THE POINT OF KNOWING

Sony CSL: The First 25 Years

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A Sony CSL Production

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Sony CSL: The First 25 Years

The Story So Far

BEGINNINGS

When Dr. Toshitada Doi of Sony Corporation visited Dr. Mario Tokoro of Keio University in the spring of 1987, he had a vague plan to launch an ambitious initiative but had no idea exactly what form it would take. He was hoping that Tokoro might offer him some guidance.

Doi, who had helped to create the compact disc, would later win acclaim as the creator of the robot dog AIBO among other stellar achievements. Tokoro was known for his expertise in computer science and some obscure futuristic thing that the U.S Department of Defense was calling "the Internet." Not many people were putting together campus-wide networks at major universities in those days, but Tokoro had done exactly that at Japan's renowned Keio University back in 1981. He was also becoming known for expressing what proved to be a prescient concern with the concept of "openness" in a world that was only just beginning to open its mind to the implications of an age of digital networks.

When the two men met, Doi set the scene by reviewing the wealth of computer technology at Sony, and Tokoro noted that computers did seem likely to play a key role in the future of society. So what, asked Doi, should we do?

Tokoro was ready with an answer. He was surrounded and supported by brilliant students at Keio University, but one thing in particular had been bothering him: the absence of jobs that could enable those students to really express themselves. Too often their potential was being stifled in the regimented realm of Japan, Inc.

For years, Tokoro's academic credentials had been opening international doors. He was having a great time traveling the world, speaking at conferences about the subjects he loved and making friends with other global pacesetters. On his jaunts outside Japan, he had seen for himself a variety of stimulating research labs, especially in the United States, and he wanted to create a similar environment in Tokyo. He imagined a place where conditions would be perfect for people like his students not just to survive as scientists but to thrive, giving them the chance to forge ahead in valuable new directions. And those scientists would not just be Japanese. He envisioned a place that the whole world would be interested in, and where top researchers would want to work.

"How about setting up the world's best computer science laboratory?" Tokoro suggested, with a characteristic combination of modest demeanor and ravenous ambition.

And that's exactly what they decided to do. Tokoro spent the next two weeks tapping away on the keyboard of a newfangled and still rather pricey Macintosh, and eventually had a 10-page proposal covering all the key aspects of the new facility, from size to management policy. He asked Sony Corporation for a minuscule fraction of its annual revenue to fund the operation, made absolutely sure that the researchers would have no strings attached to the Sony mothership, and in February 1988 Sony Computer Science Laboratories, Inc.—Sony CSL—was ready to roll.

Just like Doi, Tokoro was dreaming big. But back in 1987 surely neither man can have imagined that Sony CSL would end up proposing a groundbreaking vision of science itself. And yet that has been the headline story of Sony CSL's first 25 years. With Mario Tokoro in the vanguard, Sony CSL has pioneered and now champions Open Systems Science, a methodology and attitude with the power to blaze an entirely new trail to the future of knowledge—and to a better world for all of us.

THE SET-UP

So what were the original rules of engagement for Sony CSL and the researchers who worked there? What did Tokoro specify in that 10-page document?

First of all, he gave the labs an activity and a mission. Sony CSL was to "carry out computer-related technological innovation and contribute to the creation of new culture." In a pamphlet written in English, one of Sony CSL's official languages from the outset, Tokoro outlined two key goals of research: to set a high ideal based on a full understanding and critical view of the existing state of technology, and to strive for a new approach that would bring this ideal to reality.

There would be a maximum of 30 Sony CSL researchers at any time, and they would all be people committed to pushing beyond the incremental improvements that were typical of other computer-related research institutions in Japan, where studies tended to follow a direction set by research communities in foreign countries.

Beyond mastery of theory and expertise in technology, each and every Sony CSL researcher would be required to have a clear independent vision and to carry out research "full of real creativity." As someone who understood the true value of freedom and responsibility, the Sony CSL researcher would

carve out a distinct identity and mission, and this wellspring of original thought would fuel Sony CSL's ability to contribute to the world "by creating new possibilities for tomorrow."

A stimulating environment, to be sure, and in one striking respect very different from the lifetime employment or academic tenure that the first members of the team might otherwise have expected to enjoy in the Japan of the 1980s. While they were to be offered benefits equivalent to those enjoyed by researchers in leading labs outside Japan, the pay and employment of each Sony CSL researcher would be subject to annual review.

At a time when employment for life was still very much the norm in Japan, that one-year contract stood out. But Tokoro's aim was not to put pressure on researchers, or to weed out non-performers. The annual review would instead give both sides an opportunity to review a researcher's progress and come to mutual agreement about whether he or she should keep going at CSL, or move on to a different environment. For Tokoro, it was vital to identify researchers who really wanted to explore their potential within the Sony CSL environment, and also to offer them a regular opportunity to reflect on whether CSL was indeed the right environment for their work.

All of the ground rules mentioned above are observed to this day at Sony CSL, and in due course we'll look more closely at how they play out in everyday activities at the lab. Mario Tokoro's vision for Sony CSL has not changed in any fundamental way, and neither has CSL itself. For the last 25 years Sony CSL has strived to provide optimal conditions to generate a constant stream of valuable output from a diverse community of outstanding independent minds.

What does Tokoro himself do? "Only two things," he once wrote in a book about Sony CSL. "I decide on the direction of the lab, and I manage human resources: who stays and who goes."

Inventing a new way to think about science might just count as a third.

Mario Tokoro

Mario is far from a typical given name for a Japanese boy, and Tokoro is a pretty unusual family name. When he was growing up in Tokyo, Mario Tokoro's name may have contributed to his sense of feeling somehow...different, but for whatever reason feeling different felt just right. So when other people told him that he seemed somehow... different, young Mario mistakenly took this as a compliment. He's been happily different ever since. What this means in practice is that his avuncular and congenial demeanor is disarmingly at odds with any conventional preconception you may have of a viscerally driven Keio electrical engineering PhD who broke new ground in signal processing, microprocessors, computer aided design, and local area networks in the 1970s before designing the campus-wide Keio S&T network in 1981 and becoming a leading light in the world of object-oriented concurrent computing and distributed systems. Rather than an iconoclastic contrarian genius who founded Sony CSL, served as senior vice president and chief technology officer at Sony Corporation, taught at Keio University, the University of Waterloo, Carnegie Mellon University and the University of Paris VI, and received an honorary doctorate from the University of Paris (UPMC), Mario Tokoro seems far more like some amiable old charmer who's a slightly rusty golfer, loves art and opera, enjoys good food and drink—and hey, did you know he played keyboard and guitar in a high-school band? All of which is also true. At the end of the day, whether he's revolutionizing science or crooning (high baritone) "Just the Way You Are," Billy Joel's timeless Open Systems ode to coping with the real world "as is," Tokoro is simply being himself. His motivation to appreciate the essence of everything he does is right there in his name: ma-ri-o is written with characters meaning "true reason man."

"It is very difficult to explain my research even to scientists in other disciplines. But each scientist has a responsibility to explain what he or she is doing, and to explain what goal he or she is trying to achieve."

Mario Tokoro

PHASE 1 (1988 TO MID-1990s)

Having made a commitment to pursue "computer-related technological innovation" and being called Sony Computer Science Laboratories, it's hardly surprising that in its early days Sony CSL had an overriding concern with computer science.

Networks, user interfaces, distributed operating systems, and distributed artificial intelligence dominated CSL minds in the 1990s. Valuable technologies resulted, including the Aperios operating system (later employed in the famous robot dog AIBO), an advanced text input system called POBox (especially useful for Japanese text input), and Jun Rekimoto's FEEL user interface (which is now part of the international standard for near-field communication technology).

All of these breakthroughs have displayed great staying power, with an operating system descended from Aperios being incorporated in the PlayStation 3, and the Xperia Tablet Z (released in 2013) featuring both the latest version of POBox and OneTouch, a new near-field communication implementation of the FEEL interface.

By the mid-1990s a team of star performers was forming at the heart of Sony CSL. They included Hiroaki Kitano (who joined Sony CSL in 1993), Jun Rekimoto (1994), Ken Mogi (1997), Hideki Takayasu (1997) and Frank Nielsen (1997).

In 1996 Luc Steels opened a branch of Sony CSL in Paris and became its director of research. He was joined by François Pachet in 1997.

Sony CSL was quickly evolving into a stimulating intellectual environment. Even just this core group offered each other high-level access to the worlds of physics, electrical engineering, computer science, computational geometry, brain science, artificial intelligence, and linguistics.

Hiroaki Kitano was already crashing through the walls of different disciplines. His original pursuit of physics was a distant memory, and his study of machine translation was also soon behind him as he barreled on into the realm of artificial intelligence and robotics, where one of his first global contributions came in the form of RoboCup—an international robotics competition that he founded in 1997 and is still going from strength to strength.

Meanwhile Ken Mogi's adventures at the intersection of intellect and entertainment would eventually lead to the creation of "Aha!" games and help to launch his career as a very prominent media personality in Japan.

PHASE 2 (1998 TO MID-2000s)

As the years passed, a new topic began to shape conversations at Sony CSL: how to convert breakthroughs in knowledge into tangible benefits for people.

This was the beginning of the human-centric phase of CSL's development. Some scientists had left, others remained, and new people had arrived. The researchers who gathered around the CSL table now could deliver value in domains ranging from science and technology to art.

The art zone contributors were studying social interaction, interactive music, cognitive development, and language evolution. The technology zone people were focused on real-world computing, emotional interaction, and visual computing.

But it was especially in the realm of "pure" science that a future path for thought at Sony CSL was beginning to emerge. "Systems" and "fuzzy boundaries" were becoming key characteristics of the intellectual scenery. Even Hiroaki Kitano himself was surprised to discover that he was undergoing yet another metamorphosis. Setting out on a journey from a position somewhere within the boundaries of artificial intelligence, he now found himself grappling with the development of an entirely new realm of knowledge: Systems Biology. Meanwhile Hideki Takayasu was beginning to blur—or leap—the boundary between economics and physics, spurred on by a growing understanding of, and concern about, the real-world damage that economic globalization could wreak.

In the environment of openness that Mario Tokoro had built into the physical and intellectual infrastructure of Sony CSL, the talk increasingly turned to a matter of growing importance in Tokoro's own mind: openness itself.

But before we focus more sharply on Open Systems Science, let's spend a few pages getting to know a little more about the main cast of characters from this second phase of Sony CSL's development. These researchers, whose minds shaped the DNA of Sony CSL, continue to bring a significant epigenetic influence to bear on CSL's identity.

Jun Rekimoto

After pioneering work on user interfaces—including augmented reality and multi-touch interfaces for computers and smartphones—Jun Rekimoto became a leading figure in human augmentation technology. His interests moved from human-computer interaction to human-computer integration. He now seeks to build symbiotic relationships between humans and our ever-richer information environment, as we move toward the ultimate state of a "cybernetic earth." Through experiments with systems such as eye-tracking and telepresence, he aims to augment not only intellectual ability, but also physical ability and health.

Hideki Takayasu

Bridging physics and economics, Hideki Takayasu established the field of econophysics. He has been devising ways to bring stability to a worldwide financial system made vulnerable by the speed and overwhelming volume of automated trading, and is applying similar methods, very successfully, to improving the efficiency of semiconductor manufacture. He is also working on a composite money system that he hopes will solve the currency exchange rate problems faced by international companies with operations in many countries.

Luc Steels

Luc Steels is fascinated by the unique ability of human beings to create and interpret rich representations, such as graphical images and language. Interested in understanding where this capability comes from, both in our species in general and in children, he focuses in particular on how categories (like colors) can be grounded in perceptual experience and develop under the strong influence of language, and how grammars and the semantic domains expressed by grammars may emerge in a population. The applications of this work are far-reaching, ranging from adaptive communication systems for humanoid robots to evolving ontologies (lexical databases) for the web, and communication systems for mobile devices.

Luc Steels, who set up Sony CSL Paris in 1996, investigates artificial intelligence. His journey so far has taken him into such realms of knowledge as computer science, evolutionary biology, and linguistics.

He first entered the orbit of Mario Tokoro 10 back in 1987, before Sony CSL had even been established. Steels was in Japan for an International Federation for Information Processing conference, where he spoke about artificial intelligence and complex dynamics. Tokoro recalls not understanding much, but coming away from the talk believing that Steels was working on something interesting. The friendship that ensued eventually led to Steels' spending a sabbatical year with Sony CSL in Tokyo in 1995.

Steels had for some time been unsatisfied with aspects of the theoretical framework for understanding language devised by Noam Chomsky, a giant of 20th century linguistics. Chomsky's concept of a "universal grammar" shared by all humans was a powerful claim, but what Steels wanted to know was where this language thing came from in the first place, and Chomsky could offer no clues. It was during his year at Sony CSL that Steels devised a basic experimental framework for studying the emergence of language among agents that could simulate aspects of human communication.

Fast forward to the early years of the 21st century, and Steels was focusing in particular on verbs, with the help of...robot dogs. That famous computerized canine AIBO was an obedient player in a range of language games devised by Steels. In fact, a small pack of AIBOs was busily engaged in explaining aspects of their environment to each other. Later, the AIBOs were replaced by humanoid robots that could look at each other (rather eerily) and point at objects in their environment.

Based on the results of these games, Steels has been sketching the outlines of an explanation of language that goes beyond mere structure and embraces linguistic connections to the real world. He calls this new field, which is casting light on the origins and evolution of language, and on the potential for robots to learn language, "semiotic dynamics."

Philosophers of language argue that machines can simulate meaningful communication while actually understanding nothing, but semiotic dynamics may end up calling into question those philosophers' own comprehension of language.

François Pachet

Artists, musicians, writers, and cartoonists dream of being more creative, and of having their own style. Do they simply have to keep honing their skills, battling on alone? François Pachet's starting point for his research at Sony CSL was the creativity that emerges from the conversation that each of us has with the self. This led to the concept of reflexive interactions—interactions that can boost creativity and engender states of "flow" by, for example, imitating and modifying our output when we play music, or write. This feedback offers the creator fresh stimulation and new avenues to explore. His new project, FlowMachines, aims to turn a personal style into a fully-fledged computational object, thus taking Pachet a step closer to new interactive tools for authoring music and text.

Frank Nielsen

Since the days of Euclid, geometry has continually revolutionized our perception of reality. Examples in recent times include curved space-time geometry, which goes hand in hand with relativity theory, and fractal geometry, which opened our eyes to nature's scale-free properties. Frank Nielsen explores the essence and structure of information and randomness—a quest that enables him to devise algorithms for use in innovative imaging applications. The paradigm he created for his studies, computational information geometry, enables him to capture the unchanging essence of data. By then grounding datasets in geometric spaces, he is able to extract information about regularity while also taking dataset variability into account.

Ken Mogi

Qualia, subjective sensory qualities that accompany perception, represent one of the most important research issues in cognitive neuroscience today. At the heart of the human experience, qualia shape almost every aspect of our everyday engagement with the world including cognition, learning, creativity, and communication. Using psychophysics, noninvasive measurement tools (MEG and fMRI), simulation, and theory, Ken Mogi investigates the system-level properties of the brain that generate qualia.

Hiroaki Kitano

Although biological research at the molecular level has revealed much, understanding the fundamental principles of life requires investigating living systems as systems, and Hiroaki Kitano developed Systems Biology for this purpose. He is currently focused on developing a biological theory of robustness that entails understanding the basic principles of robustness in biological systems, the trade-offs present in robust yet fragile systems, and the evolvability of robust systems. Systems Biology holds great promise in the treatment of disease, including cancer, and in the development of highly robust artificial systems.

HUNGER FOR KNOWLEDGE

As a kindergarten student Hiroaki Kitano, now the CEO of Sony CSL, didn't dream of being a baseball player or a bus driver when he grew up; he expected to be an astrophysicist. Maybe one day he will visit that realm. If so, astrophysicists, stay on your toes! Kitano is ravenous for knowledge and willing to shred the status quo to get it.

At the age of eight Hiroaki Kitano was already scouring the electronics shops of Akihabara for the parts he needed to construct a calculator that would help him with his arithmetic. He made the calculator, feasted on the knowledge, and moved on—to amplifiers, remote controls, and synthesizers.

As an undergraduate Kitano devoured physics and then focused on what he saw as the happier hunting ground of computer science. While his services were briefly secured by NEC, he was never tamed. Caged in by corporate constraints in Japan, he broke free to study artificial intelligence at Carnegie Mellon in Pittsburgh, where he completed the world's first machine translation system capable of simultaneous interpretation.

Accolades followed, including The Computer and Thought Award, but Kitano was already stalking fresh prey. Enjoying rich pickings in the world of NEC software quality control at the intersection of artificial intelligence and databases, one day he caught a mental glimpse of something new he could sink his teeth into. "Networks!" he roared. But this was an appetite that back then, NEC could not help him satisfy.

It was in 1991 that Kitano first met the man who would empower him to prowl the scientific savanna as he pleased: Mario Tokoro.

Associating Tokoro with Sony (TV, audio...consumer products that Kitano didn't find especially appetizing), Kitano failed to pay much attention during their first encounter in Sydney, even though Tokoro was already a colossus in the world of computer science and networks. Tokoro for his part barely registered this ebullient young researcher who was just beginning to publish papers (Kitano's current score is 400+ publications and close to 10,000 citations).

But it didn't take Kitano long to appreciate that Sony CSL could be the perfect base from which to launch his iconoclastic forays. Tokoro, too, quickly came to value Kitano's ferocious drive to tear down artificial obstacles in the scientific landscape. By 1993, Kitano was in.

Whereas further work on machine translation would demand a team, Sony CSL was premised on the power of individual researchers. Kitano didn't hesitate to refocus—but the moment he lifted his eyes he came face to face with the real significance of choosing CSL: "Being free means having no excuses." Whatever path, direction, assistance, and guidance he chose from now on, only one person would be to blame for any false step or failure: himself. This gave him pause for thought. But he pretty quickly came to the conclusion that if he was going to risk failure at all, it might as well be a huge failure. He started studying biology.

In 1994, Kitano was one of the teachers at an elite summer course for talented Japanese students of mathematics. One of the other teachers (and this may help to put Kitano's intellectual prowess into perspective) was the Nobel laureate Susumu Tonegawa (Physiology or Medicine; 1987). Chatting about science one day, Kitano suggested that computers would soon be able to model life, and not just simulate behavior but also predict it. "No, they won't," said Tonegawa. "Simple predictions, maybe. But life's far too complex. No way that's going to happen." Kitano felt the first rumblings of hunger. And then the prey came into view.

Another teacher at the course, Shin-ichiro Imai (now associate professor in the Department of Developmental Biology and Internal Medicine at the Washington University School of Medicine) was studying the aging of cells and wondered if Kitano might be able to help him explain the data he was gathering by creating a model and running computer simulations.

In no time Kitano was devouring such essential texts as *Molecular Biology of the Cell* and *Molecular Biology of the Gene*. As he spoke with biologists he came to understand that very little quantitative analysis was being done, and he began to see tremendous potential for bringing his physics and engineering expertise to bear on the field.

Starting out with a model of the cell, it wasn't long before Kitano ran into the cell wall—and naturally he wanted to break through it. "Cells form a system," he thought. "To understand the cell, you need to understand the system." Racing ahead, he began to notice trade-offs in robustness and fragility that characterized the effects of cancer, diabetes, and other diseases in cell systems and—to cut a very long and complicated story short—by 2003 he was entering phase two of what is now known as Systems Biology with the proposal of "long-tail drugs." These would be drugs that worked with the nature of the biological system to deal with disease.

Ten years in a single area of study may look like a record for Hiroaki Kitano, and in fact another ten years later he is still regarded first and foremost as a systems biologist. But the truth here is that in 1993, Kitano began to free himself from all the conventional bonds of academic disciplines. Everything he had learned up to that point had a bearing on what he was able to do in the context of biology, and within ten years he was in fact already straddling the boundary between biology and yet another new area of study: medicine.

Names of disciplines were no longer significant. Only one thing had value: understanding reality with the aim of harnessing it sustainably for the benefit of humanity. And to do that demanded a new approach to knowledge. We're getting close to a fuller investigation of that concept. But first let's finish this part of Hiroaki Kitano's story by meeting a person he introduced to Sony CSL, because Kazuhiro Sakurada's arrival marked the launch of the third phase in the CSL's history—as the wellspring of Open Systems Science.

Kazuhiro Sakurada

Kazuhiro Sakurada explores the nature and fundamental principles of human life systems through an approach that adds an epigenetics (acquired traits) management perspective to the study of genetics (inherited traits). There is a growing sense that recent revolutions in basic biomedical science are not necessarily leading to medical products and services that are safer and more effective. To allay this concern Sakurada is developing a new biological model and a new data model for use in a big-data strategy. His goal is to make an invaluable contribution to preemptive medicine and consumer healthcare services.

Following years of pacesetting research including extraordinary work on human iPS cells, Kazuhiro Sakurada was reviewing large clinical studies for an international pharmaceutical company when he realized he had reached an impasse.

As things stood, even major discoveries such as those he had made in stem cells would not contribute to his ultimate goal of improving human health. This required more than a conventional breakthrough; Sakurada needed to revolutionize clinical science.

"For innovation it's necessary to systematize the real world in a previously unknown way," he says. "Then we can free ourselves from our current way of seeing the world." Sakurada was working on this new philosophy when, in 2008, he came to understand that Mario Tokoro had the same goals for Open Systems Science. Moving to Sony CSL, Sakurada began laying the foundations for a new field—Open Systems Medicine.

Systems Biology had already changed the biological sciences, but a different paradigm was needed to handle the uniqueness of individual human lives. In a conventional, mechanistic view, cells might be identified as the basic elements of a biological system. But for his basic elements Sakurada focused on something totally different: inter-cellular and intra-cellular *communications*. Some genetic changes are not due to DNA; they are epigenetic. But how do those changes happen? In Sakurada's view, subtly evolving patterns of communication throughout the body are a key to uncovering invaluable information about who you are, who you will be, and who you *could* be.

His approach reflects a deeply held conviction that hysteresis—the effect on the body of past actions, lifestyle choices, diseases, and environmental influences—must be taken into account when studying the human organism.

Sakurada has ambitious plans for his system of study; he hopes to use it to delve into the meaning of genes, the environment, and life itself. If he can understand the decision-making processes of the body and brain, he will take a giant step toward understanding those of the whole human being.

The way ahead is now clear, and Sakurada is picking up speed fast.

DARK SCENARIOS

In the early years of the 21st century the world was changing rapidly, and problems were proliferating.

Behind many pessimistic projections was the matter of the environment, with mounting evidence that a burgeoning human population had overexploited resources and failed to maintain an appropriate balance with the natural world. Economic challenges included surging new consumer powers and demands, and the globalization of trade. The impact on health of our evolving borderless reality included diseases that could spread vastly more efficiently and effectively. Previous assumptions about privacy were swept aside by the new expectation that all information would be unfettered and free.

The ostensible benefits of this rapidly changing world included unprecedented access to each other, to infinite volumes of raw data, and to infinite volumes of curated information. For the first time, the human race seemed to be acquiring something like a brain on a planetary scale. But all the phenomena that made this possible had emerged in less than a human lifetime, and their interactions were too complex for any human brain to comprehend, let alone predict. The human race was gaining both the wisdom of the crowd and the blinkered ignorance of the mob. How could its conflicted embryonic digital brain be guided to serve and preserve, rather than consume and destroy?

Mario Tokoro concluded that we could no longer pursue knowledge in isolation and for personal gratification; the world was too complicated and the dangers facing us too great. He became convinced that the walls separating scientific disciplines should come crashing down, and findings should be shared. New information would have to demonstrate its value, where value was defined as a contribution to a sustainable future for the human race. From now on, everything we did would have to make a positive difference in the real world. The mission of scientists would be to sow seeds of cultural sustenance that would nurture the global mind.

Clearly that would require some good methods of cultivation, and that's exactly where Open Systems Science comes in.

PHASE 3 (SINCE 2008)

"By the mid-1990s, computer science itself was no longer the theme at Sony CSL," Mario Tokoro recalls. "Many people had done a lot of work in that area and the results had been used in various applications. So in the second phase, from the mid-1990s, we turned our attention to how we could make use of computers to contribute to humankind. And since about 2008 we have been formalizing Open Systems Science as a tool for this purpose. This represents the third phase of Sony CSL's development."

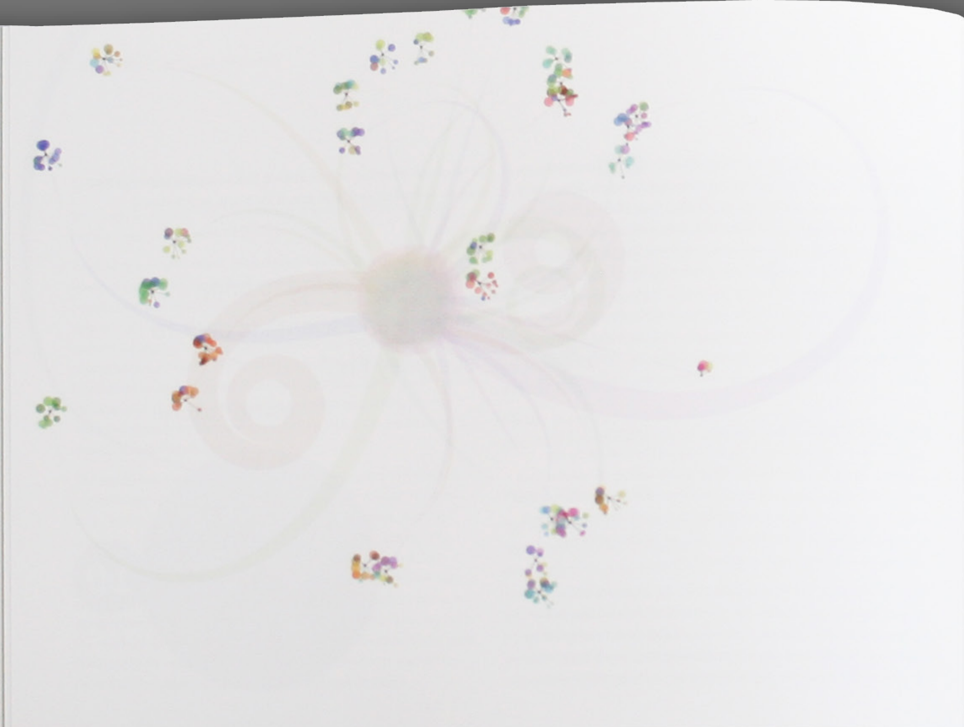
In the first years of the 21st century, Tokoro was trying to distill from CSL's rich diversity the essential elements that would contribute to a new methodology. At that time Hideki Takayasu was questioning the value of value itself, and engaging with the real world of currency trading from the perspective of physics. Jun Rekimoto was exploring the theme of human augmentation, another strictly real-world topic. Hiroaki Kitano couldn't be confined to a single scientific domain if you tied him to his chair, but he too was planning to make an impact on the real world of disease, as was Kazuhiro Sakurada, who had escaped the lab and was relishing the "real world" of CSL itself.

Suddenly, it all started to come together for Tokoro. Typical scientists weren't simply cutting bits out of the real world to analyze in artificial conditions. They were cutting themselves out of the real world. The scientists themselves were isolated from the truth. "Conventionally, a scientist has two faces: the professional face, and the face in everyday life. I felt we needed to bring science and scientists back to everyday life."

Over the centuries science had given the human race so much of value. That was undeniable. But it seemed to Tokoro that in our modern world of murky futures, science itself was now hurtling toward a dead end, just when it most needed to be shifting into top gear on the new data highway and generating fresh value.

To work out what to do next, Tokoro had to retrace the steps that science had taken and then search for a new path forward.

> "I felt we needed to bring science and scientists back to everyday life."
>
> **Mario Tokoro**



Open Systems Science

HISTORICAL CONTEXT

Since the days of Kepler and Galileo, science has given us dramatic technological advances and rising standards of living. In the mid-nineties, however, Mario Tokoro found himself among a growing number of people who were feeling uncomfortable with traditional scientific methods, suspecting they were not up to the task of dealing with the complex, interconnected problems we face today. An evolving sense that the concept of "open systems" could free up movement along the path to fresh horizons culminated in the proposal of a scientific methodology called Open Systems Science.

This new approach has guided the direction of research at Sony Computer Science Labs in the early years of the 21st century. Open Systems Science is not a rejection of traditional scientific methods, but an expansion, intended to overcome their limitations. To understand this, we first need to look at the history of conventional science.

Science has always been based on careful observation and the search for simple laws underlying the complexity of the world around us. These approaches have been around for a long time. The ancient Egyptians discovered basic principles of geometry as they surveyed their fields and raised their pyramids. The ancient Babylonians and Chinese kept careful observations of the stars and planets, and could even predict eclipses. The Indians devised the numeral system still used around the world today.

Of all ancient peoples, the ancient Greeks came closest to realizing modern science. They were enamored with the ideas of perfection and abstraction. They were the first to look at numbers as entities in themselves, untethering them from practical problems in surveying and architecture. Some began to think of the universe as governed by logical, knowable laws instead of the whims of the gods, and they set out to discover those laws. They were successful, and that is why thinkers like Euclid, Thales, Pythagoras, and Aristotle are still studied today. But Greek thought had its limits. Many Greeks never fully separated science and mathematics from religious ideas about perfection. Many also never learned the value of experiments to test their assumptions. Aristotle believed that heavier objects fall faster than light ones. A simple experiment would have proved this false, but such an experiment would have to wait for nearly 2000 years.

Scientific creativity declined after the Greek heyday. The Romans achieved great things in engineering, but they had more practical concerns, and didn't seek universal laws. After the fall of Rome, science languished. Medieval Europe was more concerned with theology and the afterlife than finding the laws of nature.

The greatest advances in science in this period were made by the Arabs, who contributed to astronomy, mathematics, and medicine, and preserved ancient Greek and Roman writings that had been lost in Europe.

With the coming of the Renaissance, people began once again to think about life in this world; focusing on questions beyond theology. The revival of science began in 1543, when Copernicus suggested that the earth goes around the sun. By the early 1600s, Kepler had put this theory on a firm mathematical foundation. Galileo believed in testing theories with observation, so he looked to the skies with early telescopes, and performed experiments disproving Aristotle's ideas about motion. By the end of the 1600s, Isaac Newton was able to formulate universal laws explaining motion both on earth and in space: realms long thought to obey different laws.

The growing realization that the universe is governed by precise laws helped usher in the Enlightenment. People began to think that nature literally ran like clockwork, and could be predicted absolutely if they just had enough information. Chemistry made great strides throughout the 1700s, while biologists began to study fossils and consider how living things were related to each other. The impact of science on everyday life was especially felt after the invention of the steam engine, which helped power the Industrial Revolution. In the mid-1800s, Darwin proposed his theory of evolution by natural selection, which offered a unifying theory for biology. Mendeleev found order among the elements by arranging them according to their properties in the periodic table. Maxwell found that electricity, magnetism, and light are all aspects of the single phenomenon of electromagnetism, thus switching on the age of electricity.

Just after the 20th century dawned, Einstein's theory of relativity showed that matter can be converted into energy. The existence of atoms and subatomic particles was proven, and the theory of quantum mechanics revealed that the universe wasn't quite as predictable as scientists had thought. Hubble discovered that the universe is expanding, leading others to suggest that the universe had begun in a Big Bang. The logical insights of people like Turing and von Neumann led to the development of the electronic computer. Computer modeling helped expand the pace of discovery to ever-greater levels, and by the late 20th century, the internet had given people around the world the ability to communicate instantly. The human genome was sequenced in 2000, and in the 21st century, scientific knowledge has continued to expand in every domain.

THE VALUE OF ANALYSIS

Many of the accomplishments of science can be traced back to methods that developed in the 1600s, when the scientific revolution was getting started. In 1637, just a few years after Galileo came into conflict with the church for promoting the Copernican worldview, René Descartes attempted to identify the fundamental methods of science, mathematics, and philosophy. In his *Discourse on the Method*, he outlined four precepts for seeking truth and knowledge. These would have an enormous influence on science and philosophy. Here they are in abbreviated form:

- *Never accept anything as true that I cannot accept as obviously true.*
- *Divide each of the problems I am examining into as many parts as should be necessary to solve them.*
- *Develop my thoughts in order, beginning with the matters simplest and easiest to understand, in order to reach little by little to the most complex knowledge.*
- *Make my enumerations so complete and my reviews so general that I can be assured that I have not omitted anything.*

The first of Descartes' principles has become a fundamental feature of science: science never accepts anything as true unless it can find observational evidence for it. If a theory does not match observation, it is rejected. Descartes actually derived this idea from mathematics, in which logical deductions follow from basic axioms that seem self-evidently true. He applied the idea to philosophy as well, arguing that even if all his perceptions were false, he could not be mistaken about the fact that he was having perceptions. He also could not doubt that he himself existed, because there must be someone to do the perceiving. This is the source of his famous maxim, "Cogito, ergo sum": I am thinking, therefore I exist.

Descartes' second precept would become equally influential in science. Here he argues for dividing complex problems into smaller, simpler parts. If we want to understand a complex thing, he argued, we need to take it apart and examine the parts it is made of. This approach came to be known as analysis, from Greek words meaning "break apart." Today, we use the word analysis to mean any close examination of a problem, rarely stopping to think that it originally meant "break into pieces." This approach has also come to be called reductionism, because it reduces complex problems and systems to their most basic parts, in order to study them better.

Reductionism and analysis have been incredibly powerful tools. Biologists only began to truly understand living things when they discovered that they are made of the simpler units called cells. Physical scientists only began to understand matter when they discovered it is made up of simpler units called atoms, which are themselves made of even simpler subatomic particles. "Divide and conquer" does not only apply to warfare.

THE VALUE OF SYNTHESIS

Science was slower to realize that analysis by itself is not enough. For example, if you want to understand how a computer works, it helps to take it apart and look at its component parts. But this isn't enough, because you do not truly understand it until you can put the pieces back together again so that the computer works. In other words, analysis—the breaking into parts—is complemented by synthesis—putting the parts together into a working whole.

Descartes touches on synthesis in his third and fourth precepts. In the third, he holds that we must begin with simple ideas (analysis), but we must also build on them, little by little, until we can understand how they fit together into more complex ideas (synthesis). Traditional science has a history of synthesis as well as analysis. Once biologists had identified cells, they could start thinking about how cells fit together to form tissues and organs. Once physical scientists had identified atoms, they could work out how they fit together into molecules and other more complex forms of matter.

Science also works toward theoretical synthesis, by combining once-separate ideas into a unified theory. Newton united ideas about motion on earth and in the heavens. Darwin found a common theme—evolution—that ties all living things together. Today, physicists have explained many of the basic laws of physics with a theory known as the Standard Model.

Still, science has often focused on analysis at the expense of synthesis. Too often, we try to break things apart and understand them in isolation, without stopping to think that they have to be understood in terms of larger wholes. This brings us to Descartes' fourth precept—to make sure your theories are complete and that they don't omit anything important.

Mario Tokoro believes that this fourth principle has been neglected. When it comes to extremely complex systems, such as the global environment or huge computer networks, we can't always understand each part in isolation. One part may only make sense as a part of a larger system. For example, a computer's processor will not do any computing by itself. To be useful, it must be combined with all the other parts that form a system known as a computer. Just as we can't understand computers by learning only about processors, we can't understand more complex systems by focusing on just one piece of the whole.

THE VALUE OF CONVENTIONAL SCIENCE

Sony CSL researchers are trained scientists, and they are unanimous in their belief in the value of conventional science. When asked what they appreciate about conventional science, they have a range of answers.

Some emphasize the value of experimentation, which is perhaps the key feature of science. Science is based on testing ideas. If ideas do not match with the results of experimentation, then they must be modified or rejected. Other CSL researchers emphasize the value of rigor, logic, and mathematics—no science can function without careful measurement, logical reasoning, mathematical models, and peer review. Many of the researchers talk about the value of creativity and curiosity in science. Science is not all hard logic and measurement; it also relies on creative thinking. Every new theory begins with a burst of insight.

Open Systems Science values all these pillars of science, and incorporates them. But ultimately it goes beyond them. Think of it as Science 2.0.

THE LIMITATIONS OF CONVENTIONAL SCIENCE

In the 21st century, many of the problems that have proved most difficult to solve are the ones that are so complex they can't be understood by looking at only one part. For example, global social and environmental issues are a complex mix of intertwined forces, including poverty, demographics, international law, biological diversity, and economic growth. When you try to fix problems by focusing on only one area, it may lead to unintended consequences in other areas. Pesticides, for example, increase the food supply and help alleviate poverty, but they do so at the expense of biological diversity.

Other global challenges include health problems such as diabetes and immune disorders, which are caused by multiple factors in the body and the environment. Then there is the dependability of complex computer software and networks, neither of which anybody can understand perfectly. Tokoro points out that these kinds of issues have two things in common. First, they involve vast, complicated, and constantly changing systems whose parts are intricately connected—you can't change one part without changing others. Second, these are systems that require us to try to predict, and in many cases change, how they will behave in the future.

Conventional reductionist science has trouble dealing with these matters. One problem is that as researchers have grown ever more specialized—focusing more and more deeply on more and more precise scientific questions—they have lost the ability to communicate. Tokoro says they have become walled off into "silos" of specialization. You can't see much from the bottom of a silo. And if the people at the bottom of the deep silos around you all speak different scientific languages, you won't have much to talk about. Another problem is that complex issues often can't be understood by focusing on parts. Conventional science has not dealt well with complex systems that are constantly changing, often in inherently unpredictable ways.

WHAT IS AN OPEN SYSTEM?

Examples of open systems include computer networks, cities, living things of all kinds, and the earth itself. The problems we have today are hard to solve because they involve open systems. But what does that mean?

Let's look at an example: the human body. Our bodies are composed of a complex set of parts, whose relationship with each other may change over time. These parts cannot be completely understood in isolation. For example, the brain affects the stomach, and the stomach affects the brain. Also, you can't stop the body's processes, or take the body apart completely, in order to study it, because then you would have a dead body. You can't fully predict the body's processes. You can't look at a baby and predict with certainty that it will grow up to be obese, even if it has genes associated with obesity. One reason is that open systems are constantly interacting with their environment. If the baby grows up to interact with his environment in one way—staying active and keeping a healthy diet, for example—maybe he won't be obese. If he interacts with his environment in another way, by sitting on the couch and eating too much, maybe he will.

This brings us to another characteristic of open systems: they literally are open, to influences from their environment. They may even consume matter and energy from their environment. Humans have to eat and breathe to stay alive, and the material composing a human body changes over time. The atoms in our bodies are completely replaced every few years—it is the system that lasts, not the matter that flows through it. Finally, open systems are out of equilibrium with their environment. If you swing a pendulum, it will eventually stop—reaching an equilibrium. Open systems move away from equilibrium. We humans don't just come to a stop, like a pendulum. We move around. Our bodies stay warm, even when the air around us is cool. We are complex, open, non-equilibrium systems.

When you think about it, all systems are open to their environment to some extent. Even a simple pendulum is affected by breezes, or the temperature. Truly open systems are simply more complex, and interact with their environment in more subtle, active ways—not only being influenced by the environment, but also influencing it.

THE NEED FOR MANAGEMENT

We can never understand or predict complex open systems completely. They are too complex, and their openness to environmental influences means we can never know for certain which of those influences will affect them. All open systems are parts within a larger system we call the environment, and the environment is a crucial part of understanding the open system. This means we can never completely get outside an open system to observe it. We can only observe it from the inside, and our view from the inside will always be incomplete.

Does this mean we should give up on trying to understand open systems? Certainly not. It simply means we need to change our approach. It's true that we can't predict or understand open systems with absolute precision. But we can try to understand and predict them as best we can. We can't control them absolutely, but we can try to cope with them. This is the essence of Open Systems Science, and the approach taken at Sony CSL.

Open Systems Science strives to understand open systems from the inside, without stopping them (because to stop them is to destroy them), and without leaving out anything important. This brings us back to Descartes' fourth precept, which conventional science has often disregarded. We must make sure we don't leave anything out that is essential to understanding the system, and this must include the system's real-world environment. Tokoro calls this "abstraction without elimination"—while acknowledging that it is actually an impossible dream.

In conventional science, as we have seen, problems are solved by the complementary processes of analysis (breaking into parts) and synthesis (fitting parts together). Open Systems Science keeps these elements, but adds a third: management. Since complex open systems cannot be fully predicted or controlled, the best we can do is try to understand them and, with due humility, influence them positively—bearing in mind that whatever we do, we *will* influence them. The task for the Open Systems Scientist is to create a model of an open system, and make the model as complete as possible. As the system changes over time, the model is adjusted or replaced. Management is a constant process, requiring the scientist to be willing to change his or her assumptions about the complicated, open-ended, constantly shifting world around us, at any time.

Descartes' first precept put the emphasis on demonstrating truth. Open Systems Science starts from a very different premise, and one that owes much to the thinking of Karl Popper, the 20th century philosopher of science: something is true only until it is demonstrated to be false.

And one day, everything now regarded as true will be demonstrated to be false—and then replaced by a new "truth."

Deal With The Real

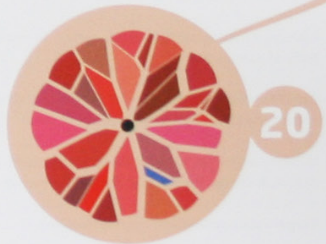
BE SKEPTICAL OF MODELS

There is an old joke among scientists, in which a farmer asks a physicist how he can make his dairy farm more efficient. The physicist does some calculations, and then tells the farmer, "I have the solution, but it will only work for spherical cows in a perfect vacuum." The joke reminds us that if we simplify our models too much, they are no longer useful for describing reality. On the other hand, we can't avoid some degree of simplification. All models are simplifications, in fact, because reality is too vast and complex to be captured in a model, or to fit in our heads. The trick is to make a model with the right level of abstraction, without forgetting that it is an abstraction.

Frank Nielsen is fond of quoting the statistician George E. P. Box: "All models are wrong, but some are useful." Mario Tokoro makes a similar point: "Abstraction itself is not generally open to doubt. However, abstraction (the process of making models), generates items (models) that must be doubted." This kind of doubt, or skepticism, is central to science. Science cannot proceed unless we check our models against reality and modify them as needed. Such skepticism is compatible with open-mindedness, however, because it requires being open to the possibility that reality is not the same as we imagined.

"The nature of open systems is such that we can only acquire imperfect information on their fundamental structure and condition, and their behavior is difficult to predict."

Hiroaki Kitano



Skepticism and open-mindedness are two sides of the same coin—a willingness to change our models when our models don't do justice to the real world.

BE OPEN TO REALITY

The balance of open-mindedness and skepticism is one of the hallmarks of Open Systems Science, which constructs useful models of complex systems by constantly checking them against reality, and improving them as much as possible. Here, in simplified form, is Mario Tokoro's methodology for Open Systems Science:

1. Define the problem and its domain.
2. Construct a model of the problem domain in detail, without elimination.
3. Apply the model and see whether it contradicts the behavior of the system, as the system changes over time.
4. If it does, revise the model or devise a new model. Expand, reduce, or change the problem domain if necessary.
5. Repeat until a satisfactory result is obtained.

As these steps show, Open Systems Science starts with the assumption that systems in the real world are complex and ever-changing. To understand and manage them, we have to keep updating our models. While abstraction is unavoidable, we need to remember to practice abstraction without elimination as much as possible. In other words, we have to make sure we haven't left any crucial element out of the system. We also have to remember that reality is ever-changing, and to update the model to reflect the changes in the real world. Open Systems Science requires us to be open to reality as is actually is; in all its messiness and complexity. Cows simply aren't spherical.

However, reality is difficult to model for many reasons. Let's review some of the tricky characteristics of the real world, and see how Sony CSL researchers have addressed them.

Irreducibly complex: Complex things such as ecosystems, living cells, and financial markets are composed of an enormous number of parts interacting in subtle ways. Sometimes, if we try to simplify our models too much, we find that they no longer describe the behavior of the systems. The real world is not obligated to be easily understood, and some systems are irreducibly complex. Hiroaki Kitano has tried to reveal this complexity by drawing maps of the relationships between molecules in the metabolism of a living cell. Each map is a network with hundreds of connections. It looks

"I'm aiming for a better understanding of the whole system, so that we can manage the body in a better way."

Hiroaki Kitano

complicated but...that's life. And these complex maps have allowed Kitano to identify core networks and processes. By respecting the complexity of life, he has been able to find an underlying simplicity.

Unknowable and unpredictable: We cannot always know everything about complex open systems. In particular, changes in such systems are extremely difficult to predict. For example, we may be almost certain that an earthquake will occur in a certain location, but we cannot know exactly when it will strike or what its magnitude will be. The econophysicist Hideki Takayasu is especially familiar with this problem, having studied tectonic activity before applying some of the lessons he learned there to economic phenomena—which are just as stubbornly resistant to prediction.

Uncontrollable: Systems that are not fully knowable are not fully controllable. Control is more difficult than understanding, even in simple systems: understanding the physics of billiards doesn't make you a good billiards player. Open Systems Science recognizes that some systems can't be fully controlled. At best, they can be effectively managed.

Ever-changing: During the Enlightenment people thought of the universe as a great clockwork machine following precise, predictable laws. This describes the movement of stars and planets reasonably well, but not more complex systems. People like Lyell and Darwin showed that the world changes over time, often in unpredictable ways. The universe is not static or perfectly cyclical; it evolves. Kazuhiro Sakurada talks about this in terms of the philosophical distinction between being and becoming. When it comes to complex systems, the world is not static "being", or a perfectly predictable machine. It is a dynamic, organic process of "becoming."

Interconnected: Open systems are not just a jumble of random parts. The parts fit together in subtle ways, giving the system properties that aren't present in any individual part. This means we have to pay as much attention to interactions between parts as the parts themselves. Sometimes these interactions can have unexpected effects. For example, it is known that certain cancer drugs are more effective when given with other drugs that aren't by themselves used to treat cancer. In other words, the cancer drug is effective by itself, but much more effective in combination with another drug—a drug which by itself has no effect on cancer. The interaction is far more powerful than the sum of each drug taken separately.

Unique and non-reproducible: Every complex system is unique, which means that what works for one system may not work for another. A drug that cures one person may make another person sicker. Every complex system is unique in part because of how it interacts with its environment. Identical twins may have the same genes, but they may look and behave differently, or get different diseases, because of differences in their experiences and environments. Meanwhile the concept of non-reproducibility has profound consequences for Open Systems Science methodology. If we accept that the conditions for an experiment can never be perfectly repeated, the emphasis then shifts from experimenting to hypothesizing, and then using computer simulations to test the hypothesis. If the hypothesized phenomenon can be simulated, then the underlying theory can be regarded as sound—at least until it is eventually disproved. This draws attention to the fact that Open Systems Science is a child of its time. Even if the idea of conducting simulations had occurred to Descartes—or Karl Popper, for that matter—the tools simply didn't exist to enable them to do so.

Unexpected: Reality will always be full of surprises. This can be a good thing, because one of the main engines of discovery in science is serendipity—unexpected findings that lead to new insights. Hiroaki Kitano gives the example of Russian researchers who tried to breed tamer foxes. They selected foxes based on only one trait: tameness. After several generations, the foxes began to resemble dogs: whining for attention, playing with people, and even developing dog-like color patterns. It turns out that these doglike traits were genetically linked to tameness. This suggests that the differences in appearance between dogs and wolves may be unexpected byproducts of selection for tameness. As Kitano says, "This is interesting because it's completely unexpected."

Every time nature surprises us, it's an opportunity to learn something new. To find these surprises, Kitano believes, it's important to get out of the lab, to see how things are in the real world. Masa Funabashi also believes it's crucial to see the real world in all its messy reality. Some scientists use the Latin term *in natura* (in nature) to talk about the world as it is in nature, as opposed to in the lab (where experiments are conducted *in vivo* and *in vitro*), and Funabashi has an unusual teacher to thank for drawing his attention to the value of studying the world that way.

He was coming to the end of his studies in Paris, and felt a strong urge to be somewhere that was the complete opposite. His thoughts turned to Yakushima, a mountainous island in southwest Japan that is covered in an ancient forest. "People get lost on the trails that wind through the forest; some even die. I decided to go on my own to Yakushima and live like a wild animal there for a few days." He had a supply of food, and mountain huts where a hiker could rest for the night were scattered along the paths. One night, the sound of a small creature woke him. It was a mouse, and it had found his food supply. Without a second thought he lashed out at it with his sandal. But this was no docile laboratory mouse; it was a ping-pong ball of vitality and swift as lightning. Martial arts training had made Funabashi pretty sharp, though, and with his second strike he killed his little competitor for resources. But with the mouse lying in his hand, its life-warmth fading, Funabashi's humanity returned. "What a fantastic creature, I thought. What have I *done*? And from that moment, I knew the only way for me to study life was *in natura*."

SHARE EFFECTIVELY

"If we are to solve problems that arise out of the properties of open systems," says Hiroaki Kitano, "then we must cross boundaries between research organizations and integrate knowledge from a wide range of disciplines."

One of the problems with traditional scientific reductionism is that it encourages scientists to focus on smaller and smaller problems. Some scientists today spend entire careers working on a single species of animal, or even a single type of molecule. Specialization is valuable in the sense that it allows people to become experts in their area—nobody can become an expert in every field, and even the most narrowly defined subject area can take years to master. But specialization can also be a problem, because it can lead to intellectual fragmentation and tunnel vision. Scientists may focus so intensely on such narrow problems—using a jargon known only to those who share much of their expertise—that it becomes very difficult for them to communicate with those studying other subjects.

As Mario Tokoro puts it, they find themselves at the bottom of silos. That makes it hard to see any common themes and overarching patterns that might link different fields. It's also a missed opportunity, because researchers in different fields might be able to offer new perspectives on old problems. Such cross-fertilization would make all disciplines stronger—but only if researchers could look beyond their own area of specialization and communicate with others who are studying different, but possibly related, matters.

This is one reason why Kitano champions the concept of acting beyond borders. Sony CSL has a policy of encouraging open communication among its researchers, and with the outside world. Researchers from widely separated fields are encouraged to share ideas with each other, and to collaborate on papers and research projects. It is not uncommon to see the names of Sony CSL biologists, physicists, and computer scientists together on the same research paper.

Sony CSL is committed to traditional scientific communication. Its researchers have published hundreds of papers in scientific journals, and written many influential books in their fields. They speak at international conferences, and maintain close communication with other scientists around the world. Most

Sony CSL scientists are able to communicate in more than one language. If an internal meeting is conducted in Japanese it's no problem for the likes of Frank Nielsen, Natalia Polouliakh or Alexis Andre. And because English has become a lingua franca in global science and industry, all researchers are expected to be able to communicate effectively in English.

Sony CSL's commitment to effective communication goes beyond the scientific community. Mario Tokoro believes that scientists also have a responsibility to communicate their ideas to the public. As more and more of the world shifts to democratic governments, it is more crucial than ever for the public to understand science and technology. Indeed, one of the aims of this booklet is to make Sony CSL's discoveries accessible to non-scientists.

Sony CSL is able to harness the twin engines of specialization and diversity by assembling experts in a wide variety of disciplines, and then encouraging them to reach beyond those disciplines to share ideas with each other. The researchers for their part enjoy being surrounded by other outstanding minds engaged in a wide variety of intellectual endeavors.

"We must cross boundaries between research organizations and integrate knowledge from a wide range of disciplines."

Hiroaki Kitano

Here And Now

So now let's meet the rest of the team and find out more about why Sony CSL is such a great place to study.

Shigeru Tajima

Shigeru Tajima is trying to solve the world's growing energy needs through the introduction of open energy systems, where everyone will be able to produce, manage, and consume their own electricity. By combining power electronics and information technologies, he hopes to bring about a transformation in DC-distributed power supply and management, thereby offering electricity to countless people in challenging circumstances all over the world, and engendering greater social stability for everyone.

Takashi Isozaki

From purchasing histories to gene expressions and geo-environmental assessments, we are now amassing greater volumes of more detailed data than ever before. Although there is huge potential to use such data for the benefit of humanity, there are currently no methods for fully extracting information from data on very complicated systems. Takashi Isozaki is developing a physics-based theory and complementary algorithms for statistical analysis to maximize the extraction of information from such data.

Tetsuya Shiraishi

With the Japanese population aging rapidly while the number of principal care providers quickly declines, Japan's present social system is not up to the task of delivering support to people in need of care. To meet diverse needs and also provide higher quality healthcare, it will be necessary to shift from a conventional approach centered on care facilities and hospitals to one that focuses on local, community-centered solutions. Tetsuya Shiraishi, himself a medical doctor, is applying ICT and robotics technologies to construct a future healthcare system able to manage these complex issues.

Michael Spranger

How do we perceive and conceptualize the world? And how do we put the world into words? These are questions that Michael Spranger addresses as he explores the theme of autonomous, open-ended, complex communication systems. He studies the fundamental principles governing the processing, acquisition, and evolution of natural language, and works toward turning these insights into human-like digital communication partners that you can actually trust. The results of his work are applicable to human-robot interaction, artificial assistants, and gaming.

Yoshihito Ishibashi

Economic development is shifting rapidly from industrially advanced countries to developing countries in Asia, South America, and Africa. Since many of these countries do not yet have established power or communication networks, Yoshihito Ishibashi sees an opportunity to directly introduce Open Energy Systems better designed to tackle worldwide environmental and energy problems. He is aiming for the universal availability of movable batteries that can be charged using natural energy, thereby freeing us from dependence on power lines and power companies, and allowing us to choose exactly where we want to be.

Peter Hanappe

Peter Hanappe works on the urgent challenge of creating a more sustainable society. He devises technology and social media to change people's behavior, then makes this technology more sustainable. His projects include using mobile phones to collaboratively measure urban noise pollution, running large-scale climate simulations on low-energy volunteer computing networks, using social media to stimulate local organic food production and exchange in cities, and building environmental sensor networks using bio-sourced and biodegradable electronics.

Yuichiro Takeuchi

Although digital technology long ago escaped the confines of the PC and now thoroughly permeates our world, so far it has had no deep impact on the nature of the architecture around us. Yuichiro Takeuchi is developing a range of technologies aimed at changing this. In his concept of synthetic space—the architectural space of the future—transforming the makeup of the surrounding built environment will be as easy as changing the wallpaper on a laptop. The goal of his research is to make this future a reality through an eclectic approach informed by multiple engineering and design disciplines.

Hiroaki Tobita

In magazines, newspapers, and various digital forms, comics are one of the world's favorite forms of graphic content. Hiroaki Tobita's goal with comic computing is to integrate attributes of comics with the user interface to make computing systems more interesting and visual. Using Tobita's comic creation and browsing applications, users can easily make their own comic books and share them over a network, thereby enjoying new opportunities for creativity and communication that transcend age, nationality, and other boundaries. Harnessing the diverse visual techniques that go into the making of a comic, Tobita is also exploring applications in information visualization and augmented reality.

Alexis Andre

Even though our computers and mobile devices grow ever more powerful and accessible, we live in a world of data overload, and the tools for extracting and understanding relevant information from this data lag far behind. Alexis Andre thinks better use should be made of our senses, by adding new tactile and auditory techniques to the current visual methods of interaction. His "interactive aesthetics" uses multi-modal interfaces that mix the physical and virtual with sensory interfaces. To explore the process of creation, he also develops new performance devices—music, games, and drawing tools that allow for fresh ways to interact, simultaneously mixing information and beauty.

Shigeru Owada

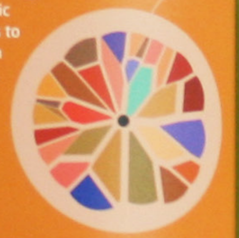
As ordinary households quickly become network-friendly environments, the realm of ubiquitous computing and life logs, previously confined to the research lab, is fast emerging in the real world and supporting everyday activities in various ways. Beyond mere smartphone applications and remote control devices, Shigeru Owada believes this new integration of technology and lifestyle will generate entirely new services and ultimately transform the structure of industry itself. He is exploring a broad range of applications at the forefront of this change, and engaging in diverse activities aimed at nurturing new forms of community.

Pierre Roy

Pierre Roy is designing tools for content generation such as written text or melodies with an emphasis on style imitation and user control. Working with François Pachet, he has introduced Constrained Markov Models, a new framework combining the power of Markov processes with constraint satisfaction programming. Constrained Markov Models are trained to learn the style of an author, such as a writer or a musician, from a corpus of his or her work. These Constrained Markov Models may then be used to control the generation of sequences in the learned style.

Remi van Trijp

Remi van Trijp dedicates his research to one of the most intriguing mysteries of humankind: linguistic creativity. Language is an open system, a unique ability that brings infinite variety to the ways in which we communicate with others about our experiences in life. Van Trijp is developing powerful cognitive language technologies in order to study open-ended and robust language processing, explore innovative linguistic applications, and find ways to manage them in large open collaborative communities.



Masatoshi Funabashi

Primary industries such as agriculture, forestry, fisheries, and stock-breeding bring people into close contact with nature. Throughout history agriculture has had destructive consequences, and modern agricultural practices still degrade the natural environment, degenerate food quality, and even threaten health. Masatoshi Funabashi is using Open Systems Science to create a new system of agriculture based on augmenting ecological interactions to restore and construct natural environments. His long-term goal is to establish a new life science that goes beyond conventional reductionist science to realize a symbiotic earth where all living species can function to their full potential.

Kaoru Yoshida

Tracing the history of the earth back to the ancient time when life first appeared, we learn how early organisms made the planet livable for the ones that followed. No organisms are either complete by themselves or unchanging throughout their lives. They need to complement each other and continuously evolve, so that the entire system stays in balance. Kaoru Yoshida has been studying the molecular mechanism of life from the viewpoint of the global cycle of nature. Her special interest is in those organisms that sustain the food chain at the bottom, such as microbes.

Yuki Yoshida

An underlying principle in the process of evolution is the adaptation of organisms to fluctuations in inherited genetic characteristics and environmental factors. Yuki Yoshida uses Systems Biology to understand and experimentally control environmental responses and survival strategies in biological organisms. Her work has important potential for drug development, tailor-made medical care, preventive medicine and therapeutic strategies, and she hopes that it will improve our understanding of cancer, as well as autoimmune and other diseases.

Yuji Yamamoto

Realizing that current medical systems have long prioritized curing disease over providing health care, Yuji Yamamoto is seeking a new type of health management solution to maintain people's health for as long and as affordably as possible. Reflecting on his experiences as a medical doctor, he believes that health should be a major target for technology in the 21st century, since it is a key factor empowering people to contribute to society. Japan's universal insurance system and standardized information infrastructure offer Yamamoto access to administrative records, lab results, and other data that can help him identify neglected patients and devise solutions tailored to each person's requirements. His ultimate goal is to change the healthcare paradigm.

Ken Endo

An early interest in robotics led Ken Endo to study biomechanics, and then to develop new concepts in physical augmentation. Examining loss of function due to disability, he realized that the human body has much untapped functionality. The technological problem of compensating for lost physical functions and adding augmented ones demands a clear understanding of neurological, reflex, brain, and muscular systems. Technology must also be developed for devices that seamlessly match the human body. And since disability is more of a problem in rural, developing areas, many social, economic, and cultural factors must also be overcome.

Takahiro Sasaki

Open systems consist of multiple sub-systems interacting and evolving over time. To understand the dynamic nature of such systems, Taka Sasaki is developing the concept of, and methods for, Open Systems Simulation. His simulations reveal possible futures and re-enact real-world events that will never happen again. As a specific task he is currently trying to develop an integrated simulation of infectious disease that includes not only the process of infection but also the evolution of a pathogen, including its co-evolution with the human host and other environmental factors. Sasaki's ultimate goal is a holistic understanding of open systems leading to essential long-term solutions.

Natalia Polouliakh

Cancer and infertility have become serious problems for humanity in the 21st century. Natalia Polouliakh's research is devoted to developing analytical tools for data-driven analysis and investigation of the biological and social aspects of these challenges. She seeks to understand the genetic and epigenetic aspects of underlying molecular mechanisms over time in order to create a dynamic network model of the formation of cellular memory. Optimization of the cellular niche (or "microenvironment") is one factor crucial to cell proliferation at the early stage of embryogenesis, as well as to disease prevention.

Annette Werth

Annette Werth sees Open Energy Systems as a radically new and decentralized way to create the next generation of smart power grids, which will be capable of exploiting a variety of renewable energy sources efficiently. She has been working on an open energy system consisting of electrovoltaic panels and a lithium-ion storage battery system, and this is being tested in the field in Ghana and Okinawa. Her current focus is on how to actually implement an intelligent and distributed power network, with the ultimate goal of providing universal access to sustainable energy and independence from national grids.

STRENGTH IN DIVERSITY

One of the key principles of Open Systems Science is holism: the idea that diverse parts can come together in a whole that transcends the capabilities of any of its parts. Sony CSL is just such a whole system, composed of very talented people with diverse backgrounds, interests, and perspectives.

Where else can you find a single well-integrated, highly communicative team whose members are studying and/or well versed in (and this is only a partial list) mathematics, brain science, linguistics, cell signaling, consumer behavior, geometry, epidemiology, conscious experience, cartoons, artificial intelligence, medical insurance, factory efficiency, human augmentation, electronics, music, energy systems, art, agriculture, computer systems dependability, biology, networks of objects, and physics?

Sony CSL researchers have followed many paths. The protean Hiroaki Kitano literally seems to know no bounds when it comes to the pursuit of knowledge, but he's far from alone at CSL. Luc Steels has studied computer science, semiotics, and evolutionary biology. Alexis Andre is from France, but went to Japan for graduate work in computer science. Now he applies his computer skills to studying aesthetics and creativity. Masatoshi Funabashi went in the opposite direction: from Japan to France, for a Ph.D. in Complex Systems Science. Now he has crossed into the realm of agriculture, investigating ways to maintain a balance between productivity and sustainability. Natalia Polouliakh, who studies cell signaling, once studied linguistics in her native Russia.

CSL researchers also come from a range of professional backgrounds. Tetsuya Shiraishi is a neurosurgeon who applies Systems Biology to the study of cancer. Kazuhiro Sakurada is a pharmacologist and a former corporate executive. Today he studies how stem cells and neurons adapt to changes in their environment.

Individually the Sony CSL researchers have acquired a wide range of experience, and they can use what they have gained to explore many different directions of knowledge. Collectively, they can bring an extremely wide range of perspectives to bear on a specific challenge, revealing many dimensions of a complex problem, and moving forward efficiently and effectively with each other's help.

How does the CSL workplace provide physical and social incentives to do that?

OPTIMIZING INTERACTION AND SERENDIPITY

Fundamental to the CSL way of thinking about the workplace is that day-to-day communication is the most important source of new information. Interaction is encouraged by an open-door policy set from the top—Mario Tokoro insisted on it. People feel they can chat over a coffee or walk into anyone's office at any time without being rebuffed. Even those not located close together physically will lunch together, or just walk around and pop their head in at a colleague's office to stay in the loop. So unless it is essential for a researcher to concentrate on something for a few hours, the doors at CSL stay open.

To stay in touch outside the office, the usual communication tools are available, of course: email, text messages. But as day-to-day communication is considered so key to the lab, it is not surprising that researchers feel that an excess of digital interaction can lead to a loss of what Hiroaki Kitano calls "collateral information and serendipity." It's essential to have minds interacting in shared physical spaces, offering participants access to a mental network that is optimized for catching valuable information as it flows by on the tide of the times.

Kitano believes the key to serendipitous interaction is having an open, accepting, and varied set of minds. That increases the potential for ad hoc interactions sparking new ideas. "People mingle so well here," he says. "Researchers recognize the value of a casual 'Hi' and 'Oh, by the way....'"

It is also recognized that both personal and digital interaction will only work effectively to encourage creativity if people really feel free to interact across the board. Diversity is but one aspect in another key piece of the puzzle—to ensure the lab has the right people on board. And that's a constant challenge for the two people reviewing the researcher line-up: Tokoro and Kitano.

But on a day-to-day basis, the open-door policy and physical environment supporting it discourage hierarchies that could allow senior researchers to get too busy, or ensconced in ivory towers, to foster other colleagues. CSL aims for a responsive and responsible workforce that does not feel straitjacketed by hierarchy and tradition. CSL not only respects but demands researcher autonomy, and aims to optimize "transversal activity." CSL researchers are expected to be individuals acting responsibly, open to their other colleagues and also to the external community.

LATERAL CONNECTIONS

Transversal activity is at the heart of the CSL approach. The interaction it encourages is evident in all fields and projects at all levels. It is assumed that it will lead to positive outcomes regardless of the huge differences between individual research themes. A tangible event embodying the value of this lateral sharing is the offsite research review meeting held every year in both Japan and France.

This opportunity to review everyone's activities outside the office environment is a key event in the CSL calendar. Individual researchers do presentations on their studies, covering fundamental concepts, goals, progress, and the eventual benefits that their research promises to offer. They work hard to communicate effectively to those who do not come from the same academic background, then they field searching questions as the whole room reflects on the potential for a new cross-fertilization of ideas.

Similar but smaller gatherings called general meetings take place every two weeks on site. On these occasions researchers report on recent study progress and findings, learn from guest speakers, and share information about conferences attended or institutions visited.

A rather different kind of event is CSL Open House, which is held every two years on site in Tokyo and in Paris for the benefit of invited guests. This is an opportunity for CSL researchers to present and demonstrate their work at various stages to an external audience of interested people. Open House once again reminds researchers of their duty to make themselves understood, especially as their audience may include people with no background in science at all. Open House is sometimes a catalyst for a longer-term relationship with invitees. If an attendee brings something of interest and shows they have potential, they could even end up on staff as a researcher.

The environment at CSL encourages free internal and external interaction and cross-inspiration. This happens in interactions within the Sony corporate structure, too, as we will see in more detail a little later. Sony Corporation/Sony CSL research interaction is fluid and open. It eschews the common corporate model in which the business drives the research agenda, while still ensuring that a business perspective is factored into CSL's activities.

THE THINKER'S CHOICE

Sony CSL prides itself on the lack of certain features that are not uncommon in large organizations: written reports, team leaders, project managers, detailed pre- and long-term planning.

The goal is to have a transparent, streamlined, flexible administrative framework for researchers to get on with their work. Everyone is on an annual contract with a clear renegotiation process that is based on the research review meeting preceding it.

Hiring doesn't conform to a strict procedure. A researcher can be taken on as a result of attending a CSL Open House and sparking interest in their "weird PhD," as Alexis Andre puts it.

Once on board, people are not weighed down with potentially demotivating and distracting tasks. Nor do they have teaching duties that they have to find time for on top of their research—unless they themselves choose to work at a university, for example. And importantly, pre-planning for a project is not so detailed that it "inhibits serendipity and creativity," as Kazuhiro Sakurada describes it, once again emphasizing the importance of fortuitous exposure to new information and ideas.

By limiting paperwork, unproductive meetings, and reporting requirements, CSL's administrative structure seeks to optimize conditions for study and the creative destruction of intellectual boundaries. It encourages rigor and accountability by having a clear regime of regular research reviews. It positions equality of treatment as a keystone by putting all researchers on the same one-year renewable contract. And the annual contract review itself leads to an honest, objective appraisal of CSL as the best place for the individual researcher at that stage on his or her career path.

There is no bureaucracy running CSL, just a team of autonomous researchers empowered to function to the best of their ability in the pursuit of fundamental yet applicable research.

Let's take a closer look at some of those applications.

"CSL is all about making an impact on the world."

Ken Endo

MAKING THINGS HAPPEN

How's this for a mission statement: "Gather crazy people and let them try to change the world"! Sony CSL is a small operation; there are fewer than 30 researchers. For such a small group to make a big impact, everyone has to be "crazy" enough to aim to contribute to society and make a positive difference.

Hiroaki Kitano encourages CSL to embrace—and himself embodies—this good kind of craziness, which liberates scientists and engineers to "act beyond borders," as he puts it. This slogan is a challenge to researchers to transcend the boundaries between scientific disciplines and break through the thick walls of assumptions in the individual mind. But another important border for Sony CSL to cross is the one between the world of science and the world of everyday life.

Researchers who just want to satisfy their personal curiosity aren't what CSL is looking for. They have to be driven by a powerful desire to change the world. The work an individual researcher does may not make a broad impact on society for 10 or 20 or 30 years, but the mindset that it ultimately will make a huge impact must be maintained. Researchers have to believe that they can shape the future. If their passion is palpable and their aim is true, they'll always be welcome on the CSL team.

Kitano also encourages CSL researchers to be entrepreneurial, to keep their eyes peeled for business opportunities that arise along the way to that alluring goal, chances to create new business domains—for themselves, for industry as a whole, or specifically for Sony Corporation. Opportunity might take the form of a technology transfer, a licensing deal, or a spin-off. But whatever the mechanism, Kitano is convinced that business is the bridge between laboratory and society.

He argues that for technology to contribute to global society and change the world, it has to influence a very large number of people. To do that, he says, technology must get cheaper and cheaper every year. In fact it must be as cheap as possible, while still generating value. In established business sectors serving the developed world, industry is usually chasing efficiency. Kitano wants CSL to foster a different perspective, imagining what "crazy" science and technology could do for people in the developing world.

Take solar panels, for example. While the market in advanced countries pushes for 30% efficiencies through complex silicon-based processes, solar panels with a puny 5% efficiency that could be rolled on like paint could revolutionize the developing world, where there tends to be plenty of sunshine and land. To spot these socially transformative market possibilities beyond the horizon of current business, Kitano believes it is essential for researchers to get out and embrace reality, not shut themselves away in comfortable ivory towers.

STAR PRODUCER

Think of Sony CSL's researchers as Hollywood stars of science and technology, and Sony Corporation's business units as movie moguls looking for box office hits. Tetsu Natsume is like the producer who brings them together. He's instrumental in bringing the innovative visions of CSL to "the big screen"—which for Sony Corporation is the global market.

Sony CSL is full of big thinkers with big ideas, and since it's not bound to any particular technology or business, it's a hotbed of new ideas and technology. This gives Natsume the freedom to chase whatever deals he wants. He can visit anyone anywhere in the Sony Group in order to pitch CSL's innovations. He makes presentations to business units that have the financial and engineering muscle to turn innovations into products and processes that will boost Sony Corporation's bottom line.

But Natsume himself wants to act beyond the borders of his own defined duties. He dreams of orchestrating big, blue-sky initiatives that reflect CSL's mission of contributing to mankind, and not just to Sony. He notes that in any case, CSL researchers don't feel constrained by Sony Corporation's strategy or policy: "At Sony Corporation headquarters, everyone has VAIO computers. That's only to be expected. But at CSL meetings, the room is full of Macs. We can't compete against Apple without using their products anyway. The environment at CSL is more like the real world in that respect, too."

Where does Natsume's work start? With the technology. CSL fosters a constant flow of innovations. To keep tabs on what's in the pipeline, Natsume meets individually with researchers in interview-like sessions. But his most important source of up-to-the-minute info is day-to-day interaction. Taking advantage of the open-door policy instituted by Mario Tokoro, Natsume can drop by researchers' offices or chat with them by the coffee machine: technology accessed through relationships.

How does Natsume take these ideas to Sony Corporation to pitch them as business opportunities? By meeting with, as he puts it, "literally everybody" at Sony Corporation. In-person meetings are critical to his role: that's where he scans for potential deals. Department heads are usually too busy to visit in person and see what CSL researchers have brewing (even though they'd be welcomed by CSL's open-door philosophy). So Natsume takes the initiative with an hour-long roadshow of 20-30 CSL technologies. He does one almost every week at a Sony unit somewhere around the world.

He asks in advance what technologies attendees are interested in, but he also picks some "wild cards." As we'll see, Natsume has learned from experience that ideas can grab interest in unexpected quarters. Through these meetings Natsume builds relationships at all levels of the Sony organization. This enables him to evaluate the corporation's technology needs and plan his next move. One of his required skills is gleaning nuggets of information whose value may not be apparent even to the person sharing them.

What happens when someone at Sony Corporation is enthusiastic about a CSL technology in Natsume's pitch? Well, Natsume warns that even if there is interest, it will drop by 50% within a day, just because people are busy. The whole idea might be totally forgotten in a week or so. The challenge is to forge a connection between an interested party and CSL, and so Natsume sends an email magazine to any presentation attendee who emails him. It's a tickler, stoking awareness of what a good resource for new technology CSL is. Natsume only sends the magazine to people he's already met, instead of blasting it Sony-wide. Relationships are the access point—and they need to be maintained. That's why Yoko Honjo is a key member of Sony CSL's Technology Promotion Office (TPO) team. She mirrors Natsume's activities so that she can step in at any time to keep things moving forward.

TPO SUCCESS STORIES

CSL innovations move out into the marketplace along various paths. Sometimes researchers benefit from shifting from Sony CSL to Sony Corporation, like the OS team that moved in 1996 and later created the PlayStation 3 operating system.

Sometimes the transition that needs to happen to unlock a business opportunity is to form a new startup company. A regular feature of Tetsu Natsume's roadshows is the technology of Jun Rekimoto, a one-man idea factory who always has something new and different to offer. Interface guru Jun Rekimoto has been at CSL third-longest, trailing only Mario Tokoro himself and Hiroaki Kitano. He's been there for so long because he keeps generating results, and is able to shift tack in his research on his own initiative. His pioneering augmented reality technology of the early '90s ended up in the first camera-equipped VAIO models.

Rekimoto, along with Atsushi Shionozaki and Taka Sueyoshi, first demonstrated PlaceEngine technology in 2005. PlaceEngine enables a WiFi-enabled smartphone or other device to determine its own location even inside a building or underground. Sony CSL's Technology Promotion Office took the technology to Sony's Product Groups, but while there was interest in the technology, there were also concerns about the infrastructure required to make a business out of it.

Natsume knew the three researchers had been wanting to form a new company, and he saw it as his job to help make that happen. CSL itself was not in a position to form a subsidiary, but Natsume knew through his previous contacts with So-net (the Sony Group's internet service provider) that this unit liked to invest in companies outside Sony. Natsume asked if they'd be interested in investing in a Sony CSL spinoff. And that's how Koozyt was born, with So-net providing the investment, CSL providing the technology and people, and Sueyoshi and Shionozaki becoming the new company's main executives. Recently, Yoko Honjo has been especially active in harnessing Koozyt's expertise for use in interactive museum guides, such as an iPhone app for the Gallery of Horyuji Treasures at Tokyo National Museum.

Before we leave the topic of spin-offs, we should mention that any booklet published to commemorate the 30th anniversary will almost certainly feature more Sony CSL spin-off stories very prominently, although we are not at liberty to offer any details now!

UNFORESEEN BENEFITS

Sometimes the TPO team may shepherd a promising CSL innovation through initial rejection to unexpected applications.

Sony CSL Paris researcher François Pachet is a scientist-slash-artist who, if he had one wish to change the world, doesn't know if he'd choose to institute a sustainable human civilization...or add sustain to acoustic guitars. Pachet has been exploring the complex flows of ideas and thoughts that occur in the human mind during content creation. His aim is to build a new generation of tools for music and text creation. To get a sense of what these tools may offer us in the future, just open a browser and search for "Centre Pompidou, Continuator." Not just imitative, Pachet's Continuator can develop music in your style and jam with you.

Some years ago, Natsume learned that Pachet had developed a genetic algorithm to categorize content—for example, to distinguish guitar music from piano music. First, an example of a guitar sound and an example of a piano sound are given to the program. The program then begins to evolve, creating generation after generation of formulas that are eventually able to differentiate between the sound of a guitar and the sound of a piano.

Tetsu Natsume saw this as an idea with potential, and he took it to Sony's Walkman people. But he wasn't able to move things forward successfully there, so next he went to Sony R&D in Tokyo, where interest proved to be stronger. In due course the technology was renamed ELFE and its capabilities were expanded to classify not only music, but images—something Pachet himself hadn't thought of.

With Natsume's strong backing, a researcher named Yoshiyuki Kobayashi was assigned by the Tokyo R&D group to build

on Pachet's idea. Kobayashi ultimately created a slide show application for Sony tablet computers that auto-generated music videos based on the user's photos. And in the end the technology did find its way into the Walkman line—as a music visualizer feature.

More surprisingly it also found a use in Sony factories, inspecting Blu-ray recorders. Engineers adapted the genetic algorithm for use in generating formulas to test, for example, whether screws were tight enough. After real-world testing, it was introduced on the factory floor.

This offers a perfect example of TPO's mission, to bring outside-the-box technologies to Sony engineers with domain expertise who are facing challenges for which they lack a solution.

FACILITATING ALCHEMY: THE TAKAYASU CASE

One of TPO's greatest triumphs was to turn CSL's scientific ingenuity into bottom-line benefits for a Sony Corporation business unit. Hideki Takayasu, the CSL researcher whose expertise was harnessed in this case, proved himself a master of contemporary alchemy. He turned data into pure gold.

Tetsu Natsume had a hunch that Takayasu, an expert in fractal models and statistical physics, could make a difference to Sony's semiconductor operations. Meanwhile, Sony's semiconductor researchers were searching for an expert in statistics. It was Natsume who made the crucial connection between Takayasu and a manager in Sony's semiconductor operations named Toyohiro Tsunakawa, who served as the catalyst for the project.

It all began when Tsunakawa attended a Sony CSL Open House in 2005. Takayasu and Tsunakawa subsequently began working with Sony's Semiconductor Business Group and a factory making PlayStation CPUs—the brains of the game machines. Their goal was to improve yields by using a statistical physical analysis of data. Drawing on Takayasu's expertise, Tsunakawa has spearheaded the rollout of a database system for scientific data analysis that increases awareness of the behavior of abnormal products, contributes to faster development of new devices, and improves yields. Tsunakawa describes the outcome as a "maximization of permanent benefits" resulting in "a qualitative transformation of business." The project has helped Sony defend a number one market share in this business segment, and high-ranking Sony executives have taken a personal interest in it.

As a scientist, Takayasu relished the chance to grapple with this enormous, challenging real-world data set. And if he hadn't been based at Sony CSL, the opportunity would never have come his way. The benefit to Sony? Tens of millions of dollars saved per year.

FREEDOM TO EXCEL—AS AN OBLIGATION

Despite their significant contributions to Sony Corporation, Sony CSL researchers are under no pressure to contribute to quarterly business results or hit sales quotas. They are free to focus on whatever fans the fires of their intellectual passion. But couldn't they do that in a conventional academic environment?

A widespread image of academia is of scholars happily exploring the esoteric aspects of their field. But—in addition to the various requirements to teach, test, and administer students—many academics are under constant pressure to deliver publishable findings. They are also subject to the whims of senior colleagues and the larger academic organization. Ken Endo points out that "even in MIT in the US, a professor needs to write out a proposal and then ask for a grant. That doesn't happen at CSL." Sony CSL combines the real-world support and drive of a company with academia's freedom to explore.

"CSL is all about making an impact on the world," says Endo, who needs freedom in his work to identify the best way to deliver real-world impact in biomechanics and physical augmentation. In fact he has turned down offers from companies in the US precisely because he doesn't want to lose the freedom he has at CSL.

A new researcher may actually find that freedom befuddling at first. Shigeru Owada admits that initially, he experienced the opportunity to do as he wished as a tremendous pressure. Whereas a conventional company might have presented him with a set of instructions linked to specific business goals, Owada found himself wandering around in the mists of his own mind, straining to identify an appropriate direction. Eventually he found one, thanks in part to a serendipitous encounter with a dynamic young government official, Shinsuke Ito, who became a fan of Owada's proposals for playful interaction with household appliances. But having battled his doubts in an environment where there was nowhere to hide from them, Owada now has greater confidence in his vision of where he's going and how he'll get there.

Looking back he says he appreciates having been given the space and time to reflect. It enabled him to come up with an efficient and effective strategy, a way to pave his own path to a better future, rather than being trundled off along a ready-made road to nowhere. Today, aspects of freedom feature high on the list of CSL characteristics that he values most: "The freedom to choose who to collaborate with, the number of student assistants I hire and so on, plus a sufficient budget—and the right amount of pressure."

Of course CSL offers more than the freedom to explore new fields without excessive schedule and budget constraints. If Hideki Takayasu had remained a university professor, he wouldn't have gained access to the detailed manufacturing data that are

vital to his research. He says he relishes being in touch with the real world, and having the ability to speak with and learn from people involved in other types of study.

Indeed, while university researchers may in principle have access to experts in other fields, at CSL cross-disciplinary engagement is actively encouraged. On his own initiative, human-augmentation researcher Jun Rekimoto set up informal meetings from which Mario Tokoro and Hiroaki Kitano were politely excluded. They're weekly events where up to about ten people get together to discuss a particular subject and everyone has a chance to speak. He says his goals are simple: "To provide a common space and time for a diverse group of researchers from different areas of study."

Rekimoto's background means that he will discuss an issue from a technological viewpoint. "Others will talk from a health viewpoint or a biological viewpoint," he explains. "We get very different opinions on the same topic." Being in such a diverse group offers everyone exposure to a range of viewpoints, and the researchers share information in a way that Rekimoto believes would be impossible anywhere else.

Yuichiro Takeuchi joined Sony CSL to explore a new research domain that he calls synthetic space. After a time he realized that he needed a deeper knowledge of architecture, and with CSL's support he then went to Harvard. Once he had earned his MA at Harvard, he went straight back to Japan, having reached the conclusion that Sony CSL was "a great environment to do research even compared to top US universities." At Sony CSL, he says, "the possibilities are endless."

For Shigeru Owada the very open-endedness of CSL freedom was clearly a challenge at first, but Mario Tokoro says, "Ultimately, each researcher is his or her own manager. We want them to think, rather than telling them what to do."

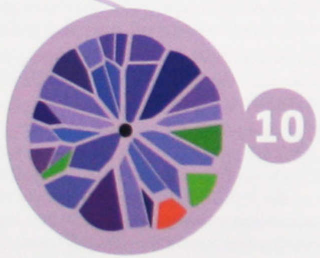
That sits very well with Shigeru Tajima. Not only has Sony CSL given him freedom *to* (in his case, freedom to imagine a new energy business), it has also given him freedom *from*. Specifically, freedom from "negotiating with fat-headed bosses." And he draws attention to another aspect of CSL freedom when he points out that no researcher is *obliged* to seek anyone else's opinion.

But Tokoro does mention one vital factor in selecting and keeping CSL researchers: "Passion. Without it, you cannot sustain interest in any area of study."

Just in case you yourself are a researcher and all this talk of the wonders of working at Sony CSL has you itching to dash off a letter of self-introduction to Mario Tokoro, you might want to bear another of his criteria in mind: "We expect each researcher to create a completely new research area." You don't have to be an iconoclastic genius to work at Sony CSL, but it helps.

"Here is my message to the world community of scientists: our responsibility is to people, to humanity."

Mario Tokoro



This freedom (or should we now say "obligation"?) to redefine and shape new fields in new combinations gives researchers an exhilarating opportunity to do what's best for their research and data, instead of trying to shoehorn their experience and expertise into the confines of a traditional discipline. Taka Sasaki, for example, says he no longer knows how to categorize himself.

Human-augmenter Rekimoto agrees that trying to confine his work to a single academic discipline is self-defeating. Considering the challenge of offering augmentation as a university degree course, he says, "To do it properly you'd need to study things like basic computer science, technology, cognitive science, how humans behave with technology...and design, with a focus on how to make things better."

BE ALL THAT YOU CAN (HUMBLY) BE

"Here is my message to the world community of scientists," says Mario Tokoro. "Our responsibility is to people, to humanity."

How are you contributing to humanity? That's what Tokoro wants to know. Researchers at CSL don't just need a ready answer to that question, they must display a fierce desire to make a real contribution.

The work these men and women do is not undertaken for personal glory; Tokoro is very clear about the need for humility.

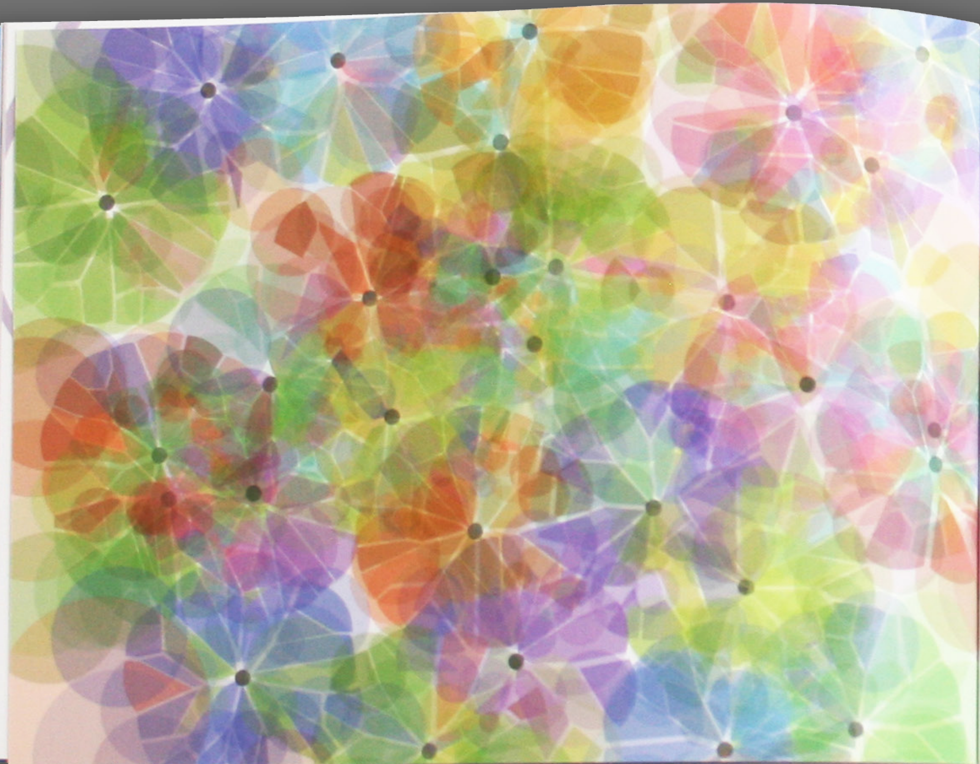
"Science is for humans, science is for humanity. If I contribute to humankind, to humanity, then that is a real reward that I can receive."

Takashi Isozaki says an important purpose of scientific research is to provide new perspectives that guide us to an improved understanding of the world. He hopes that his own work will result in "better philosophical and technological ideas that lead us to better lives."

Yuji Yamamoto trained as a doctor believing that the purpose of medicine should be to keep people healthy, not wait until they fall ill. Frustrated by the medical profession's narrow focus on treating disease, he decided to change the system. Since his training left him clueless about how to alter organizations, values, or society he chose to do a Harvard MBA. The experience was an eye-opener. "I learned that business isn't just about making money," he says, "but about making something valuable, something new for society."

Hiroaki Kitano focuses on a key difference between CSL and academia. "If research is just about writing a paper or furthering your career, it's personally important. But that doesn't translate to more value. There are fewer than 30 people at CSL so everyone has to aim to contribute to society and make a difference. We need a mindset that we are contributing to society, rather than just satisfying our curiosity."

Instead of trudging along a conventional career path, bound by a job description and forever wondering what he might have achieved on his own, Shigeru Owada was offered an opportunity at Sony CSL to think through his wondering and reach a conclusion. What has he learned in his time there? "Responsibility."



The Science Of Personal Empowerment

WHAT IS HEALTH?

To ask this question is to invite an endless series of others. What is life? What does it mean to be human? What is the purpose of existence, as individuals and as societies? How do our bodies interact with the environment? What of disease, disability, aging, death?

It quickly becomes obvious that human health forms an archetypal open system—huge, complex and integrated, containing many mutually related time-varying subsystems, and also inevitably involving constant, deep interaction with the outside world. "No man is an island" indeed—the course of each human life is profoundly affected and governed by external factors: political decisions, global and local; exposure to disease or natural disaster; the randomness of being born in a rich, safe country or born poor in a land with few resources; the changes to our living environment caused by large man-made systems like agriculture, food supply, and industry.

In this sense, health neatly illustrates Mario Tokoro's vision for Sony CSL, a vision of applying Open Systems Science methodology to understanding, managing, and solving the problems that hold us back from optimizing the life of each individual and humanity in general. We exist in a world of interconnected systems that interact and affect each other in highly complex ways, so we need ways to resolve issues while the underlying systems are alive and operating.

SIGHTS SET ON MOVING TARGETS

"The traditional approach to medication was essentially to administer medicine and chemicals and see what happened," says Hiroaki Kitano. "There was no in-depth understanding." Now, though, thanks to genomics and other breakthroughs we are starting to understand how chemicals affect molecules and genes. But while we have acquired a better awareness of how a drug is delivered to specific molecules or genes, a great deal remains to be known about the system itself.

The pioneer of Systems Biology, Kitano has been focusing in particular on cancer and, more recently, immunology. "I'm aiming for a better understanding of the whole system, so that we can manage the body in a better way."

What factors might be affecting the system? The drug itself, of course, but the physiological state of the person can also be changed, such as by exercise or by surgical intervention. Kitano is seeking the best combination of factors to prevent and cure disease. "I think we will start to get computational tools to help us understand what's going on in the next five to ten years. That will help us to form theories about what we should target in this very complex dynamic system. Actual tests would start with microbes and eventually move on to clinical trials."

DETENTE WITH DISEASE

Taka Sasaki was working on computer models to simulate evolution when he came to see the study of infectious diseases as a natural application for the multi-agent simulation method he had developed.

"Adaptation," he notes, "can refer to both how pathogens adapt, and how humans adapt to them." While many researchers model epidemics, mostly they simulate specific cases of pathogen spread. But because pathogens also change, Sasaki believes any realistic model has to take that into account, too. Other matters he considers vital include the immune memory that each host acquires, and population flow (births and deaths). Complex data, changing over time. The essential message? No disease outbreak ever occurs in exactly the same conditions.

The onset and spread of disease are, in fact, prime examples of phenomena that are impossible to reproduce artificially. Each instance is different from every other instance. You cannot study an open system phenomenon of this sort in the lab under conventional experimental conditions, but what you *can* do is feed data to a computer and simulate what might happen when various potential conditions are brought into play.

As Sasaki sees it, one constant among these changing conditions has to be the pathogen itself. Rather than aiming for a simulation where the pathogen is destroyed, he argues that it should best be regarded as part of the real world and accommodated. This seemingly compassionate stance appears to let pathological pathogens off the hook, but it is underpinned by robust logic: "If we exclude a species from an ecology, that ecological niche will become vacant for a while. But sooner or later the vacant space will be filled by a new species."

So his take on pathogens is not so much "Live and let live" as "Better the devil you know than the devil you don't." If a disease is mild, why try to eradicate it? "Its disappearance may open the door to a new and perhaps stronger disease."

FIELD STUDIES

Approaching the complex dynamic challenge of human health management from a very different direction is Masa Funabashi. His aim is to feed the world not just sustainably, but in a healthy way. "Even today, a lot of agriculture reflects the reductionist mindset, and this is not just having a devastating impact on the natural environment; it is undermining food quality and ultimately threatening our health."

Funabashi notes that while right now we can feed the world in terms of calories, we have no idea about the long-term health effects of this simple calorie-count approach. "It took a million years of evolution to establish the physical and metabolic characteristics that make us human, but agriculture has a history of only 10,000 years." For the previous 0.99 million years we were hunter-gatherers and had a metabolism that depended on eating wild plants and wild animals.

Consider too that the food we eat now is quite different from what we consumed just 200 years ago: "Recent studies indicate that if we grow plants with fertilizer to increase productivity, it changes their whole metabolizing profile compared to what it would be in the wilderness, in competition and symbiosis with other species." The same seed, he notes, can have a vastly different morphology in different conditions and "when I see these huge broccoli produced using modern techniques they remind me of fat people, actually."

Funabashi's goal is not to return to the old days, but to establish a new relationship with agriculture that will give us food that's a good fit for our metabolism. When you ask for Funabashi at Sony CSL, you'll often be told he's "out in the fields somewhere." These studies in the real world both contribute to, and benefit from, the personalized approaches to future health being explored by other more medically oriented researchers at Sony CSL.

A MODEL OF HEALTH

"I call myself a health capitalist," says Yuji Yamamoto. "I believe health is the most basic capital for each person, community, nation, or state."

In his years as a doctor, Yamamoto came to realize how inefficient and unproductive the medical industry was, and how its values had become distorted—doctors and hospitals weren't promoting health, they were merely waiting for people to become ill and then treating them. "The medical industry is tainted by current concepts. The more severe the disease, the more money certain stakeholders get. I think they should get more money for ensuring longer health."

What Yamamoto wanted was a new management solution to maintain health as long and as affordably as possible, and he came up with the concept of health capitalism—taking health as the major value proposition rather than money.

He identified five key players in the industry: providers (doctors, hospitals, healthcare service providers, even fitness clubs), suppliers (pharmaceutical companies, food suppliers), payers (insurers and other companies that pay for the services), subscribers (patients, the general public—the beneficiaries), and managers (governments, administrators, regulators).

The essence of his idea is to introduce new incentives. Most people routinely ignore their health, seeking treatment only when illness strikes. Yamamoto's system shifts responsibility to the payers, providing strong incentives to keep subscribers healthy: "If a subscriber goes to a doctor, the payer has to pay. If subscribers don't need a doctor because they're healthy, the payer doesn't need to pay."

He wants to change everyone's mindset, but especially the payers, who conventionally have a weak, passive role. How to do this? "Give them evidence, show them numbers, visualize their activities, and make the various stakeholder relations more clearly understandable." Open Systems Science offers him a framework for considering how to use available resources in the most effective way possible. Yamamoto has started to manipulate big sets of previously unused data from insurers, such as medical and hospital billing data. And Sony Corporation is following his progress with interest.

A STORY WORTH SHARING

"We are both being and becoming, constantly changing and interacting with the world. A problem with the conventional mechanistic way of thinking is that the becoming part is eliminated." The alert reader will recall this as a key argument in the philosophy of Kazuhiro Sakurada.

In his previous career at the forefront of medical science, researching new pharmaceuticals, regenerative medicine, and human iPS cells, Sakurada became convinced that for all its recent advances, biomedical science could not provide the answers to humanity's health issues. "Basic science is a knowledge-driven system to capture the commonality in living systems, but clinical science is a data-driven system to capture uniqueness. Each patient has a different genotype, so we should use the best solution for each condition." In other words, treat the patient, not the disease.

The US National Institute of Health has declared that future medicine will be personalized, predictive, preventive, and participatory, where participatory means that the patient participates in prevention and treatment. Sakurada started looking for an Open Systems model that would take each individual's uniqueness into account. He needed to escape the trap of statistics, averages, and abstraction that results in common health solutions tailored to fit the disease, rather than the extremely varied human beings who catch that disease and react to it in very different ways. "Variation from individual to individual within a population is the reality of nature, whereas the mean value is only a statistical abstraction. How to capture individuality as it is, not from the average—that's the way to overcome the problems of medical science."

Sakurada's starting point is an understanding that the genetic sequence is not working deterministically; that lifestyle is strongly linked to the onset of many diseases. This is clearly shown by data on twins—only 10% of monozygotic twins will develop the same type of breast cancer, for example. "The human organism permits more phenotypic possibilities than are actualized. If you live in different conditions you will be different. The phenotype of the human organism is undetermined and open."

So if we can't rely on our genetic makeup and family history to confidently predict lifetime health problems, what data can we use? Sakurada has long kept what he calls a life log—a daily record of everything he does and all that happens to him. This allows him to learn from his past when making decisions about the present and the future. But for a full picture of our health we also need the life data of people whose bodies, experiences, lifestyles, and environments mirror ours.

That's why he's exploring the power of big data. Just as online shopping sites use the huge amounts of personal data they amass to help customers make purchase choices, Sakurada believes big data could be enrolled in the cause of optimizing health.

"Real-world problems are problems of choice. If you think about your health, you have to wonder what you should be eating, whether you should be drinking, how long to sleep, what kind of exercise to do—everything is choosing."

He stresses that choosing will always be a matter for the individual, and that each context is unique: "Universal solutions are impossible, but what we can do with technology is to help people choose." With enough life logs in the public domain, you would be able to compare any situation in your life with those being experienced by tens of thousands of similar people. Some of those people would be older than you, and that might enable you to see the future consequences of choosing one lifestyle over another. Every day throughout your life, you'd be able to make informed decisions about how to avoid disease and optimize your wellness.

If privacy were guaranteed for this detailed personal information, it might also be used to support life choices in many fields other than health—a bottom-up approach that would empower us as individuals, as opposed to the top-down use of data for social control.

"Few people can write a book," says Sakurada. "But everybody—literally *every body*—tells a story. If your story can be shared, it will have the power to change many other lives for the better."

AUGMENTED LIVES

Changing lives for the better is what Ken Endo is all about, too. And in typical Sony CSL fashion he has no lack of ambition: "I want to eradicate physical disability," he says.

If technology can be made good enough to completely compensate for a missing physical function, then in practical terms the disability is gone. Why stop there, though, when you can augment both body and mind with enhanced capabilities. Endo compares this to the way Paralympics sports are developing: "Paralympics today is not pure athletics. It's becoming more like F1 racing—an integration of sports and technology."

What led Endo to throw himself into this work with such passion? He was doing pioneering work in robotics design and augmented reality technology when an old school friend was diagnosed with a life-threatening cancer. Inspired by his friend's determination to keep pursuing his acting dream in the face of crippling disease, Endo decided to devote his skills to transforming prosthetics technology. An Open Systems approach allows him to integrate the extremely wide range of interlocking factors involved, and the open environment at Sony CSL gives him access to the likes of Jun Rekimoto for guidance on electrical muscle stimulation and control, or Yuji Yamamoto for advice on medical aspects.

In his current prosthesis project, Endo is working closely with a partner in India. Japanese and Indian prosthesis users have different needs but the underlying technology is similar, and assembling and testing prototype limbs in the field in India is a very effective way to ensure that his new ideas work in tough real world conditions. This process will become more efficient once 3D printers are readily available in India, allowing the "printing out" of customized limbs. All Endo will need to do then is transmit data, speeding up the feedback loop. Ultimately, he hopes to transfer any technology he develops to local manufacturers in developing countries.

Endo is waiting eagerly for smaller, lighter motors to be developed. This will allow him to make the jump from mechanisms like springs that simply restore physical function to motorized prostheses that actually augment the wearer's capabilities.

THE VALUE OF A SMILE

Well before smartphones appeared, Jun Rekimoto was pioneering multi-touch displays and other methods of human-computer interaction that we now take for granted. He created the world's first augmented reality marking system, implemented by Sony in the first laptop ever to be fitted with a built-in camera. And today? "My ultimate goal is the augmentation of human ability."

Not content with augmented-reality eyeglasses, Rekimoto wants to have eyeballs outside his body, using flying objects and streaming video to provide telepresence. His team is creating the world's smallest eye-tracking system to make the augmented experience completely seamless, with hardware the wearer won't even notice. His gaze-aware wearable computer will track your eye movements and correlate them with its intelligent camera view to identify what you're focusing on. "Eye movements reveal a lot about user concentration, what kind of activities are being done—the eye can be a gateway between the computer and yourself."

In terms of transforming lives, the first beneficiaries of these systems are likely to be the disabled, especially those who can only communicate by moving their eyes. Rekimoto believes his work on augmentation can help to increase human happiness, and another project, the HappinessCounter, is an application of the established fact that by smiling we change our mood.

This system uses a Sony camera with a smile recognition function to provide positive feedback. Smile at the mirror and you're rewarded with a happy icon and sound. In a trial with people living alone, the system was fitted to the refrigerator door. Smile, and the door opens easily. No smile, and you have to tug harder. The results were immediate—within days the subjects were feeling better about themselves.

POWER TO THE PEOPLE

The War of the Currents refers to a clash of scientific titans in the late 19th century. When the dust cleared, Thomas Edison, a proponent of direct current (DC) for power distribution, had been defeated by Nikola Tesla, an advocate of alternating current (AC).

Since then electric power companies have set up countless power-generating facilities including thermal plants in places close to centers of human habitation, as well as hydroelectric and nuclear plants in more remote locations. These plants are often hundreds of miles away from the people who want to use the power they produce, and to transmit it efficiently a high voltage is required. So the electricity output by the power generators is up-converted to a high voltage, transmitted, and then, to make it safe to use in the home, it is down-converted again. Both conversions are done by transformers—which can operate only on AC power. Since the days of Tesla, AC has ruled the roost.

Shigeru Tajima and his associates at Sony CSL are out to change all that. The goal of their work in Open Energy Systems is to enable everyone not just to consume energy, but also to produce and manage it. This vision is built around a commitment to direct current. There are solid reasons for selecting DC. Most sources of renewable energy generate DC power, batteries handle only DC power, and almost all modern devices that use electricity are designed to operate on DC power. In addition, great advances have been made in the efficiency of DC-to-DC converters, and batteries now offer a level of performance that was unthinkable even 20 years ago.

Tajima envisions a smart power grid built from the bottom up, with each and every one of us making and storing power. This approach would work even in remote locations in the developing world, where countless millions of people could generate the energy they need using affordable, portable, readily manufactured photovoltaic panels, windmills, and other personal power plants, and then store that energy in batteries.

Tajima dreams not just of revenge for Edison, but of power for the people.

HAPPIER EVER AFTER?

"A better world" is a theme that Open Systems Science can explore in so many different and useful ways. Where will Sony CSL lead us over the next few years?

In parallel with Kazuhiro Sakurada's transformative approach to using medical data, Masa Funabashi plans an agricultural database that will enable us to determine the optimal types of food to grow in each set of environmental conditions, to achieve different health objectives.

Other researchers will continue to pursue more directly medical-related themes, such as Natalia Polouliakh's work on cellular memory, which has led to research on aging and infertility.

Shigeru Tajima has conducted proof-of-concept DC-energy demonstrations in Ghana, and feasibility studies are currently advancing in Okinawa. Annette Werth is the latest researcher to bring a new perspective to the challenge of Open Systems Energy, and this realm of expertise is certain to grow in importance in the years ahead.

As Hiroaki Kitano puts it, "Our research interests are never static but shift freely over time, dynamically adapting to societal changes and advances in scientific knowledge. For us, to commit to research is to invent the future—a future that embodies humanity's hopes and dreams."

Constantly adapting to the requirements of real-world complexity, Sony CSL researchers seek ways to keep moving efficiently and effectively toward their prime objective: a brighter future for us all. Open Systems Science holds enormous promise for the betterment of human life, even as it poses tougher and tougher challenges for the scientists committed to this goal.

Scenes from a recent general meeting in Tokyo. On this occasion Sony CSL researchers were making presentations to colleagues before making similar presentations to invited guests at an Open House event in May 2013.

A Way Of Mind

THE SECRET OF SONY CSL

Mario Tokoro and Hiroaki Kitano are sometimes asked how they've managed to keep Sony CSL going so successfully for so long. The answer is actually right there in the question: they manage. Their management skills are essential to establishing the best possible conditions to fulfill Sony CSL's commitment "to contribute to the world by creating new possibilities for tomorrow."

You've already read about some of the factors that contribute to the unique appeal of working at Sony CSL: diversity, freedom, empowerment, excellence, openness, commitment. Tokoro always knew that Sony CSL would need to offer these features in order to generate great results, and that's why he built them into the DNA of CSL. In other respects, he's relied on another CSL virtue: serendipity. Why a maximum of 30 researchers, for example? "I don't know," says Tokoro. "That was just intuition." The validity of this intuition was tested some years ago when Sony CSL went through a brief period of expansion. "But once the number rose above 30," Kitano recalls, "a middle management layer formed, and that transformed CSL's social dynamics." The new hierarchy threatened to undermine CSL's very identity. So Tokoro and Kitano reined in the numbers until once again they could take a direct, personal interest in the activities of everyone working at CSL.

As both men are greatly respected by the CSL researchers, that personal attention is welcome. The respect derives in part from a sense that each researcher's requirements are understood. Someone like Frank Nielsen, who explores the distant reaches of computational geometry, may not be able to generate knowledge of practical value quickly, but Tokoro and Kitano, having satisfied themselves that Nielsen is heading in an important direction, are more than willing to wait. For guidance in such matters, Kitano can recall his own experience. He may have blazed a trail for Systems Biology in the early 1990s, but it was four years before even a minor academic journal would publish any of his findings, and eight before his work appeared in a major journal. These days he's published regularly in *Science* and *Nature*.

As the work of Sony CSL researchers has attracted more attention, other researchers have become more interested in joining the CSL team. Kitano's achievements with Systems Biology sent a powerful message to the likes of Kazuhiro Sakurada and Yuji Yamamoto, whose arrival at CSL in turn sent a powerful message to Sony Corporation. Success breeds success—an ironic counterbalance to the philosophy on which Sony CSL, and Open Systems Science itself, is built:

"Everything we do will fail the test of time." Rigorous skepticism is the lifeblood of Sony CSL, and of its researchers' approach to science.

OPEN SYSTEMS DEPENDABILITY

Mario Tokoro's own research explores the development of new ways to improve dependability in computer software and networks.

In recent years, networks have become so intricate and interconnected that it can be hard to tell where one ends and another begins. Smartphones, tablets, electronic commuter passes, and smartcards are all points of entry to a complex digital infrastructure that is increasingly taken for granted in spite of its huge potential to disrupt everything that the inhabitants of wealthier countries now regard simply as "everyday life." Just imagine the consequences of an abrupt system failure in emergency services, air traffic control, financial transactions, power transmission, or national defense.

Years ago, when most software was simpler and ran on stand-alone computers, software engineers could try to anticipate all the ways that it might fail before releasing it. Once it was released, it was out of their hands, and remained unchanged until it was replaced by a newer release. In those days, software development was separate from software operation. Development came first, followed by operation. There was little overlap between the two.

Now, though, everything is in flux. Service objectives and user requirements change, technology advances, regulations and standards are revised. Meanwhile each system is connected through networks to other systems. Linked systems are often owned by different service providers. And countless devices are connected to the systems via networks. Given this reality, it is no longer possible to design software that will stay reliable without frequent updates. The development phase is now inseparable from the operation phase, because these days development continues after the software is released.

And while the purpose of any update is to cope with new requirements or to improve efficiency and effectiveness, an update may inadvertently introduce new bugs and other problems. You cannot know or anticipate every possible interaction within an open system, or between one open system and another. Every networked device is connected to other devices and software that can never be fully understood, and you never know exactly when those other devices and pieces of software are going to change, or how.

The notion of dependability, too, therefore has to change. Instead of trying to secure dependability by anticipating every potential problem in a piece of software before it is released, these days

it must be accepted that there will be problems, even outright failures. In a complex world, they are inevitable. Nevertheless, efforts can be made to anticipate and minimize these problems and failures. Perfect uninterrupted service may be an impossible dream, but it is a goal that everyone involved in dependability must keep trying to approach.

How is this done? You monitor the system's states and outputs to see if it is conforming to expectations. If it is not, you make adjustments, and monitor the effects of the adjustments on the states and outputs. As part of your efforts to keep the service running without interruption, you also need a robust contingency plan for any unexpected events, including failures. But this is not enough. In addition you will need to modify the system to improve its resilience to changes that occur in the real world. The process of defining, refining, and redefining the system to make it increasingly dependable never ends. This is Open Systems Dependability, a realm of study pioneered by Mario Tokoro.

In some ways, the Open Systems Dependability concept plays a part in the sustained success of Sony CSL itself. But whereas the dependability of a manmade software system is threatened by the unexpected, the serendipitous, and the unpredictable, Sony CSL's dependability thrives on these factors. Sony CSL is a diverse team of talented people, and they are free to move in any direction that leads to a better future. The dependability of Sony CSL hinges on that freedom.

SONY CSL AS AN OPEN SYSTEM

Mario Tokoro says Open Systems Science is an attitude. It's a way of mind, requiring practitioners to recognize that the real world is constantly changing, and that reality is far more subtle and complex than any model of it. Open Systems Science does not seek permanent solutions, but instead commits researchers to a never-ending process of adaptation and management. Each model is continually reviewed, revised, and rebuilt to improve its fit with reality.

Researchers are not encouraged to work toward a single, limited goal, but to think of each achievement as a vantage point from which to move on to fresh challenges. Mario Tokoro admires researchers who, instead of saying "This is the solution!" say, "We solved this, but we also see these related issues that still have to be addressed."

The Open Systems Science attitude now permeates the culture of Sony CSL, and Tokoro regards it as one of his proudest achievements. It is a culture of forward-looking skepticism, where researchers are constantly checking their models against reality to see if they need to be revised or even abandoned.

That can be hard to do. One of the dangers on any path of knowledge is path dependency. No one wants to believe that they've been walking in the wrong direction for years, but Sony CSL has created a culture where turning around and going back to the drawing board is not just accepted, but encouraged.

Like other open systems, Sony CSL must keep running reliably and smoothly—but not by being constant, like a pocket watch. Rather, it needs to be dynamic and creative. Sony CSL has been able to thrive not just because it is always moving forward in an appropriate direction, but also because it can change course quickly. With the exceptionally diverse expertise and experience at its disposal, Sony CSL is well adapted to coping with every eventuality on the road ahead.

OVER TO YOU

So there you have it, all you need to know to embark on your own adventures in Open Systems Science. Mario Tokoro says this challenge demands four qualities: vision, passion, skill, and humanity. (But don't forget the starting point: a rigorous skepticism of every scientific model, including your own.)

If you need some ideas for an Open Systems Science project, here are a few questions from Hiroaki Kitano:

How can we establish a financial system that is fair and sustainable?

How can we furnish simple and inexpensive ways to purify water?

How can we make sustainable energy systems?

How can we provide affordable ways to diagnose and treat tuberculosis and influenza?

Refer in particular to the methodology outlined on page 38, and when the going gets tough you now know where to turn for the world's best guidance on Open Systems Science: Sony CSL.

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The playwright Eugène Ionesco once wrote: "Not everything is unsayable in words, only the living truth." Even so, I'm sure I could have approximated the living truth more closely in this booklet, and for that and other failings I alone am to blame.

Adam Fulford, 2013