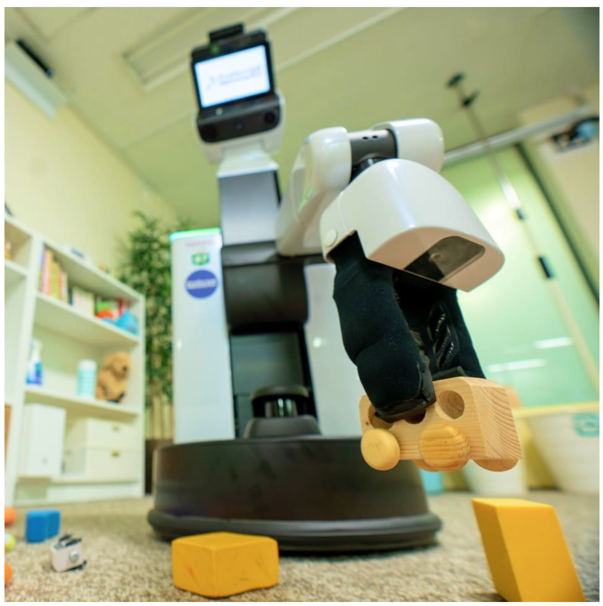
IN1632

Case Study

Preferred Networks:

A Deep Learning Startup Powers the Internet of Things



Source: https://preferred.jp/

10/2019-6477

This case study was written by Pavel Kireyev, Assistant Professor of Marketing at INSEAD; Theodoros Evgeniou, Professor of Decision Sciences and Technology Management at INSEAD, and Nancy Brandwein. It is intended to be used as a basis for class discussion rather than to illustrate either effective or ineffective handling of an administrative situation.

We thank Daisuke Okanohara and Toru Nishikawa, Hiroshi Maruyama, Kiyoshi Yamamoto, Shohei Hido, Takuya Akiba, Yoichi Saito, Keigo Kawaai, Taizan Yonetsuji, and Richard Calland for their invaluable help in the development of this case.

To access INSEAD teaching materials, go to https://publishing.insead.edu/.

"In this business, if you're not doing something that seems crazy to some people, you'll never do something interesting."

Daisuke Okanohara, Co-Founder, Preferred Networks Inc.[1]

The large boxy yellow robot could not look less human, but it performs exponentially better than one. Made by Japanese robotics giant Fanuc, the robot hovers crane-like over a bin of metal cylinders piled at random. With each cylinder the robot attempts to pick up with the pincers at the end of what looks like a tapered metal snout, it encodes data on whether the pick-up was a "success" or a "fail." The robot uses these data to train a deep neural network to predict bin-picking success from the images it generates. The more data samples it uses, the more the robot's prediction accuracy increases—so much so that after eight hours the robot can achieve a 90% success rate, performing better than human "pickers" and without the exhaustion and tedium that would plague factory workers doing the same job.[2]

The Fanuc robot is using deep learning technology developed by a Japanese startup, Preferred Networks (PFN). Started in Tokyo in 2006 as a search engine company, Preferred Infrastructure (PFI), by University of Tokyo graduate students Daisuke Okanohara and Toru Nishikawa, the company became Preferred Networks in 2014 when their focus shifted to marrying deep learning to the Internet of Things (IoT). From having almost no capital, the startup entered into lucrative partnerships with Fanuc and Toyota. In February 2017, the two young founders posed with Japan's Prime Minister Shinzo Abe at his office, where they were awarded a prize for promising new ventures. By 2019, PFN had garnered $130 million in investment by Toyota, Fanuc, and other companies. PFN had also gone from employing only a handful of employees to over 200. Their partnerships continue to grow and now span the globe; aside from Toyota and Fanuc, major partners include Nippon Telegraph and Telephone (NTT), Hitachi, Hakuhodo DY Holdings, Cisco Systems, IBM, Intel, Microsoft, and Nvidia.[3]

In the Ōtemachi business district in central Tokyo, co-founders Nishikawa and Okanohara are meeting with their COO and CFO in one of the company's drab conference rooms. "Our main business is to build totally new software services that did not exist before," says Nishikawa, reminding the others of the company's key mission: to take on challenging problems for partner companies only if they believe no one else can solve them.

As PFN grows, they must ask and answer hard questions about realizing that mission: What business model is most appropriate for a business seeking to capitalise on the possibilities enabled by deep learning? How does such a business prioritize in a world of infinite opportunities? Monetize technologies that are made available on open platforms? Manage an organization of 200 employees in a way that allows for constant innovation?

AI, Machine Learning and Deep Learning: What Are They?

It helps to think of deep learning as one method of machine learning, which is a key part of artificial intelligence (AI), the theory and practice of computer systems that can "be intelligent." Arguably a system that cannot learn is not as intelligent. Machine learning algorithms build mathematical models based on training data to make predictions or decisions without being explicitly programmed to perform a particular task. In a sense, the computer writes the program, which is often in the form of a complicated mathematical function that defines outputs (e.g., whether to move a robot's hand up or down) for given inputs (e.g., images of the environment and the goal of the robot).

Within machine learning, one can make the distinction between shallow learning and deep learning. An example of the former is a simple linear regression that involves quantifying the relationship between one or more predictor variables and one outcome. This kind of system has a limited ability to learn and adapt to complex environments—rarely can a linear equation describe or approximate reality. Since the publication of the Weierstrass Theorem in 1885 and the Stone-Weierstrass generalization in 1948, it has been known that highly non-linear shallow learning methods do have the ability to learn complex relationships between variables: they can be thought of as "universal learning machines."[4] Well-known modern shallow learning methods include, for example, random forests, boosted trees, and support vector machines. However, in some practical cases, deep learning has worked better than shallow learning—despite no clearly understood theoretical reasons to date as to why. For example, in 2012, a University of Toronto team entered a contest in which they built computer vision algorithms that could learn to identify objects in millions of pictures. By sorting 1.2 million images into 1000 different classes, the U of T's neural network architecture—AlexNet—beat contenders by a whopping 10.8% points. Since then, Google, Microsoft, and IBM, along with other tech giants and startups like PFN, have used such ideas, codified into the branch of machine learning now called deep learning by some people, to improve onscreen character recognition, search engine speed, data compression, and other tasks that rely on pattern recognition to make accurate predictions and better decisions.[5]

The AI Landscape Today

The influence of AI in business is growing. For example, we use AI to conduct many of the 3.5 million Google searches made each day. AI allows Siri to answer a wide range of spoken questions, while Apple's iPhone X recognizes your face to unlock your phone. These applications spur investment, with "billions invested in AI startups across every imaginable industry and business function."[6] In 2017, AI attracted a record $15 billion in venture capital.[7] According to Price Waterhouse Cooper, AI could add up to $2.7 trillion to the economy by 2030, and some studies say that early adopters could double their cash flow by that date.[8]

The Founding of Preferred Networks

Both keenly interested in programming as youths, Okanohara and Nishikawa met as sophomores at the University of Tokyo.[9] In 2006, while the two were in graduate school, Okanohara was developing the core algorithm for natural-language processing programs and search engines. He, Nishikawa, and two other friends used this technology to start Preferred Infrastructure. While the group was a veritable brain trust of programming knowledge, they struggled to build a business. They invested their own funds in the company, which was hemorrhaging money. At one point, Nishikawa's savings were down to 600 yen ($5.40), and he lived on a diet of cabbage until a venture capital company sent new customers their way.[10]

Even with an increase in business, Okanohara wanted the company to move in a different direction. "I was always thinking about how we could beat Google and Microsoft," he remembers, not in search engine technology—it was too late for that—but in some new technology that hadn't come along yet.[11] Fortunately, Okanohara and Nishikawa excelled in the nascent field of writing software for image analysis. Their progress coincided with the pivotal advances in deep learning mentioned earlier. Around this time, their strength in the developing field caught the attention of Sony executive Junichi Hasegawa, who headed the development of Sony's PlayStation 3 game console. Preferred Infrastructure's founding duo reminded Hasagewa of Akio Morita and Masaru Ibuka, the men who founded Sony in post-war Japan and turned it into a global powerhouse.[12]

Hasegawa left Sony and joined Preferred Infrastructure in 2011 as Chief Strategist. He spearheaded the company's transformation into PFN in March 2014 and helped engineer some of the partnerships that shot PFN into the limelight. Seemingly overnight, they went from a company that had no external investors to one funded by the biggest names in Japanese manufacturing.

Teaming Up with Toyota

The importance of manufacturing to most of the world's developed economies has declined in the past two decades. Yet, Japan is one country that has managed to build a robust industrial sector even in the face of daunting global competition and relentless technological change. After all, it was Japan that pioneered the concept of kaizen, or "continuous improvement," which was famously exemplified in Toyota production plants. A history of continuous improvement in manufacturing technologies is what also drove Japanese manufacturing giants Fanuc and Toyota to take a keen interest in PFN and the deep learning technologies that could transform their manufacturing processes into ones that are "smart" and "collaborative."

Connected cars share internet access, and hence data, with other devices inside and outside the vehicle. By 2025, connected cars are supposed to be exchanging 10,000 times the volume of data per month (10 exabytes) than they currently do.[13] When Hasegawa helped launch PFN in 2014, he wrote to Kenichi Murata, a former Sony colleague and General Manager of Connected Strategy at Toyota. Murata told Ken Koibuchi, the chief of Toyota's autonomous vehicle project, about PFN. Koibuchi, who had become all too aware of Toyota's dearth of AI and computer science knowledge in general, had already been looking beyond Toyota's own resources for expertise in this area.

Toyota invested $8.2 million in PFN in December 2015, acquiring an approximate 3% stake in the company. "This will strengthen our partnership as our collaboration has begun to show various results," said Murata, although Toyota had not released any details on exactly what this meant during the entire year they had worked together. It wasn't until the Las Vegas Consumer Electronics Show in January 2016 that the world got a glimpse of PFN's and Toyota's combined power. Rather than chase after Waymo and other companies consumed with the idea of putting driverless vehicles on the highway, Toyota's autonomous driving and connected car vision is about making cars safer and more user friendly, and replete with features that help drivers stay productive on the road.[14]

At the Las Vegas show, PFN's demonstration using a half dozen mini Toyota Priuses was one of the most exciting. With no prior driving experiences, the grey toy cars used raw sensor data and deep neural networks to understand the surrounding environment and learn to drive better. By learning from their interactions with other cars, in just two hours they managed to successfully drive around a pre-set course. In four hours, they were able to adapt to more difficult traffic situations.[15]

Toyota is using its R&D partnership with PFN to achieve far-reaching goals: to enhance object recognition technology, analyse big data collected by connected cars, and create smart car manufacturing systems that will maintain Toyota's edge as a global auto giant. About 100 researchers from PFN are involved in the partnership, and Toyota invested another $95.4 million in 2017.[16]

PFN president Toru Nishikawa offers a key to how work on autonomous driving technology fits into the company's mission.

> *"Autonomous driving," he says, "is very related to robots, because I think a car is a type of robot. Autonomous cars need highly accurate vision recognition systems."*

Yet, Nishikawa admits that there are already so many players in the autonomous driving field that PFN—and by extension, Toyota—are interested in bringing their technology to robots more generally. "Currently there are many large investments for autonomous driving, so we can get enough money to research very accurate vision recognition systems. Then, we would like to bring such technology to robotics." He goes on to say that "the robot is the next computer."[17] Indeed, the first early investor that saw promise in PFN's deep learning expertise was industrial robot giant Fanuc.

"We, Robots": PFN Helps Fanuc Robots Learn

Fanuc's brilliant lemon-yellow robots are on bold display working in factories worldwide. Its most famous, Robodrill, hammers out the metal cases for Apple's iPhone at China's Foxconn plant.[18]

In early 2015, Hasegawa gained entry to Fanuc headquarters to sell PFI's search engine technology. Only within the last five minutes of the meeting did they discuss the idea of deep learning and AI for other business goals.[19] Fanuc's CEO Yoshiharu Inaba was interested enough to ask the two founders to visit, this time inviting 50 more Fanuc executives and focusing only on PFN's deep learning technologies. Ushered into one of the top-secret factory floors, the founders watched robots being built around the clock by large groups of other robots. Nishikawa remembers:

> *"What I witnessed was robots making other robots without human intervention. If you keep the robots operating, data can be collected infinitely [from sensors on the robots themselves]."*

Nishikawa admits, "AI technology wasn't used widely, and I felt there was a big opportunity."[20] Robots were not necessarily "intelligent"—they were not learning and improving over time.

Fanuc saw this opportunity, too. Keigo Kawaai, a PFN business developer who oversees the Fanuc collaboration, says, "It was a coincidence, but it was also destined. Fanuc's problem consciousness and PFN's technology matched perfectly."[21] For Fanuc, PFN's deep learning technology would allow them to add intelligence and collaborative functions to stand-alone robots.[22] In PFN, they saw a partner that would help them realize their mission. The usually guarded Inaba concurred: "I felt we were on the same wavelength," he admitted in a rare interview.[23] Fanuc not only bought an approximate 6% stake in PFN for $7.9 million in August 2015, but also prepared four robots for PFN to train in the basement of their office building.[24]

Nishikawa's insight about the possibility and value of an "infinite" collection of data led to a wide-ranging collaboration between PFN, Fanuc, Cisco Systems, Rockwell Automation, and NTT Group. Together they created the Fanuc Intelligent Edge Link and Drive, or "FIELD" IoT manufacturing system. Introduced in 2016, the open, connected platform allows manufacturers to collect global manufacturing data in real time, on site, on a previously unheard-of scale, and send it to self-teaching robots. This is the technology behind the bin-picking robot's success in teaching itself how to get to a 90% success rate in eight hours.

PFN's relationship with Fanuc serves as a model for its relationship to Toyota and other large companies. This "integrator" arrangement is quite common in Japan, where large companies will often reach out to small startups for technologies. The advantage of working this way is that a company like PFN can gain access to all of the expertise and data that Fanuc has on industrial robots (or Toyota has on driving).[25] An application programming interface (API) allows more than 200 companies to develop applications for the FIELD system, and PFN will sell the apps it makes with Fanuc.[26] As Nishikawa says, "The business of industrial robots in Japan is already very large. Our strategy is to collaborate with a large company like Fanuc, to create a product with Fanuc, and sell the product to customers."[27]

Computing on the Cutting Edge with Edge-Heavy Computing

Even though Okanohara's early motivation to "beat Google and Microsoft" helped the two founders form PFN, it was the company's focus on AI applications not dominated by Google, Microsoft, and Apple that propelled it forward. See Exhibit 1 for four example quadrants of AI applications divided by type of customer and technology. Google, Microsoft, Facebook, and Apple are duking it out in the consumer-facing cloud, whereas PFN dominates the business-facing IoT (physical) quadrant. A weakness of most standard machine learning methods is that they perform less well when the data-generating process changes, for example in response to changes in company policy, industry competition, or consumer behaviour—what is also technically known as "non-stationarity" or "concept drift." This is common when operating in the cyber/consumer quadrant. In physical settings, however, well-established laws govern the processes, which tend to be stable over time. Hence, there are many opportunities for successful—in a sense, easier—automation with deep learning.

PFN specializes in providing "edge-heavy computing" for industrial-use cases (the "Edge" in the FIELD acronym). By playing to their country's strengths and linking their technology to Japan's manufacturing prowess, PFN has gained a first-mover advantage in AI and manufacturing. "Deep learning has just started to gather speed, and worldwide efforts to apply that technology to the IoT have just begun," said Nishikawa. "If we could combine them with areas where Japan is way ahead, I think we have a chance to win."[28] Machine learning in the IoT relies on raw data, generated in real time, from sensors on actual things. Edge-heavy computing ensures that latency—the time it takes for a packet of data to get from one designated point to another—remains low enough for data to be analysed in real time on the factory floor.[29]

But edge-heavy computing comes with a cost. Speaking at Stanford University in October 2018, PFN Fellow and former Chief Strategist Hiroshi Marayuma talked about a well-known technical challenge of deep learning, the heavy computational load it induces. “There are lots of parameters, so we have to do lots of iterations in training.”[30] This is why, in September of 2017, PFN created its own supercomputer in collaboration with NTT. The location of the supercomputer is a closely guarded secret but its capabilities are not: just two months after launch, PFN announced that the MN-1 was ranked 12th in the world and 1st in Japan among industrial supercomputers.[31] It’s highly unusual for a startup as small as PFN to have its own supercomputer, but the decision to go deep into deep learning made this a strategic investment. The MN-1 had 1024 Pascal GPUs, and the list price for each GPU is $10K, so that gives an idea of the size of the investment. “For companies like us to have this kind of computing infrastructure is extraordinary,” says Marayuma. “That’s one of the strengths that we have… how we differentiate ourselves.” Exhibit 2 shows the specifications of the MN-1 as well as future iterations of the supercomputer, MN-1b and MN-2.

Values and Business Proposition—Going Deep but Wide

By 2018, PFN had been touted in the business press as the highest-valued startup in Japan. The company was edging toward 200 employees—up from a few dozen in 2014. It was at this point that PFN initiated what would become a yearly activity, “PFN Values Week,” in which everyone would come up with the company’s values and operating principles, via face-to-face small group meetings, brown bag lunches, and online Slack discussions. In this first meeting they came up with four values they felt differentiated PFN from other companies.

- Motivation Driven
- Learn or Die
- Proud but Humble
- Boldly Do What No One Has Done Before

In terms of organizational structure, the two founders make all strategic decisions, and employees—90% of whom are researchers or engineers—operate one layer beneath them. In order to make sure employees are “motivation driven,” PFN uses the 20% rule, popularized by Google, in which employees have 20% of their time to work on whatever they like. Such 20% projects may help employees develop their code portfolio and lead to interesting solutions for PFN and its clients.

As the company grows, it must continuously think about how its culture aligns with its business proposition. In PFN’s early days, Ken Kutaragi, former head of Sony Computer Entertainment and known as “the Father of PlayStation,” advised the founders to organize their business goals around a single compelling proposition: deep learning (or broader machine learning and AI) within the industrial IoT. PFN followed a portion of Kutaragi’s advice. The company organized their business around deep learning technologies. However, they happily applied these technologies to meet any industry’s needs. News of Toyota’s and Fanuc’s large investments in PFN drew interest from new partners. This is how PFN branched out into biosciences and healthcare.

Deep Learning for Cancer Detection and Drug Discovery

He was trained as a veterinary doctor, but at PFN he is leading ten different deep learning projects, all centred on bioscience and healthcare. Yoichi Saito, who went on to work in the pharmaceutical industry after his medical training, now heads up business development for PFN's healthcare business. He says that though the company started out firmly in manufacturing IoT, it now views biotech and healthcare as a priority.

Saito says that PFN is using deep learning technology in three different areas: drug discovery, the process by which new drugs are discovered; genome diagnostics for cancer detection; and medical image diagnostics, the analysis of MRIs, CT scans, and other radiological images, also for cancer detection.[32] For drug discovery, PFN entered into a partnership with Chugai Pharmaceutical, Co. Ltd., a division of global pharma behemoth Roche. After signing the agreement with Chugai, which invested about $6.5 million in PFN, Okanohara said, "With the expertise and performance that Chugai have cultivated in the pharmaceutical business and PFN's technologies, together we strive to create new drugs and services."[33]

In both genome analysis and medical imaging diagnostics, PFN is working with Japan's National Cancer Center (NCC) and so has access to tremendous volumes of data. The most exciting project underway is the use of blood samples for early diagnosis of 14 different types of cancer. For this project, PFN is forging ties with NCC for data, internet company DeNA for regulation and marketing in Japan, and Mitsui & Co. for regulation and marketing in the U.S. PFN can use deep learning to accurately detect the presence or absence and type of cancer based on levels of ExRNA in the blood, a genetic biomarker for cancer detection. One possible business model PFN envisions for its health care projects is a joint venture scheme in which the profit is shared across the stakeholders.

Areas that beckon PFN in the future include construction, which is becoming more digital with the combination of CAD and 3D printing, and processing industries such as oil refining. In order to attract new business, PFN does not rely on sales or marketing staff but on cutting-edge technology demos to keep new clients beating a path to their door.[34]

Managing Research

One of the PFN's primary objectives is to reduce the time required to train deep learning models. A self-described "addict of programming contests," Chief Research Strategist Takuya Akiba has been at PFN for almost three years, where he concentrates on paring training time through several means. "If we can reduce the training time," he says, "then we can conduct more trials [part of the process through which statistical learning models are developed], so we can create better models than other companies." Akiba was on the team of researchers who came in 2nd in a Google AI Open Image Challenge in August 2018 using the supercomputer MN-1b. It was the second time they had come in second, but this time the difference in predictive accuracy between them and the leader was only .023%! One of Akiba's roles is to lead grand challenges—large-scale experiments—several times a year. By participating in these grand challenges within PFN, on Kaggle, or on other online platforms for data science and machine learning contests, PFN can test their models and potentially develop interesting solutions for future business problems.

Akiba stresses that hyperparameter optimization is a key means by which PFN can increase the training speed of their models. A hyperparameter is a variable whose value is used to define the "version" of the machine learning model to be applied. For example, the architecture of a neural network includes an important set of hyperparameters that must be decided upon before the model is trained, such as the number of layers and nodes per layer. However, it is not clear a priori which architecture will yield the best performance for a given problem. One project Akiba expects to be particularly impactful is an open-source framework he developed called Optuna that automates the process of finding the optimal values of hyperparameters. The main contribution of Optuna is that it excludes humans from the trial and error cycle and, as Akiba says, "If we can exclude the human, the human's time can be used for more creative activities."[35]

Okanohara and Nishikawa decided to offer the key frameworks developed at their company as open-source tools. Optuna can be obtained from GitHub and used freely by machine learning researchers around the globe. Chainer, which is perhaps PFN's most visible contribution to the machine learning ecosystem, is also an open-source project. It took PFN engineer Seiya Tokui ten days—during his vacation time—to develop Chainer, which makes it possible to write deep learning programs for those with knowledge of the popular programming language Python.[36] When Tokui revealed Chainer to his bosses at PFN, Okanohara was surprised by the high level of refinement and sophistication of the project. He immediately decided to publish it as open-source software. His hope, which was soon realized in Japan, was that it would become the industry standard. Five months after PFN released Chainer, Google unveiled TensorFlow, its own deep learning framework. Facebook entered the framework competition with PyTorch, and Microsoft with CNTK. In 2017, a new iteration of Chainer, Chainer Multi-Node (MN), in conjunction with the MN-1 supercomputer, broke the world record for the training speed of a deep neural network on the ImageNet database, clocking in at only 15 minutes.

Thinking broadly of the key challenges for research and development, Okanohara is concerned with the data burden of deep learning algorithms. Okanohara looks to the possibilities of simulations. "For some programs, it is actually impossible to collect all of the data. For example, when we develop a new drug, and we cannot conduct many trials by using this new drug on patients. In this case, we need to simulate their results." From very few examples, Okanohara hopes that, ultimately, they can create a generalizable model. However, he says, "current AI is not like this. It often requires at least several thousands or millions of examples. It is good for major problems like image recognition… but when it comes to the very specific or small problems, such data-hungry algorithms do not perform well."[37]

Pick a Business Model, Any Business Model

When PFN was PFI, its business model was strictly a licensing one, in which it sold its search engine software to customers. As the company morphed into PFN, the thinking on business models changed. According to Okanohara:

> *"The business model depends on each market—autonomous driving or industrial robots or machine tuning or life science. Each market requires a different business model."*[38]

As PFN's CFO since late 2015, Kiyoshi Yamamoto brings a wide range of global business experience to bear on the issue of which business models will be most profitable. Before PFN, he was Vice President of Business Development for Wal-Mart, and before that, he was with Exxon Mobil for more than 20 years. Now, he is “fundraising like crazy.” He was involved in the initial investment from Toyota, when PFN was “kicking into expansion mode.” Going back to that conference room at PFN’s headquarters, it is Yamamoto who expresses concern about PFN’s main business challenge, finding the right business model. There are several to consider:

Integrators and Partnerships: The arrangements with Toyota, Fanuc, and Hitachi are based on what some call an “integrator” or “partnership” model. “From a fundraising standpoint, PFN was pretty easy to put forward,” says Yamamoto. “Once we got kick-started [by investments, such as those from Toyota and Fanuc], then funds began coming in.” In addition, these companies provide a pipeline of projects for PFN to engage in.

Profit-Sharing Arrangements: A different business model is a “share the spoils” one that PFN envisions with biotech and health companies. The goals of these organizations are aligned with those of PFN because they are all working to expand a new market. As Yamamoto puts it, if they are both dipping a toe to test the waters of a new market, “our big toe is the same.”

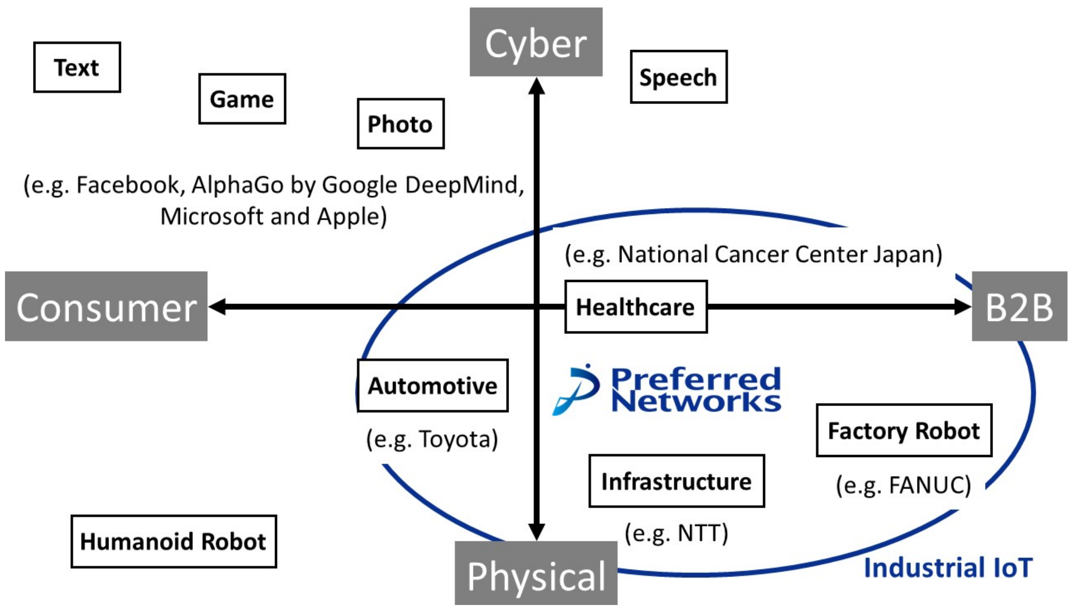
Product Development: Another strategy PFN considers involves building and marketing its own products, such as personal robots. “Eventually…we have to build our capability to sell a product. A product might be hardware or software, I don’t know yet,” says Yamamoto. “But eventually, we have to directly go to the consumers.” He sees that as 10 to 20 years down the road.[39] Vice President of R&D Shohei Hido sees potential in developing an operating system for robots of all kinds and selling that—being the Windows of personal robots.[40]

Sale of Intellectual Property: Finally, there is the model of developing a portfolio of patents, technologies, and talent for acquisition by another company, similar to how DeepMind, a prominent deep learning research organization in the UK, was acquired by Google in 2014. Right now, this is not something under discussion at PFN.

The Road Ahead

What path should PFN take? Where are the opportunities? How should they navigate the fast-evolving AI and machine learning technological and business landscape? So far, PFN’s success is predicated on applying “data-hungry” deep learning algorithms in a variety of industries. Yet, given the combined brainpower and computing power of PFN, Okanohara and Nishikawa are hopeful that they will be able to overcome the limitations of the technology that brought them success—by following the “Learn or Die” dictum and continually pioneering AI research.

Exhibit 1
Preferred Networks' Strategic Positioning



Source: Company documents.

Exhibit 2
Specifications of PFN's Supercomputers

Category		MN-1	MN-1b	MN-2	Performance difference from MN-1b to MN-2
Total CPU Cores for computation		2,048	2,304	**5,760**	+150%
Total GPUs for computation		1,024	512	**1,024**	+100%
Performance of GPUs for computation※1		19.1 PetaFLOPS	57.3 PetaFLOPS	**128 PetaFLOPS**	+123%
Main performances per GPU node					
GPU	Model	NVIDIA P100 PCI-e	NVIDIA V100 PCI-e	**NVIDIA V100 SXM2**	–
	Interconnection bandwidth	32 GB/s	32 GB/s	**300 GB/s**	+837%
Network	Ethernet	1 GbE	10 GbE	**100 GbE x 4**	–
	InfiniBand	FDRx2 (112Gbps)	EDRx2 (200Gbps)	**No**	

Source: https://medium.com/syncedreview/preferred-networks-builds-state-of-the-art-supercomputer-mn-2-powered-with-nvidia-gpus-dcc9aed19d67).

1 Pavel Alpeyev, "This $2 Billion AI Startup Aims to Teach Factory Robots to Think," *Bloomberg Business Week*, May 16, 2018, https://www.bloomberg.co/news/articles/2018-05-16/this-2-billion-ai-startup-aims-to-teach-factory-robots-to-think, accessed March 20, 2019.
2 Pavel Alpeyev, "This $2 Billion AI Startup Aims to Teach Factory Robots to Think."
3 [Company information]: Interviews with Preferred Networks engineers and founders at PFN in Tokyo on February 4, 2019, by Pavel Kireyev, Assistant Professor of Marketing, INSEAD. [Award from Shinzo Abe] Pavel Alpeyev, "This $2 Billion AI Startup Aims to Teach Factory Robots to Think." [Investment data] "Top-10 Artificial Intelligence Startups in Japan," *Nanalyze*, February 2019, https://www.nanalyze.com/2019/02/artificial-intelligence-japan, accessed April 30, 2019. [Partnership Data] Takashi Sugimoto and Shoji Yano, "Last Japanese Unicorn in Pipeline Talks Big to beat Google in AI, *Nikkei Asian Review*, June 22, 2018, https://asia.nikkei.com/Spotlight/Startups-in-Asia/Last-Japanese-unicorn-in-pipeline-talks-big-to-beat-Google-in-AI, accessed April 11, 2019.
4 Stone, M. H. (1948), "The Generalized Weierstrass Approximation Theorem," *Mathematics Magazine,* 21(5), 237-254.
5 Patchen Barss, "Toronto Researcher Wins Prize for Work in AI," *The Toronto Star*, April 2, 2012, https://www.thestar.com/news/insight/2012/04/02/toronto_researcher_wins_prize_for_work_on_artificial_brain.html, accessed May 7, 2019.
6 Simon Greenman, "Who is Going to Make Money In AI? Part I," *Medium*, May 6, 2018, https://towardsdatascience.com/who-is-going-to-make-money-in-ai-part-i-77a2f30b8cef, accessed March 21, 2019.
7 Pavel Alpeyev, "This $2 Billion AI Startup Aims to Teach Factory Robots to Think." [in 2nd Video].
8 Clifton Leaf, "Why A.I. Is Business's Next Frontier," *Fortune*, October 22, 2018 [Statistics in video]. http://fortune.com/2018/10/22/artificial-intelligence-ai-business-next-frontier/, accessed March 20, 2019
9 Takashi Mochizuki, "Startup Tries to Shake Japan's Tech Slump—Preferred Networks Presses for Advances in the 'Deep Learning' of Artificial Intelligence," *The Asian Wall Street Journal*, December 1, 2015: B1.
10 Takashi Sugimoto and Shoji Yano, "Last Japanese Unicorn in Pipeline Talks Big to Beat Google in AI."
11 Pavel Kireyev interview with Daisuke Okanohara on February 4, 2019.
12 "Preferred Network Wants to be Sony of IoT, Targets ML Edge-Processing, *ReThink Research*, June 15, 2018, https://rethinkresearch.biz/articles/preferred-networks-wants-to-be-sony-of-iot-targets-ml-edge-processing/, accessed April 25, 2019.
13 "Automotive Edge Computing Consortium Shifts Connected Car Market into High Gear," *Business Wire*, February 22, 2018, https://www.businesswire.com/news/home/20180222005425/en/Automotive-Edge-Computing-Consortium-Shifts-Connected-Car, accessed May 7, 2019.
14 John Lippert, Bryan Gruley, Kae Inoue, and Gabrielle Coppola, "Toyota's Vision of Autonomous Cars Is Not Exactly Driverless," *Bloomberg Businessweek*, September 19, 2018, https://www.bloomberg.com/news/features/2018-09-19/toyota-s-vision-of-autonomous-cars-is-not-exactly-driverless, accessed May 9, 2019.
15 Autonomous car robot control demonstration in CES2016, https://www.youtube.com/watch?v=7A9UwxvgcV0, accessed May 7, 2019; Pavel Alpeyev, "This $2 Billion AI Startup Aims to Teach Factory Robots to Think."
16 Takashi Sugimoto and Shoji Yano, "Last Japanese Unicorn in Pipeline Talks Big to Beat Google in AI."
17 Pavel Kireyev interview with Toru Nishikawa on February 4, 2019.
18 Joshua Hunt, "This Company's Robots Are Making Everything and Reshaping the World," *Bloomberg Businessweek*, October 18, 2017, https://www.bloomberg.com/news/features/2017-10-18/this-company-s-robots-are-making-everything-and-reshaping-the-world, accessed April 19, 2019.
19 Kazu Komoto, "Deep Learning Startup PFN Partners with Fanuc, Could Save Japanese Manufacturing," *Robotics Business Review*, January 1, 2017, https://www.roboticsbusinessreview.com/manufacturing/deep-learning-startup-pfn-partners-fanuc-save-japanese-manufacturing/, accessed May 2, 2019.
20 Kana Inagaki, "Preferred Networks Teaches Robots to Collaborate Through Deep Learning," *Financial Times,* March 16, 2017, https://www.ft.com/content/02a2bc84-1040-11e6-91da-096d89bd2173, accessed March 26, 2019.
21 Kazu Komoto, "Deep Learning Startup PFN Partners with Fanuc, Could Save Japanese Manufacturing."
22 Kana Inagaki, "Fanuc's Sets Sight on Army of Interconnected Robots," *Financial Times,* May 9, 2016, https://www.ft.com/content/02a2bc84-1040-11e6-91da-096d89bd2173, accessed May 2, 2019.
23 Joshua Hunt, "This Company's Robots Are Making Everything and Reshaping the World."
24 Kazu Komoto, "Deep Learning Startup PFN Partners with Fanuc, Could Save Japanese Manufacturing."
25 Tim Romero, "This Startup Just Built Japan's Most Powerful Supercomputer," Disrupting Japan [Audio Podcast], May 15, 2018, https://www.disruptingjapan.com/startup-just-built-japans-most-powerful-supercomputer/, accessed April 17, 2019.
26 Kazu Komoto, "Deep Learning Startup PFN Partners with Fanuc, Could Save Japanese Manufacturing."
27 Pavel Kireyev interview with Toru Nishikawa on February 4, 2019.
28 Kana Inagaki, "Preferred Networks Teaches Robots to Collaborate Through Deep Learning."
29 "Preferred Network Wants to be Sony of IoT."
30 Hiroshi Marayuma, Preferred Networks, Inc., "Preferred Networks: Smart Physical Systems from the Standpoint of an AI Company," Topics in International Technology Management, Presentation at Stanford's Center for Professional Management, October 4, 2018, https://graduatex.stanford.edu/#/graduate/seminars/656, accessed April 2, 2019.

31 “Preferred Networks Launches One of Japan’s Most Powerful Private Sector Supercomputers,” *Business Wire*, September 20, 2017, https://www.businesswire.com/news/home/20170919006762/en/Preferred-Networks-Launches-Japan%E2%80%99s-Powerful-Private-Sector, accessed on May 10, 2019.

32 Pavel Kireyev interview with Shohei Hido on February 4, 2019.

33 “Chugai Pharmaceutical Co. Ltd.; Chugai Enters Into Comprehensive Partnership Agreement with Preferred Networks,” *Cancer Gene Therapy Week*, August 6, 2018, p. 61.

34 Hiroshi Marayuma, Preferred Networks, Inc., “Preferred Networks: Smart Physical Systems from the Standpoint of an AI Company.”

35 Pavel Kireyev’s interview with Takuya Akiba on February 4, 2019.

36 Takashi Sugimoto and Shoji Yano, “Last Japanese unicorn in pipeline talks big to beat Google in AI”; “Application of Preferred Networks Deep Learning; Nikkei Excellent Products and Services Award,” *Nikkei Industrial Journal*, February 4, 2019, https://www.nikkei.com/article/DGXMZO40853860U9A200C1X20000/?n_cid=SPTMG002, accessed on May 15, 2019.

37 Pavel Kireyev interview with Daisuke Okanohara on February 4, 2019.

38 Tim Romero, “This Startup Just Built Japan’s Most Powerful Supercomputer.”

39 Pavel Kireyev interview with Kiyoshi Yamamoto on February 4, 2019.

40 Pavel Kireyev interview with Shohei Hido on February 4, 2019.