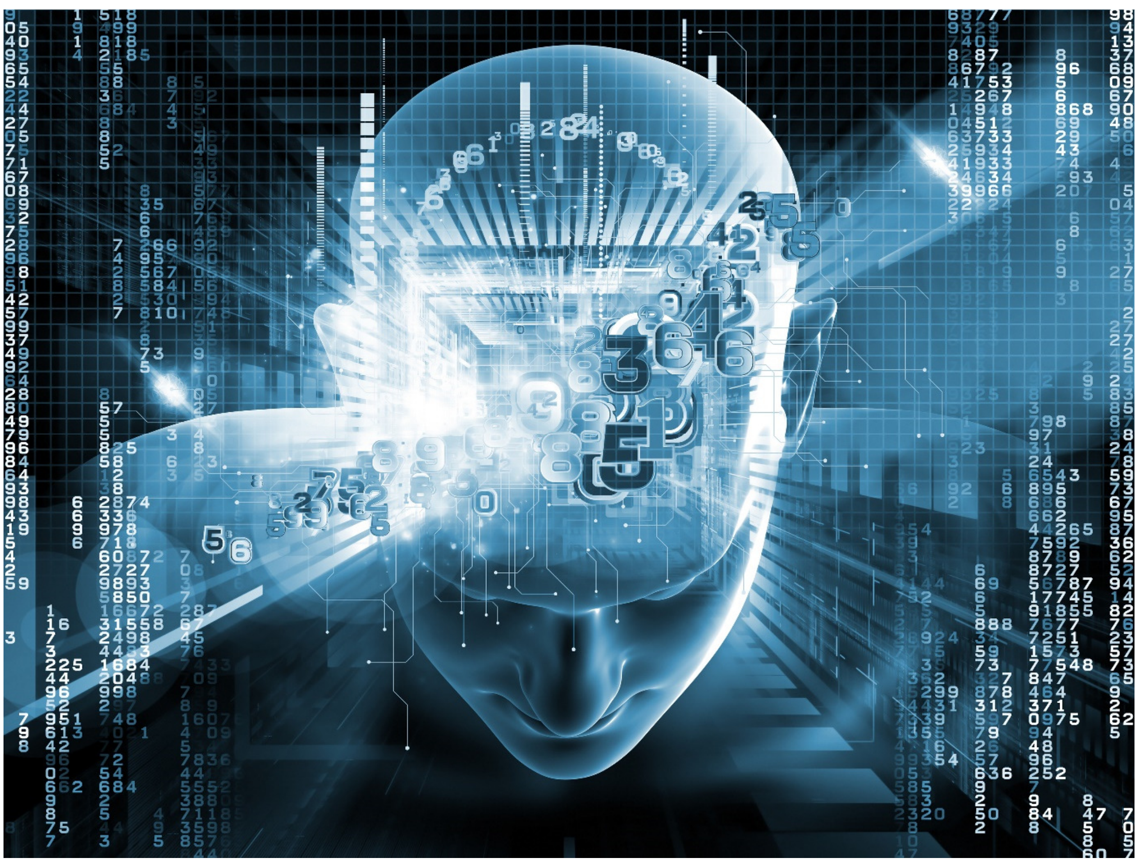
ANNEXES A-8

ARTIFICIAL INTELLIGENCE: ITS EVOLVING NATURE AND FUTURE PROSPECTS



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Intellectual Property Notice

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CONTENTS

1 KEY FINDINGS

1.1 Advanced algorithms necessary to boost business competitiveness in digitised industries

Well-established Artificial Intelligence (AI) algorithms such as neural network, clustering and support vector machines have witnessed the highest innovation activity over the past decade and have penetrated across all technology fields.

In particular, advanced AI algorithms such as convolutional neural network, deep neural network, recurrent neural network, long short term memory and deep belief network have been gaining traction since 2015. These algorithms are in the initial stage of deployment in data-rich technology fields present in the following industries: retail, finance, logistics and healthcare, where the abundance of digitised data makes it easier to deploy AI. With potential for widespread deployment in these industries, adopters of AI need to keep abreast of the development of these algorithms and incorporate them into their businesses to boost competitiveness.

1.2 AI-powered personalised services will be a major modus operandi in the retail industry

The retail industry is a fervent adopter of AI technology, with AI technology being deployed in a variety of application areas including data processing, consumer electronics, and social media network. In particular, the ubiquitous collection of consumer behaviour data through social media network and consumer electronics is beginning to shape the direction of the retail industry towards data-driven marketing.

Through AI-powered data analytics, retailers are now able to better understand consumers' habits and needs, and provide personalisation of retail services to consumers. Particularly, innovation activities in AI-powered personalised retail services have registered a high growth of 37.6% per annum over the period 2013-2017. The concept of personalisation has long existed in the retail industry as personalisation allows customers to feel valued and creates a "feel-good" factor in the retail experience. The marriage of AI and customer data now provides a convenient conduit for easier access to customer information, thereby allowing businesses to enlarge its customer base and market segment. It is likely that powering of personalisation by AI will very soon be established as the new norm in retail services, further shaping consumer behaviour and preferences. As such, service providers in the retail industry will need to anticipate these technology influences and make strategic decisions regarding AI incorporation.

1.3 Robotics is the next frontier for AI applications in healthcare

Innovation in AI for the healthcare industry has seen the fastest growth in the recent years. Largely because of high commercial interest, healthcare has therefore become one of the more promising industries for AI deployment.

Innovation of AI-enabled healthcare mainly relates to the use of AI in prediction and diagnosis of diseases. A fast growing area of interest within the healthcare industry is AI-enabled robotics. Examples include utilizing computer vision with robotic arm systems for medical procedures, robot-assisted surgeries and exoskeletons to aid rehabilitation of stroke patients. Despite being at its nascent phase, inventions relating to AI-enabled robotics in healthcare has increased three-fold from 2016 to 2017. As innovation in AI-enabled robotics continue to develop and shape the healthcare industry, medical practitioners need to anticipate the necessary skills required and upgrade themselves to ensure seamless human-machine collaboration.

1.4 Explainable AI a potential R&D area

Commercial entities have been concerned over how an AI system arrives at a decision, or if the system may unknowingly introduce bias. Deliberating such decisions expose a business to risks and make it difficult to answer to the stakeholders. Despite being a long-recognised problem in the AI research community, explainable AI technologies are only experiencing a quiescent innovative scene with a modest growth rate of 16.3% per annum in the period 2013-2017. This stark contrast to the active innovative activities in the development of AI algorithms with an annual 30.8% growth in the same period indicates the priority stakeholders place on productivity-focused AI solutions over transparent AI-systems.

The impact AI will have on society and the increasing attention from regulatory bodies may place pressure on service providers of AI applications to explain how these systems work so as to be answerable to the stakeholders. As evident from the growth rates in innovation activities, the laggard developments in explainable AI may cause existing explainable AI technologies to be incompatible or inefficient with the fast-evolving AI algorithms. Therefore, to match the rate of development of AI algorithms in the industries, the need for explainable AI innovations will grow, making this a potential R&D area.

2 INTRODUCTION

Stemming from research to building machines with intelligence in the 1950s, artificial intelligence (AI) has now evolved into a field promising indefinite opportunities. It has advanced beyond the research phase and penetrated into various industrial sectors, delivering real value and benefits such as improved productivity, higher-quality products and services.

AI is predicted to be the most disruptive class of technologies in the next ten years [1]. With enabling factors such as the availability of data, the continual advances in computation powers and the development of novel and highly versatile algorithms, AI is poised to unleash the next wave of digital transformation and redefine the relationship between man and machine. While the ultimate aim in AI technology continues to be developing machines with higher intelligence, i.e. artificial general intelligence, the work ahead also involves leveraging these machines to augment the way we work and consume the technology.

Supported by a forward-thinking government and a thriving digital ecosystem, Singapore is one of the early adopters of AI. In Singapore, AI is projected to double the local annual economic growth rate and increase labour productivity by 41% by 2035 [2]. While Singapore has been active in driving adoption in the country, it is important for the city-state to continuously keep abreast of the AI developments. This would not only enable us to embrace and leverage on new AI technologies for immediate values benefits, but also to spot potential R&D opportunities so as to take part in the global AI race.

This report is a detailed analysis of inventions relating to the field of AI. It is based on worldwide patent applications published between 2008 and 2017 and covers three algorithm-oriented domains - learning, computer vision and natural language processing, and AI hardware (Exhibit 1)[a]. The report also covers the adoption of AI in four major industries – retail, finance, logistics and healthcare. It also highlights an emerging area, explainable AI.

Since patent data represents a large and important source of information on scientific and technological advances of the present knowledge-based economy, analysis of the AI-related patent data in these technology domains allows us to better understand the technology trends, the respective domains, and areas of innovation opportunities pertaining to AI.

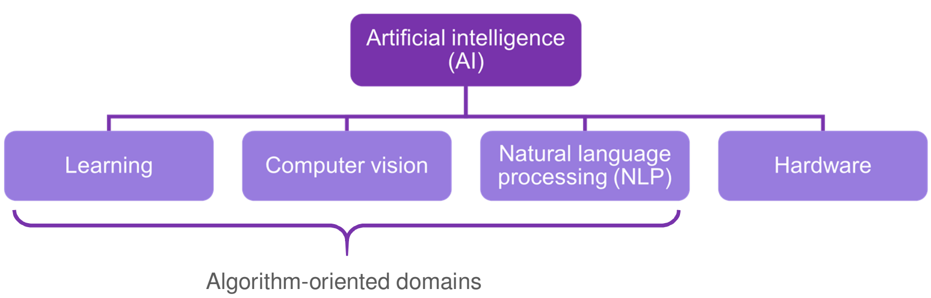


Exhibit 2: Scope of the patent analytics study

[a] The technology segmentation was derived with input from the Info-communications Media Development Authority (IMDA) of Singapore.

3 OVERALL TRENDS

3.1 Global Publication Trend

With companies increasingly adopting AI systems to improve operations, services and products, the market is growing rapidly. By 2022, the global spending on AI systems is expected to reach $77.6 billion, three times the $24 billion forecast for 2018 [3]. The enormous interest in AI is also evident from worldwide patenting activity, wherein a total of more than 180,000 inventions [b] relating to AI were published worldwide in 2008-2017[c] with an annual growth rate of 21.4% over the recent 5 years (Exhibit 2).

Innovations from the U.S. and China accounted for approximately 70% of the global AI inventions (Exhibit 3), indisputably making them the powerhouses driving the development of AI. Both U.S. and China are two of the major countries leading in setting of industrial standards for AI [4]. With their current technical expertise, and huge investments [5] [6] poured into the AI race, it is expected that both countries will continue leading the pack in AI innovation.

Initially lagging the U.S. and Japan in 2008-2009, China's AI innovation output has picked up rapidly in recent years (Table 1). In particular, the number of inventions from the Chinese published in 2017 has reached a whopping number of approximately 21000, almost doubling of that of the U.S. and more than the rest of the world combined. Such tremendous growth is supported by aggressive national policies, such as its "New Generation Artificial Intelligence Development Plan" [7], which aims to make China a leader in AI and set standards for the industry. In view of the above, it is likely that AI innovation from China will continue its fast growth in the near future.

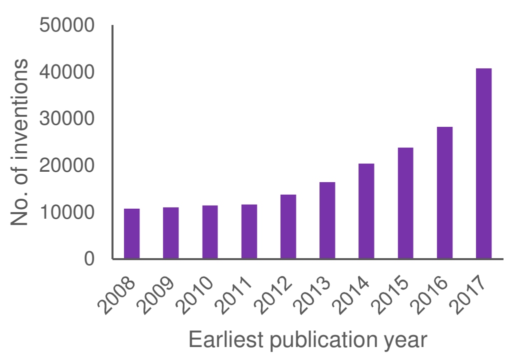


Exhibit 3: Worldwide innovation trend of artificial intelligence

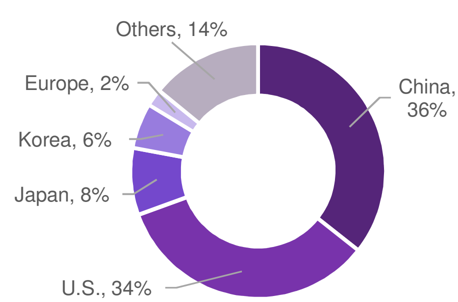


Exhibit 3: Breakdown of global patent publications by country

[b] Number of inventions is calculated based on the number of unique DPWI patent families (see Appendix A: Methodology). Note that an invention can be counted in multiple technology domains as the invention can involve different technological aspects.
[c] Data collected on 5 October 2018. Note that some patent publications in 2017 have yet to be classified. Thus, these publications were not retrieved by the search queries using patent classification.

Country of origin	Earliest publication year										Grand Total
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	
China	1321	1742	2252	2765	4120	5769	7465	9344	11429	21055	67262
U.S.	4112	4172	3986	4091	4725	5550	7124	8234	9963	11683	63640
Japan	2052	1850	1943	1456	1325	1375	1243	1368	1507	1955	16074
Korea	791	931	823	924	985	1057	1258	1213	1241	1592	10815
Europe	366	293	335	260	341	362	456	512	569	645	4139

Table 1: Top 5 countries of applicant origin according to the number of inventions

The increasing innovation activity in AI is enabled by several factors. Firstly, the abundance of data allows training of AI algorithms and fine tuning of their systems and applications. The increased connectivity brought about by the Internet and the widespread use of wireless devices enable data collection across many industries and virtually all aspects of our daily life. Access to huge amounts of data has, in fact, been a key factor behind the recent Chinese AI success. The Chinese society heavily utilises mobile applications such as WeChat, for grocery shopping, booking of appointments and monetary transactions etc. Such vibrant interaction and information flow between individuals and businesses is a source of large amount of data allowing China to innovate aggressively in AI.

Secondly, the continual improvement in computing power and speed has enabled millions of complex calculations that form the basis for AI systems to learn and make real-time inferences. Such improvements are seen not only in terms of increasing computing speeds that have prevailed since the era of Moore’s Law, but also new chip architectures such as graphics processing units (GPUs) that performs rapid mathematical calculations particularly suited for the purpose of rendering images and high performance computing.

Lastly, emergence of efficient AI algorithms has enabled AI systems to handle increasingly complex data like images and videos. Development in novel AI algorithms has also allowed AI systems in getting closer to mimicking how humans learn and make decisions, i.e. continual learning/training with new data to arrive at a more experienced decision.

The fast development in AI is also present in all technology fields (Exhibit 4). Using the International Patent Classification (IPC) and technology concordance table as a proxy, the AI-related inventions published in the last decade were categorised into the thirty-five technology fields.

Being essentially computer-implemented technologies, it is unsurprising that the majority of the AI inventions (> 150,000) resides in the field relating to Computer Technology. At the same time, as the current state of AI technology commonly involves (or is used for the purposes of) measurements and control, these two fields are, as observed, naturally among the key technology fields of focus in AI inventions.

Beyond the aforementioned fields relating to AI inventions, the applications of AI in IT Methods for Management (ITMM) with more than 16,000 inventions are noteworthy. ITMM encompasses areas such as commerce (in particular e-commerce), financial technologies, logistics, general management such as utilities and tourism. The strong presence of AI inventions/applications in these areas is driven by the availability of vast amount of data and digitalised infrastructures that allow an ease of data collection and utilisation. Likewise, data-rich technology fields such as Digital Communication, Telecommunications, Medical, and Audio-visual technologies have also seen a high degree of AI applications. This is also in line with the market view that these digitisation forerunners see AI as the new wave of digitisation [8] and implies thriving AI deployment in the near future

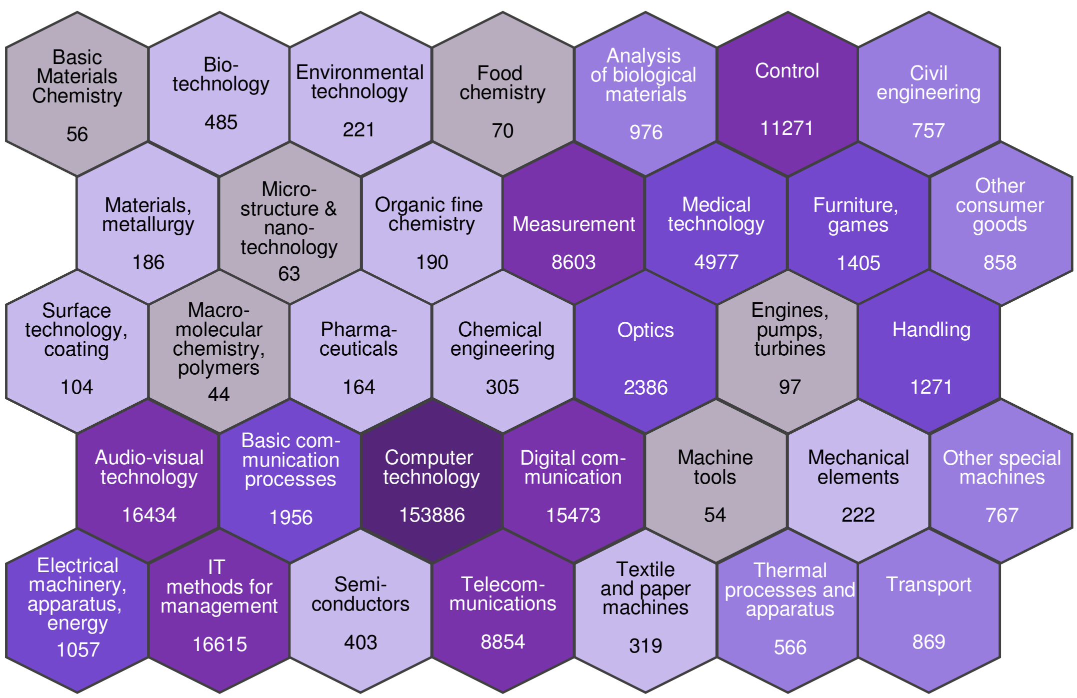


Exhibit 4: Penetration of AI across technology fields

Categorisation of inventions into the respective areas were performed according to the technology concordance table by the World Intellectual Property Organisation (WIPO). International Patent Classification (IPC) codes assigned to patent applications were linked to the thirty-five technology fields in the technology concordance table, which aids in understanding how AI has penetrated the technology fields. The WIPO's IPC and technology concordance can be accessed in this link: http://www.wipo.int/meetings/en/doc_details.jsp?doc_id=117672. Numbers in the exhibit represent the number of inventions in each technology field.

3.2 Algorithm-oriented Domains

The three algorithm-oriented domains – Learning, Computer Vision and Natural Language Processing (NLP) - have registered tens of thousands of inventions over the last decade (Exhibit 5). Such high innovation activities could stem from the low financial barrier of entry. The capital investment in developing algorithms is low as all that is required to get started is a desktop/computer.

AI realises the ability for computers to learn from known data, and subsequently generalises the knowledge to extrapolate future unseen data. As learning forms the basis for all AI systems to be trained, it comes as no surprise that this domain occupies the largest number of inventions of more than 87000 (Exhibit 5). Among the top players innovating in the learning domain are large AI service platform providers, such as IBM, Microsoft, Google, Baidu and Yahoo, each with more than 800 inventions (Table 2). In addition, these players are armed with platforms for harvesting large amounts of data, giving them the competitive edge in training AI models for a variety of purposes.

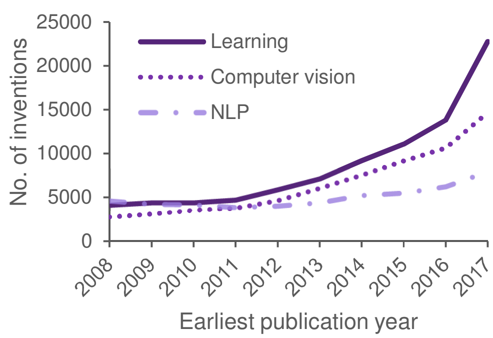
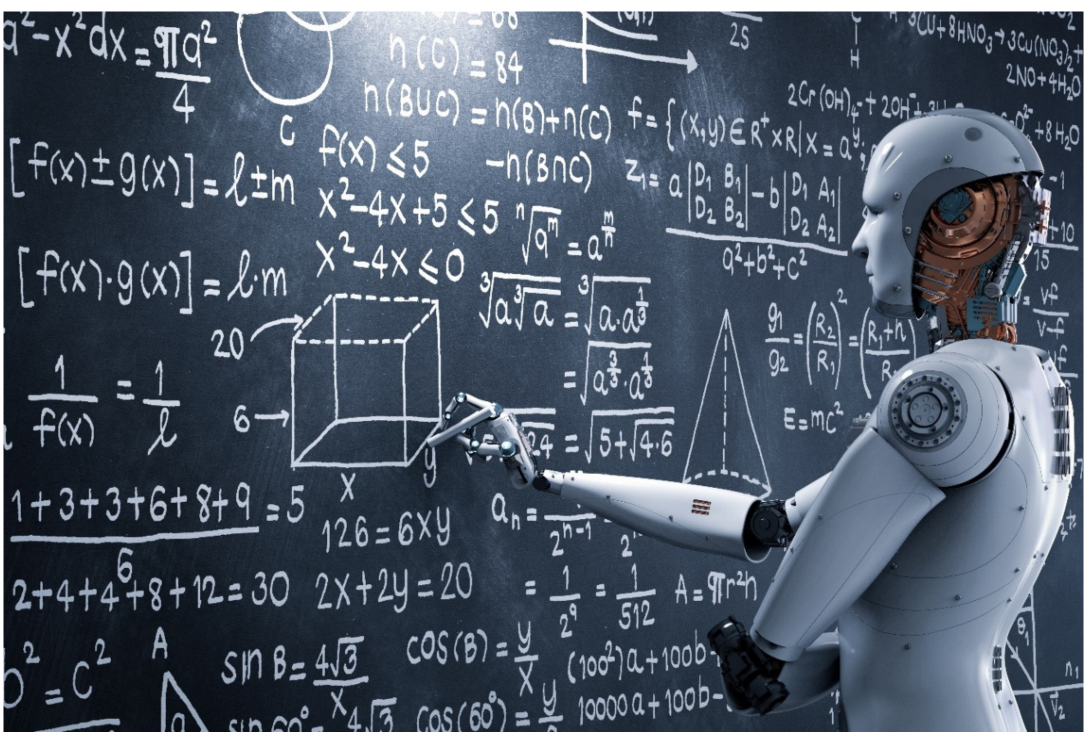


Exhibit 5: Worldwide publication trend of algorithm-oriented domains



NLP and computer vision are two branches of AI algorithms. NLP relates to the use of AI algorithms to understand, analyse and interpret human language while computer vision is directed towards image/video recognition, acquisition and processing. The innovative activities of these two domains are often built on top of learning algorithms. With the establishment of their building blocks, i.e. learning algorithms in the learning domain, NLP and computer vision are areas which innovation activity, though smaller, would pick up after the learning domain.

Leaders in the NLP and Computer Vision domains are mainly application developers such as Samsung, Canon, Sony, NTT and AT&T (Table 2). As NLP and/or computer vision are among the key features of their products/services, these commercial players are actively ring-fencing their technologies through patent filings while seeking continual technological breakthroughs and improvements. The immense patenting activities have made these three domains an overall highly congested space that is challenging for players without strong expertise to navigate. It is therefore imperative to identify, within the crowded space, specific areas with higher promise and opportunity.

Ranking	Learning	Computer vision	NLP
1	IBM (4232)	Samsung (1776)	IBM (1500)
2	Microsoft Corp (2586)	Canon (1555)	Samsung (1210)
3	Google Inc (1840)	Sony (1271)	Microsoft Corp (1005)
4	State Grid Corp China (1493)	Microsoft Corp (1093)	Google Inc (995)
5	NTT (951)	Google Inc (928)	NTT (944)
6	Baidu (875)	NEC Corp (621)	AT&T (932)
7	Yahoo Inc (864)	Intel Corp (551)	Nuance Communications Inc (907)
8	Samsung (803)	Panasonic (543)	Sony (863)
9	Univ Xidian (730)	Qualcomm Inc (542)	Yamaha Corp (750)
10	NEC Corp (720)	Toshiba KK (535)	Huawei Technologies Co Ltd (671)

AI service platform providers | Application developers | Hardware developers

Table 3: Top applicants of algorithm-oriented domains. Number in parenthesis represents the patent portfolio size

3.3 Deep Dive into the Forms of Learning

The learning domain is broadly categorised into supervised, unsupervised, reinforcement and transfer learning (Exhibit 6). Supervised learning refers to learning based on examples of labelled inputs, unsupervised learning relates to finding patterns in unlabelled inputs, reinforcement learning is learning based on maximizing a reward function, and transfer learning relates to the reuse of a trained model on a new problem.

Supervised and unsupervised learning are the current prevailing approaches among the four learning forms and have registered the bulk of the inventions. In particular, there have been strong interest in neural network, clustering and support vector machines, with large number of inventions, as seen in Exhibit 7. This is due to the highly versatile nature of these algorithms and have been successfully deployed in many areas. Another group of algorithms that is of particular interest include convolutional neural network, deep neural network, recurrent neural network, long short term memory and deep belief network. While they may not be the dominant AI algorithms given their low number of inventions, the high growth rates imply a fast-growing interest from the industry in these advanced AI algorithms (Exhibit 7).

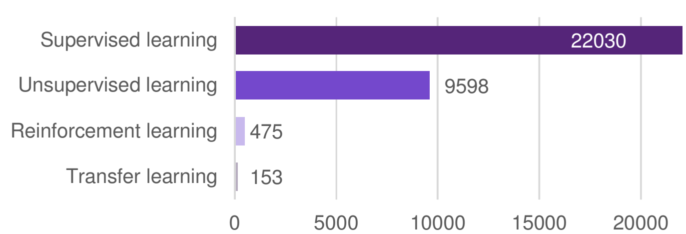


Exhibit 6: Number of inventions for different aspects of AI learning during 2008-2017

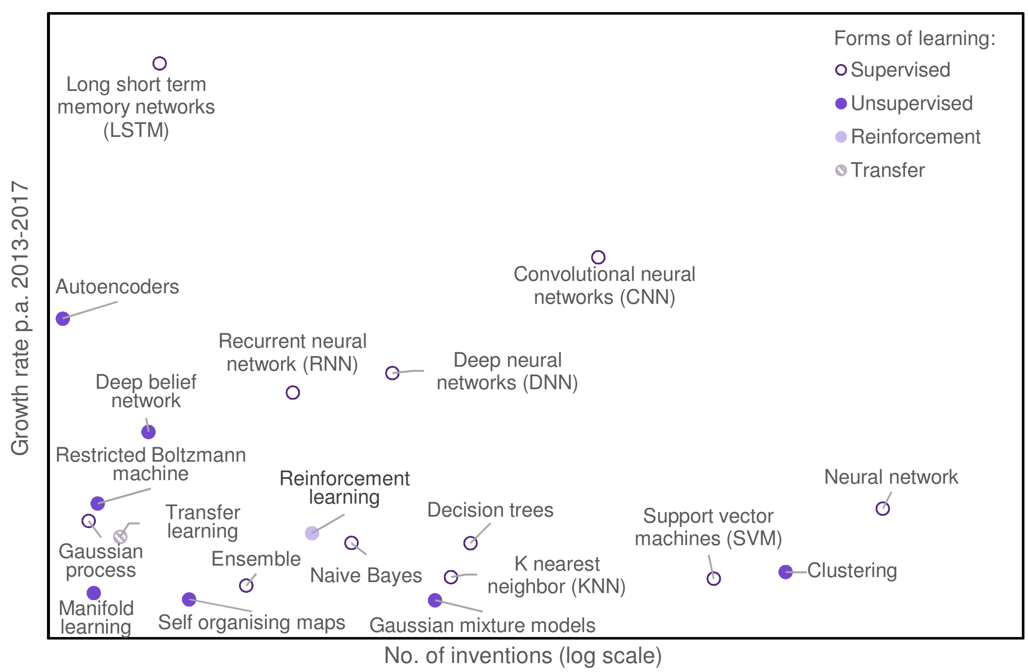


Exhibit 7: Growth rates of various algorithms for AI learning

Concurrent with the fast development of more robust and sophisticated algorithms, the use of AI algorithms are spreading across numerous technology fields. Unsurprisingly, the data-rich technology fields - IT Methods for Management, Digital Communications and Medical Technology, are the main users of various AI algorithms (Table 3) as digitisation in these fields provides the much needed data and infrastructure to ease the adoption of AI into these technology fields. For the same reasons, these digitisation forerunners are the early adopters of the aforementioned advanced AI algorithms to maintain their competitive edge in the business. Nevertheless, the deployment of these algorithms have only started to pick up recently in 2015-2017. An example is the use of recurrent neural network and long short term memory in Google's translation platform [9], Baidu's text-to-speech engine [10] and Apple's Siri [11]. These advanced techniques have significantly improved the accuracy in terms of natural language processing.

The fast evolution of AI algorithms demands the AI users to be constantly aware of up-and-coming enhanced AI algorithms. Equally, players from various industries need to keep abreast of the development in AI algorithms to identify those unique to their technology field, so as to timely incorporate them to boost the efficiencies of their operations and products, and to maintain their business competitiveness.

	Technology Fields / Specific Algorithms	Measurement	IT Methods for Management	Control	Digital Communications	Medical Technology	Audio-Visual	Analysis of Biological Materials	Electrical Machinery	Telecommunications	Biotechnology	Handling	Transport	Civil Engineering	Engines, Pumps, Turbines	Other Consumer Goods	Furniture, Games	Machine Tools
Supervised learning	Neural Networks*	1513	1168	1321	620	396	202	240	258	135	56	78	55	60	36	13	18	22
	Support Vector Machine*	619	410	288	216	178	84	101	69	46	67	6	19	11	8	3	2	3
	Nearest Neighbours	90	56	38	87	21	15	24	2	6	18	3		1		3		
	Convolutional Neural Networks**	76	57	41	54	43	51	4	1	8	4	6	4			2	1	
	Decision Tree	56	135	40	77	28	20	51	1	15	42		2	1			2	
	Naïve Bayes	45	66	22	53	9	12	8	4	5	7		2	1		1		
	Deep Neural Networks**	28	29	20	39	19	14	2		4	2	4	2			1		
	Ensemble Learning	23	21	6	19	22	13	10	1	4	8			1		2	4	
	Recurrent Neural Nets**	18	26	32	20	8	3	1	3	2	1	4	1			1		
	Gaussian Processes	13	7	19	6	3	1	4				1						
	Single Shot Detectors	4	1	1		1	1											
	Long Short Term Memory**	3	19	10	8	3	1						1			1		
	Generalised Linear Models	1	4		1			2			1							
	VGG Networks	1	1	1	1		2											
	Inception		1															
	ResNet						1											
Unsupervised learning	Clustering*	509	871	251	702	110	170	81	69	83	68	5	15	15	2	4	6	2
	Gaussian Mixture Models	41	20	49	31	26	75	6	4	10	7	4	4			2		
	Self-organising Maps	27	23	10	26	7	6	19	2	3	2			2	1			1
	Deep Belief Networks**	15	12	8	9	4		3	1								1	
	Manifold Learning	11	3	2	9	4	2	1			1					1		
	Restricted Boltzmann Machines	7	11	2	2	3	1	3	1					1				
	Autoencoders	5	6	5	3	2	2				1			1		1		
	Generative Adversarial Networks	1			1													
	Reinforcement Learning	9	55	89	67	5	3		10	3		8	9		1	3	2	
	Transfer Learning	7	11	6	9	6		1	1				1					1

Table 2: Penetration of specific AI algorithms in various technology fields according to the WIPO technology concordance. Values represents number of inventions

Besides computer technology, these 17 technology fields lead the adoption of AI algorithms.

*Algorithms with the highest innovation activities.

**Algorithms with the fastest growth rate in the recent five years.

3.4 AI Hardware

Compared to the intensive innovative effort observed for each of the three algorithm-oriented domains, Hardware is a niche domain with only approximately 2000 inventions published in 2008-2017 (Exhibit 8). As observed, long-existing graphics processing units (GPUs), central processing units (CPUs) and field-programmable gate arrays (FPGAs) account for about 50% of the innovation activity in this domain and are considered to be the current state of the art in providing computing power to AI platforms. The significantly lower innovation focus in this domain suggests that current hardware is sufficient for most of the present AI applications.

Though CPUs, GPUs, and FPGAs are already well-established, advancements in semiconductor technology have been made to develop more powerful, faster CPUs and GPUs capable of handling large amount of data and complex algorithms. FPGAs are also gaining traction as an important tool to research new AI algorithms, to train AI systems and enable low-volume deployment. Interestingly, 99% of inventions relating to CPUs also involve either GPUs or FPGAs, suggesting that a combinational use of them may be the optimal solution to power an AI system.

The commercial availability of CPUs, GPUs and FPGAs present them as convenient options for market adoption. However, AI-specific processors are also being developed for specific AI uses. Neuromorphic chips, accounting for 3% of the inventions in hardware, promises to handle larger, more complex datasets with less energy and power consumption, making them useful for AI applications at the edge[d]. An example is Brainchip's Akida NSoC, suitable for advanced driver assistance systems (ADAS), autonomous vehicles, drones, vision-guided robotics, surveillance and machine vision systems [12]. However, neuromorphic chips face a key obstacle to mass deployment in AI platforms in the precise control of the analog signalling intensity [12] [13]. This has been an area of research interest for many players in the neuromorphic chip space.

As AI-systems get increasingly sophisticated with burgeoning needs to handle larger, more complex data, the demands on computing power will increase. It would be a matter of time that the computing power of GPUs, FPGAs and CPUs will not meet the demands of AI, calling for a need to research and develop new processing units.

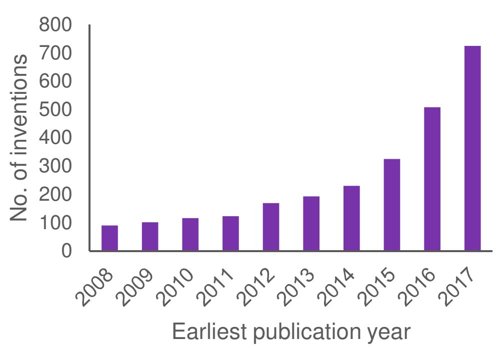


Exhibit 8: Worldwide publication trend of AI hardware

[d] AI applications at the edge refer to the use of AI systems/processing of algorithms locally on devices outside the cloud, e.g. autonomous vehicles and consumer electronics.

4 AI APPLICATIONS IN INDUSTRY

4.1 AI in Retail, Finance and Logistics Industries

Retail, finance and logistics[e] are three industries which heavily utilise AI. AI-enabled applications in the logistics industry (approximately 1000 inventions), revolve around inventory management, optimisation of distribution routes, task allocation and scheduling and shipping. On the other hand, AI is being applied in the finance industry (approximately 3000 inventions) in the areas of authentication and verification of identity, banking transactions and payment. Comparatively, the retail industry has seen the largest adoption of AI, recording 8246 inventions scattered across various applications areas between 2013 and 2017. Application areas labelled in Exhibit 9, with strong interest in the retail industry (indicated by a higher density of yellow markers) are as follows.

(1) Personalisation – recommending products and services based on consumer browsing habits and purchasing behaviour

(2) Language, display, conversation – a range of applications including collecting data on consumer behaviour in a shopping facility or keeping track of the stock in a store based on text displayed

(3) Information/data processing – collection and/or usage of data on a variety of retail aspects such as consumer behaviour, pricing, payment and sales etc.

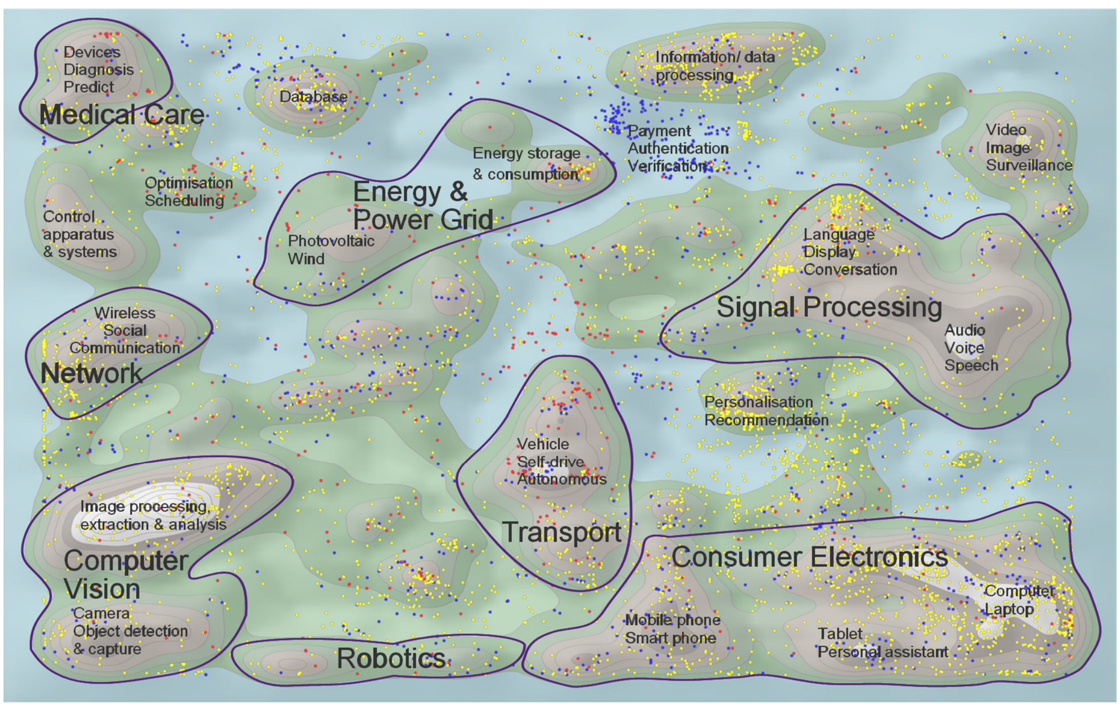


Exhibit 9: Topographic map of AI-enabled retail, finance and logistics industry applications.

This topographic map is generated by analyzing keywords in the disclosure of AI-enabled patents published in 2013-2017 that have been applied in one or more technology areas. Using word semantics, the inventions are clustered according to topics which they have in common. The topics with more inventions, or higher innovation intensity are represented by taller peaks on the map. This map provides an overview of the AI-enabled application areas in the recent 5 years. Subsets of inventions pertaining to retail, finance and logistics are further highlighted by yellow, blue and red markers respectively, where their density indicate an area of strong interest within these industries.

[e] AI inventions relating to retail, finance and logistics were derived from those classifying under the technology field IT methods for management according to the WIPO IPC and technology concordance table.

(4) Consumer electronics – devices for consumers to engage in retail services, while retailers push recommendations to consumers

(5) Network – the use of social media network is a mode which enables collection of consumer data, further allowing recommendations to be pushed to consumers

These application areas reflect the direction of how AI innovations are changing the retail industry. Of note, innovations in AI-powered personalised retail services have grown at 37.6% per annum in 2013-2017. Prevalence of consumer electronics (such as smart phones, tablets) and social media network have resulted in a wealth of data on consumer behaviour. AI is able to make sense of these data to draw inferences of consumer's preferences, habits and needs. This information, together with consumer electronics and social media network as two of the channels, allow for personalised retail services to reach the masses. Hence, businesses now are able to enlarge their customer base and market segment. Examples of AI-powered personalised retail services include improved search results on e-commerce platforms and targeted recommendations based on consumer purchasing habits, thus reducing marketing costs.

Hence, AI-powered personalised retail services are expected to become the new norm in the near future. The evolving retail scene will in turn shape consumer behaviour and preferences further, pushing for more customised services, resulting in a reinforcing virtuous cycle. In order to remain competitive, retail service providers will need to anticipate and accommodate these AI influences and make strategic decisions regarding any AI incorporation.

4.2 AI in the Healthcare Industry

The healthcare industry[f] registered significant innovation interest amidst its large commercial interest (see Appendix A: Methodology). The high interest of deploying AI in healthcare is attested by the positive market forecast of $6.6 billion by 2021 [14], and increased number of acquisitions of healthcare-focused AI start-ups in recent years, from 20 in 2012 to nearly 70 in 2016 [15].

AI-enabled applications in the healthcare industry have been concentrated in medical care, computer vision and signal processing (Exhibit 10). These inventions mainly revolve around using AI to assist in diagnosis of diseases from abnormalities detected in medical images, electroencephalogram (EEG) or electrocardiography (ECG) signals. In fact, AI has been proven to outperform doctors and physicians with years of experience in these areas [16] [17]. Other inventions relate to AI-enabled medical devices, prediction of diseases and medical treatment.

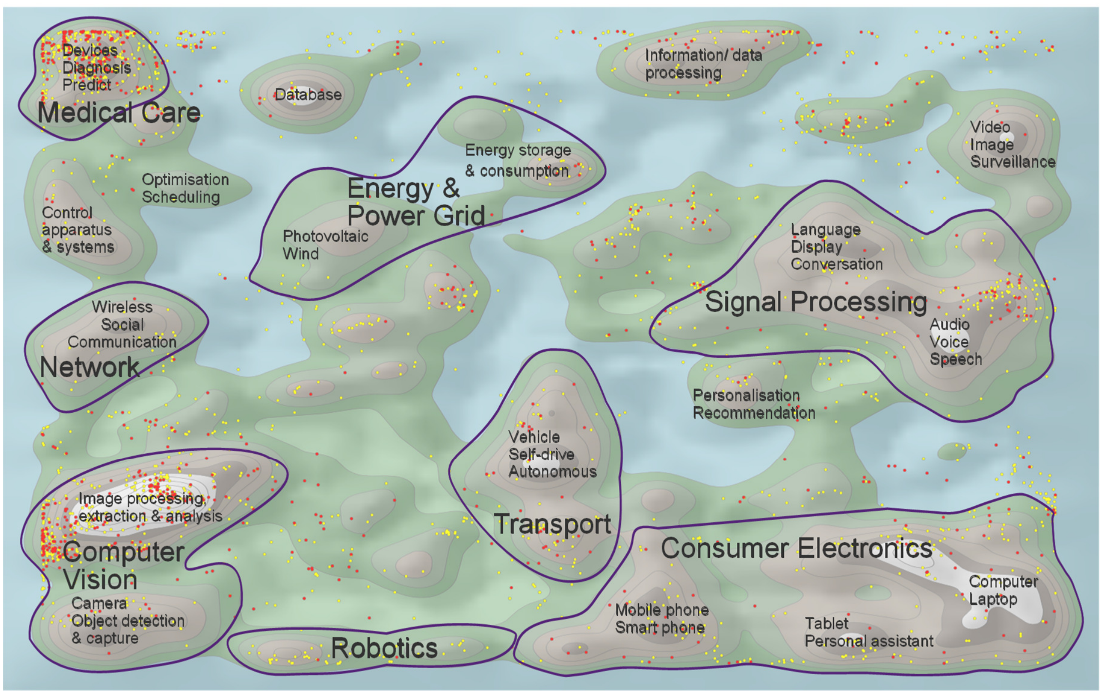


Exhibit 10: Topographic map of AI-enabled healthcare industry application

On the same topographic map as Exhibit 9, inventions pertaining to healthcare published in 2013-2014 and 2016-2017 are highlighted by red and yellow markers respectively.

[f] AI inventions classified under Medical technology, according to the WIPO IPC and technology concordance table, is used as a proxy to AI inventions for healthcare industry.

AI-enabled robotics in healthcare has emerged only recently, between 2016 and 2017 (Exhibit 10). Inventions relating to AI-enabled robotics in healthcare surged to more than 60 inventions in 2017 (Exhibit 11), an approximately three-fold increase as compared to that in 2014. The spike in the number of inventions is attributed to Kawasaki Heavy Industry, contributing to approximately a third of the total inventions relating to AI-enabled robotics in healthcare in 2017. Their inventions mainly fuse computer vision with robotic arm systems suitable for medical procedures. To boost its strength in robotics, Kawasaki has collaborated with Sysmex, a manufacturer of testing and diagnosis technologies, to form Medicaroid, which specialises in medical robots. The area has also seen a growing number of players with expanding portfolios of inventions. These inventions include exoskeletons to assist rehabilitation of stroke patients and robot-assisted surgeries.

Overall, AI has demonstrated tremendous successes in the healthcare industry, particularly in terms of diagnosis and medical treatment. As the nascent field of AI-enabled robotics have started shaping the industry, medical practitioners need to anticipate the necessary skills required and upgrade themselves to ensure seamless human-machine collaboration.

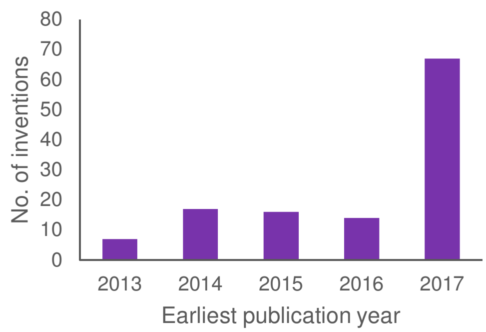


Exhibit 11: AI-enabled robotics in healthcare

4.3 Emerging Area: Explainable AI

Current AI systems take input and, after training of the AI models, produce output that are observable by the users. However, the user is unable to understand how knowledge or decisions are formulated between the input-output pairs. This opacity in AI is termed as the "black-box" phenomenon and could be further obscured as the training data presented to the systems could unknowingly introduce bias in favour of or against a subset of the data.

This is a long-recognised problem in the AI research community. However, the push for an explainable AI system has not been translated to a wide-scale innovative activity. The focus on providing AI solutions catered for enterprise needs and productivity has eclipsed the need to provide a system that is able to explain itself. This can be seen from the relatively small number of less than 1000 inventions over the past decade, and a modest growth of 16.3% per annum for the period 2013-2017 (Exhibit 12) in contrast to the rapid development of AI algorithms at 30.8% in the same period. In addition, no dominant players are actively ring-fencing this technology area, with IBM as the leading innovator holding 51 inventions (Table 4).

With the increasing impact of AI on society, it is expected that service providers of AI applications will need to provide explanations behind any automated decision-making, to be answerable to the stakeholders. This concern is also observed from the heightened social behaviour of a spike in online search terms such as "explainable AI", "black-box AI", "bias AI" in the recent years (Exhibit 13).

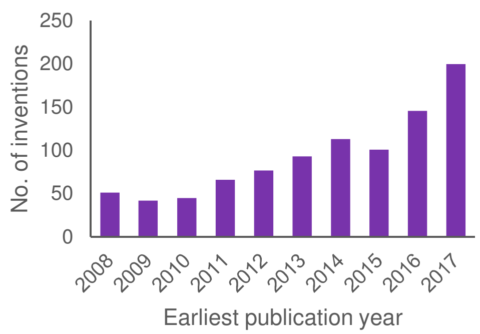


Exhibit 12: Worldwide patent publication trend of explainable AI

Top applicants	No. of inventions
IBM	51
FTI Consulting	20
Microsoft Corp	16
Google Inc	14
NEC	9
Univ. Wuhan	9

Table 4: Top applicants of explainable AI

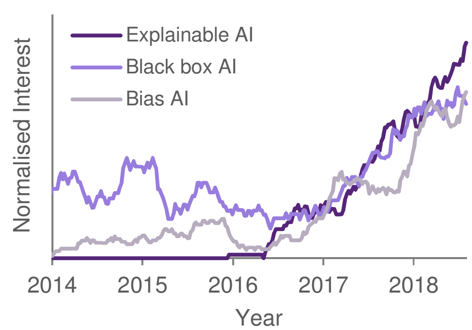


*Exhibit 13: Explainable AI online search trend**

*Data derived from Google Trends: https://trends.google.com/trends/?geo=US

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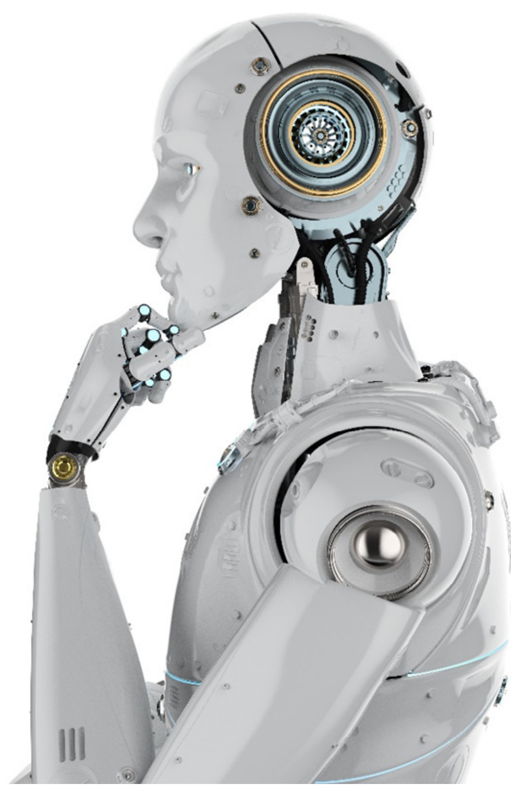
The push for explainable AI also goes beyond individual consumers. For commercial entities that are keen adopters of AI, automated decision-making has a direct impact on their businesses. Some examples include the real-time automated loan approval service provided by a bank[g] and the AI-computed scheduling optimisation solutions implemented within a company[h]. Without a sound understanding behind these automated decisions, businesses could be exposed to unnecessary risks that run contrary to their initial business models. Seeing this as a business opportunity, software service provider IBM has rolled out solutions to support businesses in building trust and transparency into their AI systems in 2018 [18].

Explainable AI also stems from the concerns over regulatory requirements. The year 2018 sees, for example, the implementation of the General Data Protection Regulation by the European Union, which set out rights to 'meaningful information about the logic' of how personal data are used and a right to challenge decisions made from this logic [19]. In addition, similar legal requirements for enterprises to provide reasoning behind the decisions made, have been legislated in the U.S. The Fair Credit Reporting Act of USA recites "the consumer shall be provided all of the key factors that adversely affected the credit score" in Section 609(f)(1) [20]. The Monetary Authority of Singapore (MAS) has also issued principles for use of artificial intelligence and data analytics, outlining fairness and transparency as one of the key aspects of automated decision making in the financial sector **Error! Reference source not found.**. While current measures are limited to finance, automated decision-making will spread to other applications. Increasingly, these measures are in place to protect consumers' interests.

With such wide-spread implications from the social, commercial and regulatory fronts, explainable AI is an area that AI adopters should monitor with great concern. As evident from the growth rates in innovation activities, the laggard development in explainable AI may cause existing explainable AI technologies to be incompatible or inefficient with the fast-evolving AI algorithms. Therefore, the need for explainable AI innovation makes this a potential R&D area.



[g] CN 106651570 A: System and method for real-time loan approval
[h] CN 106549378 A: Collaborative scheduling method of power distribution network for output uncertainty of distributed power supply

5 CONCLUSION

Spurred by the immense amount of data available, improvements in computing power and sophisticated algorithms, innovation in AI has grown tremendously over the past decade. In particular, the continual development of new algorithms with improved features enables AI systems to handle increasingly complex data, allowing AI to be deployed in more advanced applications, across various technology fields and industries. The use of AI promises improvements to efficiency, effectiveness and quality of products and/or services.

As advanced algorithms are poised for widespread deployment in various industries, adopters of AI need to keep abreast of the developments and incorporate these algorithms into their business in a timely manner to boost competitiveness. In addition, it is essential that players in different technology fields and industries anticipate the impact which AI would bring, such as AI-powered personalised services in the retail industry and the AI-enabled robotics in the healthcare services, and accommodate the changes or upgrade manpower skills in advance. As AI continues to evolve and shape the world, embracing its influx would allow businesses to maintain a competitive edge.

With the growing incorporation of AI in many applications, there have been concerns regarding how automated decisions are arrived at. In particular, the social impact of AI and increasing attention from regulatory bodies place pressure on AI adopters to understand the rationale behind outcomes derived from AI systems. However, modest development of this area may result in a non-optimised integration with fast-evolving AI algorithms. Hence, to keep up with the rate of development of AI algorithms, the need for explainable AI innovations will grow, making this potential area for research and development.

APPENDIX A: METHODOLOGY

Dataset

The final dataset relating to artificial intelligence was retrieved on 5 October 2018. The dataset consists of worldwide patent applications published from 2008-2017, retrieved from the Derwent World Patents Index™.

Search string

To ensure optimal recall and accuracy of the datasets retrieved, the search strings used in this study were formulated incorporating keywords (and their variants) and/or patent classification codes and indexing, e.g. International Patent Classification (IPC) and Cooperative Patent Classification (CPC).

Detailed lists of the main keywords and the patent classification codes used are presented in Appendix B.

Grouping by patent family

A patent family is a group of patents related to the same invention. Analyses based on unique patent families can reflect the innovation productivity more accurately. Considering individual patent applications will inevitably involve double counting as each patent family may contain several patent publications if the applicant files the same invention for patent protection in multiple destinations.

Data cleaning

The dataset retrieved was first subjected to automated data cleaning using an IPOS' in-house proprietary patent data cleaning platform for the following purposes:

1) Removal of duplicates of a patent application record in a jurisdiction as a patent application may be published with different kind codes ('A1', 'A2', 'B1', 'B2' *etc.*)
2) Deletion of non-patent specifications, e.g. utility models and search-report-only publications
3) Grouping/collapsing of different patent applications relating to a common invention to one patent family. In this report, the representative for a patent family (i.e. an invention) is chosen to be the earliest published family member.

Manual review was subsequently carried out to ensure the relevance of the dataset prior to carrying out the analyses.

Growth rate calculation

Annual growth rate refers to the average annual growth and was derived by using the best-fit exponential line method for the set of data, $y = a*e^{bx}$, where b is the growth rate.

Grouping of technology domains

Grouping of individual patent records into the respective technology domains and sub-domains were carried out based on patent classifications codes, text-mining and semantic analysis of the patent specifications in particular claims, titles, original and/or DWPI abstracts, as well as a manual review of the individual patent applications.

Refinement of the applicant field

IPOS' in-house proprietary patent data cleaning platform and automated algorithms from commercial tools were used to refine applicants' information, e.g. by removing various spelling and punctuation mark discrepancies.

The refined results were manually checked for accuracy. Top patent applicants were also checked for known subsidiaries and acquisitions, and were named according to the parent company.

Patent indicator

Commercial interest

A patent is a territorial right granted to an invention and gives the assignee the sole right to market the invention and exclude others from making or selling the invention. Hence, players who seek protection for their inventions in multiple jurisdictions are likely to be motivated by the commercial potential of the inventions. Therefore, the average family size of a published invention is used as a proxy to indicate the applicants' interest in commercialising the particular technology.

As fillings into different jurisdictions might be delayed due to factors such as PCT applications, and/or existing patent applications might not be captured due to delays of publications at various patent offices, the family sizes of various portfolios of recent inventions are projected so as to depict a more accurate estimate of the eventual family sizes, and as such, a more accurate assessment of commercial interest by industry players.

APPENDIX B: SEARCH STRING

Learning

Main keywords used
Artificial intelligence, machine learning, computational intelligence, artificial general intelligence, soft computing

Supervised, unsupervised, semi-supervised, deep, ensemble, reinforcement, transfer, extreme learning, self-learn

Neural network, convolutional network, generative adversarial network, support vector machine, genetic algorithm, naive-Bayes

Cognitive computing, bio-inspired, hippocampus, brain, evolutionary

Swarm, ant optimisation

Clustering, k-nearest neighbour, mean shift, spectral clustering

Main patent classification codes used
G06N 3/+, G06N 5/02+, G06N 5/04+, G06N 7/+, G06N 99/005

G06F 17/+, G06F 19/24, G06F 19/707

Computer Vision

Main keywords used
Computer vision, machine vision

Scene understanding, face recognition, face detection, iris recognition, gesture recognition

Motion analysis, image captioning

Main patent classification codes used

G06K 9/+, G06K 2009/00395, G06T 7/+

Natural Language Processing

Main keywords used
Natural language

Talkbot, chatterbot, artificial conversation, virtual chat, chat robot, virtual pet, virtual assistant

Text-to-speech, speech-to-text, text-to-voice, voice-to-text, speech-text conversion, voice-text conversion

Main patent classification codes used
G10L+

Hardware

Main keywords used
Neuromorphic, tensor, neuro-synaptic

Vision processing unit

GPU, FPGA, ASIC, VLSI

Main patent classification codes used
G11C 11/54, G06F 15/78+, G06F 15/80+

Explainable AI

Main keywords used
Explainable

Predict, prescribe, recommend, suggest, reason, generalise

Decision support, decision making, root-cause, causality, cause-effect, causation

Knowledge, sematic, concept, hierarchical

Representation, graph, net, web, map, relation

Rules extraction

Main patent classification codes used
A61B 5/7275, G06Q 30/0202, G06N 5/02+, G06N 5/045

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