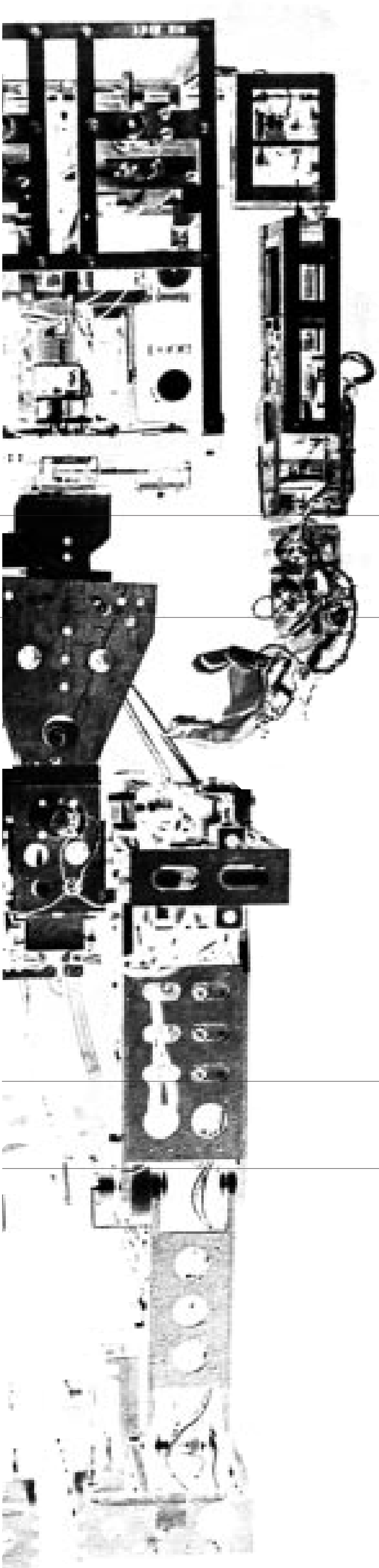


ASADA Minoru and SAKURA Osamu

Robot Ecosystems

ASADA Minoru

SAKURA Osamu

The Trials and Topics of RoboCup

ASADA Minoru── About six years ago KITANO Hiroaki,[*1] KUNIYOSHI Yasuo[*2] and myself started a project called "RoboCup." It was a new sort of challenge to the approaches to AI (Artificial Intelligence) prevalent at that time in the West. Lately it has become quite well known, but it emerged from a series of workshops, actually.

Robotics scientists use the phrase "behavior skills" to distinguish embodied intelligence (intelligence which emerges from the interactions of the hands, legs, head and other physical body parts) from the intelligence of symbolic reasoning. There was a debate among roboticists about whether such embodied intelligence could rightfully be called "intelligence," or whether new aspects of intelligence could be extracted from such approaches. In 1993 we were looking at ways to express it.

Mr. KITANO had just come back from a robot contest sponsored by the AAAI (American Association of AI). He said it was boring. They were doing things like holding time trials to see how quickly robots could take a paper cup off a desk. Their robots would first observe their environment with a video camera, and reconstruct world models based on these images. They would sit perfectly motionless for 10 minutes doing this, and then move 10 cm or so and then repeat the process. Classic symbolic reasoning, but not really a spectator sport, nothing to capture the viewer's imagination. That's where we came up with the idea of having the robots play soccer, and the result was RoboCup.

At the time my research group had been developing shooting robots, a departure from the industrial robots made to serve in factories, something a bit more fun. We were interested in instilling some of these new concepts in them, and both Mr. KITANO and Mr. KUNIYOSHI had similar concerns. In the fall of 1993 we decided to hold the first RoboCup in Nagoya, in 1997. We had four years to prepare. Now, this may look like only so much fun and games, but as a research theme it was quite meaningful, really defining a lot of priorities for us, even among complex issues like multiagent hierarchies.[*3] It is even being proposed as a standard problem.[*4] Just as winning at chess remained a standard problem for years for symbolic reasoning in AI, so might RoboCup become a standard problem for embodied intelligence. Something which AI researchers everywhere can attempt to solve.

While as one of its organizers I believe that the RoboCup contest is an interesting general theme, personally I expect that they become used as a basis for developing the model of cognitive robots, including learning, evolution and cognition processes. Chess was a standard AI problem for 40 years, but once IBM's Deep Blue had beaten world champion Garry KASPAROV, it had achieved one level of completion. It is important that our new objectives develop a contrasting set of thematic concerns.

Chess was static, dealing entirely with perfectly organized information, in a one-to-one battle of the wits. RoboCup, on the other hand, deals with multiagent hierarchies. What is decisive about this is, I suppose, the existence of multiagents making autonomous decisions towards a common purpose. This is a problem for which there is no final goal. I think that this is the essential difference, and solving it is our mission. We need to discover how to create the robots so that they achieve a sense of society—as surely they must if they are to work towards a common

Soccer server screen shot

goal—including ways of regulating themselves and cooperating with others. We need to explore exactly how far they can evolve from emergent behavior based solely on the design of their internal structure.

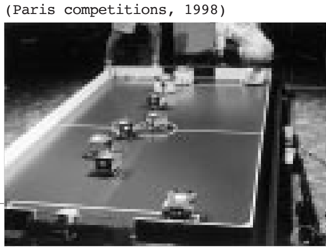
There are three leagues in RoboCup. The first is the "simulation league," for those who haven't the financial, human, architectural or other resources to actually build working robots. The games are played out in software on a "soccer server," so it's a league that's easy for even computer scientists to contribute to! (laughs) Each team consists of 11 programs (one for each player), so a total of 22 programs run simultaneously in a competition between two teams. It looks like a video game, though because there are 11 programs in contest with 11 other programs, it involves issues of complete dispersal, flocking behavior, and other problems associated with how to gain coherent, or at least coordinated learning behavior. The simulation agents are made to have characteristics like the physical robots with their 90 degree visual fields, using video technology, meaning that things become more vague with distance, more precise up close. They can exchange information with their teammates, though their opponents can also overhear them. Because they're "live," they can try and fool their opponents, or engage in noise battles. If they rely on too much transmission power, however, they naturally expend their energy, and fatigue more easily, just as they will fatigue if they expend too much energy too early on in the game. The simulation league reproduces these kinds of "realistic" conditions, including having the players adhere to "soccer-like" movements.

The other two leagues use actual robots, one for "little," and one for "middle" sized units. The "little" robots are roughly 15 cm in diameter. Equipping them with sensors, video apparatus and CPU's was beyond the scope of the technology at that time—though it is possible today—so we created instead five robot bodies operated by one CPU, on a playing field with one observation camera, affording a continuous view of the entire playing field, mounted on the ceiling. We're using a ping pong table as our field, and playing with a golf ball.

The robots from the "middle" league are around 45 cm in diameter, and because these units can each carry their own perceptual gear, the ceiling cameras have been forbidden (although they were permitted in part of the first meet in Nagoya). These robots each act on their own, relying purely on the information received from their video apparatus. The fields in this league are nine times that of a ping pong table, or about one fifteenth that of an actual soccer field. At present, they aren't able to make "throw-ins" and so

RoboCup “Middle League” field
(Paris competitions, 1998)

RoboCup “Little League” field
(Paris competitions, 1998)



we have the field surrounded by a wall. It's actually more like ice hockey, but there just aren't as many hockey fans as there are for soccer (laughs), so we're calling it "soccer."

The reason that we didn't select baseball is that most of the action occurs between the pitcher and the batter, and that the rules are so complex. In terms of simplicity of instantaneous attack and protection, and sharing of space, one other game in consideration was basketball, but dribbling was too difficult for most robots. Soccer was just the simplest available.

SAKURA Osamu——When I was researching chimpanzees in Africa, the local kids used grapefruits as soccer balls. You're right about soccer being a simple sport. Maybe that's part of its attraction.

ASADA——Both for us and for the robots, the rules are simple and easy to work with. We've already got enough on our hands, keeping 11 robots in competition with each other. Our stated final goal is to be able to take 11 humanoid robots to the world cup in 2050, and defeat the champions. In other words, the solution of a new standard problem, much like defeating the world's grandmaster in chess, was the solution for a standard problem for some 40 years.

SAKURA——Originally they estimated that computers would be able to defeat humans in chess by the 1960s, though it actually took 30 years longer than expected. So while we might say that soccer with humans is a goal for the end of the 21st century…….

ASADA——I'd be 97 years old in 2050, so I have no assurance that I'll even be alive at that time. Take for example the time frame for evolution from the Wright brothers' invention of flying machines to the commercial application of the jumbo jet. Predicting the potential for growth in scientific technologies is extremely difficult, even for things previously deemed impossible. The computing power that used to fill an entire room now fits in one's pocket. Some people say that considering scientific advances like this, the idea of a team of robotic humanoids beating, if not the world champions, then at least a team of ordinary mortals, does not seem that out of the question.

SAKURA——I find the fact that you, Mr. KITANO and Mr. KUNIYOSHI each independently came upon the same ideas at the same time quite interesting. Throughout history, at the beginning of important movements we often find places where several people come upon strikingly similar ideas at the same time. Take for example the great Hungarian scientist John Von NEUMANN (1903-1957). From the Hungary of his youth also came the POLANYI brothers (Karl, 1886-1964, and Michael 1891-1976), György LUKACS (1885-1971) and many others. For whatever reason, there are many synchronicities making prewar Hungary a sort of "smart spot" on the map. DIAGHILEV's (1872-1929) Ballets Russes must have been a similar phenomenon, having NIJINSKY and KARSAVINA dancing to music written by STRAVINSKY or RAVEL, in front of sets designed by PICASSO or to a script by Jean COCTEAU. In many genre we find that there are periods and places that have attractors, if you will.

One other thing that I thought was interesting was how you mentioned that chess was the standard problem in the West, whereas Japan, being a latecomer to the field, was in effect exempt from this issue, and in fact may have gained a kind of "late justice" in having a fresh position to envision the next generation of issues from.

ASADA——I had never really thought about it that way. It was more a matter of Mr. KITANO coming around and discussing the idea with me when I had already begun researching soccer playing robots. Mr. KUNIYOSHI was onto very similar sorts of things.

SAKURA——And none of you had any idea that the others were doing this, right?

ASADA—— I'm sure that we weren't completely ignorant of each others' existence, but we certainly didn't know of such projects, no. To be frank, Mr. KITANO was researching it from an AI point of view, and Mr. KUNIYOSHI from a robotics standpoint, but the ideas that they were able to explore just weren't all that interesting. They were looking for a project that would be more productive. That's really what it came out of. Mr. KITANO's thinking doesn't really mesh that well with most Japanese anyway, he really just wants research themes that are engaging to himself, but that ingrates him more to Americans and Europeans than it does Japanese. I do think that your perception of our synchronicity is interesting, though.

A Robot with Vision Wants A Body

SAKURA—— My understanding is that you were originally interested in researching machine vision, which then led to work in motor skills and body issues. Where did you find the limitations to purely visual research, and why did you move on from those studies?

ASADA—— I felt limitations in recognition issues themselves. At that time, I was interested in machine recognition, so I entered research in the fields of pattern recognition and computer vision, but I didn't realize what I was getting myself into. The problem you're faced with is, to give one famous example, asking a machine "Is this an orange or an apple?" The machine takes a picture of an apple, makes analyses of color, shape and size, and calculates that a round red object, approximately 15 cm across "is an apple." But how do you know that it actually recognized it as an apple? When we recognize an apple, we're not only relying on visual recognition. We have senses of smell, touch and weight. When we bite into an apple we taste the tart sweetness. Our gums might even bleed. We have so many ways of recognizing it as an apple, and it is only through the sum of these that an apple takes on the meaning of what we know to be "apple."

We live in a three-dimensional environment, and the experiences of modeling "apple" and recognizing "apple" take place simultaneously in our minds. There is simply considerable doubt in my mind that bypassing that process, and simply using template matching[*5] to tell the computer that an apple is something which is "red, round and about 15 cm in diameter" actually produces recognition. It is not the symbols, but the body which is important. Only from having a body—that holds the apple, touches it, smells it and bites into it—do we finally learn what an apple is. I believe that the semantics of recognition come from our corporeal experience, and not from the symbolic confines of a computers' interior.

SAKURA——From the perspective of someone who researches living creatures, the faculty of vision is an extremely high level information activity. Most mammals rely on their sense of smell as their primary information medium. Humans and other primates are the only ones who do rely on vision first. Among all other animals, birds are about the only ones that rely on vision. Most can only see in black and white, or only distinguish some brightness or darkness, for example. A sense of smell or pheromones, in short sensitivity to chemical compounds, is the primary sensory medium of most living things. This is why if we trace the process of animal evolution in terms of system lineage occurrence, physical recognition comes first, and slowly finds sophistication, with visual recognition coming really much later.

I always thought it interesting that, because it is humans that are doing the research, when they begin to build robots, the visual faculties always "naturally" come first. Or when doing AI research, they always tend towards linguistic processing, and quickly come to the extraordinarily high barrier that this presents. But what you're saying is that researchers are recognizing the limitations to this approach, and changing their AI and robotics approaches to more closely reflect other characteristics of life on earth?

ASADA——Well, that's precisely what I've done. And mechanics issues are exactly the same. When you begin researching human recognition, there is a kind of tacit approval for dealing with the visual faculties right from the beginning. The problem is that, precisely as you've mentioned, vision is a capability that only came at the end of a long process of refinement. Even then it is only one element. And when you try to study processes of recognition in a living environment, it is futile to use only this one element, because you invariably run up against the frame problem.[*6] That's why you cannot look at vision, or any other function, without looking at issues of the entire body.

You also mentioned the issue of language. This is another area that can only be begun to be understood from body issues because visual information only finds currency in the context of the robot's relation to its environment being abstracted, behavior patterns emerging from the robot's relations with specific situations, and these becoming symbols within the stimulus-response diagram.[*7] In other words, codifying the robots' reactions to reoccurring situations. It is not that these were symbols to begin with, but rather that their conduct produced a symbol. Well, I'm wishfully expecting that a type of language may emerge when that symbol is shared by multiagents.

In the case of RoboCup, there are multiagents in collusion, so it is essential that some form of communications language emerge. Moreover, this language must be quite tacit, so that once "eye contact" has been made, both players share a common symbology. If this is indeed possible, then a case can be made that a common linguistic structure has been established. This is, of course, not simply an experiment for the unit's visual faculties. There are many experiments that I have in mind which include linguistic functions. I have many test cases to articulate.

SAKURA——In the spring of 1998, when we were both on the panel at Yokohama's Minato Mirai, the topic of a "theory of mind," concerning how animals understand each others' feelings came up. It is commonly thought that when humans understand each other

they do so through language, when in fact any animal communicates, it is primarily through eye contact and implicit gestures. And your comment was, if I recall it correctly, that when it came to porting these to a robot, the operating algorithm itself has to change. Now I'd like to ask, simply, if you know of any computer program presently available that would allow us to do this?

As someone admittedly unfamiliar with the issue, I imagine that because computer programs are languages, the discussion must begin and end with how to best use them. And yet, issues of "theory of mind" and understanding the other come not from usage, but from the murky and ill-defined elements which "emerge"[*8] into language as a structure of and for understanding, and therefore, there seems a very real obstacle that remains completely unaddressed.

ASADA—— When considering the structure of the robot's brain, you need to clarify whether your concern is in creating the essence of language, or whether you're using it as a tool for imagining how to reproduce language. For example, if you were able to use a wetware (biological) body, the changes in the body's structure would invalidate all concepts of traditional computers. I'd be happy to be able to make it that far, but in my research facilities we're busy trying to verify important concepts through simulating linguistic processes. Creating a body capable of growth is pretty difficult. Right now we're sticking with a fixed mechanical one that runs on computer software, and tinkering with the mechanics while we look for our results. Of course, in the end we will need to consider evolving wetware bodies or we will never reach the truth about our work.

Robotic Mortality

ASADA——To change the topic a bit, I think that the ultimate issue is whether the robot recognizes its own mortality. A sense of one's own death is the real condition for the emergence of self. Unfortunately, the brains we're working with aren't up to the task. The autonomic nerve isn't developed yet, so it can't even tell where it hurts, or feels out of shape. Only when the robot has an awareness of its creation leading to its death, in short, when a sense of time is possible, will we finally be able to return to the analogy of the biological animal. To test this we will need a body that biodegrades, and this will bring us to wetware. Right now we have motors and gears, a body made of steel and plastic. If a gear is missing the robot doesn't feel "under the weather." To create a robot capable of replacing its own parts is completely within the realm of possibility. They could have robot hospitals where they go and request "a new arm, please, this one's no longer performing to spec." They need an autonomic nerve for even this, though.

Actually, this topic is related to the idea of robots eventually playing against human beings, because the robots will have to be able to feel pain for it to be a fair match. A human being can have a concussion heading a ball. We can't have the robots indifferent to their battle scars. (laughs) Yes, the robots have to have bodies that feel the bruises just like the humans. Precisely as in ASIMOV's Three Laws of Robotics,[*9] the robots need to learn to protect their own bodies.

SAKURA—— In order to be able to monitor themselves, right? And this is an essential function?

ASADA—— That's something that we haven't worked out yet.

SAKURA—— Just monitoring them with language, it's hard to imagine how you would arrive at "death." I believe that death and procreation are two sides of one coin. Death is the reset button after reproduction. By the previous generation passing on, the next generation is provided for. Life is because death is.

ASADA—— With robots, when their bodies become aged, it seems like you should be able to just pull out their brains, and put them in a new body, but in fact the whole point of what we've been saying is that it is through the body that the brain evolves, so, in fact, just replacing the head would be a moot exercise.

SAKURA—— It would be a problem of aesthetics? (Laughs)

ASADA—— When the media covers the RoboCup competitions, the single most common phrase that they use to describe it is, "robots equipped with artificial intelligence." I really wish that they'd knock it off. No matter how carefully you explain to them that it is not a matter of AI being here and bodies there, that in fact the intelligence emerges precisely because of those bodies, they run back to their office and print it as "robots equipped with artificial intelligence." If we tried taking their brains out and replacing their bodies, the value of who they are would be changed. It would be just like Jerry Lewis, in *The Nutty Professor* (1963). Change the bodies and everything else changes with it. The body changes the sense of values, and what is imaginable. Just changing the heads won't work, either. What we need are biodegradable bodies. Then we'll have to deal with reproduction and everything will get strange. That's where the real questions begin.

SAKURA── To put it another way, if you don't manage that aspect properly you'll never arrive at incalculable intelligence.

ASADA── We'll never get to wonder "what they're up to today?" Of course, there are a lot of limitations. Should we give them a default one-day time cycle, or let them infer their own time frame from their environment? A 12-hour period might be one day to a robot. Whatever the conclusion, if we don't at least see a concept of time emerge in them they'll never get a recognition of their own selves, far less that of others. Awareness of the "other" comes with senses of past-present-future. Living on an axis of continuum is what allows for an understanding of others' actions.

In soccer terms, we need to create robots capable of feinting actions. Feinting means a psychological grasp of the others' actions, that they can read beyond the surface of what is presented. You need to have a sense of self to fool others. You also have to be able to stand in their shoes, see what they're seeing, know who they are. Whether this is something which is genetically or experientially stipulated is an essential point.

SAKURA──That's interesting. It does implicate both nature and nurture. At Kyoto University Primate Research Institute they are testing the chimpanzee "Ai" for species differentiation competency. She understands the difference between photographs of humans and chimpanzees. But when you show her a photograph of herself, she always responds that it's a "human"! (laughs)

ASADA── According to recent developmental cognitive psychology both elements do fundamentally exist. There are ways to enable a connection to inherent knowledge. Experience, environment and other factors work together in certain patterns. It is something that I understand theoretically, but my job is to build robots. So until we really know the specifics of how to plant the seeds of this recognition, it's tough for me to just "believe."

Individuation: Result or Cause?

ASADA── What I'm working on now is, for example, using PC's to gauge changes in the others' size, position and direction to predict their movements, and judge how to move accordingly. Developing descriptions of the other, in a sense. Quantifying one's actions in relation to one's observations of the other's actions. The problem is that there isn't much psychological play that's going on. I mentioned eye contact earlier, but we've not at all come that far. When we have two robots in play, in order for the other robot to recognize this robot's actions, we need them to understand each others' perspectives. At present we have no way to secure this recognition. Of course, it is possible to recognize the other's eye or neck movements when they get the ball, or the ball's movements and infer a causal relationship between the line of play and their apparent perceptual facilities, but we cannot claim that this is the line of their reasoning. Just a posteriori inference, and only partial a posteriori knowledge at that, especially if we begin dealing with sentient beings. So the question is, "what kinds of core knowledges need these robots be embedded with?"

SAKURA── With living beings there are so many different possible cases and exceptions. The simplest form of feinting signal are those which are genetically formed, but abused for duplex ends. You have, for example, a species of firefly that eats another species of firefly. The female of the predator species knows to send the mating signal of the prey species. The male comes, ready to mate, and is promptly eaten instead. The original meaning of this call is buried deep in the female's genetic inheritance, but its application is quite clear.

There are also birds that live in the Amazon basin, who flock with other species—as a survival measure—which works when there is enough food, but when there isn't enough to go around these birds are capable of imitating their flocking partners' alarm calls. Once their partners have fled, they divide the food source among themselves. They are able to employ imitation to instill confusion to their advantage. You can see phenomenon like this in many other species of animal, but trying to translate this into a workable feint in soccer is a whole other issue. Trying to second guess the other players' strategy is really high level technology.

ASADA── The question is really why and how so many such templates were created within the history of evolution.

SAKURA── Isn't it a matter of so many genetic transformations, and various remnants of adaptive measures, part conclusions of trial-and-error, or natural selection?

ASADA── I recently heard the biologist DAN Marina from Osaka Prefecture University say that there is an unambiguous reason for these, that it is latent survival traits. Maybe it is correct to interpret that at some genetic level or cellular level some reason has made itself clear. Yet how can we be sure that a given template was an evolutionary by-product? I

find interesting the question whether it is something that has naturally come out of the individual, is genetic, or whether it is some kind of coding, or . . . ?

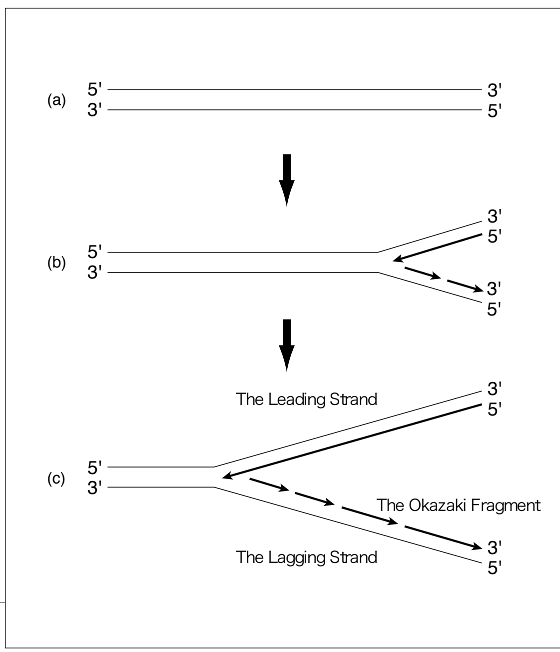
To put it another way, whether you're speaking of bugs and birds, there are relatively few template changes within one life span. When speaking of primates, however, and the developed cerebral cortex, where the plasticity of what you're dealing with increases, these kinds of changes become possible within one generation. And if the mechanism for skill accumulation exists in one experiential cycle, one lifetime, then perhaps it is something that we can apply to robots.

SAKURA——Yet even in birds there is a great deal of potential for learning. Even within one fowl generation considerable change is possible. And signals may well change according to territorial issues as well. Even fireflies may have some potential for generational development. In this sense I don't think that you can describe the phenomenon as a potential based on genetic templates versus experience, but rather that of each having quantitative differences. Recently it is popular to say that learning-based behavioral changes lead genetic adaptations, that actions function to promote biological evolution. With behavioral changes the habitat itself changes, so after a few generations it is natural that the genetics would naturally follow in turn.

When you mentioned templates versus plasticity it reminded me of "Disparity Theory of Evolution," a fascinating hypothesis about genetic evolution by Daiichi Pharmaceutical Company's researcher FURUSAWA Mitsuru. In it, FURUSAWA deals with the fact that of the two strands of DNA, only one strand is used. The other appeared dormant, like a redundancy, or back-up of sorts. But this never quite set well with him. His new "Disparity Theory of Evolution," however, puts this strand into the spotlight, stating that it is the basis of evolutionary leaps.

You see, these two strands of DNA are not identical. One has a higher propensity for mutation (the continuous, or "leading" strand) and the other is relatively more stable (the discontinuous, or "lagging" strand). Now, DNA reproduction goes from the 3' end to the 5' end, and they face each going in alternate directions. [See diagram (a).] During DNA replication, when both strands are copied in their entirety, they are read in sequence, according to their base distribution.

DNA two-strand structure
and non-continuative replication



The continuous strand replicates itself, but at the same time, the discontinuous strand reads it backwards, and for this reason it cannot read the entire strand in sequence, so it reads a section, returns to base, reads another section, returns to base, and so on. [Diagrams (b) and (c)]

This phenomenon was discovered by biologist OKAZAKI Reiji[*10] in 1966, while he was at Nagoya University, and is called "Okazaki fragment," after him. Well, once the discontinuous strand has collected a sufficient number of these Okazaki fragments, it strings them together into one DNA strand. It is called "non-continuative replication," but because it takes such a convoluted way of going about things, it is filled with inconsistencies and variations. The result is that the discontinuous strand is filled with far greater potential for mutation. But why increase the potential for copy errors, why have such a convoluted replication process? It is the same question as why there need be two DNA strands. But since the discovery of the Okazaki strand 30 years ago there still hasn't been a satisfactory explanation.

FURUSAWA's explanation is that mutation potential is the basis for having two DNA strands. The continuous strand can conduct the copying accurately, and keep the organism functioning within its existing environment at its present level of adaptation. This much information is taken for safekeeping. On the other, discontinuous strand we have all of the copy misses, the random factor entered, so that it is relatively easy to produce different genetic information. The greater percentage of what is created here is meaningless, but occasionally an important strand will be created, and this becomes part of what will be copied in the next replication.

This is what FURUSAWA calls "genetic principle security," an interpretation which says that once the organism is assured that the status quo is met, it takes chances in an analog medium. And this would mean that DNA has an extraordinarily effective evolutionary mechanism built into itself. And this is why, he speculates, organisms retain DNA and not RNA or other media for their genetic information. Until now it was always speculated that the subjects of mutation were a mass of genetic material which was unable to adapt, and that this was the reason for their evolution. It is a long standing question. Well, with this hypothesis that problem is also addressed. I really consider it an interesting perspective.

I'm not really sure if it ties in directly with what you were talking about a minute ago or not, but the idea of an unchanging template on one hand, with audacious plasticity on the other seemed close. Without both, the potential for the organism to learn and grow would seem too limited.

ASADA —— Interesting topic. Take crickets for example. The females mate with the male with the most beautiful song. But crickets whose song doesn't really get the girls will group around a male whose does, and steal their females—getting close enough together that the females can't tell which one has the winning tune. How do these male crickets know that their song doesn't quite do it for the ladies, and why are they so smart as to know whose song does, and set a successful strategy to get their females? This appears to be pretty intelligent conduct.

Because insects assume this behavior, does this mean that we can assume that they have a sense of individuation? Some might think not, but I believe that this conduct is related to the individuation that we are trying to develop in robots.

SAKURA —— What you just described, the "sneaker strategy" can be found in toads, fish, and other animals as well. It's hard to say how they know that they're not singing well, but it's not just the absence of females. Also, what are the conditions which need to be satisfied for defining self awareness? I'm not sure that I understand all of what you're saying, but I suppose that it comes back to the issue of the development of the central nervous system.

ASADA —— Birds maintain quite a strong social element including things like monogamy. I believe that this indicates a strong sense of individuation. Crickets, on the other hand, will mate with anything in sight. Not a very developed social sense, or indication that individuation has taken place.

SAKURA —— I think that it's hard to imagine a sense of self in society among crickets. Animals which lay so many eggs have quite a severe sense of survival forced upon them from conception, and their having a developed sense of self is not what is going to save them. It's a battle of overwhelming the odds. Whoever's left standing when it's all over is ok. With fowl and mammals, who only have a few offspring at one time each individual counts, so individuation may be much more important. Of course, there may be differences from one cricket to another, but I'm not very hopeful that that is the defining difference in their actions.

ASADA —— So your thoughts are that without the need to assert one's individuality, individuation does not appear. If you follow the history of evolution, however, I don't know whether the cause and effect

relationship of individuation is that clear.

SAKURA——Within the evolution of living things, I think that you can draw two paths. The first is where you find individuation only in statistical averaging of a species. With crickets you have a society of anonymity established, just as with honey bees and ants, which doesn't rely on individuation, but on group behavior to function. The other is groups such as vertebrate, in whose societies each individual is considered important. Humans are the classic example of this. Living things on this earth are somehow divided between these two. In the former, the individuals are only a statistical result. In the latter they are the essence of society. Perhaps with robots you are aiming for individuation, but you're still at a point of interchangeable anonymity.

The Self, Cognizant of Its Relations with Others in Time

ASADA—— With robots, if the inherent traits and coding are clearly written they will behave within the defined parameters, but if you even vary a bit they will become immobilized. This is one definition of a robot that functions as it is supposed to, but without a bit more plasticity, individuality and the capacity to feint in play, etc. will not emerge. I really would like my robots to evolve to this level.

SAKURA —— I know what you mean. Ethologist Konrad LORENTZ said it originally, but I, too, consider the evolution of life to be one process of learning. Genetics adapting to the environment itself can be considered one "learning." But the learning in one individual's lifetime—by a typical definition of "learning"—is impossible without some mechanism for storing the information in the central nervous system. Even cases of making robots learn will become increasingly difficult, don't you think?

ASADA—— We are using mostly reinforcement learning,[*11] but without a concept of time, it doesn't turn into memory. So my problem is really how to make them gain a concept of time. They can understand a given number of seconds, but not longer sequences, or more to the point an apparent application of sequential structure. They're still completely time reactive.

SAKURA —— And this is what's difficult?

ASADA ——It all depends on how you approach it. I would like to work out an effective structure of experiences and learning processes that would enable the robots to understand how concepts of time are arrived at. If they are presented with a space they can apprehend three-dimensional information and, therefore, project themselves into it and understand their spatial relation to things within that space. But time is more difficult. I've physically put time pieces inside of them, but they still have no subjective notion of time. They're only dealing with increments. And I don't want them to deal with increments, but learn to evolve an understanding of their own position in relation to that continuum.

SAKURA —— So your dilemma is to resolve, for shooting robots, how to learn a sense of time, subjective time, while at the same time living with a time mechanism planted inside of them.

ASADA —— They have a beating heart, which structures their activities, but I haven't specified concepts like yesterday, or the day before. I'd like them to understand that yesterday they came so far, and then today even further, to give structure and form to the sequence of their activities. Then they will be able to speak about their own pasts.

SAKURA —— But doesn't this exceed the scope of RoboCup? It is only my intuition, but even within the history of evolution this is something that never emerged to any precise degree. It is a product of human culture, institutions like education. It was only after writing and then mathematics emerged that concepts like "yesterday" and "today" developed. I don't believe that it is something that evolved naturally.

ASADA ——Yes, I've been told that by many people that our sense of time is quite specifically human.

SAKURA ——Talking about Africa once again, I used to purchase fruits from a local vendor, and I often was short on small change, so I'd have a tab running. Then one day, the fruitseller told me that I hadn't paid for five bananas from "yesterday." Looking at my records, I wasn't down for five bananas the day before or even the day before that. We got into a bit of a heated discussion about it, but it came out that I had put five bananas on credit some two weeks earlier and forgotten to pay. It was there in his ledger. In their vocabulary, time was either yesterday, today or tomorrow. (laughs) There was absolutely no distinction between one and two days previous.

Of course, it was like this everywhere else on earth until quite recently. In Japan, in the Heian Period, if a man wanted to marry a woman, he would court her for three days. It was considered a marriage process, and they would hold a "Third Day Rice Cake Ceremony." This "third day" was just a symbolic way of expressing a time greater than the present, an abstraction for an eternity, a continuum. All over the world, the emergence of precise concepts of time came only after capitalism. And if that is the case, then trying to get your robots to apprehend their selves of today versus their selves of yesterday…….

ASADA —— The question of how to apprehend time is something that I'd like them to think out for themselves. It all depends on how a robot would approach the concept of time.

SAKURA —— And when you reach this point, will distinctions like the distant past, recent past, the present day, near future, and distant future be enough? Or will you attempt to solve issues like 10 years ago, 3 months ago, 1 week ago, day before yesterday, yesterday, today, tomorrow, day after tomorrow…… Will such distinctions be necessary?

ASADA ——This may be an extreme way to describe it, but they are going to need a good enough structural grasp of the concept to be able to describe how they grew up, if they are to develop a sense of identity

SAKURA ——Who knows which will come first? Their sense of identity being unchanging and…….

ASADA ——That is the point. The fact that they see themselves as having been there throughout their existence, and understanding the same about the other. In order to be aware of this they have to be able to codify time.

SAKURA —— I would imagine that "yesterday" and "today" are concepts that will need to be taught, "top-down"[*12] learning if you will, though less specific. "Previously, presently, and from now" seem achievable aims. Chimpanzees and gorillas have this much grasp of time. But as I said before, the problem is having the tools for more refined concepts.

ASADA ——At least let us agree that the concept of self is inextricably linked with some conception of time. The other is always the other, and that this "other" constant is relevant to understanding one's self as constant is the same issue in a very essential way.

Towards A Common Evolution: Cooperation Is Harder Than Competition

ASADA ——Recently we've been studying genetic programming,[*13] particularly to what extent two agents are capable of cooperative behavior. The problem is that they aren't very cooperative with each other. With one driving force of will the concept of efficiency is usable, but with multiple will mechanisms the whole idea of efficient, coordinated action just falls apart. Figuring out how to let them work together to fool an opponent is also extremely difficult to manage. Two robots without a common enemy won't cooperate. There's no apparent necessity for them. Of course, it's more efficient for them to cooperate, but in defining priorities for their tasks, the tasks that they must divide between themselves, there are a lot of managerial adjustments that we must make or collaboration is really difficult to achieve.

Take passing and shooting for example. The robot assigned to passing's job is far more complex than the robot assigned to shooting. Not only do they have to pass accurately to the shooting robot, but if the shooting robot doesn't make their goal the pass is not appraised as having fulfilled its function. The result is that the passing robot would rather shoot the ball himself. It's easier that way. (laughs) It's easier when there are competitors on the field, but still, meaningful cooperation is difficult to achieve.

SAKURA —— That's fascinating.

ASADA —— I mentioned it at some research group recently and someone tried the experiment with their kid's junior league! There was one goalkeeper, and two other children who were supposed to be passing and shooting, but the goalkeeper was just in a far stronger position. It's easy to impede, tough to cooperate. In their game the keeper was always winning, while the attackers were losing spirit, and the kids were losing interest in the game. It was only after they put more restrictions on the goalkeeper's actions that they all started to coevolve.

SAKURA—— There is a British psychologist who conducted a classic experiment with a dominant pig and a subordinate pig, where the object was to push a button in one location to make food come out of a dispenser in another. Against expectation, the pigs did not emphasize difference, but developed a cooperative relationship. The dominant pig would push the button, and the subordinate pig would sit, immobile in front of the food dispenser. Once the dominant pig had pressed the button enough, it would come over, and chase the subordinate pig away, finishing what was left. The conclusion that this psychologist made from their behavior was that they did this because the subordinate pig would have been helpless on his own. It would have been in the way of the button, and therefore the dominant pig's capacity for getting food. With no other viable alternatives for it, it would press enough so that even after the subordinate pig had eaten some there would be enough left over. It was a reasonable compromise for both parties.

Of course, the results of the exercise would have been different had there been a different amount of food available, or if the button and food dispenser had been differently located, so this cooperation was not

limitless, but it was demonstrated that these pigs were able to demonstrate a cooperative arrangement appropriate to their physical capacities.

ASADA —— That is precisely the kind of problem that is needed to organize complex relationships and synchronize behavioral patterns for coevolution.

SAKURA —— ppose so. With human beings, societal rules function as such external guiding principles. Of course, humans may be one animal that is inherently good at cooperation, but I suppose that this is the result of a long road of conflict with various external groups. For example, groups that found plentiful water supplies were bound together to protect it. External pressures. The existence of a third party is what forwards the body politic.

ASADA —— I think that it's interesting that competition is innate, but collaboration is learned. Games don't often stress such situations. We've finally gotten the lower level behaviors in line, the shooters to learn shooting, but we haven't yet been able to enable the higher levels of cooperation. What we've done is to simulate human society, where in this case you would have a coach working with the team to encourage coevolution,[*14] "bottom-up" methodologies. Even though they may not learn a given skill the first time it is taught to them, after repeating the skill along with the coach several times, they begin to grasp what was being explained to them. Also, the coaches learn how to express themselves better over time. It is an experiment in collaborative development. Rather than all of the robots beginning from the same starting point, some, which are designated as coaches, are able to interact with the player robots and they both learn how to function within their roles together.

The Selfish Robot of Our Hopes and Dreams

SAKURA —— The self, awareness of time, sense of physicality, collaboration with the other—these are some of the attributes that you've spoken of today. What do you imagine the social significance, contribution to human knowledge that such robots might bring to society?

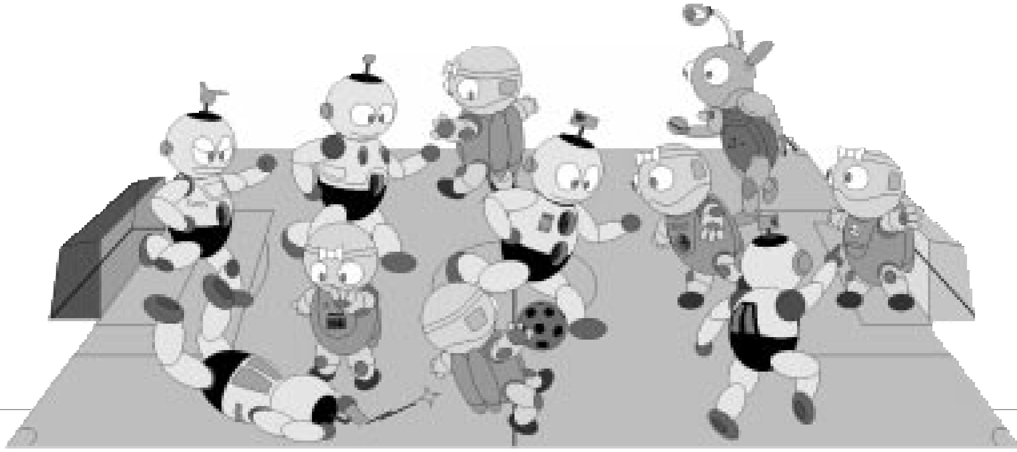
ASADA —— Well, first I should say that I'm convinced that robots will at some point cohabit human societies. The robots that we've seen to date haven't the functionality to make this transition meaningfully. They will be quite different than the specialized fragmentarily functional robots that we find in industry today. Robots capable of cohabitation will need to be multiplicit, including possessing many ways of communication with us. When dealing with humans it is not enough to merely be capable of executing specific tasks. We will need to be able to interact, whether that means helping us do our shopping, be someone to talk to, or whatever else we require. That's still quite impossible for present day robots. They will need to be more customizable, to really be able to listen to us when we want something done. In order to do this they will need to have a far greater recognition of the other, and to have some idea of what human being are.

The biggest problem now is communication. Present systems of speech recognition are assigned in a completely "top-down" manner. In other words, our objective for them is to be able to process symbols on the fly, communicating with each other as they grow up. Once this has been achieved, they will be able to function among humans much as pets do. Pets may not speak with human beings, but there is some level of communication going on. Just as infants are able to be taught linguistic skills, so must robots. We must design a mechanism for them which is customizable, and which allows them to learn how to communicate with human beings.

Just as I said in the beginning, one comes to an understanding of things through using one's body, and interacting with them. Now, I don't know if robots will pick up apples and say "this is delicious!", but they will need to be able to express things which are meaningful to them using words. This is where the potential for communication with human beings emerges. I would imagine that this is a prerequisite skill or function to cohabitation with humans, and whether we can identify this as being a sense of self or not, certain processes of recognition, and the ability to understand and express novel situations in human language are all aspects of systems that I would like to develop.

SAKURA —— A common fear, I believe, is that robots will develop too much of a sense of self, or ego, and become dangerous presences, that they will resist humans. And yet your assertion is that those with this dreaded ego will in fact be the first to be able to communicate with us.

ASADA —— We haven't yet developed the robot that can obey ASIMOV's Three Rules of Robotics. But they will need to. Firstly, protect and serve human beings. But this doesn't mean for them to be fed a computer program and execute it by rote. They'll need to be able to hear and respond to our voices. And the most difficult problem is that they'll have to learn to protect themselves.



Five-player team competitions including a referee robot

There may be different interpretations of the three rules of robotics, but if they're not able to keep themselves from harm I can't see how they could possibly contribute to society. There may be a thousand variations in SciFi novels, but my job, at least, is to create a robot that can fulfill ASIMOV's three laws successfully.

SAKURA—— Was your thinking about "coexistence" influenced in some way by TEZUKA Osamu's character "Astro Boy"?

ASADA—— Personally, no, but researching robots in Japan certainly means living under the shadow of our little animated friend. There is no similar popular cultural counterpart for European or American researchers. They see robots more as machines—that break—whereas most Japanese researchers are working towards an ideal of robotics that is at some level influenced by "Astro Boy." In this sense, I think you could say that Japanese researchers may be after something a bit more vibrant, and capable of meaningful communication with human beings than their Western counterparts.

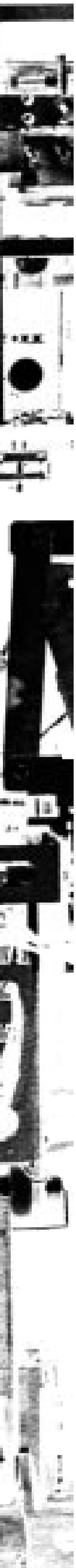
SAKURA—— I heard once that in America the introduction of factory automation was accompanied by workers striking to "not have their livelihood usurped" by robots—something like the Luddites—whereas in Japan they name them and have parties to welcome them into the work force. (laughs)

ASADA—— TEZUKA Osamu's influence is a really enormous part of a considerable cultural divide. I'm sure that Japan will be one of the first to integrate robots into its society, and that this will go far more smoothly than in many other cultures. Honda corporation recently developed a humanoid robot. That's just not an idea that comes out of Western industry.

SAKURA—— So the introduction of humanoid robots will be seen as something being "sent out into the world from Japan"?

ASADA—— I think that worrying about whether something comes from Japan is a sort of reaction to Japan's inferiority complex concerning the West.

SAKURA—— I agree. It's about time that we graduate from the now largely meaningless "Japan versus the West" diagram. The "West" isn't one coordinated entity by any means, and ignoring Korea or China's role is inappropriate. Rather than manifestations of a cultural inferiority/superiority complex, I think that there are any number of mutually provocative approaches, and complementary perspectives that deserve exploration. Who knows, even robot coexistence can, through cultural exchange, find a variety of new means for expression.✺



[This conversation took place on January 6, 1999 at the InterCommunication Center, Tokyo.]

Footnotes:

[*1] Born in 1961. Senior Researcher at Sony Computer Science Laboratories, Inc. Through researching automated audio translation systems development and ultra parallel processing computed artificial intelligence, Mr. KITANO is now attempting to develop a new intelligence systems architecture via molecular/computational biology and RoboCup.

[*2] Born in 1960. Senior Research Scientist at Intelligent Systems Division of Electrotechnical Laboratory a.k.a. Densoken (adjunct to the national Agency for Industrial Science and Technology). Engaged in humanoids, interaction, and other perception and action interactive activities intelligence research.

[*3] A research field where multiagents (including robots) act in cooperation and competition, learning and acquiring.

[*4] Just as computer chess represented, a common theme is established so that numerous researchers can have a common set of problems to address themselves to, encouraging articulation and development of the field. For purposes of unambivalent decision, win/lose competitions are common.

[*5] Without tasting the apple, the system attempts to match representations of what has been put in front of it.

[*6] A problem which arises in practical applications for intelligent expression systems (a comprehensive expression of data and its means of execution). When a given condition and its transformations provide the input for an intelligent expression system, the system cannot observe only the changes that occur at a given point in time, but must continually account for all aspects of the current surroundings before proceeding to the next.

[*7] Based on the thinking that when a given sensory input is obtained the issue of which action to take relies solely upon the condition of the input, not on the previous input or condition of the agent. What is indicated here is the assumption that by more generally considering conditions and surroundings, including the robot's on-going processes, and to a certain extent transitional periods relative to a given situation within the sensory input, operational decisions can occur through a process of learning. This can be inversely stated as that the robot itself should be able to regulate its surroundings, and this is what is essential here.

[*8] Emergence. There are several interpretations, however, the definition used here is that "emergence" consists of bottom-up and top-down mechanisms co-defining each other, a process characterized by a mutual synthesis of local and autonomous elements from the lower levels forming a broad organizational order in the upper level, which re-influences lower level operational motivations and border conditions. In living systems, for example, cells (lower level elements) forming (bottom-up) into organs or bodies (higher level broad organizations), while the condition of movements and organs influence the activities of the cells (top-down). Similar relationships can be seen universally throughout multi-layered complex systems.

[*9] Isaac ASIMOV's "Three Laws of Robotics", presented in his 1942 short story, *Runaround*:

1) A robot may not injure a human being, or through inaction, allow a human being to come to harm.
2) A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.
3) A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

[*10] 1930-75. Molecular biologist. Former Nagoya University Professor. As the discoverer of "non-continuative replication," made important contributions to the solution of DNA's replication mechanism. Died from complications due to exposure to atomic radiation.

[*11] A method where punishments and rewards are applied to the subject's behavior to reinforce preferred values. Through repetitions thereof, the agent (robot) learns to modify its own actions.

[*12] Please see [*8] above.

[*13] A method to seek a solution by means of a program written in computer language, treated as chromosomic material (genetic model), applied as a genetic algorithm, and weeded out based on appraisals of its functionality. Genetic algorithm is a process which simulates evolutive behavior. The base algorithm is made to select structures beneficial to it through a sort of "natural selection," and evolve towards an algorithm more adaptable to its environment and the transformations within it.

[*14] Where multiple processes maintain an confluent influence throughout their development. Indicating a process in natural science where multiples of seeds interact in their evolution, here it is used to show the learning process occurring between "players" and "coaches" on the robotic playing field.

ASADA Minoru

Born in 1953. Professor at Department of Adaptive Machine Systems, Osaka University Graduate School of Engineering. From robotic vision research to intelligent systems architecture, advocating and realizing the robotic soccer event RoboCup, professor ASADA has been pursuing research on body-rooted emergent intelligence, and cognitive robotics.

SAKURA Osamu

Born in 1960. Associate Professor at Faculty of Business Administration, Yokohama National University. Researches the evolutionary relationship between human beings and technology. His writings include *The Environmental Problem as Contemporary Thought [Gendai-shisou toshiteno Kankyou Mondai]* (Chukou Shinsho), *A View for Life [Seimei no Mikata]* (Houzoukan), *The Challenge of Evolution Theory [Shinkaron no Chousen]* (Kadokawa Shoten), *Adventures About Life [Seimei wo meguru Bouken]* (Kawade Shobou Shinsha).