Cognitive Computing and Advanced Robotics

Technology Overview

5.1.1 Cognitive computing redefines the nature of the relationship between people and the increasingly pervasive digital environment. The holy grail of cognitive computing is to understand human intelligence and develop agents that can augment human cognition and capabilities in various situations. Cognitive agents rely on technologies like natural speech processing and Machine Learning to enable more natural interaction between people and machines. These agents can help professionals make better decisions by understanding complex inter-relationships in Big Data, especially those that are extraordinarily fast moving. For instance, an existing cognitive agent "IBM Watson" enables partnership between humans and computers to enhance human expertise. As cognitive agents develop, they can one day take us to the "final frontier" of science and engineering – building the human brain.

5.1.2 A key application of cognitive computing is in advanced robotics, enabling the deployment of new-generation robots beyond manufacturing, industrial markets and into professional services. Some uses of robotics in industries like healthcare include automated medication dispensing systems[27], robotic surgery systems and assistive care robots that accompany elderly or disabled persons. In the household, we now see robotic vacuum cleaners, and in space, robotics enable unmanned space exploration. Significant opportunities for advanced robotics also lie in the field of co-robotics (robot-to-robot and robot-to-human communications).

5.1.3 The capabilities of cognitive agents are based on four principles:

(1) Learn and Improve: Learn seamlessly and continuously through the integration of multiple approaches;

(2) Assist and Augment Human Cognition: Intelligence to draw insights from high volume data and understand complex of relationships within data. Examples include visual insights that analyses terrain and linking "visual" information with autonomous systems;

(3) Speed and Scale: Advantages over humans in terms of speed of analysis and scale of data analysed; and

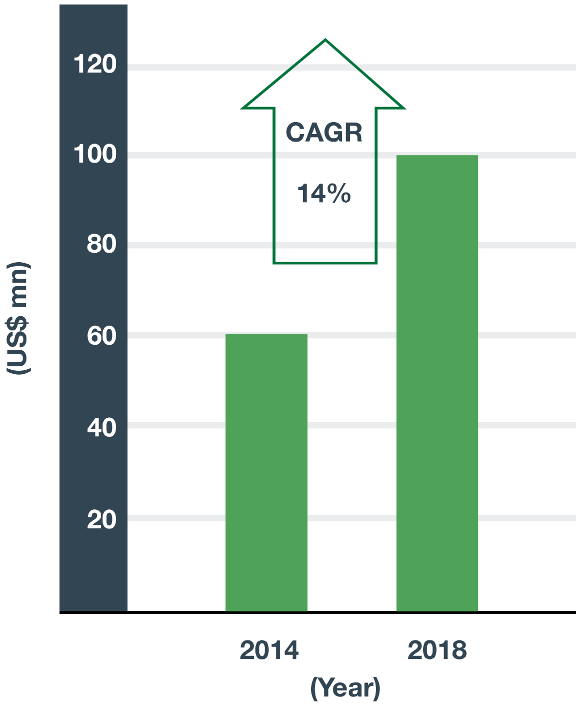
(4) Interact in a Natural Way: Adapt to human approaches, interfaces and environments such that they interact with humans in a seamless way.

Market Size

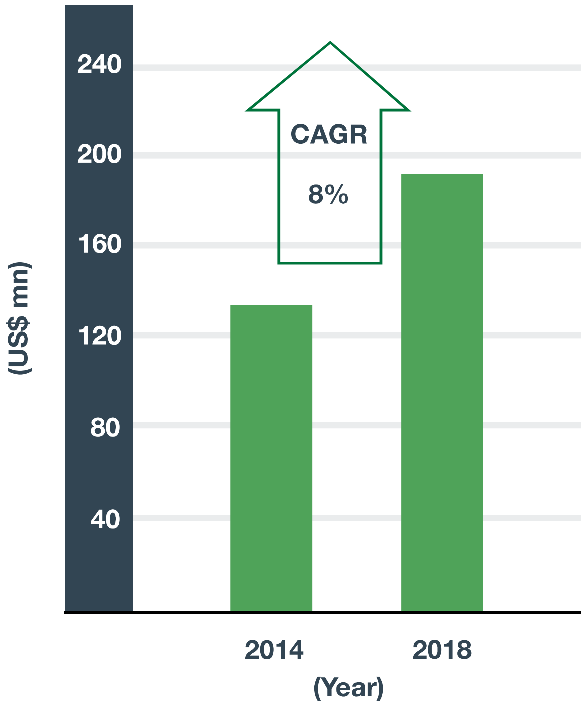
5.2.1 Cognitive computing and advanced robotics will see robust market growth in the next decade. By 2020, 85 per cent of customer relations can be managed through virtual assistants[28]. Further, cognitive agents enabled by artificial intelligence and Natural Language Processing can possibly automate knowledge work and Machine Learning. The automation of knowledge work can have a possible worldwide impact of US$6.7 trillion annually by 2025[29].

5.2.2 In Singapore, Cognitive Computing and Advanced Robotics are still very new. While the global market for cognitive computing is estimated to be US$26-30 billion in 2018, Singapore's addressable market globally is projected to be about US$100 million in 2018[30]. For robotics, the global market size is estimated at US$85 billion in 2018. Singapore would capture about US$190 million of the market globally by 2018[30]. This implies that there are ample growth opportunities for Singapore.

Singapore's Cognitive Computing
Global Addressable Market Size (US$ mn)



Singapore's Advanced Robotics
Global Addressable Market Size (US$ mn)



5.2.3 Investment in Cognitive Computing by public institutions and venture capitalists in last few years were mostly in artificial Intelligence and autonomous systems. Public institutions' investment in artificial Intelligence were mostly in areas like neuro-robotics, computational neurosciences and cognitive science. Projects by public institutions in autonomous systems were in the areas of decision support systems, management and control systems for Smart Cities[32].

5.2.4 In the private sector, expenditure was mainly in algorithms (such as those that mimic human brain function), pattern recognition and autonomous navigation[33].

Trends

5.3.1 Agent-Human Interactivity: Cognitive agents can now interact with one another and with humans to perform sophisticated tasks more efficiently and safely. For instance, the Massachusetts Institute of Technology (MIT) has developed prototypes of "IkeaBots" that work together to assemble furniture. These IkeaBots can communicate not only to humans who need help, but also understand specific form of help needed. In future, robots can assemble all our furniture, or even carry out design and furnishing work, tailored to fit the owner's taste.

5.3.2 Self-Learning Robots: Cognitive agents and robots can improve their contextual understanding and real-time response through seamless interactions among agents, robots, humans and the environment. We have seen surgical robots learn suturing from human surgeons and then through iterative learning, surpass human surgeons in accuracy and speed. Aldebaran Robotics's research platform "Nao" develops robots to teach autistic children as well as interact with the elderly[34]. Google also plans to build and test 100 autonomous car prototypes building upon their existing work on driverless cars[35]. These in turn enhances and complements human cognition and capabilities.

Technology Roadmap

5.4.1 This table reflects the industry's view of the likely evolution and mainstream adoption of Cognitive Computing and Advanced Robotics.

Demand Drivers	1-2 Years	3-5 Years	>5 Years
Improved Sensation and Perception	**Basic Information Processing and Modelling**	**Context-Specific Information Processing and Modelling**	**Integrated and Personalised Information Processing and Modelling**
	• Speech recognition • Gesture recognition • Artificial tactile sensing and haptic perception and recognition • Personal and environmental sensor networks (Wearable devices and smart places) • Localisation and navigation with centimetric precision especially in GPS denied environments	• Context-specific Natural Language Processing • Context-sensitive facial recognition • Recognition of human emotions, intentions and activities via multimodal information • Context-specific object recognition • Context-specific activity recognition • Precise object and activity recognition under controlled environments • More varieties of context-specific sensors and sensor information processing capabilities in daily life	• Systems with integrated sensing, perceptual and interaction modalities • Personalised information networks • Systems with near/extra human level performance of perception under real life uncontrolled conditions
Enhanced Cognition and Learning	**Basic Capabilities in Representation, Problem Solving, Decision Making and Learning**	**Advanced Models in Specific Contexts or Applications**	**Adaptive Frameworks of General Artificial Intelligence**
	• Elementary Machine Learning • Predictive analytics for specific domains • Uncertainty modelling for computational sensation, perception and cognition • Dynamic and real-time planning, scheduling, and optimisation	• Bio and nature-inspired models for computation and automation • Context-sensitive representation and reasoning engines • Deep learning in specific applications • Decision analytic approaches to planning and acting in real-world environments • Systems reasoning and performing tasks under controlled environments • Automated construction of knowledge databases from text, audio and video	• Emotion, Intention, and Context-aware learning and adaptation • General-Purpose Machine Intelligence • Personalised decision support • Deep learning extended to a wide variety of other domains • Systems capable of generic reasoning about dynamic environments under real life ambiguous conditions • Human brain function modelling and simulation at scale and in real-time • Systems learning autonomously by interacting with the environment

[T] is classified as Technology, otherwise as Capability.
Industry has differing views on the timeframe for mainstream adoption for some technologies.

Effective Communi-cation and Interaction	**Basic Communication and Interaction Models**	**Adaptive Communication and Interaction Models**	**Collaborative Communication and Interactive Models**
	• Speech-to-speech translation in specific domains • Context-aware robot interactions with humans • Machine-to-Machine communication (e.g. cooperative localisation, perception of multiple autonomous vehicles) • Basic formation control of multi-robot teams • Collaborative robotic systems for collective task execution • Sensor information processing, analysis, and response through specific devices and networks • Wide variety of service robotics	• Domain-specific natural language Q&A • Assistive robots capable of basic interactions with humans • Advanced distributed and autonomous robotic systems for collective task execution • Sensor and perceptual information processing, analysis, and response through heterogeneous devices and networks • Robots that convincingly mimick emotions and hold conversations	• Robots that communicate with personal and environment sensors and other information systems • Cognitive agents and robots that provide context-appropriate guidance to humans • Integrative environments for robots to share experiences and past behaviours • Distributed communication and interaction of autonomous hybrid teams of humans and robots
Flexible Auton-omous Systems	**Basic Autonomous Systems and Models**	**Interactive and Autonomous Systems with Limited Adaptability**	**Flexible Systems that can Work with and Alongside Humans**
	• Robots remotely operated by humans • Robots navigating and performing mundane tasks (e.g. transporting materials in hospitals) • Modelling and simulation of heterogeneous robotic systems • Safe robots of high dexterity for specific tasks • Robots capable of navigation and planning in partially known and controlled environments	• Robots with limited autonomy deployed for flexible small volume manufacturing • Robots aiding humans for specific tasks • Interoperability and optimisation of heterogeneous robotic systems for problem solving	• Autonomous vehicles and commercial UAVs in real-world environments • Robots capable of manipulating common objects • Robots coordinating and cooperating with one another in uncertain and complex environments • Robots that work effectively and safely alongside humans in broad but well-defined tasks

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Industry has differing views on the timeframe for mainstream adoption for some technologies.

R&D Opportunities

5.5.1 We need to align our national R&D efforts with the industry and sector development directions in the Infocomm Media 2025 report. This table highlights some examples of technology capabilities in Cognitive Computing and Advanced Robotics that we need to build to support the appropriate sector transformation described in Chapter One.

Targeted Capabilities	Sector	Next Practices (3-5 years)	Transformational Practices (>5 years)
Natural Language Processing	Health & Wellness	**Preventive Health** Complex language translation in wearables, with some latency/delay, for healthcare services	**Digitised, Personalised Healthcare** Complex language translation in wearables, performed in real-time, for healthcare services
	Education	**Personalised Learning via Analytics** Complex translation, with some latency/ delay of media contents, for learning use cases	**Ubiquitous Connectedness in Learning via Wearables and Sensors** Complex language translation, performed in real-time of media contents, for learning use cases
	Community and Social Services	**Unified Giving, Integrated Service Delivery** Complex translation, e.g. in all four national languages	**Giving Nation, Collaborating Community & Social Sector** NIL
	International Trade & Logistics	**Trade Facilitation** NIL	**Trade Multiplication** • Use Natural Language Processing to support unstructured data from FTAs and Social Media • Discover factors affecting Singapore's trade connectivity globally through cognitive computing technology
	E-Commerce	**Develop Strategic e-Commerce Trade Lanes** Complex language translation with some latency/delay	**Embrace Digital Commerce Trade Bloc** Complex language translation performed in real-time
	ICM - Subtitling and translation	**Complex Translation and Subtitling, with a Certain Amount of Latency/Delay** • Speech-to-text, text-to-Speech for English and Chinese • Basic translation for international languages such as English, French, Russian and Spanish • Injecting the four basic emotions (i.e. laughter, sadness, thinking and listening) into robotic speeches	**Complex Language Translation and Subtitling, Performed in Real-Time** • Speech-to-text, text-to-Speech for Malay and Hindi and other ASEAN languages • Expand basic expressions to express deepen emotions via the spoken words • Advanced translation for international languages such as English, French, Russian and Spanish

Human-Robot Interaction	Health & Wellness	**Preventive Health** Interactive robots with the ability to perform a range of functions to support the elderly or handicapped	**Digitised, Personalised Healthcare** • Fully interactive robots that can learn to perform multiple human tasks and effectively assist care givers and undertake mundane tasks automatically • Autonomous vehicles to improve the mobility of patients • Deployment of healthcare and wellness robots in hospitals, care centres and homes to help the physically disabled and those who need constant monitoring
	Education	**Personalised Learning via Analytics** Interactive robots with the ability to perform a range of functions to support the learning process	**Ubiquitous Connectedness in Learning via Wearables and Sensors** Fully interactive robots with the ability to perform multiple human tasks and provide visualisation of complex ideas, perform experiments virtually (without the need for physical presence) and support collaborations and teaming
Machine Learning	Manufacturing	**Innovation-Led Manufacturing** • Combination of robots and additive manufacturing for mass product customisation and on-demand low volume production • Robots for machine tending, material handling and transport	**Portfolio Enhancement for Profitable Manufacturing Niches** • Advanced robotics and Machine Learning to improve manufacturing line productivity. With additive manufacturing, it will also support on-demand personalisation and rapid production for customer's specific needs • System that can self-diagnose and repair when deployed in harsh conditions

BRIDGING CONTENT ACROSS CULTURES

NATURAL LANGUAGE PROCESSING

ON-THE-FLY TRANSLATION
Wearables that translate on-the-fly will facilitate cross-cultural communication, enabling more people to easily and conveniently access important services like healthcare, finance or education.

COGNITIVELY PERSONABLE
Robots or assistive agents powered by cognitive computing can understand and speak a variety of languages or dialects, making them more personable as they enhance our daily lives.

NATURAL MEDIA IMMERSION
Natural language processing will open up the world of media to more individuals from various backgrounds. In time, language processing can even inject emotions to enhance the immersive experience.