D4.1: State-of-the-art Review

[WP4 – AI & Robotics]

Lead contributor	Philip Jansen, University of Twente
	Email: p.h.jansen@utwente.nl
Other contributors	Stearns Broadhead, Trilateral Research Ltd
	Rowena Rodrigues, Trilateral Research Ltd
	David Wright, Trilateral Research Ltd
	Philip Brey, University of Twente
	Alice Fox, University of Twente
	Ning Wang, University of Twente & University of Zurich
	Owen King, University of Twente (reviewer)
	Raja Chatila, Sorbonne Université (reviewer)
	Virginia Romano, Uppsala University (reviewer)

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Abstract

This report describes the current state of the art in the fields of artificial intelligence (AI) and robotics. In this report, we establish definitions and demarcations for both fields that will be used in subsequent SIENNA research on AI and robotics. The report discusses the fields in terms of their backgrounds, positions, challenges, and present and expected applications. This report includes a socio-economic impact assessment (SEIA) that examines the current and expected impacts of AI and robotics.

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Task 3.1 – State-of-the-art review of human enhancement	The review of AI and robotics technologies and applications for human enhancement
Task 4.2 – Analysis of the legal and human rights requirements for HMI in and outside the EU	The review of AI and robotics applications and socio-economic impact assessment may inform legal and human rights inquiries
Task 4.3 – Survey of REC approaches and codes for HMI	The report definitions may help to identify consistencies or differences from existing REC approaches and codes
Task 4.4 – Ethical assessment of HMI	The review of AI and robotics applications and socio-economic impact assessment and will inform ethics inquiries

Table of Contents

Executive summary

This deliverable is a state-of-the-art review of the fields of artificial intelligence (AI) and robotics. It offers a thorough analysis of both fields in terms of their central concepts, their history, their present and expected technologies and applications, as well as a socio-economic impact assessment of current and expected impacts of their technologies. The analysis is based on a thorough literature review, interviews, and commentary on drafts of this report by field experts. In the remainder of this summary, we present the content of each of the main sections in this deliverable.

In section 1, we briefly introduce the fields of AI and robotics. In section 2, we offer definitions of AI and robotics, lay out the scope of these fields, and explain their core ideas, concepts, approaches, and methods. In addition, we describe the most important subfields in AI and robotics, including the particular concepts and techniques used in them, and we discuss present and future challenges for AI and robotics and potential future developments in these fields.

Our analysis has found that AI can be defined as the science and engineering of machines with capabilities that are considered intelligent by the standard of *human* intelligence. Here, intelligence is conceived of as a general cognitive ability encompassing more specific abilities, including the abilities to reason, solve problems, plan, comprehend ideas, use language, and learn. Our analysis has further found that AI research can be divided into two main areas of study: “strong AI” and “weak AI”. Strong AI is capable of carrying out any mental task that can be carried out by a human being, and is believed to be capable of having cognitive states similar to those found in human minds. Weak AI, on the other hand, can performing intelligent tasks only in specific domains (e.g., the visual classification of digital images). Weak AI research has become dominant over research on strong AI in recent decades.

Besides a focus on either strong AI or weak AI, it was found that there exist two main paradigms or approaches in AI research (besides several ancillary ones). The first is *symbolic AI*, which is a term for a group of methods in AI research that are based on high-level, “symbolic” representations of problems, concepts, objects, events, and so on. Symbolic AI approaches have been particularly influential in the research on strong AI and are best suited for the modelling of higher cognitive tasks, such as abstract reasoning and problem solving. The second major research paradigm is *connectionist AI*, which holds that mental phenomena can best be described by interconnected networks of simple and often uniform units similar to those that exist in the biological brain. Connectionist approaches, in particular *neural networks*, have recently become very popular, and are currently being used in *machine learning* approaches, where AI systems are being “taught” to recognise patterns and devise rules through processing of “training data” and feedback on performance.

Important subfields of AI were found to include: knowledge representation and automated reasoning, artificial neural networks and machine learning, computer vision, computer audition, natural language processing, expert systems, data mining, intelligent agent systems and automated planning, evolutionary computation.

For robotics, our analysis has found that this field can be defined as the design, development and use of electro-mechanical machines with sensors and actuators that can move in their environment and perform intended tasks autonomously or semi-autonomously. Autonomy, here, can be defined as the capacity to operate in a real-world environment without external control. Important concepts in robotics and robots include sensing, actuation, and decision-making ability. Sensors are needed so that the robot can obtain information from its environment; actuators are there to give the robot the ability to move and exert forces on its environment; and an on-board computational capacity is required for the robot to have significant autonomy.

Our analysis has further found that there are many different approaches and areas of research in robotics. Whereas some of the research focuses on investigating and developing new fundamental techniques in robotics, alternative ways to design and interact with robots, and new ways to manufacture robots, other research is geared towards developing robots for very specific kinds of applications (e.g., research for consumer-market unmanned aerial vehicles [UAVs]). An important trend in robotics is that robots are increasingly being developed to resemble and interact with humans. Important notions here are those of humanoid robot and social robot. Humanoid robots are robots that resemble human beings in terms appearance, mechanics and behaviour, and social robots are robots that are capable of interacting with humans through social behaviour and adherence to rules attached to their social role. Different aspects of the interaction between humans and robots, as well as aspects of the design of robots in relation to such interaction, are studied in the field of human-robot interaction.

Important subfields of robotics were found to include: robot mechanics, robot sensing, robot control (including many subareas, such as robot learning, adaptive control, developmental robotics, evolutionary robotics, cognitive robotics, behaviour-based robotics, robotic mapping and planning), robot locomotion, bio-inspired and soft robotics, humanoid robotics, microrobotics, nanorobotics, beam robotics, cloud robotics, swarm robotics, telerobotics, social robotics and human-robot interaction.

In section 3, we discuss important technologies and applications that have been developed, or may in the future be developed, within the fields of AI and robotics. The time horizon set for inclusion of future AI and robotics applications was set at 20 years from present. This was considered neither a point in time too far into the future (making the analysis too speculative), nor one too close to the present (decreasing the anticipatory value of the analysis).

For AI, it was found that significant present and expected future applications are in the following application domains: transportation, infrastructure, healthcare, finance and insurance, security (military and law enforcement), retail and marketing, media and entertainment, science, education, manufacturing and agriculture. In *transportation*, significant present applications of AI are in smart scheduling for transportation services, and expected future applications are in predictive modelling of individual user characteristics for transportation services. In *infrastructure*, significant present applications of AI are in energy management, optimization and distribution, and sensing and predictive analysis for water management, and expected future applications are in predictive neighbourhood analysis for urban planning activities. In *healthcare*, significant applications of AI are in clinical decision support, patient monitoring and coaching, preventative medicine and management of healthcare systems, and expected future applications are in automated image interpretation, personalised preventative medicine devices, and personalised diagnosis and treatment involving DNA analysis. In *finance and insurance*, significant present applications of AI are in algorithmic trading and high-frequency trading, automated financial advice and portfolio management, underwriting for credit and insurance industries, and insurance claims processing, and expected future applications are in big data analysis for market analysis and automated trading, conversational systems for personal finance and insurance, and social media scanning for underwriting in finance and insurance. In *security*, significant present applications of AI are in automated analysis of camera footage for surveillance and predictive policing, detection of financial fraud and evidence gathering from personal electronic devices, and expected future applications are in advanced cyber defence and weapons systems, and large-scale surveillance systems using wide-area imagery. In *retail and marketing*, significant present applications of AI are in recommender systems for purchase decisions and programmatic advertising, and expected future applications are in integration of biometric data in retail, cross-platform marketing and retail practices, visual search systems for finding products and conversational systems in customer service. Finally, in *media and entertainment*, significant present applications of AI are in targeted advertising, smart filters and recommender systems for optimizing and ascertaining user engagement, discovery of new target audiences, and non-player characters in video games, and expected future applications are in (co-)creation by computers and devices of media and entertainment content, and media and entertainment features of advanced virtual assistants in the home.

For robotics, it was found that significant present and expected future applications are in the following application domains: transportation, security, infrastructure, healthcare, companionship, industry, discovery, service, environment and agriculture. In *transportation*, significant present applications of robotics are in (semi-)autonomous cars, wheeled (and legged) cargo robots and exoskeletal robots for transporting heavy objects, and expected future applications are in unmanned aerial vehicles for drone-delivery services, and air taxis and pilotless passenger jets. In *security*, significant present applications of robotics are in drones for military reconnaissance and target engagement, ground robots for the handling and destruction of hazardous objects, and robots for search, rescue and recovery, and expected future applications are in military exoskeletons, surveillance drones for law enforcement, and arrest and detainment robots. In *healthcare*, significant present applications of robotics are in surgical collaborative robots, socially assistive robots (e.g., for welcoming patients) and care robots for patients and elderly people, and expected future applications are in robotic exoskeletons for disabled people. In the *companionship* domain, significant present applications of robotics are in robotic pets and sex robots, which are expected to become more life-like in the future. In *industry*, significant present applications of robotics are in material handling, welding, finishing and assembly, intelligent assist devices, and collaborative robots, and expected future applications are in robotic exoskeletons. In the service sector, significant present and expected future applications of robotics are in cooking robots, delivery robots, cleaning robots and entertainment robots. Finally, in *discovery*, significant present and expected future applications of robotics are in space exploration, deep-sea exploration and investigation of hazardous areas on land.

In section 4, we present our socio-economic impact assessment (SEIA) of AI and robotics. SEIA means an analysis used to identify and assess the social, economic and environmental impacts of AI and robotics on society. Impacts refer to (potential) changes – whether positive or negative, direct or indirect, in whole or in part – caused by or associated with the technological field under consideration. The SEIA examines social impacts (i.e., those related to society in general, specific groups and the individual, such as social inequalities, protection of particular groups, personal data and governance), economic impacts (i.e., those associated with economic effects on the individual, groups and society in general, such as employment, the conduct of business and operating costs) and environmental impacts (i.e., those related to the natural environment, such as energy use, water quality and the climate).

The central research question of the SEIA is: What are some of the main current and future social, economic and environmental impacts of AI and robotics as reported by recent literature and experts in the topic? To answer this question, we followed a multiple-step approach and abided by a prescribed methodology. First, we prepared the SEIA plan. Second, we identified social, economic and environmental impacts through a literature review (and stakeholder interviews). Third, we consulted with experts through interviews. Fourth, we assessed the impacts based on our literature review and expert opinions. Fifth, we formulated conclusions about mitigating negative impacts on the basis of the preceding steps. Finally, we reviewed the results (with publication of the SEIA to follow).

We briefly summarise here some of the highlights and findings of the SEIA. The SEIA identified a variety of positive (beneficial) and negative (adverse) social, economic and environmental impacts. Based on the literature and interviews, autonomous weapons systems will have the most negative impact, while medical diagnostic applications of AI and/or robotics will have the most positive impacts. The sector or field with the most negative impact will be military defence, while the most positive impact will come from the healthcare sector. The literature review and interviews also indicate that most impacts occur now and will continue to do so into the future, with interviewees offering insights into starting points and time ranges for impacts.

The literature review and interviews respectively highlight that the majority of social, economic and environmental impacts are (or will be) global in reach (i.e., they will occur throughout the world). Separately, social impacts most commonly affect the values of well-being, trust and privacy. Economic impacts most commonly affect values such as competiveness, efficiency and productivity and consumer choice. Environmental integrity stands out as the most commonly affected value of environmental impacts. Although the literature review and interviews pointed out the impacts affect everyone (i.e., all parties), they also highlight specific affected parties. Social impacts affect parties such as the elderly, patients and healthcare providers. Economic impacts affect, in particular, enterprises, workers and consumers. Environmental impacts affect, for example, energy providers, society and scientists.

Our interviews revealed that certain affected parties are more resilient or more vulnerable than others to social, economic and environmental impacts. For example, interviewees believe that communities based on strong unifying values are more resilient to impacts, while poor countries are more vulnerable. By and large, according to the literature and interviews, society (in general) will bear the costs of negative impacts. To reduce the negative impacts of AI and robotics, the literature and interviews propose various mitigation measures, such as policy and regulatory measures, technological or industry measures and society-level measures.

We ultimately set out conclusions about how to minimise negative impacts and maximise positive ones, drawing from what the literature review and interviews revealed about the impacts. Our conclusions for the short-term to medium-term (five to 10 years) are as follows. The effects of negative impacts without mitigation, especially for extremely destructive applications such as autonomous weapons, will potentially efface the positive impacts from AI and robotics. If the timing of impacts presented above is accurate, then regulation and other mitigation measures need implementation now to mitigate negative impacts currently occurring and projected to do so in the future. Social costs of negative impacts merit special attention, and all efforts to limit them should begin as soon as possible. Job losses and the threat to social and economic stability for workers need prioritisation in regulatory and policy discussions. Educating individuals about the positive impacts of AI and robotics could aid in their acceptance and reduce impacts associated with social strife, isolation and disaffection. However, presenting only positive attributes and impacts of AI and robotics may be perceived as disingenuous or dishonest. Consequently, increasing societal acceptance of AI and robotics should also include discussions of their negative impacts (and mitigation measures taken to reduce them). Our conclusion about the long-term (20 years and after) is: Recognise that decisions occurring in the short- and medium-terms will largely construct the state of the affairs in the long-term. As a rule of thumb, avoid any application of AI and robotics whose expected losses outweigh the probable benefits in the long run.

List of figures

List of tables

List of acronyms/abbreviations

Abbreviation	Explanation
AI	Artificial intelligence
ANN	Artificial neural networks
AUV	Autonomous underwater vehicle
BEAM	Biology, electronics, aesthetics and mechanics
CAD	Computer aided design
Cobot	Collaborative robot
DoA	Description of Action
EC	European Commission
GPS	Global Positioning System
IoT	Internet of Things
ITS	Intelligent tutoring system
MAV	Micro aerial vehicle
MEMS	Microelectromechanical system
NLP	Natural language processing
NPC	Non-player character
R&D	Research and development
SAR	Socially assistive robot
SEIA	Socio-economic impact assessment
UAV	Unmanned aerial vehicle
WP	Work package

Table 1: List of acronyms/abbreviations

Glossary of terms

Term	Explanation
Actuator	A device module or subsystem for performing actions in an environment.
Algorithm	"[A] precisely-defined sequence of rules telling how to produce specified output information from given input information in a finite number of steps."[1]
Artificial intelligence	The science and engineering of machines with capabilities that are considered intelligent (i.e., intelligent by the standard of *human* intelligence).
Artificial neural network	An interconnected network of simple and often uniform units similar to those that exist in the biological brain, which can be implemented in intelligent computing systems.
Autonomy	"[A] capacity to operate in a real-world environment without any form of external control, once the machine is activated and at least in some areas of operation, for extended periods of time."[2]
Big data	Extremely voluminous data sets that require specialist computational methods to uncover patterns, associations and trends in them.
Computer vision	An application of AI that gives a computer system the capacity to acquire, process and analyse (numerical or symbolic) information about the content presented in digital imagery.

[1] Knuth. Donald. "Computer Science and Its Relation to Mathematics," *American Mathematical Monthly*, Vol. 81, No. 4, 1974, pp. 323-343.
[2] Lin, Patrick, Keith Abney and George A. Bekey, "Current Trends in Robotics: Technology and Ethics," Robot Ethics: The Ethical and Social Implications of Robotics, MIT Press, 2012.

Term	Explanation
Connectionist AI	A group of methods in AI research that utilise interconnected networks of simple and often uniform units similar to those that exist in the biological brain.
Data mining	The process of discovering patterns in large data sets involving database systems, statistical analysis, and intelligent methods such as machine learning.
Deep learning	An approach to machine learning that applies artificial neural networks with hidden layers and the backpropagation method, in combination with powerful computer systems and voluminous training data.
Drone	Synonymous with “unmanned aerial vehicle”; an aircraft without a human pilot aboard.
Expert system	A computer system that can mimic a human expert’s decision-making ability within a particular field by reasoning through a large amount of field-specific knowledge contained in a database.
Humanoid robot	A robot that resembles a human being in terms of appearance and/or behaviour.
Impact	A potential change – whether positive or negative, direct or indirect, in whole or in part – caused by or associated with the technological field under consideration.
Intelligence	A general cognitive ability encompassing several more specific abilities, including the abilities to reason, solve problems, plan, conceptualise, use language, and learn.
Intelligent agent	An artificially created, autonomous entity that can perceive its environment by means of sensors, act upon this environment through the use of actuators, and direct its activities towards reaching goals.
Internet of Things (IoT)	The interconnection via the Internet of objects in the physical world – devices, vehicles, persons, buildings and other items – allowing them to send and receive data.
Machine learning	A set of approaches within AI where statistical techniques and data are used to “teach” computer systems how to perform particular tasks, without these systems being explicitly programmed to do so.
Natural language processing	An application of AI that gives a computer system the capacity to understand human language in written or spoken form.
Robot control system	A system that uses a robot’s sensor data to calculate and send appropriate signals to the robot’s actuators.
Robotics	The field of science and engineering that deals with the design, construction, operation, and application of robots.
Robot	Electro-mechanical machines with sensors and actuators that can move, either entirely or a part of their construction, within their environment and perform intended tasks autonomously or semi-autonomously.
Socio-economic impact assessment	The analysis used to identify and assess the social, economic and environmental impacts of AI and robotics on society.
Sensor	A device, module or subsystem for detecting (and sending information about) events or changes in an environment.
Social robot	A robot that is capable of interacting with humans through social behaviour and adherence to rules attached to their social role.
Symbolic AI	A group of methods in AI research that are based on high-level, “symbolic” representations of problems, concepts, objects, events, etc.

Table 2: Glossary of terms

1. Introduction

This deliverable is a state-of-the-art review of the fields of artificial intelligence (AI) and robotics. It offers a thorough analysis of both fields in terms of their central concepts, their history, their present and anticipated technologies and applications, as well as a socio-economic impact assessment (of present and expected impacts) of their technologies. The analysis is based on a thorough literature review and commentary on drafts of this report by field experts. In the remainder of this introduction, we offer brief introductions to the fields of AI and robotics, and then present an outline for the remainder of this deliverable.

Before we continue, let us briefly consider the relation between AI and robotics. AI is often referred to as the science and engineering of machines with capabilities that are considered intelligent, that is, intelligent by the standard of *human* intelligence. Robotics can be defined as the science and engineering of programmable electro-mechanical machines that can perform human tasks autonomously or semi-autonomously. As is apparent from these definitions, there exists a degree of overlap between AI and robotics. Artificially intelligent machines may or may not be physically embodied and (semi-)autonomous (i.e., they are robots); and robots may or may not use AI techniques as a part of their control systems. The fields of AI and robotics come together in the science and engineering of *artificially intelligent robots*. We discuss such robots in the parts of this deliverable that are focused on robotics.

1.1 Artificial intelligence

Artificial intelligence is a field of computer science that emerged in the 1950s and has roots in philosophy, mathematics, computation, biology and psychology. Its subfields include machine learning, neural networks, evolutionary computation, AI for robotics, expert systems, planning, speech processing, natural language processing, computer vision and others. The primary aims of AI research are to systematically study the phenomenon of intelligence, and to develop useful programs and tools that can execute tasks normally requiring intelligence. Here, the notion of intelligence is usually conceived of as a general cognitive ability encompassing several more specific abilities, including the abilities to reason, solve problems, plan, conceptualise, use language, and learn. Research often focuses on a specific ability and developing computer programs that are capable of performing limited tasks involving this ability.

As of present, AI capabilities are wide-ranging and include, for example, interpretation of human speech, interpretation of image and video data for object avoidance and face-recognition, control of robot and autonomous vehicle behaviour, and intelligent routing in content delivery networks.

Major applications of AI technology are in transportation, education, finance, industry, healthcare, marketing, management, telecommunications, entertainment and defence, amongst other fields. For instance, AI techniques are currently being used in cars with driver assist features (e.g., self-parking, advanced cruise controls), in intelligent tutoring systems in higher education, in algorithmic trading in financial markets, in industrial robots, in clinical decision support systems for medical diagnosis, and in virtual assistants on mobile phones. In the future, such applications are expected to become more commonplace and additional applications may emerge, including fully autonomous road vehicles, AI-based systems for improved cyber security, and chatbots for complex customer interactions.

AI technology is expected to have, and to some degree is already having, a number of profound social, economic, and ethical impacts. These include: increases in economic efficiency, economic output, and societal wealth; decreases in the time spent on repetitive and burdensome tasks for individuals; potential increases in the quality of and time spent on leisure activities; the transformation of workplaces and the nature of work; the potential for rising unemployment across low-skilled labour sectors and professional sectors; the potential for rising social inequalities and polarisation as a result of unequal distribution of benefits of AI technology; the potential for resistance to the use of AI technology; the potential diminishment of individual autonomy due increased reliance on AI technology; and the potential for abuse, misuse and dual-use of AI technology.

The field of AI has had a tumultuous history. It has experienced several waves of optimism, which were followed by disappointment and loss of funding during what are known as the "AI winters" in the early 1970s, late 1980s, and early 1990s.[3] In the twenty-first century, AI experienced a resurgence following advances in computing power, mass data storage and availability, and theoretical understanding. This allowed AI techniques to become an essential part of the technology industry, helping to solve many challenging problems in computer science.[4]

In recent decades, there has been a shift in focus from AI as a science that examines the phenomenon of intelligence to AI as an engineering discipline that develops practical programs and tools using AI techniques.[5] The initial goal of AI research had been to construct a system with cognitive abilities akin to those of a human being. Early researchers in AI often held the belief, based on advances made in digital computing and key breakthroughs in the fields of information theory and formal logic, that this goal would be reached within just a few decades. They contended that intelligent computer systems could be used to model human thought processes and thus could generate crucial insights into the workings of human cognition. This view formed the basis of the "strong AI" approach in AI[6] and is also known as the cognitive simulation approach. A strong artificial intelligence can successfully perform any intellectual task a human can and is believed to possess human-like cognitive states.

Whereas many researchers in AI embraced the strong AI approach, others had doubts whether its promises could be easily fulfilled, and questioned, for example, whether a human cognition could really be simulated with computational techniques being used. Many in the latter group wanted only to develop computer programs capable of performing intelligent tasks in specific domains. Their approach has been called "weak AI". The weak AI approach has become dominant in recent decades. The approach has combined with other fields beyond AI, integrating its methods and techniques into such areas as robotics, computer networking, data mining, computer vision, human-computer interaction, agent technology, embedded systems and ubiquitous computing.

1.2 Robotics

Robotics is an interdisciplinary field of engineering and science that emerged in the 1950s and involves (and overlaps with) mechanical engineering, electrical engineering, computer science, mechatronics, nanotechnology, and bioengineering. It concerns the design, development and use of robots, including the computer systems needed for their control and the output and processing of sensory information. Its subfields are many and include those that study more fundamental characteristics of robots (e.g., robot control, robot locomotion, microrobotics) and those that study more application-oriented aspects of robots (e.g., aerial robotics, underwater robotics, industrial robotics).

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[3] Guice, Jon, "Designing the Future: The Culture of New Trends in Science and Technology," *Research Policy*, Vol. 28, No. 1, 1999, pp. 81–98.
[4] Russell, Stuart, and Peter Norvig, *Artificial Intelligence: A Modern Approach*, 3rd Edition, Prentice Hall, 2010.
[5] Brey, Phlip, and Johnny Hartz Søraker. "Philosophy of Computing and Information Technology," in A. Meijers (Ed.), *Philosophy of Technology and Engineering Sciences* (pp. 1341-1408), Vol IX, in D. Gabbay, P. Thagard and J. Woods (Eds.), Handbook of the Philosophy of Science, Elsevier, Amsterdam, 2009.
[6] Searle, John R., Minds, brains, and programs, *Behavioral and Brain Sciences*, Vol. 3, No. 3, 1980, pp. 417–457.

Currently, there exist many different kinds of robots with greatly varying physical appearances and capabilities. Robots range from the very small (e.g., insect-sized drones) to the very large (e.g., automotive industrial robots). They may be fully autonomous, semi-autonomous, tele-operated, or attached to and directly operated by the human body (e.g., prosthetic devices). They can have a variety of sensors, including cameras, microphones, thermometers, infrared and vibration sensors. Furthermore, they can have a variety of actuators, including speakers, displays, mechanical arms and grippers, guns, and mechanisms for locomotion (including walking, driving, rolling, swimming, and flying). There are robots that can perform complex tasks that involve advanced artificial intelligence techniques (e.g., semi-autonomous cars), and robots that perform relatively simple, repetitive tasks through a limited set of pre-programmed actions (e.g., packaging robots). Finally, there are robots that resemble (to varying degrees) humans or animals in appearance, mechanics, and behaviour. In the near future, robots are expected to be able to perform tasks that are increasingly complex (e.g., advanced object detection and avoidance in fully autonomous vehicles) due to advances in AI and computing power, and they are projected to become smaller in size and more energy efficient.

Major applications of robots are in transportation, industry, healthcare, education, entertainment, space exploration, defence, retail, companionship, housekeeping and other areas. Robots are often used for tasks that are repetitive, dirty and/or dangerous. For example, articulated robotic arms are used in industry for applications such as welding, material handling, and painting. In domestic settings, robotic vacuum cleaners, pool cleaners, gutter cleaners are being used. Surgery robots and care robots (e.g., lifting robots) have found use in healthcare. In military settings, specialized bomb disposal robots and reconnaissance drones are being used. Semi-autonomous spacecraft and landing vehicles are used in space exploration. In the future, many new applications of robots are likely to emerge, possibly including fully autonomous taxis, fully autonomous policing/surveillance robots, fully autonomous lethal military robots, robotic exoskeletons[7] in industry and conversational care robots in healthcare.

Similar to AI technology, robots are expected to have a number of profound social, economic, and ethical impacts. These include: increases in economic efficiency, economic output, and societal wealth; decreases in the time spent on repetitive and burdensome tasks for individuals; potential increases in the quality of and time spent on leisure activities; the transformation of workplaces and the nature of work; the potential for rising unemployment across low-skilled labour sectors and professional sectors; the potential for rising social inequalities and polarisation as a result of unequal distribution of benefits of robots; the potential for resistance to the use of robots; the potential diminishment of (experienced) privacy due robot surveillance, to the potential diminishment of individual autonomy due increased reliance on robots; and the potential for abuse, misuse and dual-use of robots.

Like the field of AI, the modern field of robotics has had a comparatively short history. While the very idea of creating autonomously operating machines dates back to classical times, research into the basic technical functionality and possible applications of robotic systems did not substantially grow until the middle of the twentieth century. It was only in 1948 that the principles of cybernetics, as formulated by Norbert Wiener, laid the groundwork for practical robotics. The first robots emerging in the 1950s and 1960s were fairly rudimentary vehicles with simple behaviour guided by light sensors, and digitally operated and programmable robotic arms with limited degrees of freedom.

During the 1970s and 1980s, research into robotics expanded greatly and more advanced robots emerged. Japanese robotics research at both academic institutions and companies rose to prominence during this period. Notable was the development of the first mobile robots (e.g., Shakey the Robot)

[7] A human-wearable machine that allows for limb movements with increased strength and endurance.

that were capable of reasoning about their surroundings through the integration of AI and multiple sensor inputs, including cameras, laser rangefinders, and collision sensors. The first full-scale humanoid robots and androids were also introduced, which could walk in a rudimentary fashion, grip and transport objects with artificial limbs, measure distances and directions to objects and communicate with humans in very basic ways. Furthermore, industrial robots first saw significant use in industry and became more sophisticated, with more degrees of freedom and the capacity for very fine movements.

From the 1990s onwards, robots diversified greatly and became more sophisticated in terms of mechanics and intelligence. New research fields opened up, including evolutionary robotics, bio-inspired robotics, and BEAM robotics. From a predominantly industrial focus, robotics expanded to take on the challenges of the human world in healthcare, services, entertainment, education, and other sectors. The most advanced humanoid robots have improved to the point where they can walk, run, communicate with humans, analyse their environment, recognise faces and voices, and interact with their environment – albeit not yet at the level of humans. Some intelligent robots, such as Sony's Aibo pet dog and iRobot's Roomba vacuum cleaner, were created for private use in the home. Autonomous road vehicles have entered a stage where they began to be tested in small numbers on public roads, and tele-operated and semi-autonomous robots (notably unmanned aerial vehicles) have seen wide use in the military environment. Finally, the International Federation of Robotics has estimated that in 2016 there were 1.2 million industrial robots in the world, and that by the year 2019 this number will have increased to 2.6 million.[8]

1.3 Structure of the report

In the following sections, we offer a broad analysis of the state-of-the-art in AI and robotics. In section two, we will define the fields of AI and robotics, which will include a demarcation and definition of these fields, explanation of core ideas, description of their subfields, and discussion of present and future challenges. In section three, we will deliver a systematic description of products and applications that have been developed or are expected to soon be developed within the fields. In section four, we will deliver an initial socio-economic impact assessment on AI and robotics. Finally, in five, we will conclude with a summary and recommendations for further study.

1.4 Scope and limitations

This report lays the groundwork for further SIENNA work on the ethical and legal aspects of AI and robotics technologies, products and applications. As such, it provides no conclusions or commentary on any ethical and legal issues with certain AI and robotics applications that may become apparent through this analysis.

Further, in order to provide the most useful input for the development of practical recommendations in later SIENNA reports, it is helpful to set a limit on the inclusion of potential developments in AI and robotics that may only occur over larger time scales. In the analysis of potential future developments in AI and robotics research and applications, we therefore restrict ourselves to discussing developments that are reasonably possible within approximately twenty years for now, with the most emphasis put on developments five to ten years from now. We consider a time horizon of twenty years to be neither a point in time too far into the future (making the analysis too speculative), nor one that is too close to the present (decreasing the anticipatory value of the analysis).

[8] International Federation of Robotics. "World Robotics Report 2016," IFR, 2016. https://ifr.org/news/world-robotics-report-2016

2. Defining the field

It is important to have working definitions and informative descriptions of the fields of artificial intelligence and robotics prior to laying out the landscape of current and potential future applications of technologies in them. In this section, we therefore offer definitions of AI and robotics, lay out the scope of these fields, and explain their core ideas, concepts, approaches, and methods (subsection 2.1); we describe the most important subfields in AI and robotics, including the particular concepts and techniques used in them (subsection 2.2); and we discuss present and future challenges for AI and robotics and potential future developments in these fields (subsection 2.3).

2.1 Definitions of artificial intelligence and robotics

In this subsection, we define and demarcate the fields of AI and robotics, and explain their key concepts, approaches, and methods. We begin by offering a definition and description for AI, and then proceed to do the same for robotics.

Definition of artificial intelligence

In the introduction of this report, artificial intelligence is defined as the science and engineering of machines with capabilities that are considered intelligent by the standard of *human* intelligence. Here, intelligence is conceived of as a general cognitive ability encompassing more specific abilities, including the abilities to reason, solve problems, plan, comprehend ideas, use language, and learn.

Although our definition of AI is quite general, it is not a consensus definition. Over the years, a large number of definitions have been proposed. The majority of these can be categorised into four groups on the basis of two criteria.[9] A first distinction can be made between definitions that emphasise the ability of AI systems to *think and reason* intelligently and those that emphasise the capacity of AI systems to *act* intelligently. Definitions of the former kind can be seen in the light of AI's historical aim to generate a better understanding of the concept of human intelligence (i.e., human thinking and reasoning), while definitions of the latter kind can be seen as focussing more on the practical application of AI techniques. A second distinction can be made between definitions suggesting that AI systems are aimed at emulating *human* intelligence to some degree, and definitions suggesting that AI systems simply think or behave in accordance with an *ideal* concept of intelligence, which we may call *rationally*.[10] Here, too, definitions of the former kind may be somewhat associated with AI's aim of creating a better understanding of the concept of human intelligence, while definitions of the latter kind are more focused on the practical application of AI.

Our definition of artificial intelligence is phrased so as to refer to AI as both the ability to think and reason intelligently and the ability to act intelligently. This way it covers both of the two main aims of AI research: generating a better understanding of human intelligence, and developing tools that can automate intelligent behaviour. Furthermore, our definition refers to AI systems' capacity for human-like intelligence (and not just the capacity for rational thought or behaviour), since specific facets of human intelligence (e.g., planning, learning, and communicating) are the yardsticks AI systems' intelligence is typically measured by.

[9] Russell, Stuart, and Peter Norvig, op. cit., 2010.
[10] A system is rational if it chooses to perform the action with the optimal expected outcome for itself from among all feasible actions.

Core concepts, approaches and methods in artificial intelligence

The primary aims of AI research are, firstly, to systematically study the phenomenon of intelligence, and secondly, to develop programs and tools that can automate intelligent behaviour, which includes information gathering, detecting, planning, learning, communicating, and manipulating. In terms of research output, the second aim has been receiving increased attention of the past decades.

Artificial intelligence can be broadly divided into strong AI and weak AI.[11] Strong AI is capable of carrying out any mental task that can be carried out by a human being, and is believed to be capable of having cognitive states similar to those found in human minds. On some philosophical accounts, it is even held to experience consciousness (artificial consciousness). Strong AI is the object of study of some artificial intelligence research and a common topic in science fiction and foresight studies on AI. One popular approach in AI research for achieving strong AI action is *whole brain emulation*.[12] This approach relies on building a low-level brain model by scanning and mapping a biological brain in detail and copying its state into a computer system. This system then runs a simulation model so faithful to the biological brain that it will behave in essentially the same way as the brain, and for all practical purposes, be indistinguishable from it. The promises of strong AI and whole brain simulation are built on a belief in the *computational theory of mind*, which is the view that the human mind is an information processing system and that thinking equals computation.[13]

To test whether a computer system is as intelligent as a human being, the Turing test was developed.[14] Developed in 1950 by Alan Turing, this test was built on the premise that a machine must be considered intelligent if it can fool human beings into thinking it is a human. During the test, a human being and a computer are placed behind a screen, and an evaluator who is on the other side of the screen (and who thus cannot see both) then poses questions to both so as to ascertain which one of the two is the human being. If the evaluator is unable to tell within a reasonable amount of time which one is the human being, then the computer is said to have passed the test and to possess general intelligence. The Turing test is still frequently referenced as a test for general intelligence, but has not been without criticism.[15]

Compared to strong AI, weak AI's goals have been more modest and practical. The focus of weak AI research is on developing computer programs that are capable of performing intelligent tasks in specific domains. Weak AI research has become dominant over research on strong AI research in recent decades. Good progress has recently been made as a result of growth in computer processing power, availability of large volumes of data, and development of machine learning techniques. The weak AI approach has merged with other fields beyond AI, integrating its methods and techniques into

[11] Over the last few years, a similar distinction has been in use among AI scholars between "artificial general intelligence" (AGI) and "weak AI"/"narrow AI". AGI is considered distinct from strong AI in that it is focused only on *apparent* intelligent behaviour that is equivalent in depth and scope to human performance, and does not suggest that actual thinking or consciousness is involved.

[12] Sandberg, Anders, and Nick Boström. "Whole Brain Emulation: A Roadmap," Technical Report #2008-3, Future of Humanity Institute, Oxford University, 2008. http://www.fhi.ox.ac.uk/Reports/2008-3.pdf

[13] Pylyshyn, Zenon W., *Computation and Cognition: Toward a Foundation for Cognitive Science*, MIT Press, Cambridge, MA, 1989.

[14] Turing, Alan. "Computing Machinery and Intelligence," Mind, Vol. 49, 1950, pp. 433-460.

[15] Moor, James, *The Turing Test: The Elusive Standard of Artificial Intelligence*, Kluwer Academic Publishers, Dordrecht, 2003.

such areas as robotics, statistics, applied mathematics, computer networking, data mining, computer vision, human-computer interaction, artificial agents, embedded systems and ubiquitous computing.

Besides the focus on either strong AI or weak AI, there exist two main research paradigms in AI. The first is *symbolic AI*, which is a term for a group of methods in AI research that are based on high-level, "symbolic" (i.e., abstract and human-readable) representations of problems, concepts, objects, events, and so on. From about the mid-1950s until the late 1980s, symbolic AI was the dominant paradigm in AI research.[16] Its essential claim is that intelligence, both in humans and in machines, is a matter of manipulating symbols through the use of formal rules, an assumption defined by Allen Newell and Herbert Simon as the "physical symbol systems hypothesis".[17] Symbolic AI approaches have been particularly influential in the research on strong AI and are best suited for the modelling of higher cognitive tasks, such as abstract reasoning and problem solving.

The second major research paradigm is *connectionist AI*, which emerged in the late 1980s.[18] Rejecting the view that intelligent behaviour is the result of symbol manipulation through formal rules, connectionism holds that mental phenomena can be described by interconnected networks of simple and often uniform units similar to those that exist in the biological brain.[19] Connectionist approaches, in particular *neural networks*, have recently become very popular. They are currently being used in *machine learning* approaches, where AI systems are being "taught" to recognise patterns and devise rules through processing of "training data" and feedback on performance. The result of developments in machine learning is that AI systems can be self-learning, be more adaptive, and have greater autonomy. Connectionist approaches have turned out to be extremely good at carrying out particular types of intelligent tasks, such as pattern recognition, categorization, and the coordination of behaviour.

Important notions in applications of AI are those of *intelligent agent* and *expert system*. An intelligent agent is an autonomous decision-maker that can sense and act. More accurately, it can be defined as an autonomous, artificially created entity that can perceive its environment by means of sensors, act upon this environment through the use of actuators, and direct its activities towards reaching goals. Intelligent agents have found widespread use in the automation of processes in software environments (as software agents), in robots and in other devices and machines. An expert system is a computer system that can mimic (and sometimes outdo) a human expert's decision-making ability by reasoning through an extensive body of (human) knowledge represented in a database. It can be used by human operator to help solve complex problems, such as in the medical diagnosis of rare diseases. Expert systems are one of the first forms of AI software that were truly successful.[20]

Closely related to the scientific field of AI are the philosophy of AI and the ethics of AI. Important ideas and concepts in the latter fields that are of significant relevance to the former include the possibility and nature of *artificial consciousness* and *superintelligence*, amongst others. Artificial consciousness is a field of research that questions the possibility and theorises aspects of emulating human conscious experiences by AI systems. A superintelligence is a hypothetical intelligent agent or problem-solving system that possesses intelligence far surpassing that of the brightest human minds. A

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[16] Haugeland, John, *Artificial Intelligence, the Very Idea*, MIT Press, Cambridge, 1987.
[17] Newell, Allen, and Herbert A. Simon. "Computer Science as Empirical Inquiry: Symbols and Search," *Communications of the ACM*, Vol. 19, No. 3, 1976, pp. 113–126.
[18] Brey and Søraker, op. cit., 2009.
[19] Medler, David A. "A Brief History of Connectionism," *Neural Computing Surveys*. Vol. 1, 1998, pp. 61–101. http://www.blutner.de/NeuralNets/Texts/Medler.pdf
[20] Russell, Stuart., and Peter Norvig, op. cit., 2010.

superintelligence may result from the recursive self-improvement by a future strong AI (or, artificial general intelligence), and is associated with runaway technological growth leading to a so-called *technological singularity*.

Definition of robotics

In the introduction of this report, robotics is defined as the field of science and engineering that deals with the design, construction, operation, and application of electro-mechanical machines with sensors and actuators that can move (either entirely or a part of their construction) in their environment and perform intended tasks autonomously or semi-autonomously. This, however, is not a commonly agreed definition for robotics. There currently still exists a lack of consensus among roboticists on how the object of their craft should be defined.

The definition of robotics depends most on how we define a robot. In the robotics literature, there exist a number of definitions for robot, with many being problematic to some degree. For example, a robot has occasionally been defined as "a computer with sensors and actuators that allow it to interact with the external world",[21] or as "any machine that does work on its own, automatically, after it is programmed by humans".[22] Under such definitions, devices like thermostats, coffee machines and smart speakers – not to mention personal computers – may qualify as robots, an implication few roboticists would defend. For this reason, a good definition of robotics more should be precise and be able to differentiate robots from computers and other electronic or electromechanical devices.

The ISO (the International Organization for Standardization) defines a robot as an "actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks".[23] Another definition, by the Robot Institute of America, holds that a robot is "a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks".[24] Both definitions underscore the capability of robots to move in their environment. However, it is not immediately clear that robots need to be programmable – at least in the conventional sense of the notion associated with coding algorithms – since robots' control systems can employ some form of AI that is not explicitly programmed. In addition, the requirement in the ISO definition that robots be programmable "in two or more axes" would exclude so-called single axis robots that are often used in industry.

Philosophical approaches tend to describe robots as machines that "sense", "think" (or "decide") and "act".[25] Sensors are needed so that the robot can obtain information from its environment; an on-board computational capacity is required for the robot to have significant autonomy; and actuators are there to give the robot the ability to move and exert forces on its environment. The question of whether the abilities to sense, think, or act can accurately be ascribed to a machine is still a matter of significant contention. This matter aside, a crucial element in the philosophical understanding of a

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[21] Lin, Patrick, Keith Abney and George A. Bekey, op. cit., 2012.
[22] Electro Training and Servicing Institute, "Robotics Technology," ETASI, n.d. https://etasieducation.com/course/robotics-technology/
[23] International Organization for Standardization, "ISO 8373:2012(en): Robots and robotic devices — Vocabulary," n.d. https://www.iso.org/obp/ui/#iso:std:iso:8373:ed-2:v1:en
[24] Robot Institute of America. NBS/RIA robotics research workshop: Proceedings of the NBS/RIA Workshop on Robotic Research held at Gaithersburg, MD., 1979.
[25] Asaro, Peter. "How Just Could a Robot War Be?," in Adam Briggle, Katinka Waelbers and Philip Brey (eds.), *Current Issues in Computing And Philosophy*, IOS Press, Amsterdam, 2008, pp. 50-64.

robot is the idea that it exhibits some degree of autonomy, meaning that it is at least semi-autonomous. Autonomy, here, can be defined as "a capacity to operate in a real-world environment without any form of external control, once the machine is activated and at least in some areas of operation, for extended periods of time".[26] Depending on what degree of autonomy is accepted for robots, tele-operated and remote-controlled robots can be included or excluded from the class of robots

Based on this analysis of existing definitions, it seems that a good working definition of a robot would be: an electro-mechanical machine with sensors and actuators that can move (either entirely or a part of its construction) in its environment and perform intended tasks autonomously or semi-autonomously. This definition generally covers and does not exceed the range of things that people intuitively consider to be robots. It rules out simple stationary devices such as toasters, coffee machines, and printers, which are clearly not robots. It also rules out any fully remote-controlled machines, such as simple remote-controlled children's toys, since those devices are not autonomous or semi-autonomous. (That is, such machines do not make any decisions for themselves, as they are fully dependent on human input.) Many UAVs, however, would qualify as robots under this definition, because even though they are tele-operated by humans, they often make at least some navigational decisions on their own (e.g., collision avoidance and return-to-home features).

Core concepts, approaches and methods in robotics

Robots are often developed to substitute for humans and replicate human actions, the rationale being that they can in many applications perform tasks more effectively and efficiently, and reduce strain on, and safety risks for, humans. In addition, they can extend the reach of human influence to places that humans hitherto never had access to, such as the surfaces of other planets in the solar system.

As stated above, important concepts in robotics and robots include sensing, actuation, and decision-making ability. Sensing is performed through sensors, which are devices, modules, or subsystems whose purpose it is to detect events or changes in their environment, and to send information about these events or changes to other electronics for processing. Sensors allow a robot's control systems to receive information about the robot's environment and its internal components, which is then processed and used to calculate an appropriate response, and/or relayed to human operators or supervisors. Robots can have a wide variety of sensors that include cameras, microphones, accelerometers, thermometer, infrared, radar, sonar, and vibration sensors.

Actuators are the means by which a robot performs actions in its environment. They use energy to produce movement, sound, vibration, light or chemical reactions. Widely used actuators include electric motors that produce torque to rotate wheels or gears, and linear actuators hat create motion in a straight line. However, robots can have a variety of other actuators as well, including speakers, displays, LEDs, lasers, and different types of movement-producing actuators (e.g., pneumatic artificial muscles, piezoelectric motors, electroactive polymers). By means of its (electro)mechanical actuators, a robot can drive its other mechanical components and achieve complex motions with multiple degrees of freedom that are useful for object manipulation (e.g., through mechanical arms and grippers) and locomotion (e.g., walking, driving, rolling, swimming, flying). The "hand" of a robot is usually referred to as an (end) *effector*, while the "arm" is referred to as a *manipulator*. Robotic motion is studied in the fields of *robot kinematics* and *robot dynamics*. Here, essentially, robot kinematics is

[26] Lin, Patrick, Keith Abney and George A. Bekey, op. cit., 2012.

the study of the geometry of motion of a robot's mechanical parts, and robot dynamics is the study of the forces that are responsible for this motion.

The mechanical structures of robots have to be controlled to enable them to perform tasks. Robot control systems take sensor data as input and calculate the appropriate signals to be sent to the actuators. These systems use techniques from (robot) *control theory* and can range greatly in complexity. At a reactive level, they may translate raw sensor information into actuator commands in a relatively quick and simple fashion. However, at longer time scales or with more sophisticated tasks, they may need to use artificial intelligence and reason with *cognitive models*, which are intended to represent the robot, its environment, and the interactions between the two. Furthermore, robots may use pattern recognition and computer vision to track objects, techniques in *robotic mapping* to build maps of the world and localize themselves within these maps, and techniques in *motion planning* to figure out how they should move efficiently, without hitting obstacles or falling over.

A robot's control systems determine its capacity for autonomous behaviour. Robots can range in autonomy from fully autonomous to semi-autonomous. If a robot is semi-autonomous, it can be largely tele-operated, or be attached to and directly operated by the human body (e.g., prosthetic devices). Fully autonomous or semi-autonomous behaviour in robots can range from very basic, such as the behaviour displayed by packaging robots that use simple pre-programmed algorithms, to very sophisticated, such as the behaviour shown by semi-autonomous cars that employ techniques from the AI subfields of computer vision and machine learning.

Robots come in many forms, but they are increasingly being developed to resemble humans and animals in appearance, mechanics and behaviour. *Humanoid robots* (or *anthrobots*) are robots that resemble human beings in important ways. Such robots may be developed to enable more natural, effective and efficient interactions with humans, so as to increase the likelihood of a robot's acceptance in certain applications where they replace human beings. It has further been suggested that advanced humanoid robotics research will facilitate the enhancement of ordinary humans.[27] Humanoid robots can be designed to replicate human locomotion, speech, gestures, cognition, or facial expressions, amongst other characteristics.

Somewhat related to humanoid robotics are the emerging areas of *bio-inspired robotics* and *biomimicry*, which study concepts from biological systems, simplify, enhance and then apply them to the design of new robots. Both fields have contributed to the development of a branch of robotics called *soft robotics*, which deals with constructing robots out of highly compliant (i.e., flexible) materials, similar to those found in living organisms. Bio-inspired roboticists draw inspiration from, for example, biosensors (e.g., the human eye), bio-actuators (e.g., muscles), biomaterials (e.g., spider silk) and different modes of animal locomotion (e.g., insect wing motions).

As a result of the continuous progress in integrated circuit design and manufacturing technology of the past few decades, robots and their subsystems (i.e., their sensors, actuators, and control and communications systems) have been greatly miniaturized and decreased in cost. This development has made possible entirely new categories of robots, such as small consumer-oriented UAVs. More recent progress in so-called *microelectromechanical systems* (MEMSs) holds promise for the development of microbots, which are very small robots with characteristic dimensions of less than 1 mm.

[27] Kazerooni, H., "Human Augmentation and Exoskeleton Systems in Berkeley," *International Journal of Humanoid Robotics*, Vol. 04, No. 03, 2007, pp. 575–605.

Much of the research in robotics does not focus on developing robots for specific kinds of applications, but on investigating and developing new fundamental techniques in robotics, alternative ways to design and interact with robots and new ways to manufacture robots. A distinction can therefore be made between *fundamental robotics*, which studies essential aspects of robot design and behaviour independent from robot applications, and *application-oriented robotics*, which focuses on robot design and development for specific applications.

In recent decades, robotics research, education and product development have seen increasing interest in the development of open-source software and free to use blueprints and schematics for robotics hardware. These open-source blueprints and schematics for robotics hardware generally make use of standard, commonly available, components. Related to this, the popularity of do-it-yourself robotics has been increasing, with several companies now producing kits for building simple robots.

Finally, an important recent development has been the introduction of 3D printers, which arguably fall under the definition of robots used in this report. 3D printing allows objects of almost any shape to be created through a process called additive manufacturing. It has been suggested that 3D printing will revolutionise manufacturing by allowing individuals to do their own manufacturing instead of buying physical products manufactured by companies.

2.2 Subfields of artificial intelligence and robotics

This section offers brief descriptions of the most important subfields of artificial intelligence and robotics, including some of the main concepts and techniques used in them.

Subfields in artificial intelligence

The following is a listing of arguably the most important subfields in AI. It should be noted that many of these subfields overlap to a significant degree (i.e., sharing important techniques and methods with other subfields) or are interdisciplinary combinations with non-AI fields.

Knowledge representation and automated reasoning. Knowledge representation deals with the fundamental challenges faced in representing information about the world in a form that a computer system can utilize to solve complex tasks, such as diagnosing a medical condition or having a dialog in a natural language. Things that an AI system may need to represent include: concepts, categories, objects, properties, situations, events, states, time, and causes and effects. Knowledge representation goes hand in hand with the capacity for automated reasoning about that knowledge. Tools and techniques of automated reasoning include classical logics, fuzzy logic, Bayesian inference, reasoning with maximal entropy, and a large number of less formal *ad hoc* techniques. Knowledge representation and automated reasoning are foundational to the development of expert systems (a subfield that we discuss later).

Machine learning. Machine Learning is a broad subfield within AI where statistical techniques and data are used to “teach” computer systems how to perform a particular task, without these systems being explicitly programmed to do so. For example, in image recognition, computer systems might learn to identify images containing cats by analysing example images that have been manually labelled as "cat" or "no cat", without *a priori* knowledge about defining features of cats. The field is closely related to computational statistics and has many different approaches, which include artificial neural networks, Bayesian networks, reinforcement learning and others. It has been a key contributor in the success of AI applications for product recommendations, image understanding, speech recognition, fraud detection, and other task which only humans could perform not so long ago. Machine learning task or approaches can be divided into two broad categories: supervised learning and unsupervised learning. In supervised learning, a system is provided with example inputs and desired outputs for these inputs and tasked to learn through iteration the general rule(s) that map the inputs to the output. In unsupervised learning, no pre-specified output is given to the learning system, thus leaving it to find structure in the input on its own.

Artificial neural networks. Artificial neural networks (ANNs) are computing systems vaguely inspired by the biological neural networks that constitute human and animal brains. Such systems have found application in machine learning, where their use has become very common. In machine learning, the use of advanced ANNs with more than one hidden "layer" and a method called "backpropagation"[28], in combination with powerful computer hardware and large amounts of training data, is called *deep learning*, which in some areas of application produces results comparable to, and in some cases superior to, human experts.[29] An important limitation of deep learning methods and neural networks in general, however, is the low interpretability of the inference models that result from the learning process. Artificial neural networks and machine learning have been applied to subfields such as computer vision, machine hearing and natural language processing, where they have been shown to produce cutting-edge results.

Computer vision. Computer vision is the ability of a computer system to take in, process and gain a high-level understanding of content presented in digital images or videos. High-level understanding in this context means the creation of symbolic descriptions of what is visually presented using models constructed with the aid of geometry, physics, statistics, and learning theory.[30] Sub-domains of computer vision include scene reconstruction, event detection, video tracking, object or face recognition, 3D pose estimation, learning, indexing, motion estimation, and image restoration.

Computer audition. Computer audition is the capacity of a system to register and process audio data (e.g., music, speech), and to focus selectively on a specific sound against many other competing sounds and background noise (the latter ability is called "auditory scene analysis"). The field has a wide range of application that includes speech synthesis, speech recognition (in natural language processing) and music recording and compression.

Natural language processing. Natural language processing gives machines the ability to understand human language in written or spoken form. Sufficiently powerful systems for natural language processing enable the use of natural language user interfaces and the extraction of knowledge directly from speech or human-written sources (e.g., email correspondence). Some straightforward applications of natural language processing include information retrieval, text mining, question answering, conversational agents, and machine translation. A common method of processing and extracting meaning from natural language in text is called *latent semantic analysis*, which works with the assumption that words that are close in meaning will occur in similar pieces of text.

[28] Backpropagation is an abbreviation for "backward propagation of errors". This is a common method used to train artificial neural networks. It is typically used in combination with an optimization method such as gradient descent. In backpropagation, the gradient of a loss function is calculated with respect to all weights in the network.

[29] Thomsen, Michael, "Microsoft's Deep Learning Project Outperforms Humans in Image Recognition," Forbes, Forbes Magazine, February 19, 2015. https://www.forbes.com/sites/michaelthomsen/2015/02/19/microsofts-deep-learning-project-outperforms-humans-in-image-recognition/#4fb4d93d740b

[30] Forsyth, David A., and Jean Ponce, *Computer Vision: A Modern Approach*, Prentice Hall, Upper Saddle River (New Jersey), 2003.

Expert systems. Expert systems are computer systems that emulate the decision-making ability of a human expert by reasoning through an extensive body of human knowledge represented in a database. They are built by applying knowledge engineering techniques, and are typically composed of two subsystems – the *knowledge base* and the *inference engine*. The knowledge base is an organised collection of facts and rules relevant in a particular domain, and the inference engine applies these rules to these facts to logically deduce new facts. Expert systems can be used by human operators to solve complex problems, and were among the first truly successful forms of artificial intelligence software.

Data mining. Data mining is the process of discovering patterns in large data sets involving database systems, statistical analysis, and intelligent methods such as machine learning. The overall goal is to extract information from large data sets and transform it into an understandable structure for further use. Applications of data mining are in manufacturing, marketing, finance, insurance, healthcare, and transportation, amongst other sectors.

Intelligent agent systems, automated planning. As explained in subsection 2.1, intelligent agents are autonomous, artificially created entities that perceive their environment through sensors, act upon their environment using actuators, and direct their activity towards achieving goals. For agents to be able to set goals and achieve them, they need to be able to make predictions on the future state of their environment, on how potential actions will change it, and on what would be the best course of action. Automated planning and scheduling is the area where solutions to these problems are devised. In multi-agent planning, cooperation and competition between many agents are used to achieve a given goal. Multi-agent planning forms the basis for swarm intelligence.

Evolutionary computation. Evolutionary computation is a subfield of AI that studies algorithms for global optimization that are inspired by biological evolution. Techniques in evolutionary computation can produce highly optimized solutions for a wide range of problems, making them popular in computer science. Essentially, an initial set of candidate solutions is generated, which is then iteratively updated through an evolutionary process. Each new generation is produced by stochastically removing less desired solutions, and introducing small random changes. In biological terminology, a population of solutions is subjected to natural selection (or artificial selection) and mutation. As a result, the population will gradually evolve to increase in fitness.

(Intelligent) Information retrieval. Information retrieval is a subfield of computer science that studies effective and efficient algorithmic methods for search processes in which a user tries to identify a subset of information within a large amount of information. The problems of how to properly represent information in indexes and how to match imprecise representations has led to the application of AI techniques.

Subfields in robotics

The subfields in robotics are many. They can be usefully divided into two main categories: fundamental robotics and application-oriented robotics. Fundamental robotics studies essential aspects of robot design and behaviour, largely independent from robot applications. On the other hand, application-oriented robotics is focused on robot design and development for specific (types of) applications. Below, a listing of subfields is only provided for fundamental robotics research and innovation, and not for application-oriented robotics, since robot applications in various domains are already described at length in subsection 3.2. It should be noted that the listing presented below is an attempt at describing the most important fundamental robotics subfields, but that, given the many specialized subfields that exist, it may not be complete.

Robot mechanics. Robot mechanics is a subfield of robotics that covers the mechanical engineering aspects of robot design. Principles of robot mechanics are involved in the development of all robots. The subfield includes the study of factors such as inertia, stress, load-carrying ability and dynamic response in the design of robot arms and grippers, transmission systems, hydraulic and pneumatic couplings and related design areas.

Robot sensing. Robotic sensing is a subfield that studies and develops techniques to give robots sensing capabilities (i.e., the ability to detect events or changes in their environment, and to send information about these events or changes to other electronics for processing). Such techniques can relate to sensor design and (pre-)processing of sensor data. Robots can have a wide variety of sensors that include cameras, microphones, accelerometers, thermometer, infrared, radar, sonar, and vibration sensors.

Robot control. Robot control is a broad subfield of robotics that deals with the application of methods and techniques from control theory in controlling the mechanical structure of robots. Robot control systems can vary greatly in complexity. Below are descriptions of a number of important subfields of robot control.

- *Robot learning.* Robot learning is a subfield of robot control that combines machine learning and robotics. It studies techniques that allow robots to acquire new skills or adapt to their environment through application of learning algorithms and/or neural networks.
- *Adaptive control.* Adaptive control is a subfield that studies how control methods employed by a control system can adapt to parameters which are changeable or are uncertain at the start. For instance, in a flying aircraft, total mass will decrease over time due to fuel consumption, thus necessitating a control law that can adapt to changing conditions like this.
- *Developmental robotics.* Developmental robotics is a subfield that studies the developmental mechanisms, architectures and constraints that allow for lifelong and open-ended acquisition of new skills and knowledge in robots. It is directly inspired by the developmental principles and mechanisms responsible for cognitive development in children.
- *Evolutionary robotics.* Evolutionary robotics is a subfield that studies methods that enable automatic incremental improvements in autonomous robots through a process akin to natural selection. Robots in this field are seen as artificial organisms that, through close interaction with their environment and without human interference, can develop their own unique skills. The best or fittest of these robots are iteratively selected and used as a basis for further diversification.
- *Cognitive robotics.* Cognitive robotics is a subfield that studies methods to endow robots with intelligent behaviour that borrow from animal cognition models rather than more traditional artificial intelligence techniques.
- *Behaviour-based robotics.* Behaviour-based robotics is a subfield that studies how to create robots that are capable of exhibit complex-appearing behaviours despite having little internal variable state to model its immediate environment. Robots developed this way are adaptable in that they require no pre-set calculations to deal with a situation, and they are reactive in that they can correct their actions directly via sensory-motor links.
- *Robotic mapping and planning.* Robotic mapping studies techniques for robots to build maps of the world and localize themselves within these maps. These maps are used in robotic (path) planning, which applies techniques in motion planning to determine how robots should move efficiently in their environment, without hitting obstacles or falling over.

Robot locomotion. Humanoid robotics is a subfield that studies the various methods that robots use to transport themselves from place to place. This involves the design of both mechanical systems and control systems. A major goal in this subfield is the development of capabilities for robots to autonomously decide how, when, and where to move. Different types of locomotion that are being studied include bipedal walking, walking with more than two legs, running, rolling, hopping, metachronal motion (i.e., wavy motion), slithering, swimming, brachiating (i.e., arm swinging).

Bio-inspired and soft robotics. Bio-inspired robotics is a subfield that studies concepts from biological systems, simplify, enhance and then apply them to the design of new robots. Both fields have contributed to the development of a branch of robotics called *soft robotics*, which deals with constructing robots out of highly compliant (i.e., flexible) materials, similar to those found in living organisms.

Humanoid robotics. Humanoid robotics is a subfield focused on developing and studying robots that resemble humans in terms of appearance (body shape) and/or behaviour. Robots may be designed to have human resemblance for functional purposes, such as for purposes of interacting with human tools and in human social environments, or for experimental reasons, such as the study of human locomotion. Usually, humanoid robots have a torso, a head, two arms and two legs, while some humanoid robots may mimic only particular parts of the human body (e.g., only the upper body). Some advanced humanoid robots have heads with faces that can replicate human facial features (e.g., human eyes and mouth) and display human-like behaviour (e.g., speech, facial gestures).

Microrobotics. Microrobotics is a subfield that focuses on creating mobile robots with characteristic dimensions of less than 1 mm, which are sometimes called “microbots”. These microbots usually feature simple designs and lack the computing power of larger robots. One of the major challenges in microrobotics is to achieve motion using a very limited power supply. Due to their simplicity and small size, however, microbots are potentially very cheap and could be used in large numbers to explore environments that are too dangerous for people or too small for people and larger robots. It is expected that microbots will be useful in applications in search and rescue, and medicine, amongst other fields.

Nanorobotics. Nanorobotics is an emerging subfield that focusses on the creation of robots the components of which are at the scale of a nanometer or close to it. Presently, research and development of such *nanomachines* is largely still in the early stages, although some simple molecular machines, including nanomotors and nanosensors, have already been tested. Useful applications of nanomachines are expected to be in nanomedicine (amongst other fields), where such miniscule robots could be injected in a person’s body to identify and eliminate cancer cells.

BEAM robotics. BEAM (Biology, Electronics, Aesthetics and Mechanics) robotics is a subfield that uses simple analogue circuits mimicking a network of biological neurons, in order to produce unusually simple robot designs. Generally, BEAM robots trade flexibility for robustness and efficiency in performing the tasks for which they are designed.

Cloud robotics. Cloud robotics is an emerging subfield that utilises cloud technologies centred on the convergence of information and communication infrastructures and shared services – including cloud computing, cloud storage and related internet technologies – in the development of robotic systems. When connected to data centres in the cloud, robots can benefit from these centres’ powerful (and relatively inexpensive) storage, computation and communication resources in the processing of data and the exchange of information with other robots. This makes it possible to build lighter, cheaper and more intelligent robots that have their “brains” in the cloud.

Swarm robotics. Swarm robotics is a subfield focused on the development of methods for the coordination of large numbers of (usually) simple robots in multi-robot systems. Researchers in the field work on the assumption that programming individual robots for interaction with one another and their environment can produce coherent and desired collective behaviours. Swarm robotics builds on the AI subfield of artificial swarm intelligence, as well as on the behavioural study of insects and other fields where swarm behaviour can be seen.

Telerobotics. Telerobotics is a subfield concerned with the control of semi-autonomous robots from a distance by means of wireless or wired communication. The field can be subdivided in two other fields: teleoperation and telepresence. Teleoperation refers to the operation of robots at a distance, while telepresence refers to capability of robots of allowing a person to feel or appear to be present at a place that is not their true location.

Social robotics and human-robot interaction. Social robotics is a fairly recent subfield focused on the study and development of autonomous robots that are capable of interacting with humans through the display of social behaviour and adherence to rules attached to their social role. On a broader level, human-robot interaction is the study of how humans interact with robots, and how best to design and implement robots capable of accomplishing interactive tasks in human environments in ways that are effective, safe and convenient for humans.

2.3 Present and future developments and challenges in AI and robotics

In this subsection, we discuss some important present and future developments and challenges for AI and robotics.

Artificial intelligence

Currently, the field of AI is developing in several important ways. One of the most significant overall developments is the continued advancement of the connectionist, data-driven paradigm. In particular, we are witnessing the maturation of neural-network-based machine learning methods and architectures, which are often supported by cloud computing resources and large-scale, web-based data gathering. It is expected that systems based on these methods and architectures will evolve to become increasingly human-aware.[31] This means that they are specifically designed for, and can accurately model, the characteristics of the people they will interact with (e.g., their mental capabilities, their personalities).

To an important degree, machine learning is being propelled forward by deep learning (see subsection 2.2). Much of the current research effort in deep learning (and machine learning in general) focuses on scaling algorithms to work with very large data sets.[32] While normal sized data sets allow for the application of traditional data analysis methods in which several complete passes are made over the data, with extremely large data sets the use of such methods becomes impractical. Often such sets can only be analysed using sublinear methods, that is, methods that only consider a comparatively small portion of the data. In addition, deep learning is making significant inroads into areas besides computer vision (e.g., object/activity recognition, video labelling), such as audio, speech and natural language

[31] IBM. "AAAI-17 Workshop: Human-Aware Artificial Intelligence (HAAI-17)," IBM, July 25, 2016. https://researcher.watson.ibm.com/researcher/view_group.php?id=7446

[32] Grosz, Barbara, Alan Mackworth, Russ Altman, Tom Mitchell, Eric Horvitz, Deidre Mulligan, and Yoav Shoham, "Artificial Intelligence and Life in 2030," September 2016. https://ai100.stanford.edu/sites/default/files/ai_100_report_0831fnl.pdf

processing. Furthermore, a specific type of machine learning called reinforcement learning is making strides, in part owing to developments in deep learning. Reinforcement learning allows machines and software agents to automatically determine the ideal behaviour within a specific context, in order to maximize their performance. The recent success of Google Deepmind's AlphaGo AI system, which beat a human Go champion in a five-game match, was in large part attributed to the use of reinforcement learning.[33]

Within machine perception, computer vision is currently one of the most prominent areas. In computer vision, the interplay of large-scale computing, the availability of large datasets (e.g., through crowdsourcing on the internet) and more refined neural network algorithms has brought dramatic performance improvements in benchmark tests.[34] Only recently have some AI systems become capable of performing some visual classification tasks (narrowly defined) better than human beings. Much of the research that is currently going on is focused on automatic image and video captioning, and great progress is being made in this area.[35]

Natural language processing (often coupled with automatic speech recognition) is another very active area of research in machine perception. Google announced in 2016 that roughly twenty percent of present mobile web search queries were done by voice,[36] and recent experiments have showcased the feasibility of real-time machine translation. Focus is now shifting towards the development of systems that move beyond the ability to react to stylized requests and can use natural conversational dialog to interact with people.

Further, a growing body of research is devoted to the study of models and algorithms for collaborative systems composed of artificial agents and humans.[37] Applications where the complementary strengths of machines and humans are brought together have been an area of significant interest. Humans may help AI systems to overcome their limitations, while intelligent agents and systems may augment human abilities and activities.

Significant research is being done on AI methods to analyse and use the huge amounts of data that result from interconnected devices that are a part of the Internet of Things (IoT). Such devices can include appliances, vehicles, buildings, cameras, and other things. Currently, these devices use a bewildering array of incompatible communication protocols, and AI methods are expected to be able to help in making the devices communicate more effectively and efficiently.

With the success of AI methods based on neural architectures, some researchers are pursuing alternative models of computing that are a better match for these methods in terms of efficiency. Presently, connectionist AI mostly employs traditional Von Neumann-based computer architectures in which there are different modules for input and output, memory and instruction-processing. In the

[33] Silver, David, and Demis Hassabis. "AlphaGo: Mastering the ancient game of Go with Machine Learning." Google Research Blog, January 27, 2016. https://research.googleblog.com/2016/01/alphago-mastering-ancient-game-of-go.html
[34] Grosz, Barbara, et al., op. cit., 2016.
[35] PetaPixel, "Google's Image Captioning AI Can Describe Photos with 94% Accuracy," PetaPixel, September 23, 2016. https://petapixel.com/2016/09/23/googles-image-captioning-ai-can-describe-photos-94-accuracy/
[36] Sterling, Greg. "Google says 20% of mobile queries are voice searches," Search Engine Land, May 18, 2016. https://searchengineland.com/google-reveals-20-percent-queries-voice-queries-249917
[37] Grosz, Barbara, et al., op. cit., 2016.

future, however, we could see neural networks being trained and executed on dedicated so-called "neuromorphic" hardware that are inspired by what is known about biological neural networks.[38]

Robotics

The field of robotics will also see a number of important trends and developments within the next twenty years. On a global level, these include the increased use of AI techniques in robots, lower development and production costs of robots and smaller dimensions for some categories of robots. As previously mentioned, AI systems are evolving to become ever more capable, and it is likely that future AI advances will also find their way into robots and enhance their capabilities. For example, next-generation machine-learning algorithms are expected to significantly improve the navigational abilities of mobile robots,[39] and give humanoid social robots more human-like expressions and reactions.[40] Lower development, production and implementation costs are expected as a result of advances in computational power and software development and networking techniques[41],and will likely enable the deployment of robots in new application areas.'[42]

Increased use of sophisticated AI techniques (e.g., machine learning, computer vision) in robots will allow them to gain ever more autonomy, especially in terms of mobility and navigation. In the medium term, we may see the maturation of fully autonomous cars and unmanned aerial vehicles that are capable of transporting people and goods in public environments. AI techniques may allow for sophisticated coordination among robots themselves (e.g., in swarms of small robots deployed in industry, the military and disaster relief) and by robots in the interaction with humans. Robots acting in public will be designed to anticipate, to some degree, the behaviour of humans around them and to take explicit decisions in situations that pose a moral dilemma (e.g., in autonomous cars).

A significant development in robotics is the increasing use of cloud storage[43] and computation in robotics.[44] As explained in subsection 2.2, robots can benefit from external data centres' powerful storage, computation and communication resources in the processing of data and the exchange of information with other robots. Cloud robotics allows for the development of lighter, cheaper and more intelligent and flexible robots, the creation of networks of intelligent, autonomous robots, and the analysis of large data sets produced by sensor rich robots (e.g., autonomous surveillance aircraft).

Another key area for growth in robotics are social robots. Advances in AI will allow for the development of robots that display increasingly complex social behaviours, such as recognizing, following and assisting humans and engaging them in natural conversation.[45] These social robots are likely to find

[38] Dent, Steve, "Intel Unveils an AI Chip That Mimics the Human Brain," Engadget, September 26, 2017. https://www.engadget.com/2017/09/26/intel-loihi-neuromorphic-chip-human-brain/
[39] Tharsus Group. "2018 Trends in Robotics," Tharsus, n.d. https://www.tharsus.co.uk/2018-trends-in-robotics/
[40] Deloitte Development LLC, "Future of Robotics Technology," Government 2020, n.d. http://government-2020.dupress.com/driver/robotics-technology/
[41] Gupta, Satyandra K. Six Recent Trends in Robotics and Their Implications," IEEE Spectrum, September 8, 2015. https://spectrum.ieee.org/automaton/robotics/home-robots/six-recent-trends-in-robotics-and-their-implications
[42] Tilley, Jonathan. "Automation, robotics, and the factory of the future," McKinsey Insights, September 2017. https://www.mckinsey.com/business-functions/operations/our-insights/automation-robotics-and-the-factory-of-the-future
[43] Gupta, Satyandra K., op. cit., 2015.
[44] Deloitte Development LLC, op. cit., 2015.
[45] KPMG Advisory. "Social Robots," KPMG, 2016. https://assets.kpmg.com/content/dam/kpmg/pdf/2016/06/social-robots.pdf

increased use in a range of domains, including healthcare, education, retail and entertainment.[46] In the short term (5 years from now), their social "dexterity" may improve to an extent that they are able to sense a person's emotional state and act as a "teammate" in solving problems in structured situations, while in the medium to long term some may have the capacity to understand a person's feelings and act as a coach to humans.[47]

A category of robots that has overlap with social robots and is expected to develop significantly in the coming years is that of collaborative robots (or co-bots). These robots are starting to be introduced in industry, where they are transforming production and manufacturing by working alongside human workers in a collaborative fashion.[48] They are designed to be small, safe, flexible and trainable, and can help in, for example, the assembly or packaging of products along a conveyor belt. Collaborative robots with significant social capabilities can also be considered social robots.

[46] Ibid.
[47] Ibid.
[48] Bernier, Catherine, "What Is a Collaborative Robot?," RobotIQ, September 20, 2013. https://blog.robotiq.com/bid/66463/What-is-a-Collaborative-Robot

3. Present and future applications

In this section, we discuss many of the products and applications that have been developed or may be developed within the fields of AI and robotics. First, subsection 3.1 offers an overview of present and future developments in AI applications based on the domain of application (e.g., transportation, finance, healthcare, education, security). Then, subsection 3.2 provides a similar overview for robotics applications.

Many developments in robotics and AI fall into both the robotics category and AI category; that is, they are examples of artificially intelligent robotics applications. To avoid repetition, such applications are exclusively discussed in subsection 3.2 on robotics applications.

It should be noted that discussing future applications of emerging technologies is a speculative endeavour, and this is especially true for such complex (relatively poorly understood) and pervasive technologies as AI and robotics. Longer anticipatory timeframes increase the level of uncertainty. Some of the anticipated applications we have referenced may not materialise within the given timeframes – if at all – even in cases where at present there seems to be a consensus. In addition, this review of applications may omit some important future applications that are currently hard to foresee. One should therefore keep in mind that this review lists future applications that at this point in time seem possible and sometimes quite likely, but are not guaranteed.

The time horizon set for inclusion of future AI and robotics applications in this study is set loosely at 20 years from present. This is considered neither a point in time too far into the future (making the analysis too speculative), nor one that is too close to the present (decreasing the anticipatory value of the analysis).

3.1 Artificial intelligence

This subsection offers an overview of important present and expected future applications of AI. Applications are discussed for the following application domains: transportation, infrastructure, healthcare, finance and insurance, security (military and law enforcement), retail and marketing, media and entertainment, science, education, manufacturing and agriculture.

Transportation

AI use in autonomous vehicles is discussed in subsection 3.2.

Present applications. Cities have been investing in AI systems connected to sensor networks that are aimed at improving the use efficiency of the limited resources in the transportation network.[49] New York City has started using a system that combines networks of video cameras, microwave sensors and pass readers to detect vehicle traffic within the city.[50] Other sensors that can be used in such networks include radar and GPS. AI methods are used in various ways to optimise transportation services such as bus and subway schedules and to track traffic conditions, enabling, for example, dynamically adjusted speed limits and smart pricing on the use of highways, high-occupancy vehicle lanes and

[49] Lohr, Steve, "Bringing Efficiency to the Infrastructure," *The New York Times*, April 29, 2009. http://nytimes.com/2009/04/30/business/energyenvironment/30smart.html

[50] Access Science Editors, "Active Traffic Management: Adaptive Traffic Signal Control," *AccessScience*, 2014. accessscience.com/content/active-traffic-managementadaptive-traffic-signal-control/BR0106141.

bridges.[51] In addition, traffic light timing can also be optimized using AI systems and sensor networks for improved traffic flow.[52] On-demand peer-to-peer ridesharing services, such as provided by Uber[53] and Lyft[54], have emerged as another significant application of AI systems (and connected sensor networks),[55] with algorithms that can match passengers to drivers in specific locations by various suitability factors.

Future applications. AI systems are likely to have increasingly significant impacts on transportation systems in major cities. Predictive models that accurately describe the movements by individuals, their preferences and their goals are expected to emerge with the growth in sensing and data processing capabilities, which may contribute to improved management of transportation services and networks in real-time.[56]

Infrastructure

Present applications. Energy companies are increasingly making use of AI technologies like machine learning as increased competition and advances in new energy technologies require solutions for problems in energy management, energy optimization, energy distribution and building automation.[57] The deployment of such technologies into the energy sector has resulted in sophisticated devices for auto-detection of energy demand and precise sensors on energy infrastructure. In addition, AI technologies are being used in water management. For example, UrbanFlood is an Internet-based early-warning system designed to gather and analyse data produced by very large sensor networks in flood defences like embankments, levees, dikes and dams. This system uses AI and real-time sensor data to quickly calculate the likelihood of dike failure, as well as potential scenarios regarding dike breaching and flood spreading.[58] Further, AI technologies are being used for crowd simulation for major events and urban planning. For example, AI-based simulation programs have been used to ensure the smooth flow of traffic in the Grand Mosque in Mecca.[59]

Major companies including Microsoft and nVidia are currently offering software platforms that use AI technology to aid cities in dealing with urban planning challenges including shrinking revenues and budget cuts, aging citizens, limited natural resources, outdated or inefficient road infrastructure, rising

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[51] Jang, Kitae, Koohong Chung, and Hwasoo Yeo, "A Dynamic Pricing Strategy for High Occupancy Toll Lanes," *Transportation Research Part A: Policy and Practice*, No. 67, 2014, pp. 69–80.

[52] Sims, Arthur G, and Kenneth W Dobinson, "The Sydney Coordinated Adaptive Traffic (SCAT) System Philosophy and Benefits," *IEEE Transactions on Vehicular Technology.* Vol. 29, No. 2, 1980, pp. 130–137.

[53] See http://uber.com for more information

[54] See http://lyft.com for more information.

[55] Meyer, Jared, "Uber and Lyft Are Changing the Way Americans Move About Their Country," *National Review*, June 7, 2016. http://nationalreview.com/article/436263/uber-lyft-ride-sharing-services-sharing-economy-are-future

[56] Grosz, Barbara, et al., op. cit., 2016.

[57] Wood, Laura, "Artificial Intelligence Market in Energy & Utilities - Forecast (2017-2022) - Research and Markets," *Business Wire*, December 29,2017. http://businesswire.com/news/home/20171229005229/en/Artificial-Intelligence-Market-Energy-Utilities---Forecast

[58] Pengel, Bob, Ludolphy Wentholt, Valeria Krzhizhanovskaya, et al., "The Urbanflood Early Warning System: Sensors and Coastal Flood Safety," 2010. http://edepot.wur.nl/197116

[59] Thankappan, Jeevan, "Saudi Uses AI for Crowd Control at Grand Mosque in Mecca," *Tahawul Tech*, December 5, 2017. http://tahawultech.com/news/saudi-uses-ai-crowd-control-grand-mosque-mecca

energy demands and regulatory requirements.[60,61] A major practical application is the measurement by such platforms of pedestrian flow and vehicle traffic, using camera data and computer vision techniques, to dynamically set appropriate traffic light behaviour, thus helping to prevent congestion and reduce pollution.

Future applications. In the future, advanced computer vision techniques may be used to gain insights that can serve as input for urban planning activities. For example, MIT's Media Lab have been developing a computer vision system that, when trained with human-produced data, can determine how safe a neighbourhood would appear for human observers by analysing photos taken of it at street-level.[62] It is expected that systems such as this will be used by cities to detect early signs of urban decay and will lead to more effective interventions.

Healthcare

AI use in robotic surgery is discussed in subsection 3.2.

Present applications. Significant applications of AI in healthcare are in clinical decision support, patient monitoring and coaching, preventative medicine, and management of healthcare systems. [56] However, current use of AI systems in these areas is still at a minimal level. Some recent successes, such as social media mining and machine learning to infer people's health risks, AI-based personal health monitoring devices (e.g., health and fitness functions on Apple's iWatch), and tele-robotics to support surgery, have clearly demonstrated the potential of using AI systems in the healthcare domain.

Future applications. It has been suggested that in the next fifteen years advances in AI – when combined with sufficient data and well-targeted systems – will lead to significant change in the cognitive tasks assigned to at least some groups of healthcare professionals.[63] Currently, physicians usually request that patients present themselves in person and provide verbal descriptions of their symptoms. The physicians will subsequently correlate the patterns against his or her knowledge of the clinical presentation of known diseases. Through the use of AI systems (e.g., virtual assistants or chatbots, equipped with natural language processing, knowledge management and sentiment analysis capabilities[64]), the physician could instead supervise the process, guiding patient input into the system through application of his or her experience and intuition and then evaluating the system's output. This would have the potential to unburden overworked physicians and generate significant cost and time efficiency improvements. Limitations and challenges for the use of such systems are presented by the continued need for hands-on supervision by physicians, which would always remain critical, and the integration of the human dimensions of care with automated reasoning processes.

In the future, smart devices such as smart phones and smartwatches may be equipped with more than just basic health and fitness monitoring capabilities. Smartwatches can currently be used to monitor a person's hearth rate, activity levels, and energy expenditure. Soon, however, they may use machine-

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[60] Please see http://enterprise.microsoft.com/en-us/industries/citynext for more information

[61] Please see http://nvidia.com/en-us/deep-learning-ai/industries/ai-cities for more information.

[62] Hardesty, Larry, "Why do Some Neighbourhoods Improve? Density of Highly Educated Residents, Rather than Income or Housing Costs, Predicts Revitalization," *MIT News*, July 6, 2017. http://news.mit.edu/2017/highly-educated-residents-neighborhoods-improve-0706

[63] Ibid.

[64] Siwicki, Bill, "AI Chatbots Might be the Money-Savers Hospitals are Looking For," *Healthcare IT* News, September 18, 2017. http://healthcareitnews.com/news/ai-chatbots-might-be-money-savers-hospitals-are-looking

learning algorithms to predict on the basis of relatively few variables (including heartrate, blood sugar, steps, etc.), whether a person has or is at risk of developing certain health conditions, including diabetes, high blood pressure and sleep apnoea.[65] Some of these devices may also be used to give traction to AI diagnosis. As IBM's Watson is already able to match recommended treatments with 99% of the cases it has been tested on, increasing the data available to this AI may very well lead to increased accuracy and faster diagnosis times compared to conventional methods of diagnosis. If effective, this will also help to reduce cost and resource constraints on existing healthcare systems[66].

Another promising area in healthcare that will gain momentum in the coming years is automated image interpretation. The use of large amounts of medical image data contained in electronic patient record systems will enable the application of large-scale machine learning techniques (e.g., deep neural networks) to train AI systems in medical image interpretation. Academic research in this area has shown that deep neural networks, when trained by large medical image data sets, can produce basic radiological findings with high reliability.[67] It is not expected that the next twenty years will bring fully automated radiology, but second-level checking by AI systems will likely lead to significant cost and time efficiency improvements in medical imaging.

AI also holds promise in the area of population health. Future AI systems can mine and analyse data contained in large electronic patient record systems to enable more fine-grained and personalized diagnoses and treatments.[68] They may have the capability to suggest treatment options based on the analysis of a medically similar cohort of patients. Somewhat farther into the future, they may also allow for the discovery of numerous genotype-phenotype connections, even at the level of individuals, thus enabling even more targeted and personalized treatment options. Machine learning may be used to examine how patients respond to medicines on a genetic level and what medicinal changes need to be made to enhance patient well-being.

Finance and insurance

Present applications. In the financial industry, AI is currently being used in a number of ways. It is used by large institutional investors in *algorithmic trading* and *high-frequency trading*, which involves the use of highly complex AI systems that can perform millions of (low-margin) trades a day without human intervention.[69] In addition, AI is used for financial market analysis. Large financial institutions have invested in AI systems (e.g., Aladdin[70], Sqreem[71], Kensho[72]) to assist with their investment practices and those of their clients. Such systems use big data, machine learning and natural language processing techniques to gather and analyse financial news, broker reports, social media feeds, and other sources, in order to assign ratings to potential investments. AI is also used in so-called *robo-advisors* that

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[65] Simonite, Tom, "AI Can Help Apple Watch Predict High Blood Pressure, Sleep Apnea," *Wired,* November 13, 2017. http://wired.com/story/ai-can-help-apple-watch-predict-high-blood-pressure-sleep-apnea/

[66] Galeon, Dom and Kristin Houser, "IBM's Watson AI Recommends Same Treatment as Doctors in 99% of Cancer Cases," *Futurism,* October 28, 2016. http://futurism.com/ibms-watson-ai-recommends-same-treatment-as-doctors-in-99-of-cancer-cases/

[67] Shin, Hoo-Chang, Holger R. Roth, Mingchen Gao, et al., "Deep Convolutional Neural Networks for Computer-aided Detection: CNN Architectures, Dataset Characteristics and Transfer Learning," *IEEE Transactions on Medical Imaging* Vol. 35, No. 5, 2016, pp. 1285–1298.

[68] Ibid.

[69] For a more detailed definition see http://investopedia.com/terms/a/algorithmictrading.asp

[70] For more information on Aladdin see: http://blackrock.com/aladdin/offerings/aladdin-overview

[71] For more information on Sqreem see: http://home.sqreem.com/home/?

[72] For more information on Kensho Global Analytics see: http://kensho.com/

provide automated financial advice and in portfolio management services. The AI systems here can tailor their advice and management services to the investment goals and the level of risk tolerance of a financial company's clients and can adjust in real-time fashion to changes in the market and modify portfolios accordingly.[73] Furthermore, AI is being used for underwriting purposes in the credit industry. Lenders are using machine learning techniques (e.g., Zest Automated Machine Learning by ZestFinance[74]) to analyse a large variety of variables – from purchase transactions to the manner in which a customer fills out a form – in order to develop risk models and assign scores to borrowers. Finally, in personal finance, several products have emerged that utilize AI to assist people with their personal finances, including optimization of their spending and saving practices.[75]

Insurance providers have also begun to use AI systems. They have automated some aspects of their claims processes to reduce costs, improve underwriting, improve customer experience and fight fraudulent claims.[76] Instead of relying on humans to manually comb through reports to catch fraudulent claims, insurers now often employ AI algorithms that can identify patterns in claims data and recognize attempts at fraud.

Future applications. In the financial industry, most market participants expect that AI will be adopted further.[77] In the future, the financial industry will see continued use of sophisticated algorithmic trading algorithms on the stock market involving an ever-greater percentage of market volume, if current trends are expected to continue.[78] In addition, AI systems will increasingly be used to generate news stories about economic statistics and company earnings results as these are released; and this information will increasingly form direct feeds into other AI systems that will trade on it. AI systems in finance may also use new sources of information, including satellite data and other big data, in making market predictions.[79] Furthermore, the use of AI in fraud and money-laundering detection, capital optimisation and portfolio management is expected to become more commonplace and develop further. In personal finance, conversational AI systems or chatbots (based on natural language processing and deep neural networks) will find use on people's smartphones, supporting natural language flows similar to what people have with their personal bankers.[80]

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[73] Faggella, Daniel, "Machine Learning in Finanace—Present and Future Applications," *TechEmergence*, March 27, 2018. http://techemergence.com/machine-learning-in-finance-applications/
[74] Arvizo, Sarah, "ZestFinance Introduces Machine Learning Platform to Underwrite Millennials and Other Consumers with Limited Credit History," *Business Wire,* February 14, 2017. http://businesswire.com/news/home/20170214005357/en/ZestFinance-Introduces-Machine-Learning-Platform-Underwrite-Millennials
[75] Kaushik, Preetam, "Is Artifical Intelligence the way Forward for Personal Finance," *Wired.* http://wired.com/insights/2014/02/artificial-intelligence-way-forward-personal-finance/
[76] Morgan, Blake, "How Artificial Intelligence Will Impact the Insurance Industry," *Forbes,* July 25, 2017. http://forbes.com/sites/blakemorgan/2017/07/25/how-artificial-intelligence-will-impact-the-insurance-industry/#5255ab2e6531
[77] Financial Stability Board, *Artificial Intelligence and Machine Learning in Financial Services*, November 1, 2017. http://fsb.org/wp-content/uploads/P011117.pdf
[78] Glant, Morton, and Robert Kissell, *Multi-Asset Risk Modeling: Techniques for a Global Economy in an Electronic and Algorithmic Trading, Academic Press,* 2014, pp. 258.
[79] Faggella, Daniel, "From Past to Future, Tracing the Evolutionary Pathj of FinTech—A Conversation with Brad Bailey, *TechEmergence*, December 2, 2017. http://techemergence.com/from-past-to-future-tracing-the-evolutionary-path-of-fintech/
[80] Chowdhry, Amit, "How Artificial Intelligence is Going to Affect the Financial Industry in 2018, Forbes, February 26, 2018. http://forbes.com/sites/amitchowdhry/2018/02/26/clinc-artificial-intelligence/#80f299f481f9

In the insurance industry, chatbots will find increased use in dealing with clients' basic question and claims, as well as in the selling of products and ensuring proper coverage of clients. [76] In addition, insurance companies' AI bots will be used to scan customers' social profiles to find pattern and trends that can improve the underwriting process (from the insurers point of view).[81] For instance, such a system could recommend lower car insurance premiums for a person that has a healthy lifestyle and a steady job, since these factors can be linked to being a safer driver. Finally, telematics (e.g., the wireless communication and subsequent analysis of driving data) is expected to be a significant area of growth.[82]

Security

Present applications. Current applications of AI in security are focused around national defence and law enforcement. For example, AI is already being utilized in law enforcement and border control by many federal agencies, and it is predicted that the use of AI in these areas will only become more ubiquitous. Current expansions to the use of AI in security include cameras and drones for surveillance and biomonitoring, algorithms to detect financial fraud, and predictive policing. Additionally, there seems to be much interest in the involvement of private corporations and R&D projects involving the data gathered from AI in security.[83] A few of the most prominent private Chinese companies in this case being Baidu, Alibaba and Tencent, and a dynamic start-up ecosystem, including iFlytek – a leader in speech recognition technology, and SenseTime – focusing on innovative computer vision, have become global leaders in AI[84]. Baidu, for instance, spent billions on R&D in AI, successfully launching its super intelligent voice interaction system DuerOS, and an advanced autonomous driving platform Apollo.[85] As a world leader in technology-surveillance, it is no surprise that China provides an apt example for dominating uses of AI in security[86].

In terms of law enforcement, scientists in Europe are currently developing a system called VALCRI, Visual Analytics for Sense-Making in Criminal Intelligence Analysis. VALCRI combines notable AI applications such as facial recognition, object recognition, and sentiment analysis to make more in-depth connections beyond what human investigators can manage[87]. Canada-based Magnet Forensics provides a more in-depth look at Machine Learning in digital forensics with their Internet Evidence Finder (IEF). IEF is a software platform that helps investigators find and analyse digital evidence across multiple sources. Its newest offering is Magnet.AI—a contextual tool that uses Machine Learning techniques to sift through data from computers and mobile devices. More specifically, Magnet.AI is

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[81] Ibid.
[82] Ibid.
[83] Kania, Elsa B., "Battlefield Singularity: Artificial Intelligence, Military Revolution, and China's Future Military Power", *Center for New American Security*, November 2017. http://s3.amazonaws.com/files.cnas.org/documents/Battlefield-Singularity-November-2017.pdf?mtime=20171129235804
[84] Muncaster, Phil, "Say Hello, or 你好, to China's Siri", *MIT Technology Review*, November 16, 2012. technologyreview.com/s/507416/say-hello-or-to-chinas-siri/. For more information on SenseTime, see their website: http://sensetime.com/
[85] Hempel, Jessi, "How Baidu Will Win China's AI Race—and, Maybe, the World's," *WIRED*, August 9, 2017. http://wired.com/story/how-baidu-will-win-chinas-ai-raceand-maybe-the-worlds/
[86] Deahl, Dani, "Suspect Caught in China at Music Concert After Being Detected by Facial Recognition Technology," *The Verge,* April 12, 2018. http://theverge.com/2018/4/12/17229530/china-facial-recognition-technology-suspect-music-festival
[87] Nanalyze,"8 Companies Using AI for Law Enforcement," *Nanalyze*, November 12, 2017. http://nanalyze.com/2017/11/8-companies-ai-law-enforcement/

designed specifically to assist investigators working on child exploitation cases.[88] These applications raise the ethical issues of innocent people being unjustifiably monitored, systematizing human biases, and protection of civil liberties, among others.

Future Applications. The future AI security applications are clearly geared towards the so-called "machine militaries", profoundly transforming the international landscape of security innovation. While we already see the replacement of humans by machines in life-threatening situations, like Explosive Ordinance Device (EOD) robots detecting and disabling IEDs, or Improvised Explosive Devices; in the future, humans will likely delegate all dangerous, war-fighting tasks to robotic and autonomous technologies without necessarily intervening to command decisions-making.[89] Key future applications of AI—including vulnerability monitoring, threat analysis, and cyber-defence bolstering—will be critical to the future development of cyber security.[90] Cyber offense will also experience a significant improvement by AI. Nations armed with complex AI cyber weapons, like a machine learning Advanced Persistent Threat (APT) cyber-attack, will quickly hunt system weaknesses and execute hack and attack functions.[91] Again looking at China for an example, the Chinese PLA will leverage AI to enhance its future capabilities, including in intelligent and autonomous unmanned systems; AI-enabled data fusion, information processing, and intelligence analysis; war-gaming, simulation and training; defence, offense, and command in information warfare; as well as super intelligent support to command decision-making.

On the law enforcement front, an illustrative future application can be captured by the Intel-powered AI system which can help to find missing and exploited children. Intel has already designed an enterprise data strategy using a basic machine learning model that allowed them to integrate massive volume of data from hundreds of different databases and data sources. Intel is hopeful that future models will predict where to send reports to and continue to improve by using Machine Learning algorithms to extrapolate data from past cases, in conjunction with IP addresses, phone numbers, and texts to find suspects more efficiently.[92] If prediction algorithms will be a great stride for justice, secret experiments using the same technology definitely will not be. Scandals, such as the New Orleans Police Department, who quietly used a Silicon Valley company to predict crimes, alerted that while it takes time for predictive technologies to be refined and advanced, predictive machine learning tools with access to large amount of private and sensitive data is certainly not a far-fetched futuristic sci-fi scenario.

Retail and marketing

Present applications. AI applications in retail and marketing have many overlaps. With shared goals of cost-reduction, optimization, personalization, and performativity, it is no surprise that the main overlap is within the use of *recommender systems*. Recommender systems are utilized in situations where users are required to make selections from vast amounts of potential options—be it movies,

[88] Ibid.
[89] Piazza, Bailey, "Machine Militaries: The Future of Artificial Intelligence and National Security," *Diplomatic Courier*, January 23, 2018. http://diplomaticourier.com/machine-militaries-future-artificial-intelligence-national-security/
[90] Ibid.
[91] Bailiey, op. cit, 2018.
[92] Intel, "Intel-powered AI Helps Find Missing Children", *Intel*, http://intel.com/content/www/us/en/analytics/artificial-intelligence/article/ai-helps-find-kids.html

products, events, etc.[93] Within retail, recommender systems implementing *cognitive computing* are used in chatbots providing concierge-like services for clients on the phone or online to help guide customers through purchasing decisions.[94] For marketing, the use of recommender systems takes place more within the digital environment—providing users with personalized suggestions based off of the content they have consumed on the platform as well as their browsing habits: rewinding, replaying, skipping, etc.[95]

Other notable uses of AI in retail are for delivery, customer service, and payment. AI is being used to help smooth and optimize the entire retail process from placing orders to delivery. Machine learning and language processing techniques enabling AI to act as sales assistants, combining with user data and habits to find new ways of re-engaging with customers or cross-selling products. Furthermore, combinations of these technologies, as is the case with Amazon's Echo, enables users to not only receive recommendations from an AI, but also make purchases and schedule deliveries. And with the popularization of instant-delivery (drones, autonomous delivery units, etc.), the assemblages of various AI enable consumers to have a personalized, digital shopping experience from their own home.[96]

One of the most notable current applications of AI in marketing is the use of *programmic advertising*. Programmic advertising relies upon AI to buy and sell advertising data and act as a middleman between advertisers and publishers. These AI are able to analyse, buy, sell, and exchange in real time, proving invaluable to producers in optimizing the use of consumer data. Another application that aids programmic advertising is that of data and trend forecasting—which AI also place a critical role in for marketers. Another of the most recognizable applications is that of search engines or eCommerce—using user search data combined with recommender systems to customize and push certain adverts at blanket or target demographics. AI used in conversational commerce has also generated much attention within recent years: using various applications of chatbots to let users make purchases by speaking to machine (Amazon Echo), chat (Facebook Messenger), or virtual assistant (The Northface).[95]

Future applications. The future of retail and marketing seem to be further intertwined into the future with pushes on both ends for increased integration with biometric data and increasing cross-platform marketing and retail experiences. To explain more in detail, the future of retail and marketing will likely see further integration between consumer's browsing and shopping habits across various platforms (i.e., Amazon data influencing advertising in Primark). Additionally, cross-platform data composites will be used to personalize storefront advertising and shopping guidance to each user—recognizing users through biometric data and in-store surveillance.[97]

Further advances in marketing will be improvements in hitting target-audiences, reaching new consumers, and making marketing decisions on an executive level to free up the time of human CEOs.

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[93] To learn more about Recommender systems, see this explanation: https://medium.com/recombee-blog/recommender-systems-explained-d98e8221f468
[94] Faggella, Daniel, "Artificial Intelligence in Retail—10 Present and Future Use Cases," *TechEmergence*, 2018. http://techemergence.com/artificial-intelligence-retail/
[95] Faggella, Daniel, "Artificial Intelligence in Marketing and Advertising—5 Examples of Real Traction," *TechEmergence,* 2018. http://techemergence.com/artificial-intelligence-in-marketing-and-advertising-5-examples-of-real-traction/
[96] Sonsev, Veronika, "Will AI be the Future of Retail?" *Forbes Tech,* December 15, 2017. forbes.com/sites/veronikasonsev/2017/12/15/predicting-the-future-of-retail-a-vc-perspective/#6c9941387ff1
[97] PSFK Labs, "5 AI Trends Redefining the Retail Experience," *PSFK*, 2018. http://psfk.com/2018/01/5-ai-retail-trends-redefining-experience.html

This will potentially open up a much broader field of eConsultancy.[98] Another much-anticipated advancement within marketing and advertising applications of AI is that of machine vision/image recognition for searches. This would allow users to search and find product prices and information online by snapping a picture of the object with their phone, rather than scanning a barcode.

Future advances anticipated in retail is that of more personalized shopping—with 3D-knitting progressions allowing customers to order tailored clothing on demand and delivered in real-time by drones or other autonomous delivery vehicles. Natural Language Processing techniques are also expected to provide a moral personable interaction with AI and improve their abilities to factor in more complex consumer demands without the interference of a human consultant.

Media and entertainment

Present applications. The media and entertainment industries are abound with applications of AI. Currently, the dominating goals of AI in the media industry are focused on marketing/analytics, personalization, and optimization.[99] While machine learning techniques take the lead on the most common type of AI being used in media and entertainment, other notable subcategories being utilized in conjunction with machine learning are natural language processing, information retrieval, imagine processing, crowdsourcing, and collaborative filtering. Furthermore, abstraction and recommendation algorithms are also being used to further cater towards creating a more personalized experience for the user and increasing media performativity for companies.'[100] Notable examples of AI applications in media are in targeted advertising, optimizing and ascertaining user engagement (smart filters and recommender systems), and discovering new target audiences.[101] While AI in the entertainment industry employ many of the same subcategories of AI, the goals are more oriented towards novelty, consumer engagement, adaptability. Example here are the use of AI to make more creative and challenging video game experiences and increase replay value by decreasing the predictability and increasing response variance in Non-Player Characters (NPCs).[102]

Future Applications. While it is certain that future applications of AI in media and entertainment will continue to advance in their goals of optimization, personalization, marketing, novelty, and engagement, it is hard to accurately predict the future directions of entertainment and media. After all, the content and focus of entertainment and media are around the tastes and preferences of the consumers, which change and flow over time. However, the most likely future will see more applications of AI as co-creators and even sole developers of media and entertainment content. It seems likely that this field will begin to lean towards making partners of AI, rather than using them as tools—pushing for AI to use more advanced machine learning to not only increase optimization and performativity, but to also more autonomously and actively contribute to the creation of movies,

[98] Stephen, Andrew, "AI is Changing Marketing as We Know It, and That's a Good Thing," *Forbes Network,* October 30, 2017. http://forbes.com/sites/andrewstephen/2017/10/30/ai-is-changing-marketing-as-we-know-it-and-thats-a-good-thing/#2ea5197cdc40

[99] Sennaar, Kumba, "AI in Movies, Entertainment, and Visual Media—5 Current Use-Case," *TechEmergence,* November 20, 2017. http://techemergence.com/ai-in-movies-entertainment-visual-media/

[100] "Applying AI and Machine Learning to Media and Entertainment," *Towards Data Science*, 2017. http://towardsdatascience.com/applying-ai-and-machine-learning-to-media-and-entertainment-8d3ebc4b68f7

[101] Foster, Alana, "Applying Artificial Intelligence from Production to Delivery," *IBC Tech Advances*, January 23, 2018. http://ibc.org/tech-advances/ai-transforming-media-production-/2638.article

[102] Lou, Harbring, "AI in Video Games: Toward a More Intelligent Game," *Harvard University*, August 28, 2017. http://sitn.hms.harvard.edu/flash/2017/ai-video-games-toward-intelligent-game/

music, art, and stories.'[103] Other future directions may take entertainment and media consumption outside of the digital world, and into improvements of virtual assistants in the home, especially with future developments in speech recognition and emotional analysis. Enhancements to hardware involving virtual reality and haptic feedback may also lead to a future of virtual reality being the entertainment of choice, with AI assisting in immersion and novel experiences.

Science

Present applications. The applications of AI within science are numerous. Especially when working with large (i.e., in the order of petabytes) or convoluted data, AI is able to help scientists discover connections or combinations that would otherwise be impossible to detect. The dominating type of AI applied within the scientific fields that utilize them is machine learning, and more specifically deep learning.[104] One example of this is in particle physics, where machine learning algorithms can be used to sift through data on particle showers in collision experiments to find traces of hard-to-detect never-before-seen participles—finding a needle in a haystack, essentially. The use of such methods has helped with the reconstruction and discovery of the Higgs boson in the Large Hadron Collider.[105] Large data analysis and predictions have also proven quite useful in social science—analysing user data and decisions to draw conclusions about consumer habits.[106]

Future Applications. Two fields that are due to see far more AI involvement in the future are space exploration and genomics. Space exploration is taking a particular interest in future applications of distributed AI in (robotic) swarms and computing distribution, as well as in increasing situational awareness and decision support for spacecraft.[107] Furthermore, the use of machine learning to predict astronomical phenomena like solar flares or meteor showers will also be a desirable future direction in order to save time, money and effort.[108] Additionally, AI can be combined with genomics in medical and agricultural science. Here, combining machine learning and genetic information to, for example, examine how patients respond to medicines on a genetic level, or create diagnostic techniques for monitoring and improving soil quality and maintaining healthy and sustainable agriculture practices.[109] More generally, future AI applications seem to focus on increasing the data processing power and growing the layers of data that deep learning can process.

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[103] Chu, Eric, Jonathan Dunn, and Deb Roy, et al., "AI in Storytelling: Machines as Cocreators," *McKinsey & Company Media & Entertainment*, December 2017. http://mckinsey.com/industries/media-and-entertainment/our-insights/ai-in-storytelling

[104] Appenzeller, Tim, "The AI Revolution in Science," *Science Magazine,* July 7, 2017. http://sciencemag.org/news/2017/07/ai-revolution-science

[105] Science News Staff, "AI is Changing How We do Science. Get a Glimpse," *Science Magazine,* July 5, 2017. http://sciencemag.org/news/2017/07/ai-changing-how-we-do-science-get-glimpse

[106] Faggella, Daniel, "Airbnb Machine Learning—How Data and Social Science Make it all Work," *TechEmergence,* 2017. http://techemergence.com/airbnb-machine-learning-how-data-and-social-science-make-it-all-work/

[107] Girimonte, Daniela, and Dario Izzo, *Artificial Intelligence for Space Applications*, *European Space Agency,* 2007. PDF. https://www.esa.int/gsp/ACT/doc/AI/pub/ACT-RPR-AI-2007-ArtificialIntelligenceForSpaceApplications.pdf

[108] Bourzac, Katherine, "AI in Space," *IEEE Robotics,* August 21, 2017. http://spectrum.ieee.org/tech-talk/robotics/artificial-intelligence/ai-in-space

[109] Sennaar, Kumba, "Machine Learning in Genomics—Current Efforts and Future Applications," *TechEmergence,* 2018. http://techemergence.com/machine-learning-in-genomics-applications/

Education

Present applications. Although there are many opportunities for AI to be used in education, high barriers to entry in terms of cost and effectiveness prevent widespread adoption of many possible AI applications in this field. The goals, however, of AI in education are increasing accessibility, collaboration, and flexibility and combating cost and opportunity restraints. Notable AI techniques being applied in education are machine learning, crowdsourcing, and natural language processing. The use of these techniques in conjunction allows for the creation of *Intelligent Tutoring Systems* (ITS) that can supplement face-to-face instruction and provide a more personalized learning experience. AI techniques are also used in administrative tasks of evaluation, grading, advising, and scheduling.[110,111]

Future Applications. Given that field of AI as a whole is rife with hype and sometimes large gaps between promises and reality, many of the future expectations of AI in education stand out as being more modest and pragmatic. Some of the expected future gains of AI in education will result from the use of AI techniques in conjunction with big data analytic tools and recommendation systems that are used on students' performative data. This will help educators optimize students' education trajectories by better understanding and finding learning gaps and adjusting to them, thus enhancing the potential of the students to learn by mastery of a subject more easily and build upon cumulative information more effectively. Furthermore, AI may increase experiential learning in the classroom—learning by doing—by creating a more interactive learning environment through virtual reality or other immersive techniques.[112] Rather than focusing on replacing or removing educators from their interpersonal duties, AI in the future will focus on alleviating some of the more tedious and time-consuming tasks teachers face (lesson planning, grading, scheduling, etc.) so that teachers are freer to interact with students personally.[113,114]

Manufacturing

<u>AI use in manufacturing robots is discussed in subsection 3.2</u>

Much of the use of AI techniques in the manufacturing sector centres on applications in robotics (see subsection 3.2 on robotics in industry). Outside of robotics, however, a number of trends can be distinguished in the development and use of AI systems in manufacturing. The first is the use of AI in systems for predictive maintenance of industrial equipment. Pieces large-scale industrial manufacturing equipment are beginning to be instrumented with sensors, networked with one another, and virtually modelled with accurate physics (creating so-called "digital twins"), such that they can be constantly monitored and predictive analyses can be performed on their performance.[115]

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[110] Faggella, Daniel, "Examples of Artificial Intelligence in Education," *TechEmergence*, 2017. http://techemergence.com/examples-of-artificial-intelligence-in-education/
[111] Schmidt, Adrien, "How AI Impacts Education," *Forbes*, December 27, 2017. http://forbes.com/sites/theyec/2017/12/27/how-ai-impacts-education/#5e93879c792e
[112] Rizzotto, Lucas, "The Future of Education: How AI and Immersive Tech Will Reshape Learning Forever," *Medium FuturePi*, June 23, 2017. http://medium.com/futurepi/a-vision-for-education-and-its-immersive-a-i-driven-future-b5a9d34ce26d
[113] Dickson, Ben, "How Artificial Intelligence is Shaping the Future of Education," *PCMag*, November 20, 2017. http://pcmag.com/article/357483/how-artificial-intelligence-is-shaping-the-future-of-educati
[114] Houser, Kristin, "The Solution to Our Education Crisis Might be AI," *Futurism,* December 11, 2017. http://futurism.com/ai-teachers-education-crisis/
[115] Yao, Mariya, "Future Factories: How AI Enables Smart Manufacturing," *TopBots,* October 27, 2017. http://medium.com/topbots/future-factories-how-ai-enables-smart-manufacturing-c1405f4ec0e6

This development provides the manufacturing industry with important benefits in terms of reductions in wasted labour and the risk of unexpected and undiagnosed equipment failures. A second trend is the use of AI in automated quality control. High-definition cameras are combined with computer vision analysis to immediately spot defects and identify root causes of failure in production lines, thus ensuring that expensive delays in production are kept to a minimum. A third and final trend is the use of AI in demand-driven production.[116] Consumer trends and behavioural data are increasingly fed into direct feedback loop on supply chain and manufacturing activities (e.g., through the use of smart home devices such as Amazon Echo, which produces data that feeds back into Amazon's supply chain), thus reducing the risk of over and underproduction.[117]

Agriculture

AI use in agricultural robots is discussed in subsection 3.2

Much of the use of AI techniques in the agricultural sector is focused on applications in robotics (see subsection 3.2 on robotics in agriculture). Outside of robotics, however, a number of trends can be identified in the development and use of AI systems in agriculture. The first is the use of AI in systems for crop and soil health monitoring. Deep learning systems are being developed that can identify (and help mitigate) potential defects and nutrient deficiencies in soil through the camera of a user's smartphone. An analysis of acquired image data is conducted by the deep learning system, which links patterns in the foliage with specific plant diseases, pests and soil defects.[118] A second trend is the use of AI in predictive analytics. Here, machine learning algorithms are being developed that can work with satellite data to predict weather, analyse crop sustainability and evaluate farm lands for the presence of diseases and pests. These predictions can be very localised and tailored to the needs of individual clients.[119] Somewhat farther into the future, it is expected that genomics is more widely used in agricultural applications, combining machine learning and genetic information to create diagnostic techniques to monitor and improve soil quality and maintain healthy and sustainable agriculture practices.[120]

3.2 Robotics

This subsection offers an overview of important present and expected future applications of robotics. Applications are discussed for the following application domains: transportation, security, infrastructure, healthcare, companionship, industry, discovery, service, environment and agriculture.

Transportation

Present applications. Automobiles and trucks are increasingly being equipped with more intelligent technologies, including intelligent braking and parking systems, parking systems, proximity and force sensors, navigation systems and advanced motion controls. The emergence of autonomous cars (also called driverless cars or robotic cars) and autonomous trucks goes a step further— It yields vehicles that are both intelligent and autonomous. Autonomous cars and trucks are currently still in prototyping

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[116] Ibid.
[117] Synchrono, By, "2017 Top Ten Trends in Modern Demand-Driven Manufacturing," *SupplyChain247,* June 14, 2017. http://supplychain247.com/paper/2017_top_ten_trends_in_modern_demand_driven_manufacturing
[118] Sennaar, Kumba, "AI in Agriculture—Present Applications and Impact," *TechEmergence,* November 16, 2017. http://techemergence.com/ai-agriculture-present-applications-impact/
[119] Ibid.
[120] Sennaar, Kumba, "Machine Learning in Genomics—Current Efforts and Future Applications," *TechEmergence,* 2018. http://techemergence.com/machine-learning-in-genomics-applications/

but are expected to become available for the consumer and business markets soon. In public transportation, autonomous trains and subways systems are already a reality, and have been for quite some time, although only on a small scale. Such systems are easier to implement in trains and subways than in cars and trucks because their navigation complexity is lower (as they are bound to fixed tracks).

Wheeled and legged cargo robots provide solutions for transportation of small and medium-sized cargo loads over smaller distances, up to a few kilometres. Small-sized transport robots can move loads of up to 200 kilograms.[121] Different types of warehouse robots are capable of shelf stocking and moving heavy items and have found increasing use in warehouses. Exoskeletal robots, finally, are beginning to be used to assist humans with lifting and transporting heavy cargo and equipment.

In aviation, Unmanned Aerial Vehicles (UAVs) are increasingly being used for the transportation of small shipments. In addition, UAVs are used in the analysis of urban transportation flows because of their aerial visualisation and gathering information capabilities. The increasingly pressing needs in dealing effectively and directly with road congestion can be met well by UAVs, which have found significant use in the field of traffic engineering.[122]

Future Applications. Current autonomous vehicle developers have made bold claims about the development of autonomous vehicles. Tesla, Inc., Nissan Motor Co. and BMW have promised the delivery of a completely autonomous production cars by the end of 2018, 2022 and 2021, respectively.[123,124,125] Autonomous vehicles are expected to be a major growth market. When ready for the consumer and business markets, they are expected to revolutionize ground transportation. In fully autonomous cars, users may be able to engage in work or leisure activities rather than focus their attention on the road. People will also be able to call up driverless taxis easily or share cars with groups of owners. [126] Just as Uber services having increased vehicle utilization and diminished the necessity of vehicle ownership, self-driving cars will decrease the need for individuals to own a car. The introduction of significant numbers of fully autonomous cars therefore has the potential drastically decrease the number of vehicles on the roads.

Furthermore, driverless trucks, smaller cargo robots and UAVs may revolutionize transportation of goods. Experiments with surface delivery robots and with drone-delivery services for retail stores suggest that these may start to become available in the next 5-10 years.[127] Such systems will enable rapid delivery of goods on demand. In addition, autonomous trucks will allow for faster and cheaper delivery and may be broken up into different smaller autonomous vehicles along the route so as to optimize

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[121] For examples see SMP Robotics: http://smprobotics.com/application_autonomus_mobile_robots/transport-robots/

[122] Barmpounakis, Emmanouil N., Eleni I. Vlahogianni, and John C. Golias, "Unmanned Aerial Aircraft Systems for Transportation Engineering: Current Practice and Future Challenges," *International Journal of Transportation Science and Technology,* Vol. 5, No.3, October 2016, pp. 111-122. PDF

[123] Wales, Jimmy, "Elon Musk Will Make Driverless Cars a Reality Sooner than you Think," *WIRED*, January 18, 2018. http://wired.co.uk/article/fully-autonomous-cars-are-almost-here

[124] Ma, Jie, "Nissan Plans to Introduce Fully Autonomous Driving Cars in 2022," *Bloomberg* Technology, December 6, 2017. http://bloomberg.com/news/articles/2017-12-06/nissan-plans-to-introduce-fully-autonomous-driving-cars-in-2022

[125] Muoio, Danielle, "BMW Plans to Take on Mercedes by Releasing a Fully Driverless Car by 2021," *Business Insider,* March 17, 2017. http://businessinsider.nl/bmw-to-rival-mercedes-with-level-5-driverless-car-in-2021-2017-3/?international=true&r=US

[126] Davis, Alex, "Mercedes Promises Self-Driving Taxis in Just Three Years," *WIRED*, April 2, 2017. http://wired.com/2017/04/mercedes-promises-self-driving-taxis-just-three-years/

[127] Cohn, Pamela, Alastair Green, Meredith Langstaff, and Melanie Roller, "Commercial Drones are Here: The Future of Unmanned Aerial Systems," *McKinsey & Co.*, December 2017. http://mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/commercial-drones-are-here-the-future-of-unmanned-aerial-systems

distribution processes. In the more distant future (20 years or more from now), the first autonomous air taxis for commuters and pilotless passenger jets can be expected.

Security

Present applications. Military applications of robotics are wide-reaching. Robotic systems are currently being used for reconnaissance and surveillance, combat and engagement of military targets, the location, handling and destruction of hazardous objects, search and recovery, and breaching. Reconnaissance and surveillance is mainly tasked to UAVs, but there are also ground robots with similar capabilities. For combat, many robots are equipped with remotely controlled weapons but some can operate autonomously. The Samsung SGR-A1 is a sentry robot that recognizes and targets persons and fires at them unless a proper access code is supplied through voice recognition. The Goalkeeper is a close-in weapon system for use on ships that can autonomously detect and destroy missiles, aircraft and surface vessels that are in close proximity. In addition, there are many systems on the market that are capable of handling and destroying bombs and of searching and recovering.

In policing and law enforcement, UAVs have begun to be introduced for surveillance and occasionally for dispersing crowds through the use of tear gas, paintballs or other means. Ground robots are also being used for surveillance and reconnaissance, guard duty and patrol in prisons and public places. Since security robots are capable of continuously patrolling without getting tired or needing to rest, the uninterrupted, round-the-clock robotic security duty operation has become an effective way to cut security service costs. Cooperation between mobile security robots and security officers allows for efficient allocation of human resources for in critical situations, rather than incurring the expense and burden of managing security personnel to conduct routine patrols.

Robots equipped with non-lethal weapons are capable of physically countering threats to security without the presence of a security officer on site. Bomb disposal robots have been used to safely detect and dispose explosives ordnance for over 40 years, including anything from landmines to unexploded munitions.[128] These robots are controlled by operators from a safe distance and operate as a remote presence for the bomb disposal experts. Drones that can catch drones with nets are one of the latest robotic innovations for law enforcement announced by the Organizers of the 2018 Winter Olympics in South Korea. They are a safety precaution to defeat unauthorized drones potentially used to deliver a bomb.[129]

Search & Rescue/Recovery robots play an increasingly important role in the military and in policing (including disaster relief and post-disaster reconstruction efforts). These robots are being deployed to carry out tasks normally regarded as the “three Ds”— dull, dirty and dangerous. For example, search robots could start searching in places where fire or smoke in still present or other situations where human rescuers are helpless. Small, unmanned ground vehicles could penetrate the rubble deeper than humans or canine rescuers, enabling the rescuers to find victims at a faster rate. Larger, unmanned ground vehicles could also be used for logistics purposes—alleviating disaster management burdens.

Future Applications. With advancements in robotics and remote-control systems, future robots in the security field will be increasingly adaptable to their environments. For example, there are prototypes bomb disposal robots being developed that are able to jump over walls and land on the other side.

[128] Allison, Peter Ray, “What Does a Bomb Disposal Robot Actually Do?” *BBC*, July 15, 2016. http://bbc.com/future/story/20160714-what-does-a-bomb-disposal-robot-actually-do
[129] Pettit, Harry, “Drone-Catching Drones Armed with Nets could be Used to Bolster Security at this Week’s Pyeongchang Winter Olympics,” *Dailymail*, February 6, 2018. http://dailymail.co.uk/sciencetech/article-5357575/Drone-catching-drones-armed-nets-hit-Winter-Olympics.html

Robots are also being developed that have two arms, enabling great manual dexterity, such as allowing them to open car boots and look inside. Rather than using a single robot, function-specific robots are emerging, and will operate together in teams.

Military exoskeletons of various sorts are currently being tested to help military personnel carry greater weights, run faster, and increase endurance. The defence industry demands ever-lighter gears, with ever-longer battery life, and clear advantages to the troops.[130] A skeleton similar to the popularly known "Iron Man Suit", designed to protect commandos from bullets and blasts as they bust down doors in counterterrorism missions, is currently under development.[131] In law enforcement, ground robots are being considered that can fulfil functions of arrest and detainment and show of force. One can reasonably expect that, in the soon-to-come future, at least some robots used by the police will be intelligent machines capable of using coercive force against human beings. Such police robots may decrease dangers to police officers by removing them from potentially volatile situations. Those suspected of crimes may also risk less injury if robots can assist the police in conducting safer detentions, arrests and searches.[132] They are understandably controversial, however.

Infrastructure

Present applications. The most popular robots currently in use for infrastructural applications are micro aerial vehicles (MAVs). MAVs are a type of unmanned aerial vehicles (UAV) that can be used for entertainment (consumer-grade drones), combat (military-grade drones), or, in this case, infrastructure inspection.[133] Current applications of note for MAVs are the communication sector to maintain telephone lines and cell towers, as well as provide temporary cellular "hot spots" to reduce the load on existing infrastructure or provide cell coverage to areas without. Energy companies are using MAVs to inspect power lines, wind turbines, and assess storm damage.[134] Additionally, municipalities are using MAVs to inspect the infrastructural integrity of bridges, roads, and other large structures that present many costs and risks for human inspectors.[135]

Another area of note is robots for collaborative construction. Robots in this category can aid humans in difficult or tedious building tasks. The most popular robots of this type are those created by Construction Robotics. The SAM100 (Semi-Automated Mason) works with human masons by laying lays the bricks for the masons on a construction project, while the masons work behind the machine to finish and seal the brickwork. This increases the speed and consistency of laying bricks while allowing the human mason to perform the more skilful work without fatiguing. Construction Robotics also creates another collaborative construction robot called the Mule. The Mule helps with performing heavy lifting on construction sites—preventing waste from breakage, injuries, and speed.[136] The focus for robots of this nature is to remove the tediousness of repetitive tasks and the physical harm of repetitive or heavy work, without replacing the skill of human construction workers and increasing productivity.

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[130] Marinov, Bobby, "Military Wearable Exoskeleton Research," *Exoskeleton Report,* October 3, 2016. http://exoskeletonreport.com/2016/10/military-wearable-exoskeleton-research/

[131] Machi, Vivienne, "'Iron Man' Suit on Track, but Hurdles Remain," *National Defense,* May 22, 2017. http://nationaldefensemagazine.org/articles/2017/5/22/iron-man-suit-on-track-but-hurdles-remain

[132] Joh, Elizabeth E., "Policing Police Robots," *UCLA Law Review,* 2016.

[133] Dijkshoorn, Nick, "Simultaneous Localization and Mapping with the AR.Drone," *Universiteit van Amsterdam*, July 14, 2012. PDF.

[134] Walker, Jon, "Industrial Uses of Drones—5 Current Business Applications," *TechEmergence*, July 6, 2017. http://techemergence.com/industrial-uses-of-drones-applications/

[135] UK-RAS, *Robotic and Autonomous Systems for Resilient Infrastructure*, *UK-RAS Network*, 2017. PDF.

[136] Learn more about Construction Robotics here under "Products": http://construction-robotics.com/mule/#

Future Applications. The future of infrastructural robotics is ripe with opportunities. While the push for "smart-cities" provides increasing demands for robots that can perform more particular monitoring tasks: reporting on water mains, inspecting oil pipelines, and road integrity.[137] Along with this, there are also calls for using infrastructural robotics to build "resilient cities" or "self-repairing cities." This involves increasing the capabilities of MAVs to work collaboratively with one another to not only improve the accuracy of the data collected on infrastructural integrity but also increase the quality. These improved MAVs would use 3D modelling to assess problems autonomously (rather than via camera) and increase the complexity of the assessment, like Carnegie Mellon University's Robotics Institute seeks to do with their ARIA Project.[138]

Additionally, "Perceive and Patch" and "Perch and Repair" designs are exploring the possibility for future infrastructural robots to not only find and map breakdowns of infrastructure but also *fix* the breakdowns preventatively or immediately after they occur. Potential applications for these types of robots are projected to be in pothole repair and road maintenance, pipe-repair, and bridge maintenance and repair.[139] Moreover, "Construct and Confirm" robots are envisioned to surpass the collaborative construction robots to be able to construct large and small structures autonomously using CAD models and 3D printing. One such example is MIT Media Lab's Digital Construction Platform (DCP) that uses spray foam to construct structures on-demand, at any location.[140] The infrastructural robots of the future to not only maintain and monitor existing infrastructure but to create and design new infrastructure quickly and cheaply.

It also seems entirely possible that **exosuits** will also come into use in infrastructural maintenance with their increasing popularity in industrial and healthcare applications. These exosuits will be able to reduce worker strain, improve grip strength, and allow workers to lift heavier loads and perform more strenuous tasks than before.[141] Accordingly, the goals of these exosuits also align well with the goals of infrastructural robotics as well: increase safety and infrastructural conditions with as much speed and little waste as possible. For the jobs in infrastructure that cannot be completed entirely by robots, it still seems that there is a substantial chance of robotic assistance through an exoskeleton.

Healthcare

Present applications. As one of the top two fastest growing industries for robotics, the healthcare industry has no shortage of opportunities for robot assistants and collaboration[142]. One of the most well-known robots currently in use is the da Vinci Surgical System from Intuitive Surgical that belongs to a class of robots called telerobotic assistants. These robots are used to enhance a human surgeon's capabilities in the operating room by allowing the surgeon to complete certain operations more

[137] Matthews, Kayla, "Three Ways Robots Could Improve Infrastructure in Developing Countries," *Engineering for Change*, September 10, 2017. http://engineeringforchange.org/news/robots-could-improve-infrastructure-developing-countries/

[138] More information about Carnegie Mellon's ARIA Project here: http://aria.ri.cmu.edu/about-aria

[139] Highways Reporters, "Robot Pothole Fillers Being Developed," *Transport Network*, February 11, 2015. http://highwaysmagazine.co.uk/robot-pothole-fillers-being-developed/

[140] Ackerman, Evan, "Robotic Construction Platform Creates Large Buildings on Demand," *IEEE Spectrum Robotics,* April 26, 2017. http://spectrum.ieee.org/automaton/robotics/industrial-robots/robotic-construction-platform-creates-large-buildings-on-demand

[141] Zingman, Alissa, Scott Earnest, Brian Lowe, and Christine Branche, "Exoskeletons in Construction: Will They Reduce or Create Hazards?" *Centers for Disease Control and Prevention*, June 15, 2017. http://blogs.cdc.gov/niosh-science-blog/2017/06/15/exoskeletons-in-construction/

[142] Goepfert, Jessica and Michael Shirer, "IDC Forecasts Worldwide Spending on Robotics to Reach $135 Billion in 2019 Driven by Strong Spending Growth in Manufacturing and Healthcare," *Business Wire,* February 24, 2016. http://businesswire.com/news/home/20160224005169/en/IDC-Forecasts-Worldwide-Spending-Robotics-Reach-135

quickly, with greater precision, and minimal invasion. These robots do not operate autonomously, but instead, their movements are controlled by a surgeon operator through the use of a joystick or other controller.[143] A similar type of robot called a surgical cobot (short for collaborative robot), where a surgical robot does small tasks autonomously, but closely directed and alongside a human surgeon. For instance, suturing up a cut as the surgeon controls the placement and direction intermittently [144].

Robot assistants are another prominent application for robotics in the healthcare field at the moment. These robots assist with tasks like welcoming and directing patients, delivering materials, and moving patients. The TUG robot by Aethon, for example, can autonomously transport linens, sterile materials, food, or prescriptions to hospital rooms without interference from nurses or other hospital personnel—reducing staff needed and increasing the speed of delivery.[145] To add, RIKEN and Sumitomo Riko Company Limited have designed a robot named "Robear" who can lift and move patients to save nurses from repeating this arduous task constantly.[146] For a more personal robotic experience, one can look to social robotic assistants (SARs)**.** One could take SoftBank's Pepper as an example. Pepper is a humanoid robotic hospital receptionist that can greet patients, show patients to their right location in the hospital, and speak twenty different languages[147]. Some of the notable types of AI used within SARs and other care robots are: Natural Language Processing, reasoning and diagnosis algorithms, image recognition, and machine learning to adapt to inconsistent environments.[148]

Other ongoing applications of healthcare robots have been in care facilities and homes of the elderly. These robots can play games, distribute pills, and connect elderly residents to friends and family via a screen and camera. This category of robots would be called care robots, as they are supplemental to a patient's caregiving routine. These robots are able to adapt and learn to patient behaviour to provide them a source of care and company when nurses and family are unable to.[149] Additionally, exoskeletons have also offered a robotic hand to those who are disabled or unable to walk. By sensing micromovements on the skin, some of the exosuits, like Robot Suit HAL from the Daiwa House Industry, can fluidly adapt to the patients desired movements to help them regain some mobility and autonomy.[150] These exoskeletons can also be used for rehabilitation—retraining individuals to regain mobility after strokes.[151]

Future Applications. Looking towards the future, there are many expansions for telerobotic assistants and surgical cobots projected. One of these projections is the ability to undertake and create new procedures, rather than enhance and help with existing processes. Another is increasing the distance

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[143] Anandan, Tanya M., "Robots and Healthcare Saving Lives Together," *Robotic Industries Association*, November 23, 2015. http://robotics.org/content-detail.cfm/Industrial-Robotics-Industry-Insights/Robots-and-Healthcare-Saving-Lives-Together/content_id/5819
[144] Shademan, Azad, Ryan S. Decker, and Justin D. Opfermann, et al., "Supervised Autonomous Robotic Soft Tissue Surgery, *Science Translational Medicine*, Vol. 8, No. 337, May 4, 2016, pp. 337-364.
[145] More information about Aethon's TUG here: http://aethon.com/tug/tughealthcare/
[146] Szondy, David, "Robear Robot Care Bear Design to Serve Japan's Aging Population," *New Atlas: Robotics*, February 27, 2015. http://newatlas.com/robear-riken/36219/
[147] BBC Technology, "Pepper Robot to Work in Belgian Hospitals," *BBC News: Technology,* June 14, 2016. http://bbc.com/news/technology-36528253
[148] Ashok, Asokan, "The Impact of Artificial Intelligence in Healthcare," *Medium,* August 24, 2017. http://medium.com/@Unfoldlabs/the-impact-of-artificial-intelligence-in-healthcare-4bc657f129f5
[149] Tarantola, Andrew, "Robot Caregivers are Saving the Elderly from Lives of Loneliness," *Engadget*, August 29, 2017. http://engadget.com/2017/08/29/robot-caregivers-are-saving-the-elderly-from-lives-of-loneliness/
[150] Bock, T., T. Linner, and W. Ikeda, "Exoskeleton and Humanoid Robotic Technology in Construction and Built Environment," *Intech*, 2012. http://cdn.intechopen.com/pdfs-wm/25773.pdf
[151] Louie, Dennis R. and Janice J. Eng, "Powered Robotic Exoskeletons in Post-Stroke Rehabilitation of Gait: A Scoping Review," Journal *of NeuroEngineering and Rehabilitation,* June 8, 2016. http://jneuroengrehab.biomedcentral.com/articles/10.1186/s12984-016-0162-5

in which operations can be performed—telerobotic surgeries are currently performed in close range but expanding the scope of these technologies could allow highly specialized surgeons to operate on individuals around the world. Additionally, SARs and other robot assistants are projected to continue gaining momentum as the push for fully digital hospitals to combat cost and staff limitations increase. In these digital hospitals, it is projected that robots will take care of all delivery tasks, along with monotonous or repetitive tasks like administering IVs or taking blood samples. Furthermore, integrating AI machine learning algorithms and diagnostics into surgical robots and telerobotic assistants will improve their ability to work alongside humans in major cases, but also more independently in smaller operations.[152]

Another potential area of growth in the future is that of rehabilitation and prosthesis. Robotic exoskeleton suits are currently under development to enable those with lower body paralysis to walk smoothly and to help those who have suffered a stroke recover full functionality. These are indeed improvements of performativity for existing models and prototypes of exoskeletons in healthcare. If these performative improvements to exoskeletons are combined with other advancements in AI like machine learning and motion planning, as well as the integration of companion technologies (virtual reality, for example), it seems quite likely exosuits will be more natural and precise as well. Moreover, research in robotic prosthetics is currently working on developments using neural interfacing to help give users more natural operation and motion of their prosthetic limbs.[153,154]

Another of the most prominent desires for the future of healthcare companion robots is the increasing range of expression, understanding, and connection with their human counterparts. Especially with care robots, there is an increasing demand for a robot caretaker that can take care of housekeeping tasks, be integrated within a smart home, and recognize patient problems to phone the police. It seems likely in the future care robots will be moving towards becoming live-in assistants to help with increasing cost of healthcare and qualified personnel limitations.[155] Additionally, the robotic assistants of the future are looking to have many upgrades in AI that will help them fill many more roles than what they currently do including consultations, designing treatment plans, physical assessment, and sentiment analysis/facial recognition improvements.

Companionship

Present applications. One of the most notorious applications of companion robots are sex robots. Further advanced beyond their blow-up doll predecessors, the sex robots of today can have programmable personalities, lifelike expressions, and reactions. Most notably, sex robots are designed to feel increasingly more lifelike with simulated orgasms, automated sexual positions, and a physical body that feels real to the touch. While the focus of this subset of technology is to expand the range of options for sexual partners, sex robots also provide an outlet for practicing facets of niche sexual

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[152] For more future projections about AI in medical robots, please see this link at The Medical Futurist: http://medicalfuturist.com/the-technological-future-of-surgery/

[153] Bogue, Robert, "Robots in Healthcare," *Industrial Robot: An International Journal,* Vol. *38*, No. 3. 2011, pp.218-223.

[154] To learn more about advanced prosthetics, see Johns Hopkins Applied Physics Laboratory's page "Prosthetics": http://jhuapl.edu/prosthetics/program/details.asp

[155] Outing, Steve, "Your Future Companion in Your Old Age Could be a Robot," *MarketWatch*, October 13, 2017. http://marketwatch.com/story/your-future-companion-cool-socially-adeptand-a-robot-2017-10-13

desires such as rape, paedophilia, and sex with celebrities.[156,157] The AI involved in sex robots currently is focused on machine learning and perception, with most of the dolls being controlled or given commands via phone application.[158]

Beyond the use of elderly care, robotic pets are being used for therapy to treat depression or otherwise comfort individuals of all ages. One such example of this is the PARO Seal, who encourages patient engagement and focuses on relaxing and motivating patients through haptic and audible feedback.[159] These robots are primarily there to provide reassurance and mitigate feelings of anxiety or insecurity. While not distributing medical materials or reminders, robots like PARO still fulfil a crucial role of emotional support during a patient's recovery. Furthermore, in applications in which individuals are unable to take care of an organic pet, such as in cases of dementia or at an elderly care facility, robotic pets have been shown to decrease stress and anxiety in patients and reduce the need for medications[160]. As such, even robotic pets provide similar effects to a support animal in situations which therapy animals cannot be feasibly used.

Future Applications. Advancements in the field of animal-like robots may indeed lead to the replacement of therapy dogs and guide dogs in favour of robotic ones. This also helps to offset the cost of live support animals, as well as accompany their users into more places than support animals can go.[161] Given this, the current trends for this category seem to be pushing technology to become more relatable, helpful, and emotionally and serviceably integrated within the human community. While robotic pets may still be used as toys in the future, it seems that regarding companionship, there will be a push to make robotic pets more easily able to transition between comforting and aiding. Sex robots, particularly, and other companion robots, in general, will likely be looking at continued improvements towards becoming more "realistic" corporeally, with self-lubrication and increased "real-feel." But it seems the future of companion robots will also be a bit more focused on implementing improvements in the software—creating sex and social robots that utilize natural language processing, increased range of autonomous motion, social intelligence (affective computing), and creativity in responses and actions. While these specific types of AI improvements are not directly stated, the common goals of generating a more 'natural,' 'sensual,' or 'enjoyable' experience with a robot seem to rely upon improvements in these categories.

Industry

Present applications. As one of the projected fastest growing sectors of robotics applications, industrial robots have earned a stable and steady place within ongoing and future robotics developments.[162] The primary goals of robots in the industrial sector are to increase efficiency and productivity while saving on costs and reducing to risk employees. Furthermore, there is an active component of performativity

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[156] Sharkey, Noel, Aimee van Wynsberghe, Scott Robbins, and Eleanor Hancock, *Our Sexual Future with Robots: A Foundation for Responsible Robotics Consultation Report*, 2017. http://responsible-robotics-myxf6pn3xr.netdna-ssl.com/wp-content/uploads/2017/11/FRR-Consultation-Report-Our-Sexual-Future-with-robots-1-1.pdf

[157] Vice interview and impressions of a male sex doll here: http://video.vice.com/en_us/video/male-dolls/57f41d3556a0a80f54726060

[158] For more information about the AI in sex robots, please see this link: http://realbotix.com/Harmony

[159] More information about PARO can be acquired here: http://parorobots.com/

[160] Petersen, Sandra, Susan Houston, and Huanying Qin, et al., "The Utilization of Robotic Pets in Dementia Care," *Journal of Alzheimers Disease*, Vol.55, No.2, November 19, 2017, pp.596-574. PDF.

[161] Jung, Scott, "Robotic Dogs Guide the Blind: The Future of Fetching," *Tech Innovation Intel IQ,* August 5, 2014. http://iq.intel.com/the-future-of-fetching-robotic-dogs-guide-the-blind/

[162] Glaser, April, "The Industrial Robotics Market Will Nearly Triple in Less than 10 Years," *Recode*, June 22, 2017. http://recode.net/2017/6/22/15763106/industrial-robotics-market-triple-ten-years-collaborative-robots

that accompanies the use of these robots, as they can produce more consistent products and reduce waste. Given these goals, some of the most common robot applications are in material handling, welding, finishing (sanding, sealing, milling, etc.), and assembly.[163] One such example of such a machine can be Trumpf's TruMatic 600 Fiber: a robot that is able to intelligent place parts on material for cutting, cut the parts, and process them without the intervention of a human operator.[164] Furthermore, intelligent assist devices (IADs) are being used in conjunction with fully-automated industrial robots to not only increase productivity and performance but also to reduce strain on workers. These semi-automatic robots and IADs can do tasks such as lifting and moving of heavy tasks or heavy material manipulation that present adverse health consequences on workers who perform these tasks repetitively.[165] One such example of these types of robots is the KUKA Robotics lifting robots. With strong, flexible arms, these robots can help human workers lift and move heavy materials easily. The KUKA L750 Titan F can lift and move up to 750kg and has a reach of 3600mm. This allows a much wider range of product manipulation and placement than could be safely or possibly achieve by human operators alone.[166]

Future Applications. The future of industrial robots seems to be somewhat linear. These future projects are stably focused on increasing efficiency, longevity, standardization and lowering cost, error margins, and user-friendliness.[167] Another notable push for the future of industrial robotics, similarly to infrastructural and healthcare robotics, is that of collaborative robots (cobots). Some of these cobots fall into the category of IADs, looking more towards autonomously or semi-autonomously assisting human operators in tasks such as lifting, machine cutting, or planning. One such example still being tested and refined is Audi Brussels' "Walt" cobot. Walt can recognize gestures, be aware of workers around it to increase safety, and communicate through a digital face with its operators.[168] The future for these types of cobots is to increase their abilities to sense and communicate with their human co-workers, to supplement the labour market, not replace human workers or present additional, unnecessary risks.[169] Other areas of projected advancement are those of robotic exoskeleton suits that help reduce strain and increase strength on operators. While some of the exosuits for industrial applications do not utilize robotics, it has been noted that future models will be doing just that.[170]

Discovery

Present applications. One of the most notable uses of robots for discovery is that of space exploration. The use of robots for long-term or deep space travel is paramount for space agencies, as it is too

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[163] Please see RobotWorx's list on Industrial Robot Integration for more information on the types of robots used in industrial applications. Accessed March, 2018: http://robots.com/applications
[164] More information on the TruMatic 600 Fiber can be found at Trumpf's website here: http://trumpf.com/en_INT/products/machines-systems/punch-laser-machines/trumatic-6000-fiber/
[165] American Grippers Inc., "Robotics and Automated Assembly Relieve Repetitive Strain Injury in Workers," *Robotic Industries Association: Robotics Online,* February 12, 2016. http://agi-automation.com/2016/02/robotics-and-automated-assembly-relieve-repetitive-strain-injury-in-workers/
[166] For more information on the KUKA L750 Titan F please see this page (accessed March, 2018): http://robots.com/kuka/kr-1000-l750-titan-f
[167] For more information on future goals of industrial robotics, please see this link at RobotWorx entitled "Industrial Robots and the Future": http://robots.com/blog/viewing/industrial-robots-and-the-future
[168] More information about Walt can be found here: http://flanderstoday.eu/innovation/robot-human-interaction-breakthrough-audi-brussels
[169] International Federation of Robotics, *The Impact of Robots on Productivity, Employment and Jobs*, April 2017. http://ifr.org/img/office/IFR_The_Impact_of_Robots_on_Employment.pdf
[170] Strickland, Eliza, "Ford Assembly Line Workers Try Out Exoskeleton Tech to Boost Performance," *IEEE Spectrum*, November 10, 2017. http://spectrum.ieee.org/the-human-os/biomedical/bionics/ford-assembly-line-workers-try-out-exoskeleton-tech-to-boost-performance

dangerous and expensive to send humans to achieve the same tasks. Furthermore, when sending humans into space, enough equipment and supplies need to be included for their survival as well—increasing the weight and space requirements of these vessels. Some of the most notable of space robots are Spirit and Opportunity, both rovers on Mars, using the AI driving system "Autonav" that allows them to learn and adjust to obstacles and terrains. The Curiosity rover, also on Mars, uses an AI program called "Autonomous Exploration for Gathering Increased Science" (AEGIS) that allows Curiosity to decide which pictures to take and samples to collect for humans back on earth.[171] Another ongoing application of robotics is that of deep sea exploration. Diving to difficult-to-reach areas, such as Mariana Trench, proves too dangerous for human explorers; however, robots can be built to withstand higher pressures and complete dives the human body cannot tolerate. One such robot of this kind is the *Nereus*, a hybrid vehicle that combines aspects of both remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs). While the Nereus is capable of autonomously surveying its area through sonar and camera, it also can be controlled by a human operator remotely.[172] OceanOne is also an example of a hybrid vehicle that dives to shipwrecks to collect materials and bring them back to the surface. OceanOne also employs AI-assisted collision avoidance and navigation software designed by students in the Standford Robotics Lab.[173] Outside of exploration, another use of robotics for discovery is the robots being used to gather data and spot problems in uninhabitable environments. One such environment is that of nuclear disaster sites. The robots at Fukushima had been used for five years after the disaster to provide humans with the invaluable information needed to safely contain the radiation and later clean-up the radiation. As such, the robots have primarily been used to survey damage, radiation levels, and monitor humidity and temperature.[174]

Future Applications. Especially for the future of space exploration, the further automation of robots and wider use of AI seem to be the most likely directions of advancement in this sector. By making robots more autonomous, they can conduct more research and send back more data without human guidance. Furthermore, with more autonomous robots, they can operate in conditions that do not allow for direct human control or guidance: opening up the possibility for the robots to gain data from exoplanets, in oceanic trenches, or in other inhabitable areas. In contrast to industrial and manufacturing fields, the future goals for discovery robots seem to be generating more and more autonomous robots that can gather more data, more effectively, and further away from human's direct sphere of operation.

Service

Present applications. In the food service industry, there are many applications of both robots and AI in response to increasing wages and production costs. Two of the primary applications of both robots and AI are in Kiosks, delivery, and preparation.[175] Kiosks utilize AI to provide recommendations, make menu adjustments based on the time or weather, and even provide a customer-friendly experience

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[171] Ward, Tom, "NASA: AI will Lead the Future of Space Exploration," *Futurism*, June 27, 2017. http://futurism.com/nasa-ai-will-lead-the-future-of-space-exploration/

[172] Bowen, Andrew D., Dana R. Yoerger, and Christ Taylor, et al., "The Nereus Hybrid Underwater Robotic Vehicle for Global Ocean Science Operations to 11,000m Depth," *IEEE Xplore*, June 30, 2009.

[173] Carey, Bjorn, "Maiden Voyage of Stanford's Humanoid Robotic Diver Recovers Treasures from King Louis XIV's Wrecked Flagship," *Stanford News*, April 27, 2016. http://news.stanford.edu/2016/04/27/robotic-diver-recovers-treasures/

[174] Hornyak, Timothy, "How Robots are Becoming Critical Players in Nuclear Disaster Cleanup," *Science,* March 3, 2016. sciencemag.org/news/2016/03/how-robots-are-becoming-critical-players-nuclear-disaster-cleanup

[175] Sennaar, Kumba, "Examples of AI in Restaurants and Food Services," *TechEmergence,* 2018. http://techemergence.com/ai-in-restaurants-food-services/

through chat-bot style communication algorithms.[176] Robots are currently also being employed to do tedious cooking tasks, like flipping burgers, with the help of sensors and AI-decision making. One such example of this is Flippy the burger chef employed at CaliBurgers Pasadena. Robotic applications related to the food industry is that of delivery. Autonomous delivery robots (ADRs) are used for both food delivery and delivery of other goods, delivery robots can use 3G technology paired with applications to safely bring objects to the customer's doorstep.[177] Notable uses of this technology are Domino's pizza bots and Amazon's delivery drones.

Another area of robotics in the service sector is that of domestic or personal robots. This subsection of robots takes care of household chores and assist with cleaning tasks. The most notable of these tasks currently being performed is sweeping/mopping, lawn mowing, and cleaning gutters and swimming pools. These robots are created to help save humans time from doing monotonous chores routinely to both increase aesthetic appeal and cleanliness. Municipal service robots are also rather popular: taking over tasks that are too repetitive, dirty, dangerous, or inefficient for human operators.[178] One of the areas of public service robots to highlight are robot firefighters: robots that can perform search and rescue, fire assessment, and fire suppression in situations that it is too risky or impossible for human firefighters. All of the robots currently in use for firefighting operations are controlled via a human operator, despite automatically collecting data via cameras, sensors, and rangefinders to help the driver.[179]

The use of robotics for entertainment is also a subcategory deserving of note in the service category. Walt Disney World and Disneyland leading the way with robotics used for commercial entertainment: making use of robotics for live shows, amusement park rides, and even as realistic additions to park scenery. These types of robots provide a source of realism, interactivity, immersion, and eliciting emotional responses from those who see and interact with them. These types of robots are autonomous and have programmed "personalities", in a similar technique used in other social robots.[180] Another area of entertainment in robotics is that of personal entertainment: toys. Robot toys are robots designed for personal amusement and employee a pretty diverse range of features. Robot types can be static or mobile. Some of the smarter ones employ gesture and facial recognition and learning algorithms (so, not directly employing AI per se, but employing similar techniques). Some of these robots also have a personality programmed and can change personality based on interactions with their owners[181], like Sphero's BB8 or R2D2.[182]

Future Applications. The overall future goals for the service industry seem to be quite similar across the board: increasing efficiency, expanding ways of interacting and communicating with humans, improving sensors and capabilities. In the domestic sphere, creating robots that can achieve some of

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[176] Walker, Jon, "Fast Food Robots, Kiosks, and AI: Use Cases from 6 Restaurant Chain Giants," *TechEmergence*, January 27, 2018. http://techemergence.com/fast-food-robots-kiosks-and-ai-use-cases/

[177] Espinoza, Javier, "Delivery Robots Hit the Streets, but Some Cities Opt Out," *Financial Times*: *Artificial Intelligence and Robotics,* January 31, 2018. http://ft.com/content/0a2a5a76-e0ea-11e7-a0d4-0944c5f49e46

[178] Open Access: Government, "Rise of the Robots in the Public Sector," *Adjacent Digital Politics LTD*, December 15, 2017. http://openaccessgovernment.org/rise-robots-public-sector/40598/

[179] Lattimer, Brian Y., "Robotics in Firefighting," *SFPE*: *Emerging Trends in Engineering*, 2015. http://sfpe.org/?page=fpe_et_issue_100

[180] Panzarino, Matthew, "Disney has Begun Population its Parks with Autonomous, Personality-Driven Robots," *TechCrunch,* February 8, 2018. http://techcrunch.com/2018/02/08/disney-has-begun-populating-its-parks-with-autonomous-personality-driven-robots/

[181] For more examples of toy robots, please see: http://techadvisor.co.uk/feature/digital-home/best-robots-2018-3652561/

[182] As a side note, sex robots and pet robots may very well fall into the entertainment category as well. However, since the primary reason behind purchasing sex or pet robots is beyond "having fun" or "play", we will limit the discussion here to robots whose primary role is entertainment or amusement.

the more complicated tasks, like washing dishes or doing laundry, seems to be the next likely direction. Most of the difficulties of this come from being able to make judgments about differently sized, shaped, or coloured objects more accurately. Furthermore, in the future, there will more than likely be more integration and cooperation between the various household robots themselves, as smart homes are also projected to be more popular in the future.[183] Other improvements to be made, especially to mobile robots in the service industry is the continued improvement of sensors and "map awareness" to be able to integrate a bit more fluidly with humans. Especially with delivery robots or robotic chefs, being able to sense other people and even animals accurately, and adjust based on human action, is crucial to carrying out their tasks safely and effectively.

Robots in the public service sector are also projected to become more complex and integrate AI for enhanced communication and machine learning. The main reason for doing so is to use robots within more human resource positions. In the future, it seems that intelligent personal assistants will be in high demand, especially in public sectors such as tax management, social security, or other positions that have strong paperwork and filing components. As such, future robotics applications within the service sector will also be trying to employ more AI deep learning to increase the range tasks robots can manage.[184] As such, potential future jobs for these robots are in libraries, courts, and train stations.[185] The future projections for the toy and entertainment industry seem to be the one rife with uncertainty. In some aspects, it seems that the "just a toy" industry is falling out of favour for companion and care robots: robots that can be "played" with, but also perform other helpful or utility-driven functions.[186] One other area of growth for entertainment could be the advancing use of AI in video games to develop a more challenging, robust, or unpredictable experience. Robotics in virtual reality applications, perhaps even for gaming in virtual reality, may also be an application seen in the future.[187]

Environment

Present applications. Environmental robots are robots that fill the needs of protecting the environment or assisting with improving or eliminating human activities that are harmful to the environment. One such example of this practice is robotics in horticulture. The horticultural industry is faced with high labour costs, changing treatment variables, delicate plants, and high demand for more products grown more efficiently.[188] Some of the notable things that horticultural robots can do through the use of AI is plant and weed identification, collision avoidance, foreign substance detection, and mapping tree and plant locations. There are also robots[189] that are capable of sorting and differentiating between flowers

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[183] For more on future applications of domestic robots, please see SwanRobotics' discussion on Domestic Robots: http://swanrobotics.com/robot-applications/domestic_robot/

[184] Guardian Cities, "The Automated City: Do we Still Need Humans to Run Public Services?" *The Guardian,* 2016. http://theguardian.com/cities/2016/sep/20/automated-city-robots-run-public-services-councils

[185] For more information on future-projections of service robots, please see Sanbot's page on "Public Service": http://en.sanbot.com/industrial/public-service

[186] van Hooijdonk, Richard, "Will Robots be our Kids' Future Toys, Teachers, and Companions?" August 3, 2016. http://richardvanhooijdonk.com/en/will-robots-kids-future-toys-teachers-companions/

[187] Lou, Harbing, "AI in Video Games: Toward a More Intelligent Game," *Harvard University*, August 28, 2017. http://sitn.hms.harvard.edu/flash/2017/ai-video-games-toward-intelligent-game/

[188] Pekkeriet, E.J. and E.J. van Henten, E.J., "Current Developments of High-Tech Robotic and Mechatronic Systems in Horticulture and Challenges for the Future," *Greenhouse Technology Group*: *Wageningen University*, 2011. http://edepot.wur.nl/169021

[189] Hollick, Victoria, "Leading the Way in Horticultural Robotics," *University of Sydney*, October 6, 2016. http://sydney.edu.au/news-opinion/news/2016/10/06/horticultural-robotics-centre-will-revolutionise-aussie-farming.html

and pulling weeds.'[190] Other important uses of robotics in horticulture is that of pollination: robots like the QuadDuster can distribute pollen more quickly and effectively than human counterparts and act as collaborative robots within this industry.

Another application of robots in the environment is that of waste management and removal. Similar to the domestic robots, some of the environmental robots can detect and remove waste. A Waste Shark, developed by RanMarine, is called a sea drone, a class of unmanned surface vehicles (USVs) that is designed to help remove human waste (plastic, strings, other small trash) from the ocean[191]. While finding the resources to find and employ human clean-up crews for the menial task of taking wrappers out of the ocean proves to be a bit challenging, these robots can help resolve this issue with low costs and high efficiency. There are also robots that help to monitor oil spills. A robot called the SeaGlider monitors the water conditions, toxicity, and salinity, to inform human workers about the nature and scope of the oil spill. This type of robot is considered an Autonomous Underwater Vehicle (AUV). Other applications of robotics in this sense also include: maintaining reef integrity, planting trees, and monitoring global warming conditions (air quality, toxicity, etc.).[192,193]

Future Applications. The increase of autonomy and the creation of automatable environmental tasks seems to be the two most prominent goals in the future of environmental robotics. As many of the problems currently faced environmentally – pollination, soil integrity, and waste management/control – have either been provided by the environment or ignored by humans long enough to cause problems. As such, human labour for such tasks has not been needed or desired until this point, so the future of environmental robots is not to take-over or collaborate on human jobs, but to replace environment jobs or create new jobs. One of which prominently seems to be pollination—with the discussion of pollination being carried out by autonomous drones in the future.[194] Especially in horticulture, the robots of the future will also employ more AI to help robots do the more delicate or complicated tasks of assessing and functioning within a complex environment, handling and buffering very delicate products, sorting products accurately.

Agriculture

Present applications. The majority of the current applications of robotics in agricultural applications are focused around the optimization and automation of commercial agriculture. That is, focusing on resolving constraints on labour availability, cost of production, and time. Current applications of robotics are for weed control, fertilization, harvesting, maintenance (seeding, mowing, pruning, etc.), herding, and milking.[195,196] For private use, some of the robots available, at least on a limited scale, include robots for lawn maintenance (sprinklers) and lawn mowing (as discussed in domestic robots), as well as an "all-in-one" gardening assistant robot that does planning, planting, and maintenance to

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[190] For more information about ongoing uses of robots in horticulture, please visit: http://sciencelearn.org.nz/resources/2066-robots-for-horticulture

[191] Atherton, Kelsey D., "Meet 'Waste Shark', the Drone That's Picking up Garbage from the Oceans," *Popular Science,* September 12, 2016. http://popsci.com/waste-shark-is-garbage-collecting-sea-drone

[192] For more information on eco-robots, please see Robots in Service of the Environment's page here: http://robotsise.com/todays-eco-robots/

[193] Walker, Kris, "Environmentally Friendly Robots," *AZO Cleantech*, February 15, 2013. http://azocleantech.com/article.aspx?ArticleID=368

[194] More information about bee-drones here: http://npr.org/sections/thesalt/2017/03/03/517785082/rise-of-the-robot-bees-tiny-drones-turned-into-artificial-pollinators

[195] For more information on current agricultural robots, please see Into Robotic's article on "Robots in Agriculture". http://intorobotics.com/35-robots-in-agriculture/

[196] Owen-Hill, Alex, "Top 10 Robotic Applications in the Agricultural Industry," *RobotIQ,* August 1, 2017. http://blog.robotiq.com/top-10-robotic-applications-in-the-agricultural-industry

be controlled by an app. This small-scale robot is a part of a DIY kit that allows users to adjust it to the size of their personal garden.[197,198]

Future Applications. Some of the future improvements to agricultural robots are geared towards optimization and speed. As such, there is a continued push to advance and implement more AI techniques such as machine learning and predictive analytics.[199] By employing more AI software in these systems, it becomes possible for the agricultural robots of the future to handle more delicate crops, in more diverse environments, all while reducing the need for human intervention. Another improvement to these robots that will be seen in the future is also increased collaboration from robotic assistants. Data gathered from aerial drones can be combined with robots monitoring the soil to direct automated seeding, maintenance, and harvesting robots how to tend to the crops. This is projected to increase the yield, reduce waste, and prevent excessive strain on the environment through wasting water or overusing pesticides and fertilizer.[200] Another area that may see changes within animal processing, such as robotic butchers that automate the meat management process from slaughter to packaging.[201]

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[197] Vaqar, Ali, "GardenSpace is a New Personal Gardening Robot that Waters your Plants and Scares Away Animals," *Wonderful Engineering*, November, 2017. http://wonderfulengineering.com/gardenspace-personal-gardening-robot-waters-plants-well-protects/
[198] Kim, Gene, "This Robot Will Grow all the Food You Need in your Backyard," *Business Insider*, July 21, 2016. http://businessinsider.com/farming-robot-farmbot-automatically-grow-vegetables-backyard-garden-2016-7?international=true&r=US&IR=T
[199] Sennaar, Kumba, "AI in Agriculture—Present Applications and Impact," *TechEmergence*, November 16, 2017. http://techemergence.com/ai-agriculture-present-applications-impact/
[200] Thomas, Jim, "How Corporate Giants are Automating the Farm," *New Internationalist*, November 1, 2017. http://newint.org/features/2017/11/01/agriculture-robots
[201] Garfield, Leanna, "The World's Biggest Meat Producer is Planning to Test out Robot Butchers," *Business Insider*, October 26, 2016. http://businessinsider.com/jbs-meatpacking-testing-robot-butchers-2016-10?international=true&r=US&IR=T

4. Social and economic impacts of AI and robotics

As highlighted in the preceding, AI and robotics hold promise for aiding human beings in a wide range of endeavours. The current and expected consequences of AI and robotics need additional clarification as a step towards a more complete picture of the field. To this end, this section supplies a socio-economic impact assessment (SEIA), including environmental impacts, of artificial intelligence (AI) and robotics. This section endeavours to orientate and inspire forthcoming work in SIENNA, as well as assist others when studying the social, economic and environmental impacts.

We define SEIA as an analysis used to identify and assess the social, economic and environmental impacts of AI and robotics on society. Impacts refer to the potential changes – whether positive or negative, direct or indirect, in whole or in part – caused by or associated with the technological field under consideration. Following the European Commission's *Impact Assessment Guidelines*,[202] examples of social impacts include those affecting the protection of particular groups, equal treatment and opportunities, non-discrimination, individuals' private and family life, personal data, governance. Economic impacts include those on employment, the conduct of business, operating costs, small and medium enterprises, and financial burdens on businesses, workers, consumers and households. Environmental impacts include those affecting the climate, energy use, air quality, water quality and resources, land use, environmental consequences of firms and consumers, waste production, generation and recycling.

The central research question of this SEIA is: What are some of the main current and future social, economic and environmental impacts of AI and robotics as reported by recent literature and expert (interviewees) in the topic? As detailed below, we answer this question by identifying and assessing current and expected impacts based on information gathered from publications. We also consulted with experts in AI and robotics in order to answer this question and increase our understanding of current opinions about impacts associated with the technological field. On these bases, this SEIA offers conclusions about the ways in which it may be possible to mitigate negative impacts and maximise positive impacts. This SEIA should not be interpreted as a comprehensive empirical examination (neither in its aim, design or content) of the social, economic and environmental impacts of AI and robotics, but rather a qualitative study that can help to ground further research.

The following sub-sections comprise this SEIA. Sub-section 4.1 details this SEIA's approach. Sub-section 4.2 identifies the social, economic and environmental impacts of AI and robotics. Sub-section 4.3 offers the assessments of the impacts identified. Sub-section 4.4 sets out our conclusions regarding the mitigation of negative impacts (and maximisation of positive ones).

4.1 Approach

Our approach to this AI and robotics SEIA involved the following key steps.

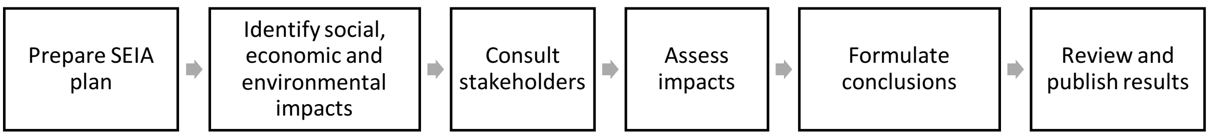

Figure 1. Steps in the SIENNA AI and robotics SEIA

[202] For detailed information and precise questions, see: European Commission, *Impact Assessment Guidelines*, 15 January 2009. http://ec.europa.eu/smart-regulation/impact/commission_guidelines/docs/iag_2009_en.pdf

Preparation

Scoping
SIENNA's Description of Action (DoA) delimits this SEIA's topic and coverage. Consequently, it broadly covers current and expected social, economic and environmental impacts of AI and robotics. Scoping occurred during SIENNA's proposal-writing phase. Our team relied on the DoA and internal team discussions in outlining this SEIA.

Design
Post-proposal preparation firstly involved designing our approach for this activity, including the SEIA's basic outline, specific methodologies and key definitions. Preparation also included the creation of materials enabling harmonised data recording and organisation amongst different researchers.

Impact identification

Search terms and searches
Our research involved a literature review on the impacts of AI and robotics. For our review, we relied on methods described by Creswell[203]. We aimed to identify contemporary research and studies that analysed social, economic and environmental impacts of AI and robotics. We carried out the identification of impacts from December 2017 to January 2018.

Given the scope of this SEIA (i.e., current and future impacts of AI and robotics), our search string queries included impact (social, economic, environmental) AND technology ("AI and robotics", "human-machine-interactions"), where the Boolean operator AND indicates a required conjunction of such terms. The complete list of search strings appears below in Table 3. The purpose and effect of such search string queries was to limit the number of results returned to those most apparently relevant. We did not rely on additional filters such as date or subject, because we found no principled reasons to exclude older studies from any field so long as they pertained to the SEIA's topic.

Search term examples	
economic impact AI and robotics	economic implications AI and robotics
economic impact human-machine interactions	economic implications human-machine interactions
social impact AI and robotics	social implications AI and robotics
social impact human-machine interactions	social implications human-machine interactions
environmental impact AI and robotics	environmental implications AI and robotics
environmental impact human-machine interactions	environmental implications human-machine interactions
impact assessment AI and robotics	impact assessment human-machine interactions
impact of AI and robotics	impact of human-machine interactions
AI and robotics human-machine interactions impact climate/biodiversity	human-machine interactions impact climate/biodiversity
negative impacts/implications/dangers/adverse consequences/risks AI and robotics	negative impacts/implications/dangers/adverse consequences/risks human-machine interactions
benefits/advantages AI and robotics	benefits/advantages human-machine interactions

Table 3. Search term examples

We chose to search for and include peer-reviewed journals, industry reports, conference presentations, working papers and media publications. We conducted searches via SSRN, Springer, ScienceDirect and Google. The choice of the search tools arose in response to the need for more

[203] Creswell, John W., *Research Design: Qualitative, Quantitative, and Mixed Method Approaches,* 4th Ed., Sage, Los Angeles, 2014, Ch. 2.

literature on the topic than initially found through academic repositories/search engines alone. Here, the choice of search tools tracks the choice to include non-peer-reviewed publications: a more expansive account of impacts. We nevertheless acknowledge that media accounts, for example, do not pass the same rigorous evaluation process as, for example, peer-reviewed publications. We scrutinised non-peer-reviewed literature to a greater extent (e.g., ensuring that the authors were recognised experts, claims made, if any, were based on cited sources).

Selection

Before selecting any piece of literature for full review and analysis, we ensured its pertinence to the SEIA's topic by adopting an inclusion/exclusion criterion that, in practice, took the form of the following question: (1) Does this piece of literature pertain to the relevant technology's (x) socio-economic [or social or economic] or environmental impact (y)? That is, variable x and y are necessary and sufficient only in conjunction.

We posed this question only after downloading and reading each result's (a) title, (b) abstract, if any, (c) introduction and (d) executive summary, if any. We excluded those pieces of literature that lacked pertinence based on our criterion. Conversely, we included literature that appeared to be pertinent. Again, we used this criterion after search queries using search strings designed to filter out irrelevant results. We collected and organised literature selected for review and analysis and then divided the task of reading publications between our team members.

Analysis and recording

We analysed and recorded each publication's description of impacts using the following process: (1) a team member read a publication; (2) the team member recorded a publication's citation in a standardised manner with the same categories of information noted by respective researchers; (3) the team member recorded a publication's identification and description of current and/or future social, economic and/or environment impacts of AI and robotics.

Although we designed the identification and data recording process during the preparation step, we adjusted and updated aspects of it during its implementation. Such adjustments were isolated to terminology used during collection and recording to present the findings more accurately. We refined the scale and terminology of various headings on the basis of the literature and consultations with experts. For example, the "likelihood of impact occurring" column required an additional data point – "currently occurring". Again, our design aim was to include findings in a harmonised and consistent way, recognising the process to be an iterative one that could change based on literature reviewed and experts consulted.

Consultations

Experts, design and aims

Our team supplemented the literature review with expert consultations – i.e., 11 semi-structured interviews. We identified interviewees using contact information collected for the SIENNA *Task 1.4 Stakeholder analysis and contact list*. Our goal at the outset was for at least 10 interviews with various types of experts in various geographic locations and academic disciplines. We endeavoured to consult as diverse a group of interviewees as possible, but we acknowledge that the number of interviews conducted only allows for an impression of what certain experts think of the impacts of AI and robotics. Our interviews do not provide a representative sample. Ultimately, we aimed to gain additional supplemental insight about the socio-economic and environmental impacts of AI and robotics through the views of individuals actively engaged in research and consideration of such topics.

We selected interviewees with knowledge and expertise in AI and robotics and their (potential) impacts. The numbers of experts and academic disciplines were as follows: 1 economist, 2 academic researchers in AI (1 assistant professor in natural language processing and 1 doctor in neuroenhancement), 2 regulators (privacy and data protection), 1 science and technology journalist, 1 senior academic researcher/professor in robotics from a related project in robotics (autonomous vehicles' systems), 2 legal experts, 1 representative from a European consumer-protection organisation and 1 academic researcher (assistant professor) in the ethics of risk.

Structure and details
Given the general aim of our consultations, we adopted a semi-structured interview methodology[204]. This methodology provides a guided structure for interviewers and interviewees to follow[205]. It also allowed for the clarification of questions, as well as follow-up and extemporaneous discussion. The opportunity for additional insights led our team away from the rigid structure of standardised interviews. Since the central research question and topic of this SEIA are clearly defined, we opted against an unstructured approach to the interviews.

Before beginning the interviews, we drafted questions (see Annex 1) that drew from EC impact guidelines. The questions focused on impacts, affected parties, costs and mitigation measures. To ensure that the questions were answerable by all experts regardless of their respective fields of expertise, we kept them brief and general. All interviews included the same questions. Again, the purpose of these interviews was to supplement our literature review.

We interviewed experts via Skype and/or phone. The average duration of each interview was 40 minutes. In accordance with SIENNA ethics requirements, we provided interviewees with project Information Sheets and obtained signed consent forms. Interview responses were summarised. We audio-recorded the interviews with the consent of interviewees. Neither interview summaries nor any interview data presented below include personal data. We deleted audio recordings after completing the interview summaries and, upon request, gave interviewees an opportunity to review the summaries.

Assessment

Overall aim
Based on the literature review, interviews and our interpretation, this portion of the SEIA summarises and synthesises the appraisals of impacts and their various qualities. The overall aim is to elucidate the identified impacts and provide a more complete picture of the ways in which they are significant. In brief, this section explicates matters connected with the when, who, where and how of impacts, as well as the changes they will bring and the ways to reduce negative impacts.

General approach to assessments
The different parts of sub-section 4.3 below provide specific assessments and details of their respective approaches; however, our general approach to assessment consisted of the following steps[206]. We qualitatively assessed the significance of impacts identified in the literature and interviews (respectively). For example, we first categorised the field from which impacts will emanate (AI, robotics or AI and robotics) as well as the nature of impacts (i.e., whether the impacts will have positive – beneficial – or negative – adverse – effects). We described and interpreted the qualities of the impacts

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[204] Lune, Howard, and Bruce L. Berg, *Qualitative Research Methods for the Social Sciences*, 9th Edition, Essex, Pearson, 2017, p. 70.
[205] Ibid, p. 67.
[206] European Commission, op cit., 2009, p. 32-42.

and their significance along additional dimensions (i.e., the application and sectors from which impacts will arise, their timing, geographical reach, effects on values, parties affected, resilience and vulnerability of affected parties and costs). We then synthesised measures proposed in publications and interviews for mitigating negative impacts.

We did not formalise the remaining steps of our approach – formulate conclusions, review and publish. The conclusions that appear in sub-section 4.4 of this SEIA rely on and draw from our synthesis of views culled from the literature and interviews, respectively. The final step of review and publication of this SEIA will occur after its completion. The next section below presents our findings during the first step of our approach – identification of impacts.

4.2 Social, economic and environmental impacts of AI and robotics: identification

Below we present the impacts of AI and robotics, grouped respectively by domain – social, economic and environmental. We also divide the impacts into separate tables according to whether they came from our literature review or from the interviews. We present those impacts interviewees identified over the course of each respective interview (i.e., interviewees identified impacts during the entire interview; thus, we do not limit identification to just one question). We removed duplicate impacts (e.g., when multiple authors and/or interviewees mentioned an impact more than once, we only listed it once in the relevant table). We also grouped similar impacts under higher order headings (e.g., multiple authors and interviewees mentioned AI and robotics' deleterious impact on privacy – whether data privacy, personal privacy etc.). Such grouping was done to avoid the proliferation of terms for equivalent impacts. After the tables, we discuss some of their content; however, more extensive consideration and substantive discussion of the impacts appear in the next sub-section and its constituent parts.

Social impacts

From the literature review

Social Impacts
Alter human interactions[207]
Alter legal and regulatory frameworks[208]
Alter moral conceptions[209]
Alter understandings of the scope and limits of analogue personhood[210]

[207] By alter, the author means both improve and diminish. Bossmann, Julia, "Top 9 ethical issues in artificial intelligence", World Economic Forum, 21 October 2016; IEEE Global Initiative for Ethical Considerations in Artificial Intelligence and Autonomous Systems, *Ethically Aligned Design: A Vision for Prioritizing Human Wellbeing with Artificial Intelligence and Autonomous Systems (AI/AS)*, version 2, 2018.

[208] Ezrachi, Ariel and Maurice E. Stucke, "Artificial Intelligence & Collusion: When Computers Inhibit Competition", Oxford Legal Studies Research Paper No. 18/2015; University of Tennessee Legal Studies Research Paper No. 267, 2015.

[209] Geraci, Robert M., *Apocalyptic AI: Visions of Heaven in Robotics, Artificial Intelligence, and Virtual Reality*, Oxford, Oxford UP, 2010; Dignum, Virginia, "Designing AI for human values", *ICT discoveries*, Special issue No. 1, 25 Sept. 2017.

[210] Burgess, J. Peter, Luciano Floridi, Aurélie Pols and Jeroen van den Hoven, *Towards a Digital Future*, European Data Protection Supervisor, Ethics Advisory Group report, 25 January 2018.

Social Impacts
Diminish individuals' control over their data[211]
Diminish privacy[212]
Improve elder care[213]
Improve healthcare[214]
Improve safety of personnel in in hazardous environments[215]
Increase bias[216]
Increase discrimination[217]
Increase harm and threat of harm from autonomous weapons[218]
Increase job losses[219]
Increase ruling class domination and wealth[220]
Increase transportation safety[221]
Prompt unintended consequences[222]

Table 4. Social impacts identified in the literature

From the interviews

Social Impacts
Diminish individuals' control over their data
Diminish pluralism in media
Diminish privacy
Improve communities through better matching of people with similar interests
Improve cybersecurity
Improve decision-making through data analytics

[211] Kania, Elsa, "The Policy Dimension of Leading in AI", Lawfare, 19 October 2017; European Data Protection Supervisor, "Artificial Intelligence, Robotics, Privacy and Data Protection", Background document for the 38th International Conference of Data Protection and Privacy Commissioners, October 2016; Edwards, Lilian and Michael Veale, "Enslaving the algorithm: from a 'right to an explanation' to a 'right to better decisions'?" draft paper, October 13, 2017.
[212] Altman, Micah, Alexandra Wood, David R. O'Brien and Urs Gasser, "Practical Approaches to Big Data Privacy Over Time", Brussels Privacy Symposium, draft paper, 6 November 2016; Pagallo, Ugo, "Robots in the cloud with privacy: A new threat to data protection?" *Computer Law & Security Report*, vol. 29, no. 5, 2013; European Data Protection Supervisor, op cit., 2016.
[213] Frey, Carl B., and Michael A. Osborne, "Technology at Work v2: The Future Is Not What It Used to Be", Citi GPS Report, 2016; Melkas, Helinä, Lea Hennala, Satu Pekkarinen, and Ville Kyrki, "Human impact assessment of robot implementation in Finnish elderly care", International Conference on Serviceology, 2016.
[214] PwC Global, *Why AI and robotics will define New Health*, June 2017.
[215] European Parliament, Ethical Aspects of Cyber-Physical System, June 2016; Pagallo, op cit., 2013.
[216] Smith, Lauren, "Unfairness By Algorithm: Distilling the Harms of Automated Decision-Making", Future of Privacy Forum, 2017; Bossmann, op cit., 2016.
[217] Smith, Lauren, op cit., 2017.
[218] Gubrud, Mark, "Why Should We Ban Autonomous Weapons?", IEEE Spectrum, 1 June 2016.
[219] Stone, Peter, Rodney Brooks, Erik Brynjolfsson, Calo, Ryan, Oren Etzioni, Greg Hager, Julia Hirschberg, Shivaram Kalyanakrishnan, Ece Kamar, Sarit Kraus, Kevin Leyton-Brown, David Parkes, William Press, AnnaLee Saxenian, Julie Shah, Milind Tambe, Astro Teller, "Artificial Intelligence and Life in 2030," Stanford University, Stanford, CA, 2016.
[220] Sterniczky, Aaron, Adam Ostolski, Ioana Banach-Sirbu, Jaakko Stenhäll, Jan Philipp Albrecht, Jaroslav Fiala, Luis Esteban Rubio, Mohssin El Ghabri, Nóra Diószegi-Horváth, Pieter Pekelharing, Tiffany Blandin "Green Observatory: Robotics and Artificial Intelligence," 2017.
[221] Hislop, Donald, Crispin Coombs, Stanimira Taneva and Sarah Barnard, "Impact of artificial intelligence, robotics and automation technologies on work", CIPD Rapid evidence review, 2017.
[222] Bossmann, op cit., 2016.

Social Impacts
Improve elder care
Improve healthcare
Improve language translation
Improve protections for workers in countries with weaker safeguards
Improve transportation safety
Improve voting security
Increase available time
Increase bias
Increase big data mining and analysis
Increase cyberwarfare
Increase discrimination
Increase harm and threat of harm from autonomous weapons
Increase job losses
Increase police profiling
Increase ruling class domination and wealth
Increase surveillance
Prompt new forms of co-operation and inclusion
Reduce repetitive tasks

Table 5. Social impacts identified in the interviews

Among other things, the above tables highlights the range of social impacts of AI and robotics. That is, AI and robotics impact many, various aspects of the social life of human beings. It bears mentioning at the outset that identifying impacts in this tabular form does not on its own indicate whether specific impacts affect all individuals and society, or whether they differentially affect certain individuals and parts of society. Such assessment appears below. However, we suggest that even without assessment of the impacts, the tables offer a useful synopsis that orientates and introduces the impacts (and their range) identified in our literature review and interviews.

Economic impacts

The tables below present the identified economic impacts.

From the literature review

Economic impacts
Accelerate economic inequality around the world[223]
Alter enterprises' organisational structures[224]
Alter industrial design processes[225]
Improve workplace relationships[226]
Increase career disruptions (i.e., multiple job changes)[227]

[223] Frey and Osborne, op cit., 2016.
[224] Dirican, Cüneyt, "The Impacts of Robotics, Artificial Intelligence on Business and Economics", *Procedia - Social and Behavioral Sciences*, Vol. 195, 3 July 2015.
[225] IEEE Global Initiative for Ethical Considerations in Artificial Intelligence and Autonomous Systems, op cit., 2018.
[226] Preimesberger, Chris, "Experts Predict How AI Will Impact Us in 2018," *eWeek*, 2017. 4 December 2017.
[227] Frey and Osborne, op cit., 2016.

Economic impacts
Increase competitiveness[228]
Increase consumer demand[229]
Increase discrimination[230]
Increase efficiency [231]
Increase job losses[232]
Increase profitability[233]
Reduce costs[234]
Reduce risk[235]
Revolutionise digital marketing[236]

Table 6. Economic impacts identified in the literature review

From interviews

Economic impacts
Alter industrial design processes
Concentrate economic power
Enhance privacy for consumer services
Improve access to retail services
Improve supply chains
Improve workplace relationships
Increase competitiveness
Increase consumer demand
Increase discrimination
Increase farming productivity (yields)
Increase job losses
Prompt tax losses
Reduce competitiveness and market share through over-reliance and investment in single technology line
Revolutionise digital marketing
Stunt technological development in poorer regions due to high capital costs of AI and robotics
Weaken trade unions

Table 7. Economic impacts identified in the interviews

[228] Arntz, M., T. Gregory and U. Zierahn, "The Risk of Automation for Jobs in OECD Countries: A Comparative Analysis", OECD Social, Employment and Migration Working Papers, No. 189, OECD Publishing, Paris, 2016.
[229] Rao, Anand S. and Gerard Verweij, *Sizing the Prize: What's the real value of AI for your business and how can you capitalise?* PwC AI analysis report, 2017.
[230] Smith, op cit., 2017.
[231] Dirican, op cit., 2015.
[232] Berriman, Richard and John Hawksworth, "Will robots steal our jobs? The potential impact of automation on the UK and other major economies", PwC global report, op cit., 2017; Arntz et al., op cit., 2016; Dirican, op cit., 2015.; UNCTAD, *Beyond Austerity: Towards a New Global Deal*, Trade and Development Report, 2017.; Hawking, Stephen, "This is the most dangerous time for our planet", *The Guardian*, 1 Dec 2016; Wisskirchen, Gerlind, Blandine Thibault Biacabe, Ulrich Bormann, Annemarie Muntz, Gunda Niehaus, Guillermo Jiménez Soler, Beatrice von Brauchitsch, "Artificial Intelligence and Robotics and Their Impact on the Workplace," The IBA Global Employment Institute, 2017; West, Darrell M., "What happens if robots take the jobs? The impact of emerging technologies on employment and public policy", Brookings Institution, 2015; Makridakis, Spyros, "The forthcoming Artificial Intelligence (AI) revolution: Its impact on society and firms", Review, Futures vol. 90, 2017.
[233] Arntz et al., op cit., 2016.
[234] Frey and Osbourne, op cit., 2016.
[235] Dirican, op cit, 2015.
[236] Orchestrate, "The impact of Artificial Intelligence & Machine Learning on the future of Marketing", 1 December 2017.

As the section's general introduction highlighted, which bears repeating and consideration here, there were multiple mentions of job losses. This impact of AI and robotics is much debated (e.g., whether the impact of AI and robotics in the workplace will result in overall job losses by substituting for human labour or whether AI and robotics will complement human labour, not leading to overall job losses)[237]. Although answering questions about net job losses (or gains) depends, at least in part, on the trajectory and implementation of AI and robotics, we found in the literature and interviews a strong indication that job losses *will* occur. If we accept this as fact, then at least some individuals will lose out to AI and robotics by altering the prospect, nature or availability of work. In section 4, we more thoroughly detail the positive and negative impacts described in the literature and interviews; however, it bears noting now that there are both beneficial and adverse economic impacts from AI and robotics.

Environmental impacts

The tables below present the identified environmental impacts.

From the literature review

Environmental impacts
Increase harm from increased robot use (their component materials generally toxic and non-biodegradable)[238]
Reduce pesticide use[239]
Reduce waste during production[240]
Reduce water and energy footprints[241]
Reduce negative effects of climate change[242]
Reduce resource-information gaps (esp. helping to understand land-use patterns and decision support)[243]
Reduce human population[244]

Table 8. Environmental impacts identified in the literature review

From the interviews

Environmental impacts
Increase energy consumption
Increase pollution through use of cars

Table 9. Environmental impacts identified in the interviews

From the literature review and interviews, we found that authors and interviewees were bullish about the beneficial impacts of AI and robotics on the environment. Whether through applications to reduce the effects of climate change or applications to diminish the need for pesticides, it seems that the quality of the environment will improve with AI and robotics. Still, this is a facile view if, for example, the negative impact of increased energy consumption undermines or outweighs the positive impacts.

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[237] For an overview of this debate, cf. Autor, David H., "Why Are There Still So Many Jobs? The History and Future of Workplace Automation" *Journal of Economic Perspectives*, vol. 29, no. 3, 2015.
[238] Parrack, Dave, "Researchers aim to build eco-friendly robots from biodegradable materials", *New Atlas*, 2 May 2012.
[239] European Parliament, Ethical Aspects of Cyber-Physical System, June 2016.
[240] Ibid.
[241] Ibid.
[242] Jibo, "Robots for a Sustainable Future", 14 July 2016.
[243] Joppa, Lucas, "How artificial intelligence could save the planet", The Guardian, 30 Jan 2017.
[244] Population Matters, "The impact of robotics on future societies", briefing paper, 1 May 2016.

Limitations and challenges in impact identification

AI and robotics are prominent topics, as (informally) evidenced by policy, academic and popular media accounts. However, the SEIA's complex topic underscores a challenge our team faced: finding, pertinent literature relating specifically to impacts. As described in the preceding methodology section, we supplemented peer-reviewed academic with a wider-range of sources, including working drafts and conference papers that directly addressed the SEIA's topic. To counteract potential quality issues, we scrutinised non-peer-reviewed publications, opting to select those focused on impacts and from known experts.

Given the diversity of sources from which we selected literature, we found (sometimes wide) variances between the depth of analyses. Some pieces of literature engage extensively with a given topic and technology, others approach the technology and/or impact casually.

In addition to variations in depth of analysis of the different pieces of literature, the authors and organisations producing such literature had various institutional motivations that may have prompted their creation. The Green Observatory report also noted this point when it described the "downplaying of the impacts depending on who authored the reports".[245]

The Green Observatory report also highlighted various authors' "infatuation with all things robotic/evangelism".[246] A 2016 report sponsored by Stanford University described "fantastic predictions"[247] about the technologies and their future impacts that some AI and robotics literature make. These features – authors' infatuation with the technology and the propensity to make fantastic predictions – represent a challenge to the description and evaluation of impacts since they require demarcation of legitimate, expected impacts and writer hyperbole.

Dignum identifies another challenge; namely, it is difficult to find consensus on the impacts of this technological field.[248] We see this challenge affecting our work in a limited respect. Consensus was never a bar by which we judged the identification or assessment of impacts. More vital to this SEIA is an overview, supported by scholarly and policy research and stakeholder-informed opinion, of the many, various impacts and their assessments. Dignum's point does, however, indicate a possible topic for future research. Researchers can explore Dignum's perspective as a research question, such as: Does expert consensus about social, economic and environmental impacts lead to more accurate predictions about them?

As highlighted in this section's introduction and consultation approach, the interviews provide opinions – learned though they may be – of a small number of individuals. More interviews with other experts could aid in developing a broader, empirics-based understanding of the impacts. Again, we provide these interviews as supplements to the literature.

[245] Sterniczky, et al., op cit., 2017.
[246] Ibid.
[247] The Stanford 2016 report states that "Contrary to the more fantastic predictions for AI in the popular press, the Study Panel found no cause for concern that AI is an imminent threat to humankind. No machines with self-sustaining long-term goals and intent have been developed, nor are they likely to be developed in the near future. Instead, increasingly useful applications of AI, with potentially profound positive impacts on our society and economy are likely to emerge between now and 2030, the period this report considers." Stone, et al., op cit., 2016.
[248] Dignum, op cit., 2017.

4.3 Assessment of impacts

In this section, we summarise and synthesise the respective views about the above-described impacts of AI and robotics. We also include our interpretations.

Category of impacts – AI, robotics or AI and robotics

The first matter considered was that of the technological field – what we call "Category" – from which the identified impacts emanate. This is, in part, a matter of terminology. As noted above, SIENNA's Description of Action (DoA) delimits this SEIA's topic and coverage – impacts of AI and robotics.

Although this SEIA abides by agreed upon terminology and definitions of AI and robotics, not all authors combined the technological fields in the same way as the SIENNA project. Consequently, we noted descriptions of impacts (in the literature) according to whether they come from AI, robotics or AI and robotics. The general conclusions that we derive from the literature is that, by and large, authors view most of the impacts as coming from AI and robotics, followed by those coming from AI alone and then those from robotics.

We add here some of our interpretation in order to help contextualise the matter of categorisation as it arose in the literature. There are clear distinctions between AI and robotics, as well as overlap between the fields: artificially intelligent robots. However, we found that authors did not always draw bright line distinctions or map out commonalities between the technological fields. For example, Rao and Verweij consider the economic impacts of AI and robotics combined (i.e., not AI and robotics as artificially intelligent robots).[249] Frey and Osborne, by contrast, focus on AI and robotics conceived of as artificially intelligent robots.[250] That is, they stay faithful to AI and robotics as only the area of overlap between fields – artificially intelligent robots. We do not present this as an indictment against any authors. Rather, we present this to acknowledge the complexity of the fields and how such complexity can affect the scope of their impacts. As Rao and Verweij's work highlights, it is possible, to present the impacts of AI and robotics combined without conflating the fields.

Classifying the responses from interviewees into the same categories (i.e., AI and robotics, AI or robotics), we found that they were generally of the view that AI and robotics was the main source from which impacts emanate. However, experts working in AI or robotics specifically, as opposed to experts in other fields who also examine AI and robotics, often drew sharp boundaries between the fields. For example, interviewees with expertise in robotics identified areas of overlap between AI and robotics but clearly delimited impacts issuing from AI or robotics. The same held true with interviewees working in AI specifically. Recognising that interviewees (as found in the literature, too) sometimes collapsed distinctions between technological fields presents a question for future research or, at least, consideration: is it common opinion that AI and robotics are equivalent technologies without many distinctions between them?

We do not endeavour to answer the above question now. Nevertheless, we view the challenges of categorisation as a potential limitation – divergent terminology or conceptions of technological fields can stymie efforts to represent and classify their social, economic and environmental impacts in accordance with distinctions between technologies.

[249] Rao and Verweij, op cit., 2017.
[250] Frey and Osborne, op cit., 2016.

Nature of the impacts

The nature of an impact refers to whether an impact is or will be positive (beneficial), negative (adverse) or positive and negative to parties (e.g., stakeholders and/or communities). The assessment of the nature of an impact represents an "all things considered" judgement, derived (respectively) from interviews and literature. Rather than lump all impacts together in the tables below, we separated impacts by domain (i.e., social, economic and environmental) to facilitate easier analysis and comparison of the impacts. Again, we offer separate tables depending on their source – the literature review or interviews. The interview table includes responses to the following question: "Do you think that AI and robotics will have beneficial or negative impacts?"

Apart from the presentation of the tables, we highlight the general value of assessing the nature of impacts. To understand and prepare for impacts, individuals and groups need some sense of whether impacts will deliver benefits, burdens or both benefits and burdens. The assessments in this sub-section offer a broad view of the nature of the impacts. Additional refinements appear below in subsequent sections.

The nature of social impacts

The following tables classify by nature the various identified social impacts.

From the literature review

Nature of impact	Social impacts
Negative	Diminish individuals' control over their data
	Diminish privacy
	Increase discrimination
	Increase harm and threat of harm from autonomous weapons
	Increase ruling class domination and wealth
Positive	Improve elder care
	Improve healthcare
	Improve safety of personnel in in hazardous environments
	Improve transportation safety
Positive and negative	Alter human interactions
	Alter legal and regulatory frameworks
	Alter moral conceptions
	Alter understandings of the scope and limits of analogue personhood
	Prompt unintended consequences

Table 10. The nature of social impacts as described in the literature (sources cited in Social Impacts table from sub-section 4.2)

From the interviews

Nature of impact	Social impacts
Negative	Diminish pluralism in media
	Diminish privacy
	Increase cyberwarfare
	Increase discrimination
	Increase harm and threat of harm from autonomous weapons
	Increase ruling class domination and wealth

Nature of impact	Social impacts
Positive	Improve cybersecurity
	Improve communities through better matching of people with similar interests
	Improve decision-making through data analytics
	Improve elder care
	Improve healthcare
	Improve language translation
	Improve voting security
	Prompt new forms of co-operation and inclusion
	Reduce repetitive tasks
Positive and negative	Increase big data mining and analysis
	Increase available time
	Increase police profiling
	Increase surveillance
	Increase available time

Table 11. The nature of social impacts as described in the interviews

The nature of economic impacts

The following tables classify by nature the various identified economic impacts.

From the literature review

Nature of impact	Economic impacts
Negative	Accelerate economic inequality around the world
	Increase career disruptions (i.e., multiple job changes)
	Increase discrimination
	Increase job losses
	Revolutionise digital marketing
Positive	Improve workplace relationships
	Increase competitiveness
	Increase consumer demand
	Increase efficiency
	Increase profitability
Positive and negative	Alter enterprises' organisational structures
	Alter product design processes

Table 12. The nature of economic impacts as described in the literature (sources cited in Environmental Impacts table from sub-section 4.2)

From the interviews

Nature of impact	Economic impacts
Negative	Accelerate economic inequality around the world
	Concentrate economic power
	Increase discrimination
	Increase job losses
	Prompt tax losses

Nature of impact	Economic impacts
	Reduce competitiveness and market share through over-reliance and investment in single technology line
	Stunt technological development in poorer regions due to high capital costs of AI and robotics
	Weaken trade unions
Positive	Enhance privacy for consumer services
	Improve access to retail services
	Improve supply chains
	Improve workplace relationships
	Increase competitiveness
	Increase consumer demand
	Increase farming productivity (yields)
Positive and negative	Alter enterprises' organisational structures
	Alter product design processes

Table 13. The nature of economic impacts as described in the interviews

The nature of environmental impacts

The following tables classify by nature the various identified environmental impacts.

From the literature review

Nature of impact	Environmental impacts
Negative	Increase harm from increased robot use (their component materials generally toxic and non-biodegradable)
Positive	Reduce pesticide use
	Reduce waste during production
	Reduce water and energy footprints
	Reduce negative effects of climate change
	Reduce resource-information gaps (esp. helping to understand land-use patterns and decision support)
	Reduce human population
	Reduce pesticide use

Table 14. The nature of environmental impacts as described in the literature (sources cited in Environmental Impacts table from sub-section 4.2)

From the interviews

Nature of impact	Environmental impacts
Negative	Increase energy consumption

Table 15. The nature of environmental impacts as described in the interviews

Based on the categorisation of impacts in each domain and separated by source – literature or interviews – there are grounds for guarded pessimism about AI and robotics: a majority of the impacts of AI and robotics are negative. A more optimistic approach to the assessments in this sub-section may be to answer the following: Which, where, when and by what means can increases in positive impacts and reductions of negative ones occur? Although we do not settle this matter, the following sub-sections offer some insights into other impacts that may assist in developing a solution.

Applications and sectors of AI and robotics with the most positive (beneficial) or negative (adverse) impact (described by interviewees)

We noticed that our literature review did not clarify a significant issue; so, we used the interviews as an opportunity to help get a sense of opinions about it. The issue: AI and robotics consist of a variety of distinct applications, yet we lacked a clear sense about which of these might yield the most positive (i.e., beneficial) or negative (i.e., adverse) impacts. Although this issue is significant because addressing it helps to complete the picture of the technological field, it can also aid stakeholders, such as policy-makers and regulators, when crafting policy and regulations. For example, if a specific application proves so odious that it consistently produces negative impacts, policy-makers will need information about that application and its impacts in order to make informed choices.

To address the above issue, we decided to gain some insight by asking interviewees the following question: “Which applications of AI and robotics do you think might have the most beneficial or adverse impacts on individuals or society?” According to interviewees, the applications with the most adverse impact on individuals and society were autonomous weapon systems. Conversely, interviewees noted medical diagnostic applications as the most beneficial for individuals and society. According to interviewees, other applications with positive impacts included autonomous cars and assistive medical applications.

We sought additional clarification from interviewees about other aspects of the most positive and negative impacts. To this end, we asked the following question: “Are there certain sectors or fields in which AI and robotics might have the most beneficial or adverse impacts?” By sector, we mean a part of an economy (e.g., service sector), and by field (as consistent throughout this report) we mean subject or area of activity (e.g., scientific field).

Based on the responses to the preceding question about applications, which highlighted the negative impact of autonomous weapons’ applications and the positive impact of medical diagnostic applications, our expectations were to receive similar opinions about the sectors and fields with the most positive and negative impacts. By and large, the interviewees’ responses seemed consistent across the two questions (i.e., the most negative impact from autonomous weapons’ applications appears to coincide with the most negative impact from the military/defence sector). However, interviewees did not always explain the reasons for their opinions. Consequently, we avoid making inferences about the relationship between interviewees’ responses to the respective questions

According to the interviewees, the military/defence sector is the one in which AI and robotics will have the most negative impact. Conversely, the healthcare sector is the one in which AI and robotics will have the most positive impact. Interviewees also expressed the view that AI and robotics will greatly benefit the automotive and educational sectors.

Timing of impacts and starting points (described by interviewees)

Preparing for and potentially mitigating negative impacts seems to depend on being able to anticipate the timing of their occurrence. So, too, does recognising and preparing for the positive impacts of AI and robotics. As our central research question underscores, this SEIA also endeavours to account for the timing of social, economic and environmental impacts.

We found that not all literature discussed the timing of impacts. For example, Pagallo described the (social) impact that robotics would have on privacy but did not specify when the impact would occur.[251] By contrast, Smith indicated that AI’s discriminatory (social) impact for certain recipients of insurance

[251] Pagallo, op cit., 2013.

and social benefits would happen in the future[252]. Still, Smith's work framed the future impact in conditional terms; namely, if no one takes action to stymie such discrimination, then it will occur. Other authors stated that the impacts of AI and robotics are currently occurring and will continue to do so into the future – Makridakis places job losses along this current—future continuum.[253] Some publications marked impacts as currently happening, as PwC did when identifying the social impact of AI and robotics to increase proactive management of healthy lifestyles[254]. We summarise the views from the literature as generally leaning towards the impacts of AI and robotics occurring now and into the future. Next, authors generally viewed the future as the starting point of AI and robotics' impacts.

We wanted to get opinions about more definite timeframes and starting points of impacts (even with the general prognoses from the literature described above). To obtain such information, we asked interviewees the following questions: (1) "Which impacts can you foresee in the next 5-10 years?" and (2) "Which impacts can you foresee in the next 20 years?"

The tables below present the interviewees' responses. We divided their answers according to starting point/timeframe of impacts, as well as the nature of the impacts (negative, positive and positive and negative).

5 to 10 years	**Negative impacts**
	• increase job losses • increase police profiling
	Positive impacts
	• increased industrial use of AI and robotics (e.g., in semi-conductors and aircraft) • substantial battlefield use of autonomous weapons systems • increased use of autonomous drones • limited use of AI in voting • more widespread use of AI retail services • increased use of autonomous vehicles • widespread instant spoken language translation • widespread use of AI and robotic personal assistants • increased use of AI and robotics in industrial design process
	Positive and negative impacts
	• widespread use of data mining/databases • widespread use of AI in finance

Table 16. Responses to "Which impacts can you foresee in the next 5-10 years?"

20 years	**Negative impacts**
	• widespread battlefield use of robots and autonomous weapons systems • substantial job losses due to automation
	Positive impacts
	• highly optimised farming solutions using AI and robotics • widespread use of domestic robots and robotic systems in homes
	Positive and negative impacts
	• Complementarity[255]

[252] Smith, op cit., 2017.
[253] Makridakis, op cit., 2017.
[254] PwC Global, op cit., 2017.
[255] Complementarity is an effect by which productivity, earnings, and demand for human labour increases because of robots in the workplace. Autor, David H., "Why Are There Still So Many Jobs? The History and Future of Workplace Automation" Journal of Economic Perspectives, vol. 29, no. 3, 2015, p. 5.

	• limited autonomous industrial manufacturing • radical changes to all interactions • widespread adoption of autonomous vehicles

Table 17. Responses to "Which impacts can you foresee in the next 20 years?"

Although the specific predictions (especially) from the above tables offer uncertain insight about the future, the interviewees' opinions at least underscore confidence in the continued existence, if not progress of AI and robotics (and the impacts they will have on society).

All told, the information in this sub-section highlights and affirms an intuition and claim about AI and robotics: the development, implementation and consequent impacts are happening now and will continue to do so into the future[256]. As the more complete picture of impacts unfolds in the subsequent assessments, and especially with respect to the suggested mitigation measures, the contemporaneous temporal dimension of impacts should be remembered. If the opinions from interviewees about the timing of impacts is accurate, then work now must continue in order to ensure that the positive impacts increase and the deleterious ones diminish.

Geographical reach of the impacts

To gain a perspective of the geographical reach of impacts – i.e., where the impacts occur or will occur – we roughly grouped semantically equivalent location terms used in the literature under common headings. For example, we found multiple terms in the literature describing the overarching and wide-reaching spread of impacts (e.g., international, global, worldwide etc.). We grouped these under the heading 'global', which we define as "distributed amongst all countries". We chose against keeping all the terms we found in order to limit the proliferation of descriptors that did not add meaningful refinement or nuance.

Based on the impacts identified in the literature review, the majority of impacts occur (or will occur) globally. The next most common heading, which admittedly is not a place, was "Not described". This heading refers to those authors (and their publications), for example Dirican[257], that did not indicate where an impact occurs or will occur. On occasion, publications made fine-grained distinctions about the impacts' geographical reach. The United States and China received special attention. Authors such as Kania[258] and Ezrachi et al.[259] view these two countries as major forces behind AI and robotics and thus the sites of many of their impacts. It should be noted, however, that some fine-grained distinctions about the geography of impacts reflect the subject of authors' investigations, rather than exhaustive analysis about the full geographical extent of impacts. For example, Melkas et al. examine the implementation and impact of robotics on eldercare in Finland[260].

Other literature-based descriptions of the geographical reach of impacts in the literature, however, indicate less precision in identifying exactly where or which countries will feel impacts. For example, some authors acknowledge the global reach of impacts but nevertheless see unequal geographical distributions and do not specify precise locations (e.g., "Global – various countries differentially" — meaning the effects will distribute unevenly through the world).

[256] Brynjolfsson, Erik, Andrew McAfee, Jeff Cummings, *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*, WW Norton, New York, 2014, chs. 2-4.
[257] Dirican, op cit., 2015.
[258] Kania, op cit., 2017.
[259] Ezrachi and Stucke, op cit., 2015.
[260] Melkas, et al., op cit., 2016.

We asked interviewees the following question about the "geography of impacts": "How far and wide, geographically, could individuals and communities feel the impacts?" Interviewees' responses showed that they believe, by and large, that the impacts of AI and robotics will be global in reach. However, interviewees also identified specific countries that will be greatly impacted. Interviewees noted that the United States and China stand to gain from AI and robotics, as do smaller countries such as Estonia, whose economy can nimbly adapt and integrate the AI and robotics and their impacts. Interviewees focussed attention on the negative impacts that AI and robotics will bring to poorer regions and countries of the world. In this regard, the concentration of beneficial impacts was seen as staying with wealthy nations, while adverse impacts reach the poorer, less-developed regions and countries.

Although the majority view about the global reach of impacts roughly fits with our expectations, the "Global – various countries differentially" heading seems the most intuitively plausible. In this sense, even if the majority of impacts have a worldwide spread, their respective extents would, in general, distribute differentially across countries. Our intuition, however, seems misplaced according to the numbers from our analysis.

Effects of impacts on values

This section details whether and which impacts of AI and robotics support (or enhance) or diminish (or undermine) community and/or society values. Furthermore, we indicate the values impacted by AI and robotics that authors or interviewees saw as being enhanced or diminished by specific impacts. To ascertain interviewees' views about the impacts' effects on values, we asked the following question: "Will the impacts support or undermine the affected communities' or societal values?"

Understanding the effects on values that AI and robotics will have is important both to help evaluate the use of AI and robotics applications and to inform their responsible design and development. This also could help provide some insight into the trade-offs that might emerge when values compete with each other (e.g., autonomy and safety)[261] or when decisions need to be made about prioritising funding or implementing regulation to protect the values that need to be safeguarded.

Social impacts – effects on values

The tables below show the key values that will be affected by the social impacts of AI and robotics.

From the literature review

Affected values	Examples of related identified impacts
Accountability	Alter legal and regulatory frameworks
Autonomy	Diminish individuals' control over their data Increase job losses
Democracy	Increase bias Increase discrimination Increase ruling class domination and wealth
Equality	Increase bias Increase discrimination Increase ruling class domination and wealth
Fairness	Increase bias Increase discrimination Increase ruling class domination and wealth

[261] A full discussion is not within the scope of this limited exercise but might fall within the ethical impact analysis during the later stages of the SIENNA project.

Affected values	Examples of related identified impacts
Human dignity	Increase bias Increase discrimination Increase harm and threat of harm from autonomous weapons Improve elder care Improve healthcare
Justice	Alter legal and regulatory frameworks Increase bias Increase discrimination Increase ruling class domination and wealth
Physical integrity (safety)	Improve elder care Improve healthcare Improve safety of personnel in in hazardous environments Improve transportation safety Increase harm and threat of harm from autonomous weapons Increase job losses
Integrity of property (security)	Increase harm and threat of harm from autonomous weapons Increase job losses
Privacy	Diminish individuals' control over their data Diminish privacy
Social relations, solidarity and cohesion	Alter human interactions Alter moral conceptions Alter understandings of the scope and limits of analogue personhood Increase job losses Increase ruling class domination and wealth

Table 18. Social impacts – effects on values – as appearing in the literature (sources cited in Social Impacts table from sub-section 4.2)

From the interviews

Affected values	Examples of related identified impacts
Autonomy	Increase job losses
Democracy	Improve voting security Increase bias Increase discrimination Increase ruling class domination and wealth Prompt new forms of co-operation and inclusion
Equality	Improve voting security Increase bias Increase discrimination Increase ruling class domination and wealth Prompt new forms of co-operation and inclusion
Fairness	Improve voting security Improve protections for workers in countries with weaker safeguards Increase bias Increase discrimination Increase police profiling Increase ruling class domination and wealth Prompt new forms of co-operation and inclusion
Justice	Improve voting security Improve protections for workers in countries with weaker safeguards Increase bias Increase discrimination Increase police profiling Increase ruling class domination and wealth Prompt new forms of co-operation and inclusion
Physical integrity (safety)	Improve elder care

Affected values	Examples of related identified impacts
	Improve healthcare Increase cyberwarfare Increase harm and threat of harm from autonomous weapons Increase job losses Increase police profiling
Integrity of property (security)	Improve cybersecurity Increase cyberwarfare Increase harm and threat of harm from autonomous weapons Increase job losses Increase police profiling
Pluralism	Diminish pluralism in media
Privacy	Increase big data mining and analysis Increase surveillance Diminish privacy
Social relations, solidarity and cohesion	Improve communities through better matching of people with similar interests Increase available time Improve language translation Increase job losses
Well-being	Improve decision-making through data analytics Reduce repetitive tasks

Table 19. Social impacts – effects on values – as appearing in the interviews

Economic impacts – effects on values

The tables below show the key values that will be affected by the economic impacts.

From the literature review

Affected values	Examples of related identified impacts
Competitiveness	Accelerate economic inequality around the world Alter enterprises' organisational structures Alter industrial design processes Improve workplace relationships Increase competitiveness Increase efficiency Increase profitability Reduce costs Reduce risk
Efficiency	Accelerate economic inequality around the world Alter enterprises' organisational structures Alter industrial design processes Improve workplace relationships Increase competitiveness Increase efficiency Increase profitability Reduce costs Reduce risk
Equality	Accelerate economic inequality around the world Increase job losses
Democracy	Accelerate economic inequality around the world
Justice	Accelerate economic inequality around the world Increase job losses
Fairness	Accelerate economic inequality around the world Increase job losses
Productivity	Accelerate economic inequality around the world

Affected values	Examples of related identified impacts
	Alter enterprises' organisational structures Alter industrial design processes Improve workplace relationship Increase competitiveness Increase consumer demand Increase efficiency Increase profitability Revolutionise digital marketing
Profitability	Accelerate economic inequality around the world Alter enterprises' organisational structures Alter industrial design processes Improve workplace relationships Increase competitiveness Increase consumer demand Increase profitability Reduce costs Revolutionise digital marketing
	Increase career disruptions (i.e., multiple job changes)
	Increase discrimination
	Increase job losses

Table 20. Economic impacts – effects on values – as appearing in the literature (sources cited in Economic Impacts table from sub-section 4.2)

From the interviews

Affected values	Examples of related identified impacts
Access	Improve access to retail services
Competitiveness	Alter industrial design processes Improve workplace relationship Increase competitiveness Increase farming productivity (yields) Increase profitability Reduce competitiveness and market share through over-reliance and investment in single technology line Stunt technological development in poorer regions due to high capital costs of AI and robotics Weaken trade unions
Efficiency	Alter industrial design processes Improve supply chains Improve workplace relationships Increase competitiveness Increase farming productivity (yields) Reduce competitiveness and market share through over-reliance and investment in single technology line Stunt technological development in poorer regions due to high capital costs of AI and robotics Weaken trade unions
Equality	Concentrate economic power Increase job losses Prompt tax losses Stunt technological development in poorer regions due to high capital costs of AI and robotics Weaken trade unions
Justice	Concentrate economic power Increase job losses

Affected values	Examples of related identified impacts
	Stunt technological development in poorer regions due to high capital costs of AI and robotics Weaken trade unions
Fairness	Concentrate economic power Increase job losses Prompt tax losses Stunt technological development in poorer regions due to high capital costs of AI and robotics Weaken trade unions
Productivity	Alter industrial design processes Improve supply chains Improve workplace relationship Increase competitiveness Increase consumer demand Increase farming productivity (yields) Stunt technological development in poorer regions due to high capital costs of AI and robotics Weaken trade unions
Profitability	Alter industrial design processes Improve supply chain Improve workplace relationships Increase competitiveness Increase consumer demand Prompt tax losses Reduce competitiveness and market share through over-reliance and investment in single technology line Weaken trade unions
Privacy	Enhance privacy for consumer services
Well-being	Concentrate economic power
	Enhance privacy for consumer services
	Increase discrimination
	Increase job losses
	Prompt tax losses

Table 21. Economic impacts – effects on values – as appearing in the interviews

Environmental impact – effects on values

The tables below show the key values that will be affected by the environmental impacts.

From the literature

Affected values	Examples of related identified impacts
Ecological sustainability	Reduce resource-information gaps (esp. helping to understand land-use patterns and decision support)
Environmental integrity	Increase harm from increased robot use (their component materials generally toxic and non-biodegradable) Reduce water and energy footprints Reduce food waste Reduce pesticide use Reduce waste during production Reduce negative effects of climate change
Regeneration	Reduce human population
Responsible resource use	Reduce resource-information gaps (esp. helping to understand land-use patterns and decision support)

Table 22. Environmental impacts – effects on values – as appearing in the literature (sources cited in Environmental Impacts table from sub-section 4.2)

From the Interviews

Affected values	Examples of related identified impacts
Ecological sustainability	Increase energy use
Pollution control	Increase pollution through increase use of cars

Table 23. Environmental impacts – effects on values – as appearing in the interviews

The above tables highlight a variety of values affected by the social, economic and environmental impacts. According to our findings from the literature and interviews, human well-being[262] (in more ways than one) is (or will be) the most commonly affected social value. The most commonly affected economic values are (or will be) competition and competitiveness, efficiency productivity, equality and equity and profitability. Environmental integrity stands out as the most commonly affected value of the impacts.

Parties affected by the social, economic and environmental impacts

Our literature review focussed on another aspect of the impacts of AI and robotics: affected parties. By affected parties (or party), we mean individual(s), group(s) (e.g., stakeholders, communities, society etc.), entities (e.g., enterprises, government etc.) and/or some aspect of these (e.g., supply chain) changed or otherwise influenced by social, economic and/or environmental impacts. Below, we separately categorise the affected parties that authors and interviewees identified.

To gather the interviewees' views on the parties affected by the impacts of AI and robotics, we asked this question: "Who do you think will be most affected by these impacts?

As highlighted in preceding sub-sections, many of the identified impacts of AI and robotics are of such nature and geographical reach that they have the propensity to affect 'all' parties – i.e., individuals and/or groups throughout the world (depending on the implementation, uptake and use of AI and robotics as well as effects of policies that support or restrict them). Nevertheless, authors and interviewees also picked out specific affected parties; we present them below according to impact (i.e., social, economic or environmental).

Specific parties affected by social impacts

From the literature review

- **Communities and groups in society:** might experience emergence of new forms of co-operation and inclusion
- **Consumers:** will see effects of increased mass-customisation of products
- **Disfavoured stakeholders:** will be affected by, e.g., bias of machines against specific individuals and/or groups

[262] The importance of human well-being in relation to AI and robotics is well borne out by The IEEE Global Initiative for Ethical Considerations in Artificial Intelligence and Autonomous Systems, op cit., 2018. The document aims to "advance a public discussion about how we can establish ethical and social implementations for intelligent and autonomous systems and technologies, aligning them to defined values and ethical principles that prioritize human well-being in a given cultural context".

- **Elderly:** might be impacted positively (assistive AI and robotics for the elderly)[263] and negatively via invasions of privacy (e.g., remote electronic surveillance of elderly people bathing or changing)[264]
- **First-responders and other workers in hazardous environments:** will reap benefits from increased safety of personnel in hazardous environments (e.g., robot replacement during search and rescue missions)[265].
- **Government (regulators, policy-makers):** are affected by inadequate legal or regulatory framework for handling potential enterprise malfeasance and antitrust practices and inadequate legal/regulatory framework for determining liable agents[266].
- **Patients and healthcare providers:** will be positively affected by increasing democratisation of access for healthcare, faster medical analysis and diagnosis and vast reduction – even elimination – of medical misdiagnosis, benefits to elder care and the institutions that provide it, promotion of healthier behaviour in individuals, and increase in healthcare decisions based on evidence and free of cognitive biases or overconfidence[267].
- **Recipients of insurance and social benefits:** might experience insurance and social benefit discrimination (e.g., higher termination rate for benefit eligibility by religious group and increasing auto insurance prices for night-shift workers)[268].
- **Tenants (especially from minority ethnic groups):** might face housing discrimination (e.g., a landlord relies on search results suggesting criminal history by race and matching algorithms)[269].
- **Workers:** will be affected by job losses[270].

From the interviews

- **Communities and groups in society:** might experience emergence of new forms of co-operation and inclusion
- **Consumers:** will see effects of increased mass-customisation of products
- **Elderly:** might be impacted positively (assistive AI and robotics for the elderly)
- **Government (regulators, policy-makers):** affected by loss of tax revenue
- **Patients and healthcare providers:** will be positively affected by increasing use of AI and robotics
- **The inhabitants of poorer regions:** many negative impacts of AI and robotics (and fewer positive ones) will be felt by the inhabitants of poorer regions, where there will be far less development of and wealth generated by AI and robotics.
- **Workers:** will be affected by job losses, including through the movement of jobs via outsourcing.

As identified both in the literature and interviews, and of special note, are the impacts on vulnerable populations: the elderly, (medical) patients and lower income countries and persons, especially. The elderly and patients appear to benefit from improvements to healthcare and assistive medical applications of AI and robotics. This tracks the most positive applications and sectors or fields identified above. If accurate, then an important, positive contribution of AI and robotics is the improvement to

[263] PWC Global, op cit., 2017.
[264] Frey and Osborne, op cit., 2016.
[265] European Parliament, op cit., 2016.
[266] Ezrachi and Stucke, op cit., 2015.
[267] PWC Global, op cit., 2017.
[268] Smith, op cit., 2017.
[269] Smith, op cit., 2017.
[270] Stone, et al., op cit., 2016.

these vulnerable populations' conditions and general well-being. Even so, the elderly, in particular, stand to have their autonomy and privacy diminished or invaded by certain applications of AI and robotics (e.g., remote electronic surveillance of elderly people bathing or changing)[271].

Such general improvements for the elderly and patients do not seem to hold for lower income persons and countries, another affected party within the vulnerable population category. Here, consider the impacts and affected parties of increased concentration of wealth in already wealthy and technologically advanced countries, diminished competitiveness of lower income countries as well as job losses.

With respect to the economic impacts too, some impacts are of a global nature, i.e., have the propensity to be felt by 'all'. These include, e.g., acceleration of economic inequality around the world, improved access to retail services, and impact on labour and wealth distribution (though this might also specifically affect workers and companies).

Specific parties affected by economic impacts

From the literature review

- **Consumers:** might negatively experience a narrowing of choice (e.g., presented ads based solely on past "clicks")[272].
- **Enterprises (all)**: Enterprises (large and small) will feel the impacts of AI and robotics at various levels. Examples of such impacts include: *reduced risk*; *increased productivity* through augmentation of existing labour force with AI and robotics; *increased consumer demand* (resulting from the availability of personalised and/or higher-quality AI-enhanced products and services)[273]; *greater profitability*; *changes in organisational structures*; *increased efficiency in financial transactions*, *increased workflow*[274].
- **Marketing community**: might see a revolution in digital marketing through changes to critical marketing processes such as lead nurturing, lead generation and social media listening (some of which is already happening)[275].
- **Medical/healthcare enterprises and patients**: Cost reductions through robot-assisted surgical procedures and other healthcare improvements through AI and robotics[276].
- **The economy:** might see impacts such as significant changes in the unemployment rate, the Philips Curve, Purchasing Power Parity, GDP, inflation, money, management and accounting, loss of competitiveness and market share through over-reliance and investment in single technology line[277].
- **Workers:** may see changed and/or improved workplace relationships (e.g., emotional intelligence and conventional intelligence will merge to facilitate improved workplace

[271] Frey and Osborne, op cit., 2016.
[272] Smith, op cit., 2017.
[273] Rao and Verweij, op cit., 2017.
[274] Hislop, et al., op cit., 2017.
[275] Dirican, op cit., 2015.
[276] Frey and Osborne, op cit., 2016; PwC Global, op cit., 2017.
[277] Preimesberger, op cit., 2017; IEEE, op cit., 2018; Dirican, op cit., 2015; Berriman and Hawksworth, op cit., 2017; Arntz et al., op cit., 2016; UNCTAD, op cit., 2017; Orchestrate, op cit., 2017; Hawking, op cit., 2016; Wisskirchen, et al., op cit., 2017.

relationships)[278], job losses (workers being replaced by AI and robots)[279]; employment and income distribution changes through various channels, increased economic inequality, disruptions in how human labour is augmented, employment discrimination (e.g., filtering job candidates by race or genetic/health information and filtering candidates by work proximity leads to excluding minorities)[280].

From the interviews

- **Consumers:** positively, consumers will see privacy enhancements for consumer services.
- **Enterprises (all)**: Enterprises (large and small) will feel the impacts of AI and robotics at various levels.
- **Farmers and agriculturists**: might see increased farming productivity (yields) through adaptive, smarter optimisation.
- **Government (regulators, policy-makers):** might be affected via tax losses.
- **Medical/healthcare enterprises and patients**: General improvements to healthcare through AI and robotics
- **Poorer and/or technologically less advanced countries and regions**: The capital costs of AI and robotics are very high, making poorer regions less capable of technological development. Countries with lower labour costs may lose out to automation.
- **Pre-existing conglomerates**: There might be a further concentration of wealth to a few companies.
- **Supply chain**: might see improvements in operations and management.
- **Technology owners and investors**: will experience further concentration of wealth from their assets and investments.
- **The economy:** loss of competitiveness and market share through over-reliance and investment in a single technology line.
- **Workers:** may see changed and/or improved workplace relationships (e.g., emotional intelligence and conventional intelligence will merge to facilitate improved workplace relationships), job losses (workers being replaced by AI and robots); weakening of trade unions; employment and income distribution changes through various channels.

Specific parties affected by environmental impacts

From the literature review

- **Scientists and researchers:** will see benefits from the reduction of resource-information gaps (especially helping to understand land-use patterns and decision support)[281]**.**
- **Society and the planet:** will benefit from reduced water and energy footprints[282], decreased human population[283] and the reduction of negative effects of climate change[284]. Consequently, society and the planet will be adversely affected by an increase in harm from increased robot use (their component materials are generally toxic and non-biodegradable though efforts are being made and might in the future be made to change this)[285].

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[278] Preimesberger, op cit., 2017;
[279] Berriman and Hawksworth, op cit., 2017; Arntz et al., op cit., 2016; Dirican, op cit., 2015; UNCTAD, op cit., 2017; Hawking, op cit., 2016; Wisskirchen, et al., op cit., 2017.
[280] Smith, op cit., 2017.
[281] Joppa, op cit., 2017.
[282] European Parliament, op cit., 2016.
[283] Population Matters, op cit., 2016.
[284] Jibo, op cit., 2016.
[285] Parrack, op cit., 2012.

From the interviews

- **Energy providers**: an increase in energy consumption (from the increased use of AI and robotics).
- **Society and the planet:** possible deleterious effects of increased energy consumption

In addition to the specific affected parties themselves, we think the above brings out a point that bears repeating: impacts do not affect all parties equally even if impacts in general affect all parties. Notably, some members of vulnerable populations benefit from impacts while other suffer from them. The next sub-section also presents assessments that may help to clarify and better delimit the parties affected by social, economic and environmental impacts of AI and robotics.

Resilience and vulnerability of the affected parties to the impacts (described by interviewees)

To get a sense of the degree to which affected parties might flourish or decline in light of the impacts, we asked interviewees about affected parties' resilience and vulnerability to impacts. In accordance with the definition from the European Commission's Communication on the EU Approach to Resilience, resilience means "the ability of an individual, a household, a community, a country or a region to withstand, to adapt, and to quickly recover from stresses and shocks".[286] Resilience has two crucial aspects: the inherent strength of a party and its capacity to bounce back. By vulnerability, we mean the inverse of resilience: the weakness and susceptibility of a party to negative impacts and its ability (if any) to recover from negative impacts.

Considering such matters of resilience and vulnerability can potentially help to frame future research and policy initiatives. In this respect, the views of interviewees are a step in better understanding not only that certain parties will be affected, but also that certain affected parties may better adapt and adjust to the impacts of AI and robotics. Here, we suggest that resilient parties may have certain values or resources that, if distributed to vulnerable ones, could increase well-being and minimise potential harms from impacts.

To gain the views of interviewees on the subjects of resilience and vulnerability, we posed these two questions: (1) "How resilient are the potentially affected communities?" (2) "How vulnerable are they to the adverse impacts?" The table below summarises the interviewees' responses to these two questions.

Greater resilience
• Western societies are more resilient • Communities based on strong unifying values are resilient • Communities of interest will be resilient • Isolated communities are more resilient • People with open attitudes and the ability to rapidly adapt to change are most resilient
Conditional resilience (i.e., dependent on other conditions being met)
• Resilience only if public sector plays a large role in aiding parties • Resilience depends on whether we can introduce the means and channel the technologies for public good • Global resilience if competitive blocs agree to regulation

[286] European Commission, Communication from the Commission to the European Parliament and the Council – The EU Approach to Resilience: Learning from Food Security Crises, COM (2012) 586 Final, Brussels, 3.10.2012. http://ec.europa.eu/echo/files/policies/resilience/com_2012_586_resilience_en.pdf

Greater vulnerability
• The global south is more vulnerable • Poor countries are more vulnerable • Workers who lose jobs are very vulnerable • Societies in which more individuals lack education are more vulnerable • Communities worldwide will see clash of values (thus more vulnerable)

Table 24. Resilience and vulnerability of affected parties

The qualities of the resilient and vulnerable parties described in the above table are largely in line with our above findings. That is, the beneficiaries of positive impacts – predominantly wealthy, educated and technologically advanced populations – are also (or will also be) more resilient. Conversely, according to interviewees' responses, the unemployed, lower income, less educated and less developed populations are more vulnerable.

We see novelty in the table with respect to (a) the specific values of certain resilient parties and (b) the "conditional resilience" category. Regarding the former, some interviewees (n=3) were keen to distinguish the values (and the communities associated with them) that produce or deepen resilience. Such values include religion, bonds developed through long-term association and co-location (e.g., neighbours and compatriots). Isolated communities (whether by virtue of chosen separation, such as certain religious sects, or luck-based geographical isolation) also fit within this framework of resilience. Whether such interest-, value-, or geography-based qualities equate to or increase resilience against the negative impacts of AI and robotics is a possible area of future research.

The "conditional responses" category also proves a valuable ground for future research. The responses roughly echo the larger pool of mitigation measures proposed below by experts; namely, without regulation guiding the development and implementation of AI and robotics, vulnerability will increase and resilience decrease (or remain the same). This general conclusion needs evaluation in future research, as does evaluation of which regulations may lead to the most equitable distributions of AI and robotics' benefits.

Costs of the impacts

In this sub-section, we determine who bears the costs – whether private, opportunity or social – of the negative impacts of AI and robotics. Although there are cost-bearers associated with positive impacts, experts provided scant description of them. Consequently, the following assessment only describes cost-bearers of negative impacts.

In order to gather opinions from interviewees about costs, we posed the following question: "What might be the costs of the impacts and who might bear those costs?"

Negative social impacts – cost-bearers

The tables below depicts the costs-bearers of negative social impacts starting from the general level and moving on to the more specific.

From the literature review

Cost bearer(s)	Social impacts
Individuals and society	Alter human interactions Alter legal and regulatory frameworks Alter moral conceptions Alter understandings of the scope and limits of analogue personhood Diminish privacy Improve healthcare Improve transportation safety Increase bias Increase big data mining and analysis Increase discrimination Increase harm and threat of harm from autonomous weapons Increase ruling class domination and wealth Prompt unintended consequences
Individuals	Diminish individuals' control over their data

Table 25. Negative social impacts – cost-bearers – as described in the literature (sources cited in Social Impacts table in sub-section 4.2)

From the interviews

Cost bearer(s)	Social impacts
Individuals and society	Diminish individuals' control over their data Diminish pluralism in media Diminish privacy Improve communities through better matching of people with similar interests Improve cybersecurity Improve decision-making through data analytics Improve elder care Improve healthcare Improve language translation Increase available time Increase bias Increase big data mining and analysis Increase cyberwarfare Increase discrimination Increase harm and threat of harm from autonomous weapons Increase job losses Increase police profiling Increase surveillance Prompt new forms of co-operation and inclusion Reduce repetitive tasks
Individuals	Diminish individuals' control over their data
Minority communities	Increase police profiling
Patients	Improve health care
Workers and society	Improve protections for workers in countries with weaker safeguards
	Improve safety of personnel in in hazardous environments
Elderly	Improve elder care
Media	Reduce pluralism in media

Table 26. Negative social impacts – cost-bearers – as described in the interviews

Negative economic impacts – cost-bearers

From the literature review

Cost-bearers	Economic impacts
Individuals and society	Increase consumer demand Increase discrimination Increase economic inequality
Business	Increase competitiveness Increase profitability Reduce risk Reduce costs
Workers and society	Increase career disruption (i.e., multiple job changes) Increase job losses
Businesses and workers	Alter industrial design processes Improve workplace relationships
Business management	Changes in organisational structures

Table 27. Negative economic impacts – cost-bearers – described in the literature (sources cited in Economic Impacts table in sub-section 4.2)

From the interviews

Cost-bearers	Economic impacts
Individuals and society	Concentrate economic power Enhance privacy for consumer services Improve access to retail services Increase consumer demand Increase discrimination
Governments and society	Prompt tax losses
Business	Improve supply chains Increase competitiveness Reduce costs
Workers and society	Increase job losses
Trade unions and workers	Weaken trade unions
Businesses and workers	Alter industrial design processes Improve workplace relationships
Business management	Changes in organisational structures
Businesses, national economies, economic blocs, workers	Reduce competitiveness and market share through over-reliance and investment in single technology line
Poorer countries and regions	Stunt technological development in poorer regions due to high capital costs of AI and robotics

Table 28. Negative economic impacts – cost-bearers – described in the interviews

Negative environmental impacts – cost-bearers

The tables below present the cost-bearers of the negative environmental impacts.

From the literature review

Cost-bearer(s)	Environmental impacts
Individuals, society	Increase harm from increased robot use (their component materials generally toxic and non-biodegradable) Reduce human population

Table 29. Negative environmental impacts – cost-bearers – from the literature review (sources cited in Economic Impacts table in sub-section 4.2)

From the interviews

Cost-bearer(s)	Environmental impacts
Individuals, society	Increase energy consumption

Cost-bearer(s)	Environmental impacts

Table 30. Negative environmental impacts – cost-bearers – from the interviews

In examining the matter of costs, again represented as cost-bearers, we note the extent to which some costs (such as those resulting from impacts such as job losses) to society appear and are stressed in experts' analysis on the topics. Although private costs to individuals also factor into this, many experts' analysis of impacts focus on the broader implications of such widely adopted and implemented technology. In this respect, individuals may incur some private costs of job losses or the harmful effects of pollution, but the widespread and estimably greatest costs will mostly be the social, infrastructural and economic ones borne by society.

Mitigation measures for negative impacts

We encountered a variety of specific proposals for how to mitigate the negative impacts of AI and robotics. However, policy and regulatory measures were the most oft-made suggestion for mitigation of adverse impacts of AI and robotics. In order to faithfully represent assessments without needless proliferation of terms, we grouped responses into three categories. They are: (1) policy and regulatory mitigation measures, (2) technological and industry-level measures, (3) society-level mitigation measures (non-policy or regulatory).

Policy and regulatory measures include international, supranational, national, regional and local policies and regulations that aim to lessen negative impacts. Main examples of these measures include:

From the literature review

- data protection regulations that takes into account threats to privacy from AI and robotics' applications[287]
- policy and regulation that preserve the reasonable expectation of privacy[288]

From the interviews

- international agreements regarding the implementation and use of particular applications (e.g., autonomous weapons)
- taxation of robot-workers for purposes of maintaining public revenues for displaced human workers
- introduction of universal basic income schemes to support displaced human workers

Technological and industry-level mitigation measures are those that, through the creation and implementation of technology by industry aim to lessen negative impacts. Main examples of these measures include:

From the literature

- the design of ethical algorithms[289]
- implementation of quality control[290]
- oversight systems of AI and robotics applications[291]

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[287] European Data Protection Supervisor, op cit., 2016.
[288] Pagallo, op cit., 2013
[289] Dignum, op cit., 2017; Smith, op cit., 2017; Bossman, op cit., 2016; Burgess, et al., op cit., 2018.
[290] PwC Global, op cit., 2017.
[291] European Parliament, op cit., 2016; PwC Global, op cit., 2017.

From the interviews

- diversification of investments in technologies to prevent loss of market share or competitive advantage

Society-level mitigation measures (non-policy or regulatory) represents a more diffuse set of measures that aim to reduce negative impacts through the efforts of diverse members and groups of society. Main examples of these measures include:

From the literature:

- the co-ordination of non-governmental global elite to diminish the impact of autonomous weapons[292]
- multiple non-governmental organisations' efforts to revise and update theories about human interactions[293]

From the interviews

- increase the possibilities for communities of interest thrive

In line with these three categories, the majority of proposed measures (both in the literature and interviews) fit within the 'Policy and regulatory' grouping. This was followed by the 'Technological and industry-level mitigation measures', with only a few society-level mitigation measures proposed.

It should be noted that only sometimes did interviewees provide highly detailed description of mitigation measures, preferring broad descriptions such as regulation (without explaining or suggesting which regulations in particular might mitigate AI and robotics' impacts).

Regardless of the relative detail or breadth of proposed mitigation measures (from either the literature or interviews), they all help to frame solutions that may address all-pervasive technologies such as AI and robotics and their current and expected negative impacts. In this respect, the message we distilled is this: collective action by the major social and economic institutions of society can mitigate negative impacts. Here, it is useful to recall the impacts' cost-bearers: Society as a whole will bear most of or the greatest costs of AI and robotics' negative impacts. The role of policy and regulatory measures is (at least in part) to limit such costs to society at large – doing so ostensibly requires the co-operation and co-ordinating power of major institutions, such as national governments and international organisations.

4.4 Conclusions

As described throughout this section, there is a wide range social, economic and environmental impacts stemming from AI and robotics. Here, we present some conclusions for amplifying positive impacts and minimising negative ones. To effectively prioritise the action needed to address the impacts, we offer our conclusions in accordance with when they should be adopted or applied: short- medium- and long-term.

Conclusions for the short-term to medium-term (five to 10 years)

- The effects of negative impacts without mitigation, especially for extremely destructive applications such as autonomous weapons, will potentially efface the positive impacts from AI and robotics. If the timing of impacts presented above is accurate, then regulation and other

[292] Gubrud, op cit., 2016.
[293] Burgess, et al., op cit., 2018.

mitigation measures need implementation now to mitigate negative impacts currently occurring and projected to do so in the future.

- Social costs of negative impacts merit special attention, and all efforts to limit them should begin as soon as possible.
- Job losses and the threat to social and economic stability for workers need prioritisation in regulatory and policy discussions.
- Educating individuals about the positive impacts of AI and robotics can aid in their acceptance and reduce impacts associated with social strife, isolation and disaffection. However, presenting only positive attributes and impacts of AI and robotics may be perceived as disingenuous or dishonest. Consequently, increasing societal acceptance of AI and robotics should also include discussions of their negative impacts (and mitigation measures taken to reduce them).

Conclusions for the long-term (20 years and after)

- Recognise that decisions occurring in the short- and medium-terms will largely construct the state of the affairs in the long-term. As a rule of thumb, avoid any application of AI and robotics whose expected losses outweigh the probable benefits in the long run.

In concluding this SEIA, we repeat that AI and robotics hold promise for aiding human beings in a wide range of endeavours. Based on the analysis in this SEIA, we believe that the more complete picture of AI and robotics and their impacts includes the possibility of great burdens, too. This is not to strike a chord of doom, but rather to say there is a need for conscientious action to reduce AI and robotics' negative impacts and maximise the positive ones.

5. Conclusion

This deliverable has presented a state-of-the-art review of the fields of AI and robotics. It offered a thorough analysis of both fields in terms of their central concepts, their history, their present and anticipated technologies and applications, as well as a socio-economic impact assessment (of present and expected impacts) of their technologies.

We determined that both fields are very broad and difficult to define. In them, we found that there exist a plethora of different approaches and areas of research, many of which promising to bring significant change in terms of introducing novel technologies and applications. For example, we expect to see further advances in AI areas such as machine learning, neural networks, computer vision and natural language processing, as well as in robot miniaturization, robot control, robot sensing, cloud connectivity and biomimicry. All of this will pave the way towards AI systems and robots that are more intelligent, ubiquitous, autonomous, mobile, flexible and sociable.

Our analysis has covered a broad array of present and future applications for AI and robotics. It was found that applications are in such varied domains as transportation, infrastructure, healthcare, finance and insurance, security (military and law enforcement), retail and marketing, media and entertainment, companionship, science, education, manufacturing and agriculture. There have already been major developments in these domains, and our analysis indicates we are at the cusp of seeing more significant development still, including fully autonomous cars, parcel delivery drones and conversational AI systems in customer service, just to name a few.

Our socio-economic impact assessment identified a wide range of social, economic and environmental impacts stemming from AI and robotics. These range from negative impacts, such as those expected for autonomous weapons systems, to positive impacts, such as those expected for medical diagnostic applications of AI and robotics. We proposed that regulation and other mitigation measures need implementation now to mitigate the negative impacts that are currently occurring and projected to do so in the future. We further suggested that the social costs of negative impacts merit special attention, and all efforts to limit them should begin as soon as possible. In addition, we found that job losses and the threat to social and economic stability for workers need prioritisation in regulatory and policy discussions. Finally, we determined that educating individuals about the positive and negative impacts of AI and robotics may aid in their acceptance and may reduce impacts associated with social strife, isolation and disaffection.

We end by noting that considering and assessing the future applications and impacts of complex and pervasive technologies such as AI and robotics is a speculative endeavour. Some of the expected applications and impacts we described may not materialise, and we may have omitted some important future applications and impacts that are presently hard to foresee.

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Annexes

Annex 1: Interview questions

1. Do you think that AI and robotics will have beneficial or negative impacts?
2. Which applications of AI and robotics do you think might have the most beneficial or adverse impacts on individuals or society?
3. Are there certain sectors or fields in which AI and robotics might have the most beneficial or adverse impacts?
4. Which impacts can you foresee:
    - In the next 5-10 years?
    - In the next 20 years?
5. Who do you think will be most affected by these impacts?
6. How far and wide, geographically, could individuals and communities feel the impacts?
7. Will the impacts support or undermine the affected communities' or societal values?
8. How resilient are the potentially affected communities? How vulnerable are they to the adverse impacts?
9. What might be the costs of the impacts and who might bear those costs?
10. Do you think it is possible to mitigate the negative impacts? If so, how?
11. Are there existing mitigation measures that have worked for these types of impacts? If so, how can we use them?