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A.I. Spring for Silicon Valley Start-ups and Google's Silent Ambition to Conquer the Robot Industry: Japan's Mighty Position in Industrial Robots Could Be in Danger.

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Abstract

Currently in Silicon Valley, start-up companies specializing in or utilizing A.I. technologies, especially machine learning, have sprung up one after another.

Artificial Intelligence (A.I.) is not a new technology, with its research and development roots going back to the 1950s. The idea was to make computers and machines think and act intelligently, just like humans. However, after initial excitement in this early stage, A.I. entered a long setback period, commonly known as the 'A.I. Winter', which endured for an extended period of time.

A.I. showed early signs of come back in 1997, when IBM's Deep Blue beat Gary Kasparov, the then world chess champion, and since has gradually picked up momentum once more. Presently, A.I. is everywhere, being fundamental to Apple's 'Siri', Google's voice search and the 'Self-Driving Car', IBM's 'Watson', Microsoft's 'Cortana' and the list goes on.

What brought about this dramatic revival of A.I. is so-called "machine learning," which is now a main branch of A.I. technology, that enables computers and machines to learn on their own by extracting notable patterns from 'Big Data'.

Some of the A.I. start-ups in Silicon Valley are now providing this machine learning technology as SaaS (otherwise known as 'Cloud Computing'), which could revolutionize a wide range of industries, not only in the U.S., but eventually throughout the entire world. Major companies are onboard, too, of course. Google, for example, seems to have begun the development of the next generation intelligent robots by building machine learning technology into them, and this development could be a serious threat to Japan's mighty robot industry in the near future.

This report focuses on the frontiers of such various A.I. developments outlined above.

Major players: Google, Nest, DeepMind, Facebook, EasilyDo, Sensor Platforms, Thomas Bayes, Sight Machine, EnerNOC, Palantir, Netflix, TeraDeep, Qualcomm, DARPA, Geoffrey Hinton, Bruno Olshausen, Sebastian Thrun, Andrew Ng, Jeff Hawkins, SCHAFT, Boston Dynamics, Preferred Infrastructure, Willow Garage

Keywords	A.I. (Artificial Intelligence), Machine Learning, Bayes Theorem, Machine Vision, SaaS, Smart Grid, Demand Response, HEMS, Neural Network, Deep Learning, Deep Neural Network, Neuromorphic Chip, SyNAPSE, Sparse Coding, Spiking Neural Network, Sensor Motor Integration, DARPA Robotics Challenge (DRC), Industrial Robot, Service Robot, ROS (Robot Operating System)
Region	U.S.

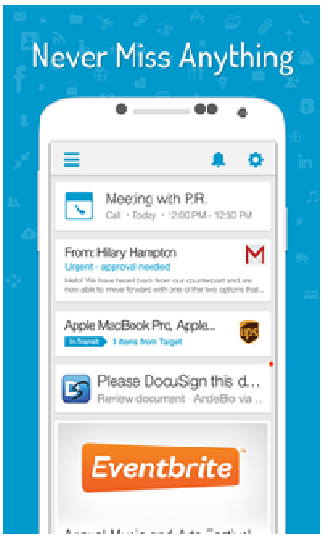
Artificial Intelligence, or A.I., was in vogue all over the world at least 2 times, namely, throughout 1950s to 60s and in the early 1980s, but at each time was soon followed by a long setback period, the so-called 'A.I. Winter'. However, the technology has now, once again, re-entered the spotlight. Google has recently acquired many A.I. and robotics start-ups including Nest, Boston Dynamics, and DeepMind Technologies. As Facebook and Yahoo followed Google's move, the price of A.I. companies has soared spurring a niche M&A bubble.

Riding on this big wave, many more A.I. start-ups are being founded one after another. What kinds of technologies do they develop and what kinds of businesses do they want to establish with their technologies? And what is the intent of Google purchasing those fresh A.I. and robotics companies? To talk about these issues, we went to Silicon Valley in February 2014 to visit a number of start-up companies and to consult experts on A.I.. This report introduces these companies, presents an analysis of the findings, and forecasts some prospects for A.I. based on the interviews conducted during the research.

1 The Emergence of Products that Learn About Users

EasilyDo, a start-up company based in Mountain View, California, produces so-called 'personal assistant' applications for smartphones. The app brings you (the user) notifications, only when they matter, extracted from a number of communication tools and social media such as e-mail, calendar, Facebook, Twitter and so on. They automatically appear on a smartphone's screen without the user's request.

【Fig. 1】 EasilyDo automatically shows what you need to know right now



What enables this service delivery is so-called "machine learning," which is now a major branch of A.I.. Machine learning is the technology that makes computers and various machines learn for themselves from so-called 'big data'. From this reference point, let me very briefly explain the evolution of A.I. from its beginning until the present.

When research and development first started in 1950s, A.I. was mainly built on human rules such as grammar, syntax and vocabulary of certain languages (to make a machine translation system, for example) or a doctor's diagnostic skills and standards (to make a so-called "expert system"). This kind of A.I., which lasted until 1980s, is now referred to as "rule-based A.I."

The A.I. researchers and developers of the era naively thought that if you just build such human rules into computers and machines, they would become as smart as humans. But the reality was later found out not to be so simple. Quite frankly, it didn't work so well because rule-based A.I., in general, lacked the flexibility to successfully respond to the real world, which is full of exceptions, nuances and metaphors.

For example, take the idea of machine translation. When you (humans) say "I'm dying to drink a glass beer," what you really mean is that you want a beer very very much. Computers or machines, however, don't take it that way. They simply apply their built-in grammars to the sentence and translate it into a sentence in a foreign language, meaning something like "I drink a glass of beer which makes me die". The main reason why A.I. declined after mid 1980s was that such fatal shortcomings were soon realized and shared by most of A.I. researchers and users of the day.

In the 1990s, however, by employing different methods A.I. has begun to gradually return to center stage. Amongst this all, the clearest difference was that the new A.I.s were mainly based on data instead of rules. They gathered large chunks of data from the Web and various sensors in the real world, and crunched them with various probabilistic/statistical methods such as "Hidden Markov Model," "Logistic Regression," "Bayesian Network," "Kalman Filter" and so on. By doing so, they could uncover hidden patterns in such huge data sets, in other words, patterns that humans can't see and only machines can see.

In other words, these new breeds of A.I. technologies could learn on their own from big data to make themselves intelligent, instead of being taught rules by humans. This is "machine learning", and it fits the real world more flexibly and better than the previous generation of rule-based A.I..

EasilyDo's app gathers bunches of information about its user from popular social media as a sort of textbook for the machine learning process. But prior to this technology, there were already a number of similar applications, such as 'Google Now', that had been operational for a significant period of time. Like EasilyDo, Google Now brings up instant notifications on a smartphone's screen only when they are relevant. So what's the difference between EasilyDo and Google Now?

"Google Now only loops Google's services, where it will leverage your search history, your gmail and your Google Calendar, whereas our service (EasliyDo) covers all the popular sites such as Facebook, Twitter, LinkedIn and even Google. Besides, Google Now learns only from keywords used for Google searches, which reflect only the users' interest, whereas our service learns from users' action in the past, such as 'what they ate', 'where they went,' and 'what they bought' which makes our prediction more accurate than Google Now," says Mr. Noam Cadouri, Business Development Manager for EasilyDo.

However, there was recently a newcomer to this area from an old camp, namely, Microsoft. In April 2014, the company released Cortana, their version of a personal assistant for Windows Phone. Cortana gathers the user's personal information from email, calendar and popular social media to learn about the user, in a similar manner to EasilyDo. Moreover, it has a voice command functionality similar to Siri, which is not incorporated into EasilyDo. According to Microsoft, Cortana is able to answer any kind of strange and silly questions and requests, and can even sometimes sing, which (if it is true) could be a significant advancement on Siri, which often lacks quality answers and just returns web-search results instead.

As IT giants like Microsoft (in addition to Google) begin to join this fight, start-up companies like EasilyDo will have to face an increasingly competitive business environment from now on.

2 Using Sensor-fusion for Machine Learning

Besides web-information such as email, calendar and social media, there is another major resource for machine learning, which are the sensors built into mobile devices such as smartphones and tablets. Nowadays, even the most basic smartphone has at least a few sensors such as GPS, accelerometer and a video camera. The most up-to-date and expensive devices are said to have up to 16 kinds of inbuilt sensors.

Sensor Platforms, a start-up company based in San Jose, about 15 miles south

of Mountain View, develops so-called sensor-fusion technology, which collects information from a variety of sensors built into a smartphone to learn about its user. More concretely, it knows where the user is now, what he/she is doing, if he/she is sitting or standing, walking or running, and similar information. The company, however, doesn't make the technology into finished products ready for market. Instead, they license their technology to customers such as device manufacturers and mobile operators, although they don't publicize the names of their customers.

According to the CTO of Sensor Platforms, their technology uses Bayes' theories, which are a series of probabilistic/statistical methods based on Bayes' Theorem. The theorem was invented by Thomas Bayes, a British cleric in the 18th century, who was almost ignored by professional mathematicians of his day. Fortunately (or unfortunately for Bayes himself), after his death, the forgotten theorem was found and further developed by Pierre-Simon Laplace, a famous French mathematician of the 18-19th century.

The essence of Bayes Theorem is as follows: there are 2 kinds of probabilities, prior and posterior probability. The prior probability is a rough (bad) probability with a big deviation, and the posterior probability is a more precise (better) probability with a smaller deviation. According to Bayes Theorem, the prior probability is improved by a measurement or observation or experiment about subject, which results in the posterior probability.

In late 1980s, Judea Pearl, an Israeli-born information scientist, used the Bayes Theorem to invent a large causal network called the Bayesian Network, which soon turned out to be a very effective way of generating probabilistic reasoning. In retrospect, this was the beginning of so-called probabilistic/statistical A.I., which brought a major breakthrough to the then stalled rule-based A.I.

Since then, Bayes theories have been introduced frequently into A.I. and Advanced robotics. One of them is the Kalman Filter, which is one of the major technological factors behind the self-driving cars currently under development by Google and big auto-manufacturers all over the world. There are many kinds of sensors built into a self-driving car, which are used to measure the locations of other cars, people and obstacles around itself.

But the very first measurement only gives the car a very rough estimate of location of such moving objects, which is the prior probability with big deviation. So the Kalman Filter applies the Bayes Theorem as well as the second measurement to improve it to a slightly better probability with less deviation, and it repeats this sequence until the deviation gets narrow enough, which means the car can locate very precisely where the moving objects around it are. Thus the car can move safely without hitting people, other cars and obstacles. This is the essence of the Kalman

Filter.

Sensor Platforms' technology basically follows the same sequence as the Kalman Filter. It measures current status of a smartphone user from various sensors and applies Bayes theorem to improve it, which eventually results in a very concrete status information such as 'sitting', 'standing', 'walking', or 'running' with high precision. Based on such understandings, it may, accordingly, change the setting of a smartphone such as turning off the GPS to save the battery. That's how their technology is being applied for practical purposes.

Currently, Sensor Platforms' technology is available for mobile devices such as smartphones and tablets. Wearable devices such as iWatch (Apple's rumored smartwatch device) and Google Glass (a smart glass technology partially released, but still in development) are expected to be the next application of their technology. An executive of the company talks about their prospect as follows:

"I believe that for wearables to succeed there should be minimum viable products, which is the minimum feature set that a product has to meet for the customer needs. For example, this could be a health-care product with an accelerometer that counts my steps, tracks my sleep and tells me something about my life, and runs for 6 months with a one-time battery charge. That is how wearables would succeed, and that's where our technology is needed," says Dr. Kevin A. Shaw, Chief Technology Officer for Sensor Platforms.

3 Machine learning as SaaS

On the other hand, there are a number of start-ups aiming to sell machine learning as so-called 'Cloud Computing', also known as SaaS (Software as a Service). Sight Machine, based in San Francisco, is one such company.

Sight Machine's technology is the combination of machine learning and so-called "machine vision", a branch of A.I, which gives machines such as robots artificial vision through the use of video cameras. Sight Machine provides their technology as SaaS to clients, which include automobile and electronics manufacturers. With their cloud service, the factories of such companies can automate the inspection processes of their products on the manufacturing line, which have, so far, been done manually.

As of February 2014, Sight Machine has 6 clients, one of whom is Chrysler, one of the Big 3 of American auto industry. SaaS can be highly standardized, and it is not necessary to modify the system at all, but in most cases, particularly for

factories of auto manufacturers, you have to customize the system. With the case of Chrysler, Sight Machine staff regularly visit Chrysler's factory and they work together to customize Sight Machine's SaaS to best fit the factory's manufacturing line. They now plan to automate their inspection processes at 10 points in their manufacturing line with the use of SaaS.

According to a Sight Machine's independent survey, the auto industry has very strong potential demand for their service. In North America only, there are more than 5 thousand auto-related factories, including the ones which provides parts to major auto manufactures such as GM, Toyota, Ford and Nissan. All of these companies are very concerned about the quality of their products, and, according to the survey, more than a few of them are particularly interested in introducing machine learning and machine vision into their inspection process.

However, so far, one thing lacking in their plans has been "the common platform of machine vision and machine learning system, which we are aiming to be," says Mr. Jon Sobel, Chief Executive Officer for Sight Machine.

The same survey also suggests that in addition to the auto industry, there are other green fields for their service. For example, a major fast food chain in the U.S. processes more than 650 thousand chicken fillets a day, which must not be baked too much nor too little. To check product quality, you must see the shape and color of the stripes on the chickens, a task for which Sight Machine's technology could be used. Also, medical equipment manufacturers, the pharmaceutical or the food industries, which are central to human life and health, are very concerned about their quality and are therefore potential customers of the technology.

And finally, Japanese electronics manufacturers could also be good prospective customers.

"We spoke to some (Japan's LCD) panel companies who said that all of the manufacturers in Japan have workers who have been looking at screens for decades, who can detect slight defects in the consistency of the screen. It's an ideal application for our technology," (Mr. Sobel).

4 Various applications of Machine Learning from Smart Grid to National Security

There are many other green fields for machine learning. Amongst these, one of the most promising ones is the so-called "smart grid", or the automatic electricity distribution system, which could use machine learning to analyze energy consumption data from numerous homes, offices, factories and so on, to distribute electricity most efficiently between consumers.

This kind of system is now also called "demand response", and is already offered as a product by EnerNOC in the U.S.. In Japan, Marubeni Corp., a major trading conglomerate, entered into a contract with EnerNOC in December, 2013, to establish a joint company to provide demand response and consulting services, primarily for corporate customers. Prior to this joint venture, Eneris, a Japanese HEMS (Home Energy Management System) company, had established a similar service for households and businesses in Japan.

A rather unconventional application of machine learning is national security. For example, Palantir Technologies, based in Palo Alto, CA, uses machine learning to analyze bunches of data from various sources such as phone conversations, e-mails and financial data, which could provide highly sophisticated intelligence about international crimes and terrorism to national security agencies such as CIA, NSA and FBI.

As explained so far, machine learning can be used for a wide range of applications. However, some experts caution that we should be wary of relying too much on the technology. Let's take the telecoms industry as an example. These days, major US telcos are seriously thinking about introducing machine learning technology to automatically detect anomalies and troubles within their communication networks. However, their huge networks covering the entire U.S. with numerous and various communication equipments installed tend to have unexpected troubles here and there, which might be beyond the scope of machine learning, as one expert elaborates:

"Once the communication equipments made by Lucent Technologies installed on such telcos' networks were chosen as targets for shooting exercises by gun enthusiasts. The reason for the targeting was that the shape and color of Lucent's logo is a red circle on white background, which is exactly right for their target. I'm very skeptical that current machine learning can predict such a highly exceptional anomaly," says a consultant specialized in the U.S. communication industry, who spoke on the condition of anonymity.

5 What is Deep Learning?

Currently, it is not clear if there is really a machine learning technology that can handle such an extremely exceptional incident as outlined above. But aiming to realize such supreme technology, many researchers and engineers are now trying to develop very flexible and applicable machine learning technologies. Amongst nascent technologies, the most promising now is Deep Learning, which is currently

drawing much attention as a cutting-edge and very powerful neural network (neural net).

Neural net is the engineered reproduction of the biological neural net in a human's brain, which consists of more than 100 billion neurons and 100 trillion synapses (junctions of neurons). Although research and development of neural net began in 1950s, it hasn't been in practical use until recently because of its performance limitation.

The breakthrough of the stalemate arrived in 2006, when very fast processors called GPU (Graphical Processing Unit) as well as advancements within neuro-scientific research, such as "Sparse Coding"(explained in detail later) have started to be introduced into the neural net. These are advancements that have enhanced its capability so much that it has finally reached the level of practical use. This is now called "Deep Learning," or "Deep Neural Network.".

Deep Learning is now highly evaluated by A.I. experts as the best method for machine learning. Because of this, IT giants such as Google, Facebook and Netflix are now purchasing start-up companies in the field of Deep Learning technology, or establishing special teams internally to independently develop the technology. DeepMind Technologies, which Google bought in March 2014, is one such start-up.

Recently, there has been a noteworthy trend in which start-ups are being founded to provide Deep Learning technology as a cloud computing service, or SaaS (Software as a Service). Ersatz Labs (Ersatz in what follows), based in San Francisco, is one such cutting-edge company.

"Our mission is to make Deep Learning available to everybody, not just Ph.Ds.. You just upload data on our cloud, and that's it, so that economists, historians and even archeologists can use it. We think that Deep Learning has already reached that stage of prevail now," says Mr. Dave Sullivan, Chief Executive Officer of Ersatz.

Deep Learning so far has established a reputation that it can work sufficiently well in the field of so-called 'pattern recognition', such as with audio and image recognition. For example, Apple's virtual assistant, Siri, is based on the voice recognition system of Nuance Communication, which uses Deep Learning as its foundation. Google's voice search is also based on Deep Learning. Also, Google Brain, the huge neural net that recognized the 'cat' among the numerous videos in YouTube, uses Deep Learning.

That is the extent of current progress. In the near future, however, the technology is expected to be applied to increasingly different fields such as natural

language processing and robotics. Ersatz is also thinking about providing their SaaS for a wider range of applications. To use their service, you just upload your data, answer some questions on their menu, and that's it. The company is already providing this as a beta service, which is free of charge for the first 60 minutes. After that, you pay 41 cents a minute. They are currently in the process of establishing their customer base, and they anticipate that one of the most promising applications will be in medical imaging.

"Whenever you go to the hospital now, you get a test such as CT Scan or MRI or whatever. Then you have to wait for more than 2 weeks or so, and they sometimes make mistakes. If they use our service, the test gets more accurate and the turn-around time on the tests gets a lot shorter." (Mr. Sullivan)

6 A New Kind of Processor which Mimics the Brain

On the other hand, a new kind of processor which specializes in executing a Deep Learning algorithm is now under development. This is a very special processor, called a "neuromorphic chip (processor)," which is hardwired to mimic the biological neural network of our brain. The basic idea of the chip was already established in 1980s, although the then elemental technologies were not matured to a level for the idea to be realized at that point in time. But now, with all the conditions being set, the futuristic chip is finally becoming reality.

TeraDeep based in West Lafyette, Indiana, is a start-up company, which is developing the neuromorphic chip. Dr. Eugenio Culurciello, one of the founders of the company, is also an associate professor of Purdue University. His research focuses upon a neuromorphic chip as a commercial product, for which purpose he has established a company.

Their chip (processor) is specifically designed to execute Deep Learning. This, however, is a so-called 'co-processor', which works as a subordinate to the conventional main CPU processor. TeraDeep's neuromorphic chip is designed for advanced energy efficiency so that once incorporated into a mobile device such as smartphone or tablet, it can be always on.

Their mission is to give a sort of 'engineered eyes' to mobile devices. TeraDeep's neuromorphic chip inside a smartphone can analyze the visual image of an object captured by its built-in video camera in real time. In effect, this will give the smartphone the ability to see and recognize its surrounding environment just like a human.

"For example, if you are in a shoe-store, your smartphone might be able to tell you that there is a pair of shoes on the shelf there, that you might like, given your preference. If they (smartphone makers) use our chip, that kind of product would be materialized," says Dr. Culurciello.

The company has already developed such a neuromorphic chip and uploaded a video to demonstrate the performance of the chip on YouTube. However, instead of producing commercial products based on the technology, they license the technology to major chip manufacturers. They say that they are already negotiating with a number of companies about the licensing rights.

Major chipmakers have also started developing processors that mimic our brain. For example, Qualcomm based in San Diego, CA, established a special team called the "Zeroth Project" inside the company to develop a new kind of neuromorphic chip that can execute a cutting-edge neural-net algorithm called "Spiking Neural Net."

Spiking Neural Net is a new breed of neural net, which has added sequences of spiking pulses to a conventional neural net. These pulses are thought to be something like a "brain-wave" so that the Spiking Neural Net is more like a real human's brain than the conventional neural net. Some researchers foresee a so-called 'Strong AI', AI that has consciousness, which may emerge on the horizon beyond the Spiking Neural Net. A manager of the Zeroth Project at Qualcomm explains the meaning and significance of the project as follows:

"Traditional processors excel at number crunching, but they are not good at recognizing objects or faces. Also, they are not able to look at partially complete information or 'noisy' information and figure out what the interesting things are in a data set, or happening in a particular scene, to extract essential information and make sense of what's going on.

We believe that a biologically inspired computing approach (i.e. Neuromorphic Chip) for such kinds of problems and domains are more efficient and powerful than the traditional approach, and that's really what we're trying to do with the Zeroth Project," says Mr. Samir Kumar, Director-Business Development & Product Management for Qualcomm Research.

In addition to computer scientists, Qualcomm's Zeroth Project has several neuroscientists in their team, and they work together to research and develop the Neuromorphic Chip. Making the technology into a commercial product is still several years away, though they announced that they are going to release a development-platform (i.e., a pilot version of the chip) for their customers such as mobile device manufacturers within 2014.

Their chip would give a mobile device, such as a smartphone, the ability to learn from big data as to how it was used in the past in order to automatically customize itself to each user. Also, it would make a virtual assistant like Siri more intelligent and talk with us more naturally.

Besides Qualcomm, DARPA is now progressing with a major project called "SyNAPSE," which aims to develop a neuromorphic chip with Spiking Neural Net architecture. Project participants include IBM's Almaden Research Center and Watson Research Center, as well as Hughes Aircraft's HRL Laboratories.

7 IT merges with Neuroscience

The developments mentioned above starkly tell us that A.I., which is a branch of IT (Information Technology), is now merging with neuroscience, a distinct break from previous developments within the A.I. industry. From the beginning of research into neural nets in the 1950s until recently, "neural" was nothing more than a word. The reality was that it was just a funky method of numerical calculation, with the exception of its core part called the "sigmoid function", which is said to be an analogy of our biological neuron. Quite frankly, the then neural net was a product of mathematics, not neuroscience.

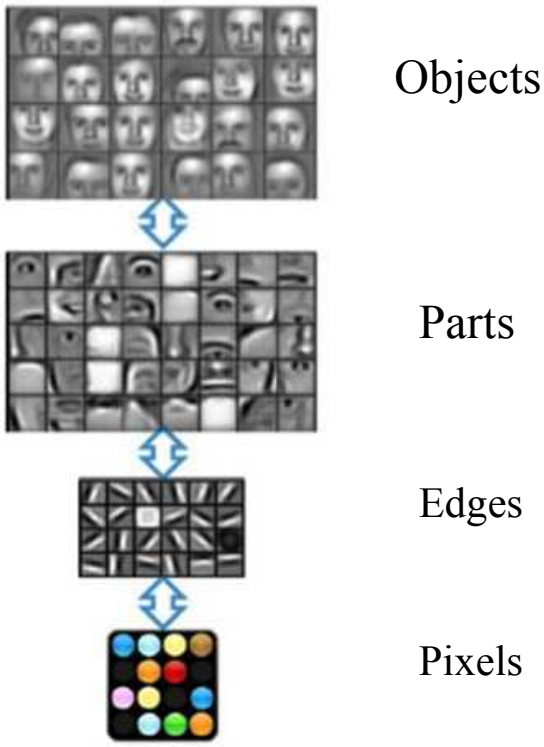
The change commenced in 2006, when a group of A.I. researchers led by Dr. Geoffrey Hinton, professor at Toronto University, Canada, introduced some advancements in neuro-science into their neural net technologies, one of which was "Sparse Coding."

Sparse Coding is the algorithm based on a mechanism of how V1 (Visual Cortex 1) of our brain recognizes objects. The theory was proposed in 1996 by Dr. Bruno Olshausen, the then associate professor at UC Davis, and currently a professor at UC Berkeley. According to his theory, the visual cortex of our brain first plucks out essential feature vectors from numerous pixels that consist of a natural image that has been captured by our eyes. It then uses the vectors to build more complex and abstract concepts step by step, the sequence of which proceeds in a way such as transitioning from the vectors, to the edges, to the parts to the final objects such as a cat's face (which as we will see below Google Brain has already achieved).

Each feature vector corresponds to a spiking neuron, or an activated neuron, and the number of the neurons spiking simultaneously at a certain time is very small compared to the entire number of neurons of our cortex, which is estimated to be more than 10 billion. In other words, the activated neurons that work as the basis of

our vision system are relatively "sparse", which is the reason why the algorithm is called "Sparse Coding."

【Fig. 2】 Deep Learning process based on Sparse Coding



（Source：" Tutorial on Deep Learning and Applications", Honglak Lee, University of Michigan）

The neural net has introduced Sparse Coding as a cornerstone of its mechanism for Deep Learning. This new kind of neural net first showed outstanding performance in the field of image recognition. For example in 2012, Google Brain, a huge neural net created by Dr. Andrew Ng, an associate professor at Stanford University, in collaboration with a Google Senior Fellow, Dr. Jeff Dean, succeeded in drawing vague images of a cat's face, a human's face, a car and so on, on a computer screen, based on the automatic analysis of a vast number of video images on YouTube. This achievement, which surprised the science community all over the world, is based on Deep Learning technology.

Regarding this technology, in the field of brain science, there is a hypothesis called "One Learning Theory," which asserts that different areas of our cortex such as the visual, auditory and sensory areas, actually use the very same algorithm to perceive our real world. If this hypothesis is correct and Sparse Coding is such a foundation, then Deep Learning, which uses the algorithm, can be used for not only

image recognition but also other applications. Put in brief, Deep Learning should, to some extent, be a multipurpose (or, in other words, universal) A.I..

And later, such universality was actually suggested by the fact that Deep Learning is very effective in other areas such as audio recognition and the development of new drugs. For example, Google's voice search and Apple's Siri are based on audio recognition systems using Deep Learning, and are now showing very impressive improvement month on month.

Mentioned above are the main reasons why IT titans such as Google and Facebook are eager to acquire the start-up companies involved in Deep Learning. To make a long story short, they are sniffing the huge potential for a variety of business possibilities from this new kind of AI, derived from the integration of our brain's universality and flexibility, and computers' extremely fast processing and enormous amounts of memory currently available.

8 Robots that Can Perceive their Surroundings and Move Smoothly

These big companies are not the only ones seeing opportunity. Some nifty start-ups are also sensing the immense potential of this new kind of AI, which could be well beyond ordinary business applications. For example, Grok (a.k.a. Numenta), based in Redwood City, C.A, which happens to be a high class residential area of Silicon Valley, is such a new company that develops their own unique neural net technology based on their research about the biological brain and its implication for A.I..

One of the co-founders of the company is Dr. Jeff Hawkins, who is well known as an innovative engineer and entrepreneur. He co-founded Palm Computing, which produced harbingers of the PDA (Personal Digital Assistant) in 1990s. Based on the fortune he accumulated from successful business ventures, he founded the Redwood Center for Theoretical Neuroscience in 2002. He hired a number of neuroscientists as staff researchers, including aforementioned Dr. Olshausen, who is now the director of the Center. Since its establishment, the center has focused on so-called 'computational neuroscience', which is an intersection of neuroscience and computer science.

Grok was founded in 2005 to commercialize results of the research by the Redwood Center. As with Deep Learning Grok's neural net adopts Sparse Coding, though, according to Grok the two kinds of neural nets have significant differences. One of the main differences in Grok's neural net lies in its ability to handle streaming data on communication networks including the Internet. Its biological metaphor is

that our brain can handle lots of information from our sensory organs such as eyes and ears on the fly, i.e. the information doesn't have to be stored somewhere in the brain before being processed. Likewise, Grok's neural net can process data on the communication network directly before they are stored in computer storage.

The company began to provide their machine learning service using their neural net as a SaaS on Amazon Web Services (AWS) in March 2014. Their very first application is anomaly detection for communication networks. The next big market they expect is robotics, especially a research field called "sensor-motor integration," which can be well explained with a biological metaphor.

Our brain can quickly perceive our surrounding using the information our sensory organs such as eyes and ears have caught, which leads to the natural and smooth movements of our limbs. But for robots, it's not that easy. First, they have to employ all of their built-in sensors such as radars, laser-range finders and video cameras to collect data around them. Then they calculate the data to perceive their surroundings, which finally leads to their control-and-drive systems that make them move.

But when they move, their surroundings, the view from their built-in video camera, inevitably changes, which requires them to employ their sensors and calculate again from scratch to perceive their new surroundings, and this continues on and on.

This endless sequence of sensory-measurement to movement to sensory-measurement is called "sensor-motor integration" and this is currently the most difficult thing to do for robots. For example, DARPA held a competition for disaster relief robots called the "DARPA Robotics Challenge (DRC)" at an auto-race track in Florida in December 2013.

DRC is a two-year project which calls for participants amongst research institutes and independent inventors from all over the world. They are aiming to develop the next generation's disaster relief robots to be able to move autonomously to some extent in very dangerous sites, such as nuclear power plants, an area which has drawn heavy attention in the U.S. and abroad, including Japan that suffered the Fukushima nuclear plant accident.

The competition in December was the qualifying round for the upcoming final to be held in June 2015. A Japanese robot maker, SCHAFT, which happens to be a spin-out from University of Tokyo's robot laboratory, got through the qualifier as the top-ranked contender. Prior to that, however, Google had announced that they would purchase SCHAFT as well as other start-ups developing next generation

robots in the U.S.. The fact that the Japanese company bought by Google won the qualifier of the DRC aroused a mixed feeling of pride and sense of deprivation amongst people in Japan.

Aside from that, the robots that competed at DRC, including SCHAFT's one, were actually not so impressive in terms of their performance. There were 8 assignments that the robots had to compete in the qualifier, such as 'to drive a car', 'to drill a hole in a thick wall', 'to climb a ladder', and so on. But frankly, their movements were very slow in general, and many of them abruptly stopped in the middle of the each assignment and froze up for a couple of minutes. They almost looked like alligators on the riverside, which move, then stop, stay there for a long time, and move again when least expected.

According to some robotics experts, the main reason for such intolerable performances of the robots was their poor sensor-motor integration, especially their recognition system. Currently, they need enormous amounts of time to calculate the data gathered by their sensory systems to recognize (perceive) their surroundings. This is the field in which Grok wants to apply their technology.

"The next thing we can do is sensory motor integration. We believe that machines (robots) that can learn from their sensory data will create whole new applications that nobody has any idea of today. But we don't believe we can do it all. The best way to do make progress in these areas is with a development community. Therefore we created an open source project called NuPIC where we've taken our algorithms and made them available to the open source community", says Ms. Donna Dubinsky, Chief Executive Officer of Grok.

To introduce the result of brain research into robotics, such as Grok intends to do, actually promises to be not so far in the future. For example, self-driving cars that Google and all of the major auto-manufacturers promised to make for the consumer market by 2020 need to do precisely this. As Professor Olshausen explains:

"Right now, the self driving car is just a computer program driving a car. So, I would never trust it. Take the example of a fly on the windshield. You (humans) know it's just a fly and you ignore it, but for computers, they have no idea what it is so that they may brake the car suddenly on freeway. It's impossible to program all these things into computer program because these are things we just sort of learned with vast amount of experience through evolution. That's definitely an area the neuroscience based approach is going to make a big contribution to within next 10 years."

He believes that introducing computational neuroscientific achievements such as Sparse Coding would greatly improve the aforementioned DRC robots and self-driving cars.

Currently leading this field is Google, which as previously mentioned have acquired many robotics companies in the last year, including Japan's SCHAFT and Boston Dynamics of the U.S., in addition to some A.I. start-ups such as Deep Mind Technologies from England, that are working with Deep Learning. It's not hard to imagine that by combining their technologies, Google is likely to lead the development of next generation's robots, utilizing some degree of computational neuroscience.

9 From Industrial Robots to Service Robots

What about Japan's robot industry that has to confront Google? It is estimated that Japan's industrial robots that are at work in factories such as in auto-manufacturers' have a little more than 50% share of the robot market of the entire world. However, these days, the industrial robot market in developed countries such as in the U.S. and Japan is becoming saturated. Considering this trend, Japan's major robot makers are vying to shift their primary business targets to emerging markets such as China and Southeast Asian countries.

On the one hand, U.S. companies including Google seem to be rather more interested in developing a new frontier called 'Service Robots', which could be a next generation of robots that literally engage in various services in numerous industries and societies. For instance, military robots such as the Unmanned Aerial Vehicle (UAV)s (a.k.a. Drones) and unmanned submarines, robots for agriculture, robots that support doctors to diagnose and nurses to take care of patients and the elderly, and so on.

Or to be used by businesses and general consumers, there are wide range of service robots such as surrogates robots (or telepresence robots) that would work vicariously such as attending an overseas conference in place of a person who cannot, home robots that clean floors and windows or mow the lawn, smart-homes that automatically control the temperature and moisture of rooms based on the lifestyle of each family member, and robots for education and entertainment, the list goes on.

The market of these service robots is now just starting to take off, and it's still very small in comparison with the market of incumbent industrial robots. However, it is expected to grow rapidly in the near future as they begin to find roles across the

length and breadth of our society.

Regarding this point, and with respect to the U.S.-Japan competition, a Japanese engineer dispatched by a major robot manufacturer in Japan to study at a robotics laboratory in Stanford University as a graduate student states the following:

"As for the sales of the conventional industrial robots, Japan and Germany have a commanding lead on other countries. However, the robot industry's current biggest challenge is to find a next generation of applications such as service robots. To develop these new kinds of robots, you need more creative ways of thinking, and this is where the U.S. seems to me to be a cut above the others."

Such service robots that work not only at home and in the office but also over a wide variety of occasions are required to have different kinds of advanced abilities when compared to conventional industrial robots. Conventional robots just repeat uniform tasks, such as spot welding and arc welding, so that they are required to have very precise control-and-motor system. On the other hand, service robots such as one designed to work in, say, laundry, to fold cleaned clothes, are required to have a high-level of recognition capability that would enable them to act deftly and flexibly just like humans do.

For example, machine vision and perception systems on conventional robots are unable to recognize that a sweater spread out on the table is the same as the one folded because the shape of the former is different from that of the latter. To be able to recognize that they are essentially the same sweater even if their shapes are different, such robots must have A.I. based on brain science such as Deep Learning or a neuromorphic chip inside their recognition system.

Although general public may think that the A.I. and robotics are close to each other, the reality is quite opposite. The main reason behind this is the difference of the academic backgrounds of the experts involved. Robotics research and engineering majors at college tend to be predominantly machine/control engineering students, whereas the A.I. researchers/ engineers' tend to be from information/communication engineering. As what they learned when they were students are so different, there tends to be a thick wall between them, even after they began to work at companies. It's often been said that robot engineers know almost nothing about A.I..

The situation, however, is now changing rapidly, especially in the U.S.. Some 1st-tier schools such as Stanford University and M.I.T. seem to be trying to integrate the fields of A.I. and robotics. The harbingers are Dr. Sebastian Thrun, who leads the development of the Self-Driving Car, and Dr. Andrew Ng, who co-developed

Google Brain, the aforementioned massive neural net. They are now working, or once worked, at Google while keeping their academic posts at Stanford University (Recently, it was announced that Dr. Ng would join China's Baidu as the head of their newly established A.I. research lab). These two top scientists' expertise is with A.I. and robotics, not just one of them. This trend of merging robotics and A.I. into a new kind of intelligent robots seem to be a significant shift presently underway in Silicon Valley.

Leading this trend in recent years has been Willow Garage, a start-up company whose staff of engineers are mainly graduates from Stanford's robot labs. Several years ago, they developed ROS (Robot Operating System) and open-sourced it to make it the de facto standard OS for intelligent service robots.

The company still exists officially, but practically it seems to have split into a couple of new robot makers for reason we could not fully ascertain. Some of these splinter ventures are the ones aforementioned that Google has recently acquired. Accordingly, it is highly likely that Google is going to develop their own version of ROS, i.e. a de facto standard OS for robots, thereby assuming the position of Willow Garage. At the same time, they probably will integrate the OS and hardware technologies that they acquired from robot makers such as Japan's SCHAFT and the U.S. Boston Dynamics into new kinds of intelligent robots, which may eventually prevail over all industries we work in and the societies we live in.

According to the New York Times and Wall Street Journal, Google may first introduce their robots into the manufacturing industries, such as automobiles and electronics, which is somewhat surprising to the general public. As is well known, these industries already extensively employ industrial robots, so that new kinds of robots that Google and others will make in the near future seem unnecessary. However, there are still many steps remaining that humans are now engaged in even in the factories of those industries, such as assembling process of final products. Google would like to place their flexible and intelligent robots there to replace or work with human workers. Starting from there, they will probably extend the applications of robots to the entire supply chain including logistics, retail and delivery services.

The aforementioned Japanese robot engineer presently studying at Stanford University is very concerned about the conceivable development of the above scenario.

"People in Japan's robot industry think in the back of their minds that when the present Chinese market for conventional industrial robots has matured, they just shift their focus of business to Southeast Asian countries, and that would be all right.

However, this kind of shift will eventually end, and when it has reached the dead-end, the main products in advanced countries' robots market will probably be the next generation's intelligent robots that Google and others are developing right now. I suspect that Japan's major robot makers may not be able to adapt to this new situation. If that is the case, there will be no future for Japan's robot industry, which is dominant in the world market at least now," says the Japanese engineer.

1 0 What should Japan do?

To catch up with Google and others, which are at the forefront of developments in A.I. and its application to the next generation's robots, recently some Japanese scientists have finally begun to take some actions. For example, three researchers of A.I. and computational neuroscience at the University of Tokyo, the National Research Institute of Advanced Industrial Science and Technology (AIST) and Fujitsu Laboratories Ltd. respectively, jointly organized a "Whole brain's architecture study group" in December 2013.

This group aims to study the mechanism of all parts of our brain such as the cortex, mid-brain, cerebrum and brain stem, which they hope and expect would eventually lead to development of better A.I. such as Deep Learning, neuromorphic chips and so on. More than 200 people, including A.I. researchers, neuroscientists and insiders from the IT industry in Japan gathered for the second meeting of the group in Tokyo in January 2014. One of the three organizers, who wants to continue the study group into the future, talks about the meaning of the study group in the following terms:

"Although this is not well known, Japan in the past produced some notable A.I. researchers such as Dr. Kunihiko Fukushima of NHK's Science & Technology Labs, who invented Neocognitron, which is said to be one origin of the current Deep Neural Network. To cultivate successors of excellent A.I. scientists like Fukushima, we organized this study group," says Yuuji Ichisugi, research scientist of human-life technology division of AIST.

As indicated in his comment, Japan in the past, especially in the 1980s, lead the world in basic research of neural net technology. However, because of the performance-limitation of computing processors and memories in that era, even the then best neural net such as Neocognitron couldn't yield so many practical applications. Facing this harsh reality, most of the neural net researchers, especially ones in private corporations in Japan gave up one after another, which eventually left them behind the frontier of neural net research in the world, and especially

trailing the U.S..

This still has a prolonged negative effect on Japan's A.I community. As for some powerful cutting-edge neural nets such as Deep Learning, "Japanese companies haven't reached the status to be able to produce commercial products, I must say, and their Deep Learning systems are still in the basic R&D phase right now", says Seiya Tokui, researcher of Preferred Infrastructure, which is a start-up company based in the Bunkyo district of Tokyo.

The company hires many students who have majored in information science/ engineering to develop up-to-date IT systems, such as cloud computing and machine learning, which are then sold to major companies in Japan. They have also recently begun to research and develop Deep Learning technology.

"Deep Learning, I think, is still in the early stage of development so that Japan's companies, including ourselves, can catch up to the U.S. companies, including Google, if we start right now. However, rather than competing head to head with Google, which develops their products for worldwide customers, Japanese companies had better start with developing some niche products specialized for Japanese markets," says Mr. Tokui of Preferred Infrastructure.

Having said that, there will still be many chances that Japanese companies have to compete with Google. But taking that risk will get you something worthwhile, which an A.I. expert explains as follows:

"The biggest advantage of Deep Learning is to be able to find variables of every problem for itself instead of humans. In other words, by using Deep Learning, computers analyze Big Data to find out what is important and essential to solve a problem for themselves. This ability to find out something important on its own is an aspect that conventional A.I.s haven't had so far. Breaking through this limit, Deep Learning has achieved status as a new kind of A.I., which could be much more useful and powerful than the past A.I.s", says Yutaka Matsuo, associate professor of Graduate School of Engineering, University of Tokyo.

Prof. Matsuo suggest that Deep Learning, which is a cutting-edge software technology, could unexpectedly be very useful to revitalize Japan's hardware-manufacturing industries, for instance the electronics makers.

"I wonder if they (the electronics makers) could find out what consumers really want by analyzing Big Data. Big Data has been buzzword these days, but it doesn't do anything good unless you clearly know what you want to do with it. With the case of the manufacturing industry, you must use Big Data to specify what you should really make. For that purpose, you can use some advanced machine learning

technology like Deep Learning, which can find out something important (like what consumers really want) on its own", says Prof. Matsuo.

Japan has long been highly regarded at hardware-manufacturing, or so-called "Monozukuri", whereas it is considered poor at developing sophisticated software such as Deep Learning. But some say it's too general a statement to make.

"You may think software is just software, but it's really a very wide range of spectrum. Certainly, Japan's software industry is far behind in the area of operating systems (such as MS Windows, Apple's iOS and Google's Android), but, unexpectedly, not like that in advanced software like A.I.. For example, decision-making systems (which are considered a branch of A.I.) actually originated in Japan. I mean, Japan has such fertile soil, so to speak, to cultivate new kinds of A.I. technologies like Deep Learning from now on", says Hiroshi Sakai, professor of Computational Vision Science Laboratory of Tsukuba University.

The integrated field of IT and neuroscience, which is a technological base of Deep Learning, has been called "computational neuroscience" since 1990s. This field, which Dr. Ichisugi and Prof. Sakai belong to, is recently drawing much attention, though there are not so many experts in this field, even worldwide. For instance, it is said that most of the scientists/engineers that can develop fully-fledged Deep Learning systems are still presently graduate students.

Regarding this point, one of the reasons why Google spent so much money to buy DeepMind, which hasn't, as yet, even shipped any product, is to recruit such rare experts of Deep Learning who have worked for the start-up company.

Prof. Sakai of Tsukuba University who emphasizes the importance of cultivating such talents, points out the difficulty of doing this in Japan.

"Judging from the graduate students that I have known in my lab, Japanese students majoring in information engineering in general seem to be excellent as well as hard workers. But once they join companies…," Sakai leaves his remark incomplete.

But once they join companies in Japan, why do they grow up so sluggishly as engineers these days, why do they perform so poorly even with their high potential? Or, why does every smarter student want to join Google Japan these days?

Of course, I'm not saying that's bad in general. But to re-establish Japan's new key-industries, such as electronics in the 1980s, we'll probably have to reconsider and reconstruct our employment/evaluation system completely, to realize the working environment where young engineers can materialize their full potential.

Also, it would be very important to facilitate the exchange of talents between private corporations and universities, such as with the relationship between Google and Stanford. It seems that the current A.I. revolution originated in the U.S. may suggest the need for more fundamental reformations for Japan's business and industry in general.

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