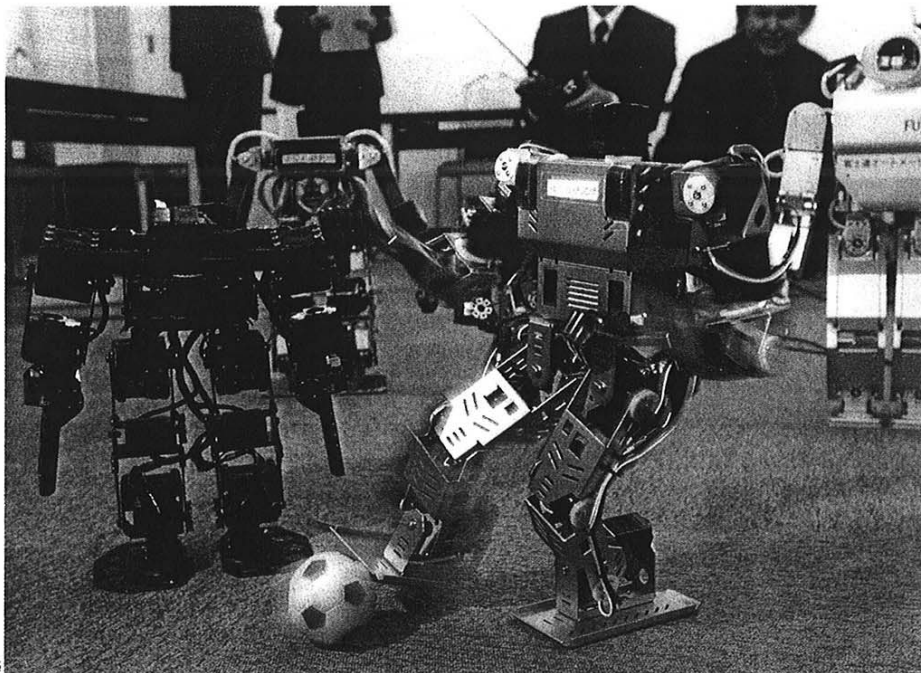
Hatano Yuji, who works in the public relations section of Honda, says, "The Kinto Cloud was like a car, and its alter ego was the same as a robot. To make young researchers understand his intentions, Tagami thought it would be easier if he conveyed the image of *Astro Boy*."

Thanks to this specific image of *Astro Boy*, researchers began developing humanoid robots without hesitation. And now that we have witnessed the birth of ASIMO, the tactic surely paid dividends.

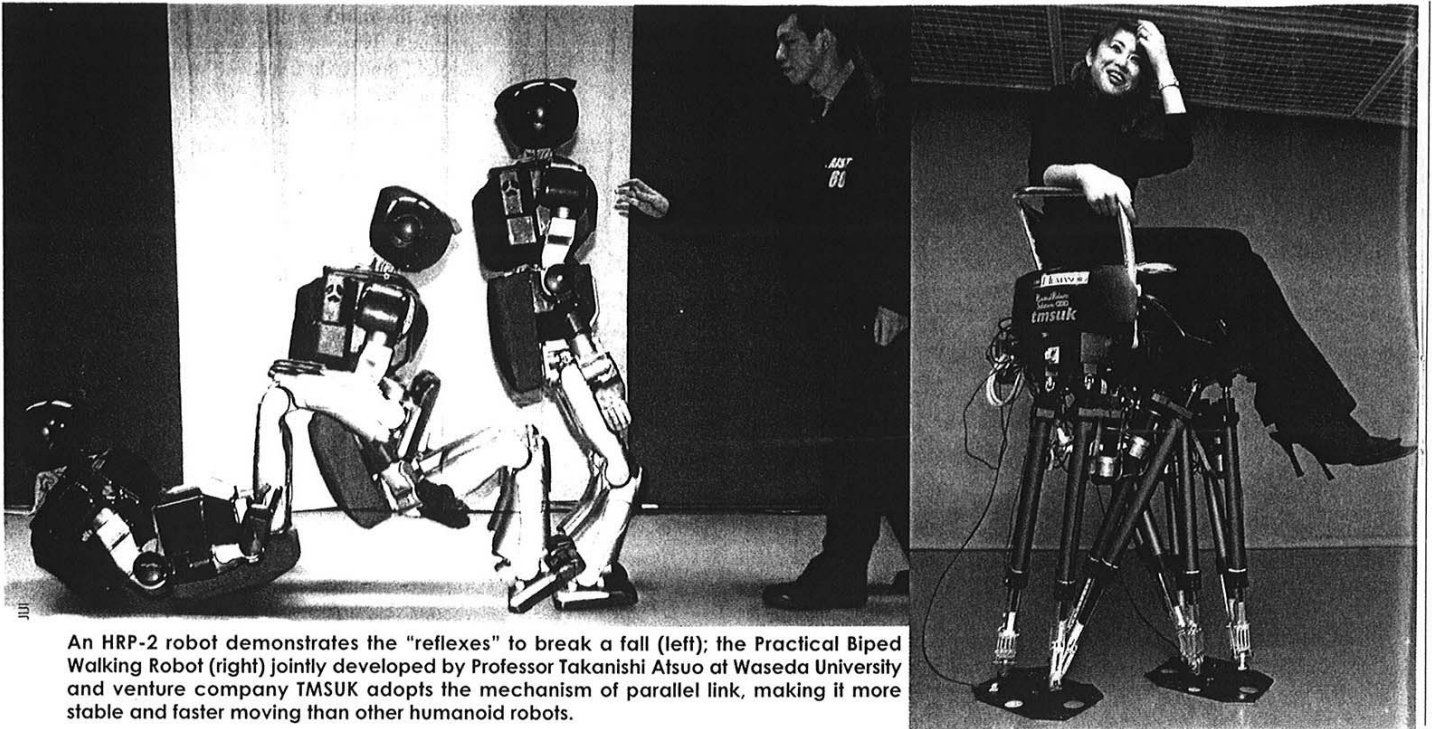
### Best Foot Forward

Images of karakuri and *Astro Boy*, however, are not enough to make a humanoid robot walk. Honda and Sony were able to achieve that milestone, partly with the support of the Zero Moment Point (ZMP) theory proposed in 1968 and defined in 1972 by Professor Miomir Vukobratovic at the University of Belgrade.

Professor Vukobratovic explains: "The foot cannot be controlled directly but in an indirect way, by ensuring the appropriate dynamics of the mechanism above the foot. So the overall indicator of mechanism behavior is the point where the influence of all forces acting on the mechanism can be replaced by one single force. This point was termed the "Zero-Moment Point" (ZMP) (*International Journal of Humanoid*



Robots show off their skills in a warm-up match before the 2005 RoboCup in Osaka, Japan. The RoboCup project aims to develop, by 2050, "a team of fully autonomous humanoid robots that can win against the human world champion team in soccer."



An HRP-2 robot demonstrates the "reflexes" to break a fall (left); the Practical Biped Walking Robot (right) jointly developed by Professor Takanishi Atsuo at Waseda University and venture company TMSUK adopts the mechanism of parallel link, making it more stable and faster moving than other humanoid robots.

*Robotics*, Vol. 1, No. 1 [2004], 157-173).

It took a team led by the late Professor Kato Ichiro of Waseda University to successfully make a robot walk on two feet for the first time, based on the ZMP theory.

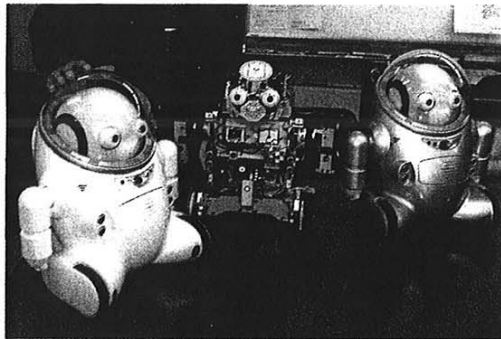
In his article, Professor Vukobratovic writes about this first example of success.

"The first practical demonstration took place in Japan in 1984, at Waseda University, in the laboratory of Kato Ichiro. The demonstration involved the first dynamically balanced robot, WL-10RD of the robotic family WABOT."

Even though Professor Kato had been involved in studies of the WABOT humanoid robot since the early 1960s, R&D at the university progressed only slowly because of budget limitations, and no truly notable trend emerged. Then, the Japanese economy entered a prolonged

slump following the collapse of the economic bubble, and corporate Japan focused on restructuring. In that environment, robot development looked likely to stall.

But studies in humanoid robotics took off when Honda announced in December 1996 the self-driven robot P2, which walks on two feet. It was ten years since Honda had started development work.



A huge international market is developing for robots like Sony's AIBO (left) and Futaba Industrial Company's Ibot (above), entertainment and healing robots that interact with their owners.



COURTESY OF SONY CORPORATION

Notes Hirukawa: "It was astonishing to see Honda's P2, with its upper body [WL-10RD was a legs-only robot] and walking smoothly on two legs. Seeing it with their own eyes, humanoid robotics researchers were certain that they could make it [a humanoid robot] walk. This was

an enormous boost in our studies."

Later, Hirukawa also succeeded in getting HRP-2, the robot he was developing, to walk on two feet, with cooperation from Kawada Industries and Honda.

P2 is 182 cm tall, and weighs 210 kg. Its body incorporates a computer, motor drive, battery, walkie-talkie, and other devices. It walks around freely, and is also capable of climbing up and down stairs and pushing a cart. It was not realistic, however, to have a robot of this size work together with humans, for safety reasons in particular. P3 was launched nine months later, and is 160 cm tall and weighs 130 kg. ASIMO, announced in November 2000, is 120 cm tall and weighs 43 kg. The robots became lighter as their functions improved. ASIMO can converse with humans using voice recognition technology, and moves as instructed thanks to image recognition technology. Incidentally, the name "ASIMO" stands for Advance Step in Innovative Mobility, and is not in fact derived from Asimov.

Today, Honda is pushing ahead with the development of humanoid robots, with its near-future vision of "one robot for each household." Even if the robots in this vision are even more advanced and lighter, their height is likely to remain the same as it is with the current version. For a humanoid robot to work in the human living environment, it cannot be made any smaller.

Honda is a company that has consistently delivered high-quality products. Where will it ultimately take ASIMO? Considerable interest is focused on the answer.

## My Robot

Sony is aiming to create a new market for robots, so the humanoid robots it is creating are small. The company's SDR-3X (later SDR-4X, and then QRIO) entertainment robot that was announced in 2000 is small, with a height of 58 cm and weighing just 7 kg (QRIO). QRIO converses with humans, walks, and dances, and will even kick a soccer ball when instructed to do so by a person.

The first robot launched by Sony was a dog-shaped creation known as AIBO. Designed for household use to offer personal entertainment and healing, AIBO went onto the market on June 1, 1999. The initial run of 3,000 units sold out in just 20 minutes. (Another batch of 2,000 units sold out in the United States in about the same time.) Although a pet robot, AIBO has joined human society. In this regard, the humans have entered the age in which Asimov's three laws need to be applied.

Sony says the current capacities of AIBO don't necessitate consideration of the level imagined by Asimov, but the company has suggested that rules similar to the three laws are necessary. The only difference is that, "The robot should listen to people's complaints patiently, but is allowed to complain itself once in a while."

Starting in the 1970s, factories have increasingly been automated in Japan, through the active development and introduction of industrial robots. Indeed, of the 807,772 industrial robots being operated in the world today, 348,834 are used in Japan (*World Robotics 2004*, the United Nations Economic Commission for Europe [UNECE]). However, movements to destroy machines, like the Luddite Movement initiated by workers in Britain in the early nineteenth century, have been missing from Japan. Workers in Britain at the time felt threatened by the Industrial Revolution and the adoption of machinery, which implied they could lose their jobs. In contrast, Japanese factory workers are known to show affection to inorganic industrial robots, giving them the names of popular singers, for instance.

"Tamagotch" is a toy launched by Bandai in November 1996, and is a game machine in which the user raises a digital pet that appears in the display. And just as industrial robots earned affection, a similar phenomenon was evident with this toy. When the toy was launched, many users gave it a name and clothes to wear, just as they do with their pets, and formed strong ties with them.

Professor Sherry Turkle of MIT points out that, "As a species, we're programmed to attach to the things that we take care of and that blossom under our care." The professor continues, saying, "We do care for

robots. People who have Sony AIBO robot dogs are teaching them tricks, are thinking about their welfare, are bonded with them, and want to take their places. Children who have created pets online are worrying about those pets, and whether they've taken care of them, and whether they should get them a new coat. But it's a different kind of caring. Just because you have a robot dog doesn't mean that a biological dog should lose all of its allure" (*Discover*, Vol. 24 No. 06, June 2003).

The same phenomenon is observed with vacuum cleaner robots sold by manufacturers in Europe and the United States. Examples include Roombas, manufactured by iRobot Corporation of the United States, and Trilobite by Electrolux in Sweden. Many users in the States talk to vacuum cleaning robots and take them on holidays. Some have even called the manufacturers or sent them letters, poems, and photographs, to express gratitude for their creation. Many have given the cleaning robot a name, and in many cases beg that the original machine be returned instead of a new one when they bring one in for repair.

Both Tamagotch and AIBO are deliberately raised by their owners, and they respond in some way to approaches made by people. On the other hand, industrial robots are mere machines and Roomba and Trilobite are vacuum cleaners that work based on a program. Despite this, people develop affection for these machines.

According to *World Robotics 2004*, the number of robots in use in homes around the world will increase by 6.65 million by 2007, from 1.3 million as of the end of 2003. The market for robots for cleaning and other household chores is expected to grow to 2.67 billion dollars, while demand for entertainment robot should rise to 4.07 billion dollars.

## Substitution

Jan Karlsson of UNECE, who edited *World Robotics 2004*, forecasts, "They will not only clean our floors, mow our lawns, and guard our homes but they will also assist elderly and disabled people with sophisticated interactive equipment, carry out surgery, inspect pipes and sites that are hazardous to people, fight fires, defuse bombs, and be used in many other applications."

That's part of the vision that drove Hirukawa to develop the humanoid robot HRP-2 in the Humanoid Robotics Project

(1998–2003), pursued jointly by the public and private sectors.

HRP-2 could replace humans in operation of industrial vehicles, and could be used in plant inspection, joint outdoor work, human services, and building and domestic services. These are areas that can benefit from the human form of the robots, as Asimov pointed out. In addition, the cost involved in making one humanoid robot is far less than that needed to turn heavy equipment into a robot.

The sales target for HRP-2 is ten units by 2005 for research and development, 100 by 2007 mainly for entertainment use, and 1,000 in total by 2010 for dangerous work. Kawada Industries Inc., which has been jointly involved in developing the robot, sells the robot for research and development for 38 million yen (360,000 dollars). The target of ten units has already been attained in 2004. If 1,000 units were sold at a unit price of 10 million yen by 2010, the market would represent 10 billion yen (95 million dollars), sufficient for establishing robot manufacturing as an industry.

But could there perhaps be a blind spot in the development of humanoid robots in Japan?

Hirukawa expresses cause for concern.



Toyota Partner Robots of different shapes and sizes will demonstrate their prowess on a variety of musical instruments at Expo 2005 Aichi, Japan.

"For now, humanoid robot development in Japan leads the rest of the world by far, and the major player here is the private sector. But companies could terminate their R&D programs if they don't produce a profit, irrespective of whether it is joint or independent research. That's the scariest scenario in work on humanoid robots."

### Toyota Motor

Even though Toyota Motor is a late starter, it offers plenty to look forward to with its newly launched Toyota Partner Robot.

Toyota, of course, is the company behind the Intelligent Transport System, a system that enables automobiles to drive automatically and which can be regarded as something like a gigantic robot. The Partner Robot, developed by Toyota for Expo 2005 Aichi, Japan, by contrast, is strictly for fun—at least for now. At the Expo, there will be Partner Robots that play the tuba, drums, horn, and trombone to entertain visitors.

Why develop humanoid robots that play musical instruments?

"The functions needed to play music can also be used by robots to handle the same tools as humans do. What we have in mind is that in the future robots or robots and humans will work in synchronicity," explains Takagi.

For the time being, Toyota does not plan to make a business out of humanoid robots. Still, Takagi is enthusiastic. "The future potential of robots will be on display at Expo 2005 Aichi. Examples include as-

sistance in the home and offices, nursing care at hospitals, manufacturing work at factories, and as vehicles for humans."

Humanoid robots and their human owners are likely to form their deepest ties at home. If this is so, Toyota might have the edge: it operates in a residential business that Sony and Honda have yet to enter.

Toyota insists that the company is interested in robots that support people in practical endeavors. The primary interest seems to be in future applications for manufacturing and automotive technologies, especially in vehicle control and safety technologies in automotive development. Toyota has gained for itself achievements and assets through its pursuit of safe, practical automobiles.

And this has in turn led to growing, albeit still largely unexpressed, expectations for Toyota, as the giant seems to have awakened.

### Quantum Robot

Many tasks need to be addressed before society will accept coexistence with robots, including the adoption of rules. A clue can be found in the evolution of information technology.

At the end of the twentieth century, a dramatic transition took place in which the conventional image of outer space was replaced with that focused on quantum space. Scientists demonstrated the existence of the so-called entanglement phenomenon, in which objects at locations tens of thousands

of light years distant influence each other instantaneously. This phenomenon had previously been inconceivable. The University of Tokyo's professor emeritus Ishii says that entanglement is the key to opening up the post digital age, and it could impact humanoid robot development also.

"Information processing in the twenty-first century will not involve the either-or approach embodied in the choice between 0 and 1. It will instead involve an approach that allows both 0 and 1 to be chosen, and several such choices could even overlap and become entangled. This enables a parallel reality to emerge, which takes place simultaneously among multiple parties instead of two parties."

Is "parallel reality" already, well, a reality?

For example, teleconferencing is possible anywhere in the world via the Internet thanks to the development of both hardware and software communications technologies. Acoustics are not that different from those experienced with an ordinary telephone, and dialogue is not interrupted. Communications via websites also enable many participants to exchange information almost simultaneously, which is different from exchanging e-mail. In addition, both computers and mobile phones can be used as terminals. This kind of multi-dimensional, simultaneous, and entangled communication is already available.

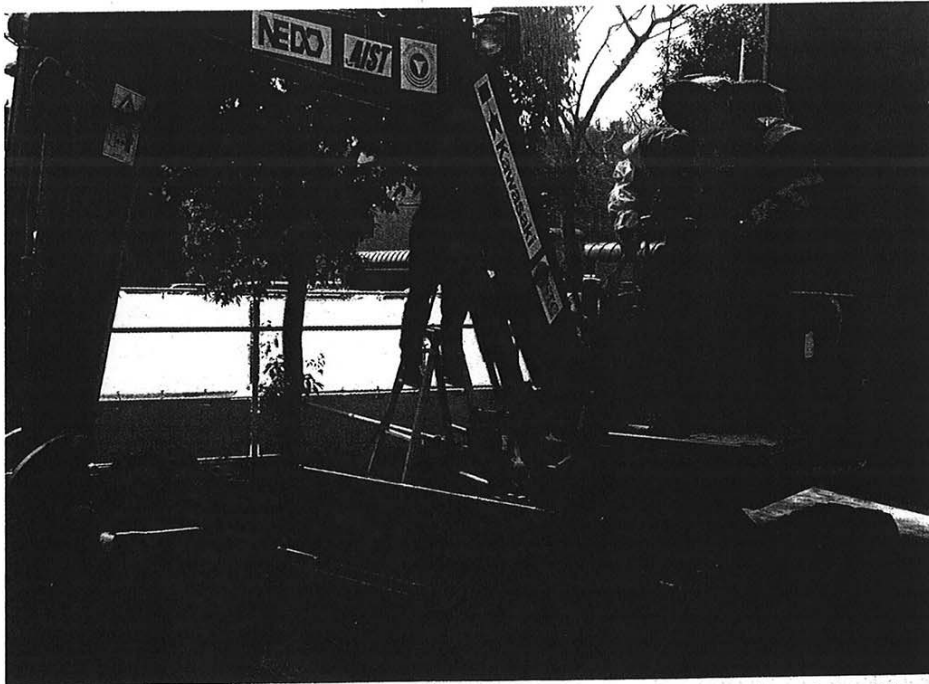
"This is to prepare for the future, and we are sharing a 'future mentality' through the process. Unlike news distribution and e-mail transmissions, which are one-way, a parallel reality is being anticipated. The content of information exchanged might be trivial, but what's important here is that people are enjoying it, and the number of users has grown each day."

Ishii continues:

"The twentieth century was the century of automobiles, and the twenty-first century will be the century of humanoid robots."

The infrastructure required to achieve this vision are quantum computers and quantum communications technologies, in addition to the new concept of space discussed above. Quantum humanoid robots that employ these technologies are likely to go beyond merely assisting humans. They will take on roles of multi-dimensional communications stations in both official and private scenarios, transcending time and place and fulfilling their functions whether they are accompanied by humans or not.

In time, a robot generation capable of harnessing these technologies will emerge worldwide. If this happens, the Japanese initiatives that started with *karakuri* and *Astro Boy* could serve as a model for future society. ■



An HRP-2 robot demonstrates its ability to operate a backhoe in wet conditions. According to developers Kawada Industries and AIST, there could be 1,000 HRP-2 robots at work by 2010.