European Commission

JRC TECHNICAL REPORTS

# AI Watch
# Defining Artificial Intelligence 2.0

*Towards an operational definition and taxonomy for the AI landscape*


Joint Research Centre

EUR 30873 EN

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JRC126426

EUR 30873 EN

PDF ISBN 978-92-76-42648-6 ISSN 1831-9424 doi:10.2760/019901

Luxembourg: Publications Office of the European Union, 2021






How to cite this report: Samoili, S., López Cobo, M., Delipetrev, B., Martínez-Plumed, F., Gómez, E., and De Prato, G., AI Watch. Defining Artificial Intelligence 2.0. Towards an operational definition and taxonomy for the AI landscape, EUR 30873 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-42648-6, doi:10.2760/019901, JRC126426.

# Contents

## Foreword

This report is published in the context of AI Watch, the European Commission knowledge service to monitor the development, uptake and impact of Artificial Intelligence (AI) for Europe, launched in December 2018.

AI has become an area of strategic importance with potential to be a key driver of economic development. AI also has a wide range of potential social implications. As part of its Digital Single Market Strategy, the European Commission put forward in April 2018 a European strategy on AI in its Communication "Artificial Intelligence for Europe". The aims of the European AI strategy announced in the communication are:

- To boost the EU's technological and industrial capacity and AI uptake across the economy, both by the private and public sectors
- To prepare for socio-economic changes brought about by AI
- To ensure an appropriate ethical and legal framework.

Subsequently, in December 2018, the European Commission and the Member States published a "Coordinated Plan on Artificial Intelligence", on the development of AI in the EU. The Coordinated Plan mentions the role of AI Watch to monitor its implementation.

Furthermore, in April 2021 the European Commission proposed a set of actions to boost excellence in AI, and rules to ensure that the technology is trustworthy. The proposed Regulation on a European Approach for Artificial Intelligence and the update of the Coordinated Plan on AI aim to guarantee the safety and fundamental rights of people and businesses, while strengthening investment and innovation across EU countries. The 2021 review of the Coordinated Plan on AI refers to AI Watch reports and confirms the role of AI Watch to support implementation and monitoring of the Coordinated Plan.

AI Watch monitors European Union's industrial, technological and research capacity in AI; AI-related policy initiatives in the Member States; uptake and technical developments of AI; and AI impact. AI Watch has a European focus within the global landscape. In the context of AI Watch, the Commission works in coordination with Member States. AI Watch results and analyses are published on the AI Watch Portal (https://ec.europa.eu/knowledge4policy/ai-watch_en).

From AI Watch in-depth analyses we will be able to understand better European Union's areas of strength and areas where investment is needed. AI Watch will provide an independent assessment of the impacts and benefits of AI on growth, jobs, education, and society.

AI Watch is developed by the Joint Research Centre (JRC) of the European Commission in collaboration with the Directorate-General for Communications Networks, Content and Technology (DG CNECT). This report addresses the following objectives of AI Watch: proposing an operational definition of AI, which will be used as a basis for the AI Watch monitoring activity.

## Acknowledgements

The authors would like to thank Filipe Jones Mourao (DG CNECT) and the reviewers from the JRC Editorial Board, Ignacio Sánchez and Ronan Hamon, for their useful comments. We also acknowledge the panel of experts who provided valuable comments and useful critiques to the first report, to which this one represents an extension: (in alphabetical order): Virginia Dignum (Umeå University and High Level Expert Group on AI), Anders Jonsson (Universitat Pompeu Fabra), Henrik Junklewitz (Joint Research Centre's Cyber & Digital Citizens' Security Unit), Ramón López de Mántaras (Artificial Intelligence Research Institute (IIIA-CSIC)), José Orallo (Valencian Research Institute for Artificial Intelligence (Universitat Politècnica de València)), Ignacio Sánchez (Joint Research Centre's Cyber & Digital Citizens' Security Unit). Similarly, the authors are grateful to Antonio Puente and Mariana Popova (DG CNECT) for their comments to the first report.

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## Abstract

We present here the second edition of our research aimed at establishing an operational definition of artificial intelligence (AI), to which we refer to in the activities of AI Watch. This edition builds on the first report, published in February 2020, and complements it with several recent developments. Since then, the European Commission has proposed a regulatory framework on artificial intelligence (AI Act) that establishes a legal definition of AI, which we incorporate in the current review. In addition to this legal definition, an operational definition is still needed to better delineate the boundaries and analysis of the AI Watch AI landscape.

The proposed AI Watch operational definition consists of an iterative method providing a concise taxonomy and list of keywords that characterise the core domains of the AI research field, complemented by transversal topics such as AI applications or ethical and philosophical considerations - in line with the wider monitoring objective of AI Watch. The AI taxonomy is designed to inform the AI Watch AI landscape analysis and is also expected to cover applications of AI in closely related technological domains, such as robotics (in a broader sense), neuroscience or internet of things.

The literature considered for the qualitative analysis of existing definitions and taxonomies has been enlarged to include recently published reports from the three complementary perspectives considered in this work: policy, research and industry. Therefore, the collection of definitions published between 1955 and 2021 and the summary of the main features of the concept of AI appearing in the relevant literature is another valuable output of this work.

Finally, alternative approaches to study AI are also briefly presented in this new edition of the report. These include the classification of AI according to: families of algorithms and the theoretical models behind them; cognitive abilities reproduced by AI; functions performed by AI. Applications of AI may be grouped also according to other dimensions, like the economic sector in which such applications are found, or their business functions. These approaches, complementary to the taxonomy used for the analysis of the AI Watch international landscape, are useful to gain a wider understanding of the AI domain, and suitable to be used in studies related to these dimensions.

## Executive summary

This report is a revision of the first edition of the operational definition published in February 2020[1]. It updates the list of existing definitions, and acknowledges alternative perspectives on how to analyse AI.

This report proposes a taxonomy for artificial intelligence (AI) and a list of related keywords, as an operational definition of AI in the framework of AI Watch, the Commission's knowledge service to monitor the development, uptake and impact of artificial intelligence for Europe. AI Watch aims to monitor the industrial, technological and research capacity, as well as policy initiatives in the Member States, uptake and technical developments of AI and its impact. The established operational definition is being used as a basis for the AI Watch monitoring activity, and it is especially relevant for the delimitation of the AI landscape and its analysis. Furthermore, the AI taxonomy aims to support the mapping of the AI landscape, and to detect AI applications in other related technological domains such as robotics (in a wider sense), big data, web technologies, high performance computing, embedded systems, internet of things, etc.

Since the first edition of the report, the European Commission has adopted a legal definition of AI in the proposed Artificial Intelligence Act, which aims at providing a risk-based regulatory approach for the safe and trustworthy development of AI systems in the EU. In addition to this definition, the need to establish an operational definition persists, since the mapping of AI activities requires a definition that can be, in practical terms, applied objectively to detect which activities are considered AI, and subsequently analyse them. To that end, the operational definition proposed takes the form of a taxonomy and a list of keywords. Based on this premises, we propose a multi-perspective analysis to structure the AI taxonomy. In particular, we provide a unique taxonomy that represents and interconnects all the AI subdomains from political, research and industrial perspective. The taxonomy reflects these perspectives and aims to cover the entire AI landscape, which consists of economic agents performing R&D or industrial AI activities. Moreover, considering that AI is a dynamic field, we propose an iterative method that can be updated over time to capture the rapid AI evolution, and that provides a taxonomy and a set of keywords. The method consists of the following steps: (i) qualitative analysis of AI definitions and subdomains emanating from reports with academic, industrial and policy perspectives, (ii) selection of definition, identification of representative keywords in AI with a natural language processing method, and taxonomy formation, and (iii) taxonomy and keywords validation.

In the first step of the method, the objective is to collect and analyse the existing definitions and identify the main subdomains covering all aspects in the AI field. Thus, we conduct a qualitative analysis in a selected set of 38 AI policy and institutional reports (including standardisation efforts, national strategies[2], and international organisations reports), 23 relevant research publications and 3 market reports, from the beginning of AI research in 1955 until today. AI has been usually described in relation to human intelligence, or intelligence in general, with many definitions referring to machines that behave like humans or are capable of actions that require intelligence. Since human intelligence is also difficult to define and measure, and although there have been different attempts of quantification, the objective definition of something as subjective and abstract as intelligence, falsely gives the impression of a precision that cannot be obtained. As a consequence, most definitions found in research, policy or market reports are vague and propose an ideal target rather than a measurable research concept. The study of the definitions found in literature leads us to identify four characteristics that are commonly mentioned in AI: i) perception of the environment and real-world complexity, ii) information processing: collecting and interpreting inputs, iii) decision making, including reasoning, learning and taking actions; and iv) achievement of pre-defined goals. Taking into consideration these features, we consider the definition proposed by the EC High Level Expert Group on AI (AI HLEG) as the starting point in developing the operational definition in AI Watch: "Artificial intelligence (AI) systems are software (and possibly also hardware) systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information, derived from this data and deciding the best action(s) to take to achieve the given goal. AI systems can either use symbolic rules or learn a numeric model, and they can also adapt their behaviour by analysing how the environment is affected by their previous actions." (AI HLEG, 2019a).

Although the AI HLEG definition may be considered highly technical for different audiences and objectives, it is very comprehensive, incorporating the aspects of perception, understanding, interpretation, interaction, decision making, adaptation to behaviour and achievement of goals, whereas other definitions do not address

[1] Samoili et al., 2020a.
[2] Van Roy, 2020.

them in their entirety. Considering that the AI HLEG definition is comprehensive, hence highly technical and detailed, less specialised definitions can be adopted for studies of different objective, such as enterprise surveys. In this scope, the definitions provided by the JRC Flagship report on AI[3] and the European AI Strategy[4], or the one from the AI module of the Community survey on ICT usage and e-commerce in enterprises 2021[5], are suitable alternatives.

From the literature collected for the study, we identify several dimensions according to which the AI knowledge domain may be explored, each of them represented by a classification or set of categories. Without the intention of being exhaustive, the report indicatively describes some of these dimensions and briefly presents the related classifications. For instance, we may classify AI according to families of algorithms used and their underlying theoretical models (symbolic, connectionist…), cognitive abilities reproduced by AI (memory processes, visual processing, navigation…), or functions performed by AI (solving and optimising, automating, perceiving and communicating, etc.) among others. The choice of the most adequate approach to classify AI is driven by the objectives of the study. A survey to analyse the uptake of AI by companies across the economy can benefit from the enquiry about AI applications by business function or by economic sector, while in a labour market impact study it may be more appropriate to use a classification of cognitive skills that can replicate AI.

The taxonomy presented here has been developed to answer the information and monitoring needs of AI Watch, in particular for the definition and analysis of the AI landscape, and it reflects the context in which it is being used. To describe and analyse the AI landscape, we search for subdomains that are representative of the AI activities performed by the industrial and research ecosystems. With this in mind, we identify a number of common topics in the definitions and taxonomies considered for this study. Besides the mentioned set of 65 documents, we have consulted the official publication of the Association for the Advancement of Artificial Intelligence (AAAI) (aitopics.org), and several top AI conferences, and applied a complementary bottom up approach with topic modelling of AI-related research and industrial documents. The proposed AI taxonomy, made of a list of representative core and transversal AI domains and subdomains, will assist us to classify R&D and industrial agents and their activities. Therefore, it encompasses main theoretical AI scientific areas, and AI related non-technological issues from industrial and R&D AI activities, as well as ethical and philosophical issues. It remains linked to the AI HLEG definition of AI in the context of AI Watch. The proposed taxonomy follows:

| | AI taxonomy | |
|---|---|---|
| | **AI domain** | **AI subdomain** |
| **Core** | **Reasoning** | Knowledge representation |
| | | Automated reasoning |
| | | Common sense reasoning |
| | **Planning** | Planning and Scheduling |
| | | Searching |
| | | Optimisation |
| | **Learning** | Machine learning |
| | **Communication** | Natural language processing |
| | **Perception** | Computer vision |
| | | Audio processing |
| **Transversal** | **Integration and Interaction** | Multi-agent systems |
| | | Robotics and Automation |
| | | Connected and Automated vehicles |
| | **Services** | AI Services |
| | **Ethics and Philosophy** | AI Ethics |
| | | Philosophy of AI |

Source: Authors' elaboration.

3 Craglia et al., 2018.
4. EC, 2018a
5 Eurostat, 2020.

To complete the operational definition of AI, a list of keywords representative of the AI subdomains is established based on the techno-economic segments (TES) analytical approach that provides an overview of the AI landscape worldwide. In the TES approach, keywords are used in text queries to identify activities and economic agents relevant to AI, for their further analysis. The list of keywords is the result of a multi-step process combining a semi-automatic text mining approach, desk research and domain experts' involvement. More specifically, the top keywords from a vast collection of journals in AI are identified though text mining in the Scopus database in three different years, from which the most frequent author's keywords per year are selected. Similarly, the industrial aspect is addressed by extracting keywords from firms' descriptions. Subsequently, the initial list of keywords is reviewed by AI experts and a short selection is made. A topic modelling is then performed, so as to detect the most representative topics and terms without the involvement of any expert that might induce unintentional bias. The initial list and the list resulting from the topic modelling step are merged and any redundancy is removed. External domain experts from several AI subdomains review the list, advising on synonyms that need to be grouped and on targeting subdomains that may not be sufficiently captured by the initial sources. The taxonomy and list of keywords is then validated and finalised.

Valuable outputs of this work are: the collection of definitions developed between 1955 and 2020; the summarisation of the main features of the concept of artificial intelligence as reflected in the relevant literature; the development of a replicable process that can provide a dynamic operational definition and taxonomy of AI.

# 1 Introduction

AI has become an area of strategic importance and been identified as a potential key driver of economic development as underlined in the European strategy on AI[6] and in the related Coordinated Plan on AI[7]. Similarly, AI has become a clear target for national governments resulting in the formulation of national AI strategies. AI Watch is the Commission knowledge service to monitor the development, uptake and impact of artificial intelligence for Europe, launched in December 2018. It monitors industrial, technological and research capacity, policy initiatives in the Member States, uptake and technical developments of AI and its impact.

The aim of this document is to establish an operational definition of AI formed by a concise taxonomy and a set of keywords that characterise the core and transversal domains of AI. The operational definition is based on a concrete and inclusive definition of AI. Such a taxonomy and keywords will assist the mapping of the AI ecosystem of interrelated economic agents, and will allow to describe their technological areas of specialisation. Also, it will expectedly overlap with other technological domains such as robotics (in a broader sense), big data, web technologies, high performance computing, embedded systems, internet of things, etc. The operational definition is to be used as a basis for the monitoring activity and to serve as a reference for the other AI Watch activities. This objective results from the need to monitor the implementation of the EC Coordinated Plan on AI on an annual basis, as reflected in the EC Communication[8].

To establish an operational AI definition to be adopted in AI Watch, we propose a 3-layer approach that allows a dynamic update. This approach consists of the following layers:

— **Review of existing definitions and taxonomies**. We review AI definitions found in a selected set of 65 documents: 38 AI policy documents and institutional reports, 24 relevant research publications and 3 market reports, in order to incorporate academic, industrial and corporate perspectives.

— **Definition selection, taxonomy formation and representative keywords selection**: We then adopt, based on this review, a general definition of AI and we complement this with a taxonomy and keywords that characterise the AI domain. The keywords are extracted based on automatic text analysis of a corpus of AI scientific references, firm-level databases, and industrial activity documents, complemented by desk research and domain experts' involvement.

— **Definition and taxonomy validation**: We validate our approach with a small number of AI experts.

In this scope, we consider documents that address the AI domain from different perspectives, acknowledging three complementary approaches under which AI is considered:

- the policy and institutional perspective, which is especially relevant for the objective of this work given the scope in which the AI definition is to be used, focuses on the development of the industry, the research capacity, and the impact on society of advanced technologies. This approach considers AI as an instrument for growth and technological development. We have collected and analysed documents from the European Commission, national strategies and policy documents (European and non-European), as well as other international institutions such as the OECD, UNESCO, World Economic Forum, ISO, etc.;
- the research perspective, which is the understanding of AI as a research field and its development as a general purpose technology;
- the market perspective, which has a strong focus on industrial development and assessment of the economic value and future market prospects.

The simultaneous consideration of the three approaches provides an overview of the past and current perceptions of AI and how the concept evolves over time. All the collected documents provide an AI definition, or identify or describe core and transversal AI subdomains, most of the documents present both types of information. These were analysed in order to identify the main aspects specified as AI features, as well as the

6 EC, 2018a.

7 EC, 2018b.

8 Footnote 19 of the Annex: "AI Watch developed by the Joint Research Centre will contribute to monitoring AI-related development and will provide a number of analyses necessary to support the implementation of the European AI initiative. Among others it will develop AI indexes addressing all dimensions relevant for policy making. Such information will be made available at the AI Watch portal https://ec.europa.eu/knowledge4policy/ai-watch_en".

core and transversal AI subdomains, so as to propose an operational definition and taxonomy that is useful for the objectives of AI Watch. The thorough investigation of the concept from an ontological perspective and the analysis of the evolution of AI as a concept and research field remain out of the scope of this study. The details of the explored definitions can be found in Annex 1. Table 3 offers a collection of the definitions and AI subdomains covered, as provided in the original documents.

The proposed taxonomy has been created to answer the information and monitoring needs of AI Watch, and it reflects the context in which it is being used. Therefore, it has certain characteristics that make it useful for this aim, like being concise and wide in the types of AI-activities that it is able to categorise. Other ways to characterise AI exist, depending on the dimension considered. For instance, a taxonomy to study AI from the perspective of the theoretical models behind the development of AI would be different from the one we present, and would be also different from a taxonomy targeting AI applications. In this revision of the first report, we acknowledge and briefly present other existing taxonomies.

The rest of the report is organised as follows: section 2 presents a review of existing definitions, including standardisation efforts on this domain, and highlights common features identified among the AI definitions. Section 3 presents existing ways of categorising AI, built across different dimensions. Section 4 develops the operational definition of AI for AI Watch, in the form of a taxonomy and list of keywords, as well as a description of the creation process. Section 5 summarises the definitions and taxonomies used in the analysed documents. Finally, section 6 presents the conclusions drawn from this study. The Annex provides detailed information about the documents analysed, including the source, the text of the definition and AI subdomains -when available-, contextual information about the source and the document itself, and the date of publication.

# 2 AI definitions

## 2.1 Definitions in market, policy and research

In this work, we consider 65 documents that address the AI domain from different perspectives, acknowledging three complementary approaches under which AI is considered: policy and institutional; research; and market. Despite the increased interest in AI by the academia, industry and public institutions, there is no standard definition of what AI actually involves. AI has been described by certain approaches in relation to human intelligence, or intelligence in general. Many definitions refer to machines that behave like humans or are capable of actions that require intelligence[9]. Since human intelligence is also difficult to define and measure, and although there have been different attempts of quantification (Gardner, 1983; 1987; Neisser et al., 1996), the objective definition of something as subjective and abstract as intelligence (Kaplan, 2016) falsely gives the impression of a precision that cannot be obtained. As a consequence, most definitions found in research, policy or market reports are vague and propose an ideal target rather than a measurable research concept.

The oversimplification of the concept of intelligence that is needed to define or even develop AI, is illustrated by Russel and Norvig (1985; 2010) and emphasised by the High Level Expert Group on Artificial Intelligence (AI HLEG, 2019a) when focusing on rational AI and hence considering benchmark against an ideal performance. "A system is rational if it does the “right thing”, given what it knows" (Russel and Norvig, 1985; 2010).

Two activities are especially considered in this study when analysing AI definitions: existing standardisation efforts, and the contribution of the AI HLEG. We also reflect hereby the recently adopted definition in the proposal for an AI Act, which is a risk-based approach to define AI systems in a context of market regulation.

## 2.2 Standardisation efforts

In order to collect information on the standardisation of AI and its applications, the International Organization for Standardization (ISO) is included in the analysis. Currently the available AI definitions are found in the ISO/IEC 2382 of 2015, established in 1993 and 1995. In 2018, in an effort to update these definitions, two sub committees with six working groups and one study group are formed with the goal to develop 10 AI standards for ISO/IEC (CEN-CENELEC, 2020). The ISO/IEC JTC1/SC42 is the first international standards committee identifying the entire AI ecosystem. JTC1’s scope for SC42 is to become “a systems integration entity to work with other ISO, IEC and JTC 1 committees looking at AI applications”. Until August 2020, three standards are published with a different objective; but an AI definition is not included. However, a definition of AI systems is mentioned in the ISO/IEC TR 24028:2020[10].

## 2.3 The High-Level Expert Group on Artificial Intelligence

The AI HLEG was appointed by the European Commission with the main aim to support the implementation of the European AI Strategy. This included the elaboration of recommendations on future-related policy developments and on ethical, legal and societal issues related to AI, including socio-economic challenges. The AI HLEG ended its mandate after its latest publication in July 2020. It was composed by 52 representatives from academia, civil society and industry. The first two outputs of the AI HLEG were the Ethics Guidelines for Trustworthy Artificial Intelligence[11], and a definition of AI[12] developed to describe a common understanding of the domain and its capabilities, serving also as a supporting document for the AI HLEG's deliverables. The AI HLEG definition is considered together with the remaining documents analysed in this study. An Assessment List for Trustworthy AI (ALTAI) (AI HLEG, 2020) has also been published to assist AI developers and deployers towards the development of a trustworthy AI[13]. In addition, ALTAI is the “operational tool of the Ethics Guidelines for Trustworthy AI”[14].

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9 US NDAA, 2019; Russel and Norvig, 1955; McCarthy, 2007; Nilsson, 1998; Fogel, 1995; Albus, 1991; Luger and Stubblefield, 1993; Winston, 1992; McCarthy, 1988; Gardner, 1987; 1983; Newell and Simon, 1976; Bellman, 1978; Minsky, 1969; McCarthy et al., 1955.

10 “…systems providing or using AI, called hereafter artificial intelligence (AI) systems.” (ISO/IEC TR 24028:2020).

11 ec.europa.eu/newsroom/dae/document.cfm?doc_id=58477

12 ec.europa.eu/newsroom/dae/document.cfm?doc_id=56341

13 ec.europa.eu/digital-single-market/en/news/assessment-list-trustworthy-artificial-intelligence-altai-self-assessment

14 ec.europa.eu/futurium/en/ethics-guidelines-trustworthy-ai/register-piloting-process-0

## 2.4 The Artificial Intelligence Act definition

Following the Communication "European Strategy for AI" (EC, 2018a), where the EC sets out an initiative to boost EU's technological and industrial capacity on AI, while preparing for socio-economic changes and ensuring an ethical and legal framework in line with the EU values, the White paper on AI (EC, 2020b) proposes policy options to join efforts at EU and national level for the development of AI, and announces a future regulatory framework to promote trustworthy AI.

The proposal for an AI Act (EC, 2021) aims at providing a risk-based regulatory approach for the safe and trustworthy development of AI in the EU. The AI Act contains new rules to make sure that AI systems used in the EU are safe, transparent, ethical, unbiased and under human control, categorising them by risk. The Act defines AI systems as:

"'Artificial intelligence system' (AI system) means software that is developed with one or more of the techniques and approaches listed in Annex I and can, for a given set of human-defined objectives, generate outputs such as content, predictions, recommendations, or decisions influencing the environments they interact with"[15].

## 2.5 Common features in AI definitions

Despite the multiple facets of AI, and consequently the lack of a common definition, there are a number of commonalities that we observe in the analysed definitions. This expression of common aspects suggests that they may be considered as the main features of AI:

- Perception of the environment, including the consideration of the real world complexity[16].
- Information processing: collecting and interpreting inputs (in form of data)[17].
- Decision making (including reasoning and learning): taking actions, performance of tasks (including adaptation, reaction to changes in the environment) with certain level of autonomy[18].
- Achievement of specific goals: this is considered as the ultimate reason of AI systems[19].

[15] The techniques and approaches in Annex I are: "(a) Machine learning approaches, including supervised, unsupervised and reinforcement learning, using a wide variety of methods including deep learning; (b) Logic- and knowledge-based approaches, including knowledge representation, inductive (logic) programming, knowledge bases, inference and deductive engines, (symbolic) reasoning and expert systems; (c) Statistical approaches, Bayesian estimation, search and optimization methods."

[16] Considered by AI HLEG, 2019a; EDA, 2019; EC, Ipsos and iCite, 2020; Latvian information report, 2019; Osservatorio Artificial Intelligence, 2019; European AI Strategy, 2018; EC JRC Flagship report on AI, 2018; Tsinghua University, 2018; Nakashima, 1999; Nilsson, 1998; 2010; Poole et al., 1998; Fogel, 1995; Wang, 1995; Albus, 1991; Newell and Simon, 1976.

[17] Considered by AI HLEG, 2019a; EC, Ipsos and iCite, 2020; Osservatorio Artificial Intelligence, 2019; European AI Strategy, 2018; EC JRC Flagship report on AI, 2018; Kaplan and Haenlein, 2018; Tsinghua University, 2018; Nakashima, 1999; Nilsson, 1998; 2010; Poole et al., 1998; Wang, 1995.

[18] Considered by AI HLEG, 2019a; OECD, 2019b; EDA, 2019; EC, Ipsos and iCite, 2020; Latvian information report, 2019; Osservatorio Artificial Intelligence, 2019; European AI Strategy 2018; EC JRC Flagship report on AI 2018; Kaplan and Haenlein 2018; Tsinghua University, 2018; Nilsson, 1998; 2010; Poole Mackworth and Goebel, 1998; Fogel, 1995; ISO/IEC 2382-28, 1995; Wang, 1995; Albus, 1991; Newell and Simon, 1976.

[19] Considered by AI HLEG 2019a; OECD, 2019b; EDA, 2019; EC, Ipsos and iCite, 2020; Latvian information report, 2019; Osservatorio Artificial Inteligence, 2019; European AI Strategy, 2018; Kaplan and Haenlein, 2018; Poole at al., 1998; Fogel, 1995; Albus, 1991; Newell and Simon, 1976.

# 3 AI taxonomies

Due to the multifaceted concept of AI, the AI knowledge domain allows several classification approaches and corresponding divisions in specific subdomains or categories. Certain taxonomies are developed to disentangle AI, each one developed from a particular perspective or for a specific purpose. Hence, we may classify AI according to, e.g., the families of algorithms used, AI applications, cognitive abilities reproduced by AI, etc. The choice of the most adequate approach to classify AI is driven by the objectives of the study in which it will be used. Even when the same dimension is pursued, e.g., a taxonomy of AI algorithms, there is no commonly agreed AI taxonomy among research communities, literature, or market, and due to the rapid evolution of the AI domain, some classifications may shortly become obsolete. In the following subsections, we present systematic attempts to arrange AI according to different sets of principles.

We derived information from the institutional, research and market literature that is collected for the state of play regarding the definitions of AI (subsection 2), and we conducted additional literature review of existing taxonomies. The presented classifications are not exclusive, namely certain categories may be found in more than one classification approach. Without a standardised classification or taxonomy of AI, the classifications outlined in this report remain mere indications, based on which different studies can develop and adopt a taxonomy that reflects their reality and objectives.

## 3.1 Theoretical models and algorithms

AI can be classified by grouping the algorithms used to develop the AI technology, according to the theoretical concepts behind them. In this way, the AI taxonomy is a classification of the technology itself with concepts primarily originated in mathematics, logic, philosophy and information theory. This very academic classification could match a classical course of AI fundamentals in a technology curriculum. It has as starting point the taxonomy of Russel and Norvig (2010), and is found in several studies of different perspectives[20]. The classification in question first divides AI into Weak or Narrow AI (ANI) and Strong or General AI (AGI).

ANI is the type of AI that exists today. ANI systems can perform one specific task and operate within a predefined environment. ANI can process data at high speed and boost the productivity and efficiency in many practical applications. While ANI is superior in specialized domains, it is incapable of generalization, i.e., to re-use learned knowledge across domains. AGI refers to machines that exhibit human intelligence. In other words, AGI aims to perform any intellectual task that a human being can[21]. The current state of development of AI is far from reaching AGI.

Under this perspective, one of the possible categorisations is that of classifying AI into symbolic, connectionist, evolutionary, Bayesian, and analogizer (Domingos, 2015). Symbolic and connectionist AI are the most dominant fields in AI history (Delipetrev et al., 2020). Symbolic was the dominant AI field between the 1970s and 1990s, a period known as the second AI cycle, with significant investments and media hype. Inspired by the human brain, Rosenblatt invented the perceptron (Rosenblatt, 1961), considered as the birth of connectionism, the foundation of Artificial Neural Networks (ANN) and Deep Learning (DL). Since 2010, DL is the dominant AI field, and the reason behind the current AI surge. Below we provide an explanation and list of algorithms for the three main fields, symbolic AI, connectionist AI and evolutionary AI[22], and present briefly the other two fields. The fields are often combined in practice, and intertwined with other fields from computer science, statistics, and signal processing, which are traditionally not included as part of AI.

— **Symbolic AI**: Rule-based, logic-based, and knowledge-based approach (previously also related to the top-down approach (Mira, 2008; Minsky, 1991)). It represents rational thought processes and reasoning (Russel and Norvig, 2010[23])). It is called symbolic, as the concepts and processes are expressed by sets of symbols, which follow a limited set of logic-based rules and use background knowledge and constraints to define the search space. Reasoning is achieved through the combination of different symbols following logic and formal rules to solve a problem (EDA, 2019). The symbolic AI was firstly implemented as "expert systems" or "knowledge-based systems". The main idea was to get human expert knowledge in a computer form and spread it as a program to many personal computers. The symbolic AI has two components: the knowledge base – a collection of facts, rules, and relationships on a specific domain; and

[20] For instance in OECD, 2019a; AI National Strategy: France. Monitoring report, 2019; US White House, 2016.

[21] AGI is often illustrated in science fiction movies with situations where humans interact with machines that are conscious, sentient, and driven by emotion and self-awareness.

[22] Goel (2020) and EDA (2019) also provide comprehensive taxonomies from this perspective.

[23] See Annex 1, subsection 2.7, right upper quadrant of Figure 1.1.

the inference engine that described how to manipulate and combine these symbols. The facts and rules had explicit representation and were modifiable. The symbolic tools and frameworks lacked sufficient expressive power to capture the breadth of the expert knowledge and behaviour required to achieve satisfactory performance. The compiled language efficiency (such as C) was better than the symbolic environment. In the 90s, the symbolic AI research and adoption slowed down. The following categories can be found under Symbolic AI:

- **Expert Systems**
    - Rule-Based Reasoning (RBR)
    - Fuzzy Expert Systems
    - Case-Based Reasoning (CBR)
    - Multi-Lingual Knowledge-Based
    - Knowledge Graphs
    - Other expert systems
- **Swarm intelligence (SI)**
    - Ant-colony Optimisation (ACO) algorithms
    - Stochastic Diffusion Search
    - Particle Swarm Optimisation (PSO) algorithms: Bare Bones, Accelerated, Hybrid
    - Artificial Bee Colony (ABC) Algorithm
    - Whale Optimisation Algorithm (WOA)
    - Firefly Algorithm (FA)
    - Cuckoo Search
    - Artificial Algae Algorithm (AAA)
    - Artificial Fish Swarm (AFS)
    - Rainfall Optimisation Algorithm
    - Other animal algorithms (Bat, Butterfly, Glow-worm, Grey Wolf, Frog (SFLA), Squirrel (SSA), Hawk (HHA), etc.)
- **Agent-based modelling (ABM) and simulation**
    - Multi-Agent Systems and Simulations
    - Virtual Agents and Digital Twins
- **Logic Programming – Logical Reasoning**
    - Deductive
    - Inductive
    - Abductive
    - Probabilistic or Statistical
    - Defeasible (Delp)
    - Other Logic Programming

— **Connectionist AI**: Probability-based, data-based and statistics-based approach. The concept behind connectionist AI, often referred to as ANN, is based on the network of interconnected neurons of the brain. In the ANN approach, concepts are formed with simple individual processing elements, units or nodes, interconnected in a network, and not with symbolic structures as in symbolic AI (Willshaw et al., 1994; Smolensky, 1987). The size of the neural network can be large with multiple layers, often referred to as Deep Learning, that allows the parallel process of information through the interconnected nodes (Smolensky, 1987). Processing is effectuated with the propagation of activations between the nodes through the nodes' interconnections (Frankish and Ramsey, 2014). The processing ability of the network is stored in the inter-node connection strengths, or weights, obtained by a process of adaptation to, or learning from, a set of training patterns (EDA, 2019). These weights carry the numeric conductivities of the effects that a node has to another and enable the propagation of the activations, in a similar manner that linked neurons affect each other through the synapses (Frankish and Ramsey, 2014, Minsky, 1991). The activation value for each node changes according to the activity of the nodes to which it is connected (Smolensky, 1987). The learning part is a result of a signal that can give a continuous output, indicating the degree of difference between the result from the network and the targeted outcome, or a discrete output, indicating success/failure (Sutton and Barto, 1998; McClelland et al., 1986).

In the last decade, DL approaches have become the preferred solution for vision, speech, language and other problems, inherently flexible by including adaptable mechanisms through learning, hence with better performance than the symbolic ones (Lieberman, 2016; Willshaw et al., 1994; Brooks, 1991; Bringsjord 1991; Smolensky 1988). However, the disadvantage is that it is difficult to understand how a solution is reached, namely how the decisions were made, which reduces explainability and transparency of the models using this approach.

Based on other comprehensive taxonomies in literature, the following ANN and DL models and algorithms can be considered connectionist approaches. Different types of networks are often combined to form complex architectures. For instance, a generative adversarial network working on images is typically composed of convolutional networks:

- NNs with up to 4 layers
- Deep NNs (DNN)
- Deep Autoencoders (DAE)
- Deep Boltzmann Machine (DBM)
- Deep Recurrent Neural Networks (DRNN)
- Deep Belief Networks (DBN)
- Recurrent Neural Networks (RNN)
- Convolutional Neural Networks (CNN)
- Generative Adversarial Networks (GAN)
- Transformer Networks

Depending on the neural network architecture and problem domain, DL can belong to multiple categories including supervised, unsupervised and semi-supervised learning.

— **Evolutionary AI**: Evolutionary algorithms are inspired by biological evolution, and are applied to a variety of learning tasks and other optimization problems (Mitchell, 1997). The solution to the problem is searched starting with a population that evolves by applying evolution-related mechanisms: reproduction, mutation, selection, among others. Every iteration of the algorithm generates a new population that is evaluated against the defined fitness measure. Some of the algorithms that fall in this category are: the genetic algorithms (GA), differential evolution (DE),harmony search algorithm (HSA), social engineering optimiser algorithm (SEO).

— **Bayesian AI**: It employs Bayesian inferential methods for the development of a software architecture for AI (Korb and Nicholson, 2010). The *a priori* hypothesis is that every input of information contains a value of uncertainty, so computing the probabilities of it being correct or occurring, and updating them based on the Bayes theorem and additional data, results in the most probable outcome. Methods used to solve probabilistic inference problems include the Hidden Markov Models (HMM) and graphical models. —
Bayesian AI is used in medical diagnosis, epidemiology analyses, meteorological forecasting, the first spam filters and more applications.

— **Analogizer AI**: The methods focus on pattern analysis, by matching relevant data and identifying similarities. New or old inputs to the system are assigned *a priori* to one of the class of entities that are created based on similarities between the data, and outputs are predicted based on generalised similarities to the members of a class. The most known analogizer models are the support vector machine (SVM) and the k-nearest neighbour (kNN) algorithms. They are widely used in recommender systems.

**Box 1. Machine Learning. Practical implementation of AI**

**Machine learning**: ML is the scientific study of computer algorithms that improve automatically through experience (Mitchell, 1997). *ML can be considered as the practical implementation of AI linked to some of the theoretical models presented in this subsection.* ML algorithms build a model based on training data, in order to make predictions or decisions without being explicitly programmed to do so. ML can be divided into:

- **Supervised learning** maps input to output values based on labelled examples of input-output pairs. Supervised learning needs considerable amounts of labelled data, which is often done by humans.
- **Unsupervised learning** helps finding previously unknown patterns in datasets without pre-existing labels. The objective is to discover the underlying data structure, for example, by grouping similar items to form clusters. Unsupervised learning does not require labelled data, but instead tries to learn by itself.
- **Semi-supervised learning** can be considered a category between supervised and unsupervised learning, where the data contains both labelled and unlabelled data.
- **Reinforcement learning** (RL) explores how agents take actions in an environment in order to maximize a reward. An example is when the RL agent plays Go against itself, learns the game, and acquires above human intelligence in Go.

More explicitly, the following families of algorithms can be considered as ML approaches. The presentation here does not follow a hierarchical approach, but rather a listing of existing groupings which may present overlaps between each other. For instance, although we propose a classification of some groups of algorithms into supervised or unsupervised learning, some can be trained in both ways, e.g. graphical models, neural networks. Similarly, classifiers can be also used for regression, and adversarial learning and transfer learning are applicable to all types of learning.

- **Supervised learning**
  - Regression
    - Linear
    - Non-Linear
    - Gaussian Process Regression (GPR)
    - Logistic
    - Probit
  - Probabilistic Graphical Models (PGM) or Graphical Models (GM)
    - Hidden Markov Models (HMM)
    - Bayesian Networks or Belief Networks or Causal Networks:
      - Naïve Bayes
      - Semi-Naïve Bayes
      - Pure Bayes
    - Restricted Boltzmann Machine (RBM) and Deep Boltzmann Machine (DBM)
  - Artificial Neural Networks (ANN) and Deep Learning (DL)
    - NNs with up to 4 layers
    - Deep NNs (DNN)
      - Deep Autoencoders (DAE)
      - Deep Boltzmann Machine (DBM)
      - Deep Recurrent Neural Networks (DRNN)
      - Deep Belief Networks (DBN)
      - Recurrent Neural Networks (RNN)
      - Convolutional Neural Networks (CNN)
  - Decision trees
    - Classification or Binary Trees - Discrete
    - Regression Trees - Continuous
    - Random Decision Trees
    - Random Forests
    - Bagged Decision Trees

        - Boosted Decision Trees
        - Behaviour Trees
        - Other Decision Trees
    - Classifiers
        - Discriminant analysis (generalisation of Fisher's linear discriminant)
        - Support Vector Machine (SVM)
        - k-Nearest Neighbour (kNN)
    - Ensemble Learning
- **Unsupervised learning**
    - Clustering
        - k-Means
        - Hierarchical Agglomerative Clustering (HAC)
        - Expectation maximisation (EM)
        - Density-based Spatial Clustering of applications with noise (e.g. DBSCAN)
        - Matrix Factorisation (used in both clustering and dimensionality reduction)
    - Dimensionality reduction – Data compression
        - Principal Component Analysis (PCA)
        - Linear Discriminant Analysis
        - Matrix Factorization (used in both clustering and dimensionality reduction)
    - Generative adversarial networks (GANs)
    - Autoencoders (AE)
- **Semi-supervised Learning**
- **Adversarial Learning (AL)**
- **Reinforcement Learning (RL)**
    - Deep Reinforcement Learning
    - Inverse Reinforcement Learning
    - Q-learning
- **Transfer learning (TL)**

## 3.2 Cognitive abilities reproduced by AI

This approach to classify AI groups the main cognitive abilities that AI automates or reproduces. It has been used to analyse impact of AI on occupations, after matching regular workplace tasks and tasks that appear as benchmarks in AI (Tolan et al., 2020). The following list of cognitive abilities is taken from Tolan et al. (2020) and Hernández-Orallo (2017):

— **Memory processes (MP)**: ability to create, process, store and recover information.

— **Sensorimotor interaction (SI)**: perception of things, pattern recognition, manipulation of things in physical/virtual environments.

— **Visual processing (VP)**: processing and recognition of visual information (both objects and symbols) in imagery and videos at several noise levels, angles, and transformations.

— **Auditory processing (AP)**: processing of auditory information, namely speech (excluding full understanding of sentences) and music (excluding subjective perception of harmony), at several frequencies and noise levels.

— **Attention and search (AS)**: Attention is the ability to focus the attention only on part of information input that meet certain criteria and ignore irrelevant objects, patterns, etc. Search is the ability to request the parts of information that meet certain criteria of the information input.

— **Planning and sequential decision-making and acting (PA)**: ability to expect the consequences of series of actions (time-dependent or differently dependent), to understand the reason of their occurrence, and to determine the best action plan in a provided case.

— **Comprehension and compositional expression (CE)**: processing, understanding, and generation of natural language and of semantic representations, through different formats: text, audio, drawings, etc.

— **Communication (CO)**: ability to exchange and understand information between peers, in formal and informal context.

— **Emotion and self-control (EC)**: understand emotional state of other agents, the impact of these emotions to their behaviour, as well as recognise and control the own emotional state of the agent, excluding the mind modelling and social interaction ability.

— **Navigation (NV)**: ability to move oneself or objects between positions, through appropriate and safe paths, and considering other objects or agents in a relevant proximity, and the ability to adapt the paths to reach a position.

— **Conceptualisation, learning and abstraction (CL)**: the ability to form an idea or operation drawing on generalisations of previous examples, to receive instructions and operate based on demonstrations, and lastly to collect knowledge at several levels of abstraction. All the aforementioned parts of the ability aim to complete a task, without the task being restricted to former learning of ideas, operations or abstractions.

— **Quantitative and logical reasoning (QL)**: the ability to represent quantitative and/or logical information essential to the task that is set, and to deduce new information that can solve the task (e.g. probabilities, counterfactuals, other types of analytical reasoning). This ability extends beyond and does not include following a combination of simple rules or instructions by processing internally symbols or numbers, such as programming languages, neurons in a network etc.

— **Mind modelling and social interaction (MS)**: create models of other agents that understand their intentions, desires, and beliefs, aiming to anticipate their actions and interests.

— **Metacognition and confidence assessment (MC)**: ability to self-assess the probability and confidence of ones actions for success, effort and risk, exceeding the planning tasks or the simple selection of the highest probability action.

## 3.3 Functions performed by AI

AI can be also classified based on what AI algorithms do, namely their functions, translated into applications of the technology in the real world. AI applications are used for: solving and optimising, automating, perceiving and communicating, and lastly experimenting and creating. Therefore, under these four main groups we can find the following indicative applications (non-exhaustive list) (EC, Ipsos and iCite, 2020; EDA, 2019):

— **Solving and optimising**

- **Decision optimisation**: e.g. demand forecasting, task allocation, expert systems, logistics/warehouse/workforce/price optimisation, etc.
- **Process or equipment optimisation**: e.g. to predict when a maintenance needs to be implemented
- **Recommendation and personalisation engines**: through matching algorithms, information retrieval, etc., they provide e.g. personalised marketing, action/treatment recommendation, etc.

— **Automating**

- **Process automation**: e.g. warehouse automation, automatic trading, robotics process automation (RPA), etc.
- **Autonomous systems**: e.g. robots (smart/autonomous), vehicles (connected, automated, autonomous), other devices (drones), etc.

— **Perceiving and Communicating**: includes text, sound, video, and image for communication either man to machine, or machine to machine (M2M), or machine to cloud (M2C), some of which are used in the automating applications:

- **Natural language communication and processing (NLP)**: e.g. speech recognition and production, chatbot, voice assistant, automatic text summarisation, term extraction (tokenisation, stopword removal, part-of-speech tagging, stemming, lemmatisation), machine translation, etc.
- **Computer vision**: e.g. image acquisition, image pre-processing/ detection/ segmentation/ recognition, high-level processing, feature extraction, face recognition, visual diagnostics, etc.
- **Sentiment analysis**: e.g. emotion and behaviour identification, extraction, analysis, and categorisation from text (including social media activity), audio, video or biometric sensors, etc.
- **Anomaly detection**: e.g. fraud detection, cyber-attack detection (evasion, poisoning, etc.), defect detection etc.

— **Experimenting and Creative activities**

- **Data generation**: e.g. automatic image synthesis, automatic scene generation etc.
- **Artificial experimentation and discovery**: e.g. virtual agent, digital twin, virtual prototyping, drug/chemical/biological discovery, multi-agent systems and simulations etc.
- **Artistic creation and design**: e.g. artificial music/painting synthesis, character animation etc.

## 3.4 AI applications

In the real world, we can find multiple applications of AI used by enterprises, government and society in general. As it is not possible to provide a full up to date list of all AI applications that can be found in market, this section provides an indicative list of them, grouped by business functions (AI applications that are used by enterprises' value chains) and AI applications by economic sector.

### 3.4.1 By business function

This type of classification lists the AI applications that can be found in each of the business functions of enterprises' value chains. The non-exhaustive classification that follows is a result of AI applications found in studies made for the design of surveys, which have as objective the analysis of AI take-up by enterprises. Nevertheless, such a classification presents challenges in their creation, since requires a prior identification of the applications per business function, in order to be as inclusive as possible (Eurostat, 2020; EC, Ipsos and iCite, 2020). Additionally, these lists of applications per business function may quickly become obsolete, considering the continuous advancement of the technology and the endless appearance of business solutions and applications.

— **Marketing, Sales**

- Customer profiling, personalised marketing offers and recommendations, price optimisation, customer service automation, targeted advertising, market analysis, automatic lead generation, churn prevention, etc., based on ML
- Chatbots based on NLP for customer support

— **Production processes**

- Predictive maintenance based on ML
- Classification of products or defect detection based on computer vision
- Assembly works by autonomous robots
- Autonomous drones for production surveillance, security, or inspection of tasks

— **Organisation of business administration processes**

- Business virtual assistants based on ML and NLP
- Voice to text conversion based on speech recognition

- Automated planning or scheduling based on ML
- Machine translation

— **Management of enterprise**

- ML data analytics to help investment or other decision-making
- Sales or business forecasting based on ML
- Risk assessment based on ML

— **Logistics**

- Demand forecasting
- Autonomous robots for pick-and-pack solutions in warehouses, parcel shipping, tracing, distribution and sorting
- Route optimisation based on ML
- Drone for parcel delivery

— **ICT security**

- Authentication of ICT users using face recognition based on computer vision
- Cyber-attack detection and prevention based on ML

— **Human resources (HR) management or recruiting**

- Candidates pre-selection screening, recruiting automation based on ML
- HR management support or recruiting, with chatbots and NLP
- Employee profiling, performance analytics based on ML
- Task automation with HR bots and electronic employees helpdesk
- Employees' sentiment and group behaviour analysis for prediction of employee turnover and for retention purposes

— **R&D processes**

- Virtual prototyping
- Product feature optimisation
- e-Discovery

— **Infrastructure and technology management**

- Smart buildings
- Analytical tool for investment optimisation and planning

### 3.4.2 By economic sector

This subsection groups common applications that are related to each industry sector, and provides a non-exhaustive list[24]:

- A. Agriculture, forestry and fishing: e.g. agricultural robots, crop and soil monitoring
- B. Oil and gas: e.g. precision drilling, predictive maintenance, failure prevention/detection.
- C. Manufacturing: e.g. process automation, process optimisation, predictive maintenance, failure prevention/detection, automated and connected vehicles.

[24] Some of the applications are taken from Desruelle et al., 2019.

- D. Electricity and Gas supply: e.g. process automation, process optimisation, smart energy storage, autonomous grid management, failure prevention/detection, smart meters.
- E. Water supply, Waste management: e.g. process automation, process optimisation, smart meters.
- F. Construction: e.g. drones, additive manufacturing, 3D scanning, distributed sensor networks, Building Information Modelling, virtual and augmented reality.
- G. Trade, retail: e.g. personalised marketing, product recommendation, price optimisation, automatic inventory management, market analysis, platforms (car-pooling, car or bicycle sharing services).
- H. Transportation and storage: e.g. process optimisation, storage optimisation, route optimisation, automatic train operation, autonomous mobility on demand.
- I. Accommodation and Food: business processes optimisation through on-line platforms.
- J. Information and Communication: e.g. anomaly detection, forecasting, process optimisation, systems optimisation, network efficiency, cybersecurity applications: protection, spam filtering, data protection.
- K. Finance, insurance: e.g. anomaly detection, forecasting, robotics process automation (RPA), high-frequency trading (HFT).
- L. Real estate: e.g. sentiment analysis, recommendation engines, forecasting.
- M. Other technical and/or scientific sectors: not a specific type of application.
- P. Education: e.g. automatic test generation, e-learning, early detection of dyslexia and attention-deficit disorders.
- Q. Human health, Social work: e.g. e-appointments, personal companions (humanoid robots), image-based diagnosis, prediction, measurement devices, medical robots for surgery.
- R. Recreation activities: e.g. creative activities, virtual and augmented reality, sport wearables.

# 4 AI Watch operational definition of AI: taxonomy and keywords

## 4.1 AI HLEG definition as a starting point

The proposed AI Watch operational definition is based on a concrete definition taken as a starting point, and is composed by a concise taxonomy and a set of keywords that characterise the core and transversal domains of AI. To reach a common understanding on the concept of AI in the framework of AI Watch, it is important that the starting point is an inclusive definition, hence covering all technological developments and activities carried out by all type of actors that make up the AI ecosystem, whether industrial, research, or government initiatives. Taking into consideration the features that many of the explored definitions share (see Table 3), as well as the aforementioned objectives, **we consider the definition proposed by the AI HLEG as the starting point for the development of the operational definition to address the objectives of AI Watch**. Although it may be considered highly technical for different audiences and objectives, it is a very comprehensive definition which incorporates the aspects of perception, understanding, interpretation, interaction, decision making, adaptation to behaviour and achievement of goals, whereas other definitions do not address them in their entirety:

**AI HLEG definition of AI**

"Artificial intelligence (AI) systems are software (and possibly also hardware) systems designed by humans[25] that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information, derived from this data and deciding the best action(s) to take to achieve the given goal. AI systems can either use symbolic rules or learn a numeric model, and they can also adapt their behaviour by analysing how the environment is affected by their previous actions." (AI HLEG, 2019a)

**It should be noted that this only covers the current AI developments**. Given the rapid evolution in the domain, AI may be subject to certain changes that can affect the aforementioned definition in the next period. More specifically, (i) in the long-term AI systems may not necessarily be designed by humans, (ii) regarding the agent-oriented perspective, it is possible that not every AI system has to act; many can be only input-output modules, components or processes, and also one can take any input-output system as an agent, considering then that certain software systems would be agents, and (iii) the "information processing" part may be included in all AI parts and may become redundant to be mentioned. Lastly, an adaptation regarding the use of both symbolic rules "*and*" learning a numeric model by an AI system, instead of "*or*", can be accepted.

**Other suitable definitions targeted to alternative uses**

Considering that the AI HLEG definition is comprehensive, hence highly technical and detailed, less specialised definitions can be adopted for studies of different objectives. **For the objectives of other approaches like surveys, where the length of the definition is as crucial as the completeness and clarity, suitable alternatives are the EC JRC flagship report on AI** (2018) (see details in subsection 1.1.8), **the European Strategy on AI** (EC, 2018a), or the definitions in the "European enterprise survey on the use of technologies based on artificial intelligence" (EC, Ipsos and iCite, 2020). Also for regulatory purposes, a new definition of AI has been adopted in the proposal of an AI Act (EC, 2021) (see subsection 2.4).

EC JRC Flagship report on AI

"AI is a generic term that refers to any machine or algorithm that is capable of observing its environment, learning, and based on the knowledge and experience gained, taking intelligent action or proposing decisions. There are many different technologies that fall under this broad AI definition. At the moment, ML[26] techniques are the most widely used."

European AI Strategy

[25] "Humans design AI systems directly, but they may also use AI techniques to optimise their design." (AI HLEG, 2019a).

[26] Machine Learning (the footnote is by the authors).

"Artificial Intelligence refers to systems that display intelligent behaviour by analysing their environment and taking action — with some degree of autonomy — to achieve specific goals."

The latter has been considered by Eurostat as the starting point for the development of a definition that has been included in the AI module of the Community Survey on ICT Usage and e-Commerce in Enterprises 2021 upon approval.

Eurostat's Community survey on ICT usage and e-commerce in enterprises 2021 (model questionnaire)

"Artificial intelligence refers to systems that use technologies such as: text mining, computer vision, speech recognition, natural language generation, machine learning, deep learning to gather and/or use data to predict, recommend or decide, with varying levels of autonomy, the best action to achieve specific goals." In the model questionnaire, this definition is accompanied by a list of examples to facilitate the understanding of the concept and the scope by the respondent:

"Artificial intelligence systems can be:

- purely software based, e.g.: chatbots and business virtual assistants based on natural language processing; face recognition systems based on computer vision or speech recognition systems; machine translation software; data analysis based on machine learning, etc.;
- embedded in devices, e.g.: autonomous robots for warehouse automation or production assembly works; autonomous drones for production surveillance or parcel handling, etc."

In general, the use of definitions and taxonomies of complex domains, such as AI, in surveys poses specific challenges. For instance, the inclusion of non-exhaustive lists of examples or response categories creates too specific options that might dictate the replies, and limit the possibility of capturing all potential answers. Also, the restrictions imposed by the questionnaire's length induces the shortening and oversimplification of the response categories, which may appear very general, rendering difficult to discern if an application selected by the respondent is employing AI or not. For example, price optimisation is a constrained optimisation process that can be performed with or without machine learning. To that end, specific survey instructions are included to facilitate a common an accurate understanding of the survey questions and response options, and the scope in which they need to be answered (Eurostat, 2020).

## 4.2 AI Watch taxonomy

Following the presentation of alternative taxonomies of AI from several approaches (section 3), the ones that mostly address our needs to monitor R&D and industrial activity, are the most inclusive taxonomies of algorithms (subsection 3.1) and functions (subsection 3.3). These two types of taxonomies are the basis for our proposed taxonomy that addresses political, research and industrial perspectives and aims to cover and classify the AI landscape, which consists of economic agents with R&D or industrial AI related activities. Therefore, this taxonomy is able to detect correspondingly a wide range of **core** AI related scientific subdomains (e.g. knowledge representation and reasoning, machine learning) and **transversal** topics, such as *applications* of the former (e.g. robots, automated vehicles, etc.), or ethical and philosophical considerations, as well as the *algorithms* that are used to develop the technology. The taxonomy is presented as a reduced list of abstract high level domains and their related subdomains. These are meant to encompass the main theoretical AI branches, as well as AI related non-technological issues. The AI subdomains are represented by a list of keywords (see subsection 4.3); these will enable us to capture the AI activities carried out by economic agents, for further analysis of the AI landscape from a techno-economic perspective.

### 4.2.1 Sources

The AI field allows several classification approaches and corresponding divisions in specific subdomains or topics. It should be noted again that there is no commonly agreed AI taxonomy among research communities, literature or reports, given the rapid evolution of this knowledge domain and varied perspectives from which AI is considered. For this part of the study, we have analysed existing taxonomies and attempts to disentangle the AI knowledge domain. We have explored the following sources:

— AITopics[27]: this website is an official publication of the Association for the Advancement of Artificial Intelligence (AAAI), presenting in ordered way information about AI. The information gathered covers different dimensions: research (through journals and conferences), AI applications, authors; and different types of sources: papers, news, tweets, etc. The documents analysed are tagged -combining machine learning with subject matter expert knowledge- and classified according to two main dimensions: technological and industrial, that is considering the economic sector in which AI is developed and/or used. We focus on the technology break down provided by this source. The following AI related fields are considered by AITopics under AI: Assistive technologies, Cognitive science, Games, Human-centered computing, Machine learning, Natural language, Representation & reasoning, Robots, Speech, Systems & languages, Vision, together with other less technology related : Challenges,. Issues, History, Science fiction, The future[28].

— Specialised conferences: we explore the top AI conferences in order to identify submission groups as proxies of the main current in research sub-fields. The following conference submission groups have been considered:

— AAAI 2018: AI and the Web, Applications, Cognitive Modeling, Cognitive Systems, Computational Sustainability and AI, Game Theory and Economic Paradigms, Game Playing and Interactive Entertainment, Heuristic Search and Optimization, Human-AI Collaboration, Human-Computation and Crowd Sourcing, Humans and AI, Knowledge Representation and Reasoning, Machine Learning Applications, Machine Learning Methods, Multiagent Systems, Natural Language Processing (NLP) and Knowledge Representation, NLP and Machine Learning, NLP and Text Mining, Planning and Scheduling, Reasoning under Uncertainty, Robotics, Search and Constraint Satisfaction, Vision.

— International Joint Conferences on Artificial Intelligence (IJCAI):

  - 2009: Agent-based and Multi-agent Systems, Multidisciplinary Topics and Applications, Robotics and Vision, Natural-Language Processing, Knowledge Representation, Reasoning and Logic, Constraints, Satisfiability, and Search, Planning and Scheduling, Uncertainty in AI, Machine Learning, Web and Knowledge-based Information Systems.

  - 2018: Agent-based and Multi-agent Systems, Computer Vision, Constraints and SAT, Heuristic Search and Game Playing, Humans and AI, Knowledge Representation and Reasoning, Machine Learning, Machine Learning Applications, Multidisciplinary Topics and Applications, Natural Language Processing, Planning and Scheduling, Robotics, Uncertainty in AI.

— Documents analysed for this study (section 6): We also acknowledge the AI subdomains mentioned in the policy, research and market reports. A summary of the main AI subdomains listed in all the documents follow (subsection 5). Additionally, we analysed the taxonomy and keywords developed by the Working Group drafting the Spanish strategy on AI[29]: Machine Learning, Natural Language Processing, Computer Vision and Perception, Knowledge Representation and Reasoning, Multiagent Systems, Data Science, Other.

— The European survey on the uptake of AI by enterprises (EC, Ipsos and iCite, 2020) and the European Defense Agency (EDA, 2019) for the taxonomies based on algorithms, and functions of the algorithms (subsections 3.1 and 3.3).

— Moreover, this top-down approach is complemented with a bottom-up approach that converges with the taxonomy. In the early results of this approach we used a natural language processing method (topic modelling) to unbiasedly identify thematic subdomains in a collection of more than 64 thousand industrial and R&D AI activities. This resulted in the identification of six thematic subdomains (machine learning, computer vision, natural language processing, connected and automated vehicles, robotics, and AI services), which have a correspondence in the proposed taxonomy.

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27 aitopics.org.

28 Additionally, some of the documents collected are classified under other main technological fields such as Architecture, Enterprise Application, Information Management, Sensing and signal processing, among others.

29 Coordinated by Professor Ramón López de Mántaras (IIIA-CSIC), who acted also as advisor in this study.

### 4.2.2 AI Watch taxonomy

In accordance to the AI HLEG, AI techniques and sub-disciplines can be grouped under two big strands regarding the systems' capabilities: (i) reasoning and decision making, (ii) and learning and perception. The first group of capabilities includes the transformation of data into knowledge, by transforming real world information into something understandable and usable by machines, and making decisions following an organised path of planning, solution searching and optimisation. This strand covers the AI subdomains of Knowledge representation and reasoning (usually making use of symbolic rules to represent and infer knowledge) and Planning (including Planning & Scheduling, Searching, and Optimisation). The second group of capabilities develops in absence of symbolic rules, and involves learning -meaning the extraction of information, and problem solving based on structured or unstructured perceived data (written and oral language, image, sound, etc.)-, adaptation and reaction to changes, behavioural prediction, etc. This second strand covers AI sub-fields related to learning, communication and perception, such as Machine learning, Natural language processing, and Computer vision.

The academic approach followed by the AI HLEG is to be complemented by considering the wider monitoring objective of AI Watch, namely to capture and measure the AI landscape that involves multifarious economic agents and complementary approaches, considering also the impact on society. Consequently, the taxonomy proposed is based on the main AI domains identified by the AI HLEG and is expanded to cover additional dimensions:

- the concept of rational agents, as entities that make decisions and act in relation to its environment, including interaction with other agents;
- research and industrial developments, and other AI applications such as cloud service models offered by service companies to accelerate AI uptake;
- other noteworthy aspects related to AI, but not necessarily technology related, arise as important subjects in policy documents and the social debate: ethical considerations such as transparency, explainability, accountability, fairness and safety, as well philosophical matters involving the deepest nature of AI and its evolution.

Taking into consideration the above and after feedback and evaluation from experts, we propose the following AI domains and subdomains as characterising the AI field. They are divided into *core and transversal domains*, the former referring to the fundamental goals of AI, the latter not specifically related to a particular academic discipline or area of knowledge, but as issues common to all the core domains.

**Table 1. AI domains and subdomains constituting one part of the operational definition of AI**

| | AI taxonomy | |
|---|---|---|
| | **AI domain** | **AI subdomain** |
| **Core** | **Reasoning** | Knowledge representation |
| | | Automated reasoning |
| | | Common sense reasoning |
| | **Planning** | Planning and Scheduling |
| | | Searching |
| | | Optimisation |
| | **Learning** | Machine learning |
| | **Communication** | Natural language processing |
| | **Perception** | Computer vision |
| | | Audio processing |
| **Transversal** | **Integration and Interaction** | Multi-agent systems |
| | | Robotics and Automation |
| | | Connected and Automated vehicles |
| | **Services** | AI Services |
| | **Ethics and Philosophy** | AI Ethics |
| | | Philosophy of AI |

Source: Authors' elaboration

It is noteworthy that the suggested domains and subdomains are related, and not disjoint, subsets of AI. This ensues from the nature of the AI field that embraces intertwined applications and theoretical advancements, with fuzzy boundaries. For instance, the fact that machine learning is exploited in either computer vision, audio processing or natural language processing does not prevent them from being separate research fields, considered by top AI conferences topics and related literature (see subsection 2.2.1.1). At the same time, computer vision and natural language processing are in turn embedded in more complex applications, such as virtual personal assistants or robotic platforms. Following this continuum, we consider theoretical advancements in one end of the taxonomy and industrial applications in the other one. We should also stress that the defined subdomains may not be fully AI-driven. For instance, while mechanical robots do not always incorporate AI techniques, robotics is considered as a relevant domain impacted by recent developments in AI techniques.

In conclusion, the AI Watch taxonomy is not meant to constitute a rigid or exhaustive classification, but *a comprehensive collection of areas that represent AI from our three target perspectives: policy, research and industry*. We acknowledge that other taxonomies are possible, certain of which are presented in section 3. **The proposed taxonomy includes the majority of the aforementioned cases from AI applications and algorithms, in a form that allows the subdomains to be related, and not disjoint, subsets of AI. In addition, it allows the reader to navigate under each subdomain and identify e.g. a technology or a business purpose, based on the function that this technology performs**. For example, searching for the computer vision technology, the user can be also informed that can be related with the audio processing technology to provide the perception of an AI system, and that is one of the core AI subdomains. In the following paragraphs, we succinctly describe the suggested domains and subdomains, highlighting their identification in different AI national strategies and reports.

**Domain: Reasoning**

**Subdomains: Knowledge representation; Automated reasoning; Common sense reasoning**

The domain of reasoning tackles the way machines transform data into knowledge, or infer facts from data. Several classifications address knowledge representation and automated reasoning as a field of AI, to describe the process of justifying (reasoning) the available data and information, provide solutions and represent them efficiently, based on a set of symbolic rules (AI HLEG, 2019a; Spanish RDI Strategy in Artificial Intelligence, 2019; National Strategy: France Monitoring Report, 2019; CB Insights, 2019; AI National Strategy: Germany, 2018; Working Paper for National Strategy: India, 2018; ETSI, 2018; National Strategy: France (Villani Mission), 2018; AI National Strategy: China, 2017; McCarthy, 2007; Nilsson, 1998).

**Domain: Planning**

**Subdomains: Planning and Scheduling; Searching; Optimisation**

The main purpose of automated planning concerns the design and execution of strategies (e.g., an organised set of actions) to carry out some activity, and typically performed by intelligent agents, autonomous robots and unmanned vehicles. Unlike classical control and classification problems, the solutions are complex and must be discovered and optimised in the multidimensional space. (AI HLEG, 2019a; Spanish RDI Strategy in Artificial Intelligence, 2019; National Strategy: France Monitoring Report, 2019; CB Insights, 2019; AI National Strategy: Germany, 2018; McCarthy, 2007).

**Domain: Learning**

**Subdomains: Machine Learning (ML)**

By learning, we refer to the ability of systems to automatically learn, decide, predict, adapt and react to changes, improving from experience, without being explicitly programmed. ML is widely included in the vast majority of efforts to identify AI categories, as the basic algorithmic approach to achieve AI regardless the type of learning, namely *reinforcement, supervised, semi-supervised, unsupervised* (AI HLEG, 2019a; Spanish RDI Strategy in Artificial Intelligence, 2019; StandICT.eu project, 2019; National Strategy: Denmark, 2019; National Strategy: France Monitoring report, 2019; Australia's Ethic Framework Dawson et al., 2019; US Congressional Research Service, 2019; CB Insights, 2019; EC JRC Flagship report on AI, 2018; AI National Strategy: Germany, 2018; OECD, 2018; Tsinghua University, 2018; Working Paper for AI National Strategy: India, 2018; National Industrial Strategy: UK, 2018; 2017; AI National Strategy: France (Villani Mission), 2018; US Department of Defense, 2018; OECD, 2017; McKinsey, 2017; Stone et al.: AI100, 2016; McCarthy, 2007).

**Domain: Communication**

**Subdomains: Natural Language Processing (NLP)**

NLP, as the main task of communication, refers to the machine's ability to identify, process, understand and/or generate information in written and spoken human communications. It is considered as an AI subdomain from several national strategies and AI experts, encompassing applications such as text generation, text mining, classification, and machine translation (AI HLEG, 2019a; Spanish RDI Strategy in Artificial Intelligence, 2019; National Strategy: Denmark, 2019; National Strategy: France Monitoring report, 2019; CB Insights, 2019; EC JRC Flagship report on AI, 2018; OECD, 2018; Tsinghua University, 2018; Working Paper for AI National Strategy: India, 2018; National Strategy: France (Villani Mission), 2018; US Department of Defense, 2018; AI National Strategy: Japan, 2017; AI National Strategy: China, 2017; McKinsey, 2017; Stone et al.: AI100, 2016; McCarthy, 2007)

**Domain: Perception**

**Subdomains: Computer vision; Audio processing**

Perception refers to systems' ability to become aware of their environment through the senses: vision, hearing, manipulation. etc., being vision and hearing the most developed areas in AI. Computer vision (CV) refers to activities that identify human faces and objects in digital images, as part of object-class detection. It is identified as one of the essential scientific fields with parts belonging to machine perception and, thus, AI. It is usually referred to as *image pattern recognition* for specific tasks, or as in a broader sense as *machine vision*, with applications on face and body recognition, video content recognition, 3D reconstruction, public safety and security, health etc. (AI HLEG, 2019a; Spanish RDI Strategy in Artificial Intelligence, 2019; National Strategy: Denmark, 2019; Australia's Ethic Framework Dawson et al., 2019; US Congressional Research Service, 2019; CB Insights, 2019; EC JRC Flagship report on AI, 2018; AI National Strategy: Germany, 2018; Tsinghua University, 2018; Working Paper for AI National Strategy: India, 2018; OECD, 2018; US Department of Defense, 2018; AI National Strategy: Japan, 2017; OECD, 2017; McKinsey, 2017; Stone et al.: AI100, 2016; McCarthy, 2007). Audio processing refers to AI systems allowing the perception or generation (synthesis) of audio signals, including speech, but also other sound material (e.g. environmental sounds, music). Speech or voice recognition, audio processing or sound technologies are also often proposed to be archived as an AI subdivision (AI4Belgium Report, 2019; EC, 2018a; EC JRC Flagship report on AI, 2018; OECD, 2017, 2018; Tsinghua University, 2018; Working Paper for AI National Strategy: India, 2018; AI National Strategy: Japan, 2017; McCarthy, 2007).

**Domain: Integration and Interaction**

**Subdomains: Multi-agent systems; Robotics and Automation; Connected and Automated vehicles (CAVs)**

The transversal domain of Integration and Interaction addresses the combination of perception, reasoning, action, learning and interaction with the environment, as well as characteristics such as distribution, coordination, cooperation, autonomy, interaction and integration.. Robotics and Automation refers to activities related to application and research of the technological intelligent tools to assist or substitute human activity, or to enable actions that are not humanly possible (e.g. medical robots), to optimise technical limitations, labour or production costs. The CAVs subdomain is regarding technologies of autonomous vehicles, connected vehicles and driver assistance systems, considering all automation levels and all communication technologies (V2X). Multi-agent systems, Unmanned systems (CAVs, drones), as well as robotics and process automation (Application programming interface (API), robotic process automation for industrial, social and other uses) are also mentioned as separate intrinsic subdivisions of AI (AI HLEG, 2019a; Spanish RDI Strategy in Artificial Intelligence, 2019; UNESCO, 2019; Australia's Ethic Framework, 2019; National Strategy: Denmark, 2019; National Strategy: France Monitoring report, 2019; US Congressional Research Service, 2019; CB Insights, 2019; EC JRC Flagship report on AI, 2018; EC, 2018a; AI National Strategy: Germany, 2018; Tsinghua University, 2018; Working Paper for AI National Strategy: India, 2018; National Industrial Strategy: UK, 2018; 2017; National Strategy: France (Villani Mission), 2018; Statista 2017; McKinsey, 2017; AI National Strategy: Japan, 2017; AI National Strategy: China, 2017; Stone et al.: AI100, 2016).

**Domain: Services**

**Subdomains: AI Services**

The transversal domain of AI services refers to any infrastructure, software and platform (e.g., cognitive computing, ML frameworks, bots and virtual assistants, etc.) provided as (serverless) services or applications, possibly in the cloud, which are available off the shelf and executed on demand, reducing the management of

complex infrastructures. In this regard, cloud computing services are often presented when describing the AI landscape(US NDAA, 2019; Chinese National Strategy, 2017). Infrastructure as a Service (IaaS) is the basis of cloud computing, providing access and management of virtual resources such as servers, storage, operating systems and networking. Subsequently, cloud platforms (or Platform as a Service (PaaS)) are service products of cloud applications, and can be used within Software as a Service (SaaS) architectures, which are cloud applications and adaptive intelligence software (AI HLEG, 2019a; Spanish RDI Strategy in Artificial Intelligence, 2019; US Department of Defense, 2018; Tsinghua University, 2018; Working Paper for AI National Strategy: India, 2018; AI National Strategy: China, 2017; Statista, 2017; McKinsey, 2017).

**Domain: Ethics & Philosophy**

**Subdomains: AI Ethics; Philosophy of AI**

Philosophical and ethical issues associated with AI are proliferating and rising citizens' attention and governments' policy interest as intelligent systems become widespread. The ethics of AI is considered as a transversal subdomain, as AI advances and applications in different areas should ensure compliance with ethical principles and values, including applicable regulation. Given the impact on human beings and society, establishing trust in AI is the focus of several frameworks and initiatives by policy bodies and institutions (AI HLEG, 2019a; OECD, 2019b; StandICT.eu project, 2019; National Strategy: France Monitoring report, 2019; Australia's Ethic Framework Dawson et al., 2019; EC Coordinated Action Plan on AI, 2018; European AI Strategy: EC Communication; National Strategy: France (Villani Mission), 2018; Artificial Intelligence for Europe, 2018).

## 4.3 AI keywords

To fulfil its objective as a monitoring tool and trace the boundaries of AI activities and domains, one of the outputs of AI Watch will be to provide an overview of the worldwide landscape of AI. The analysis of the AI landscape will be conducted by applying the Techno-economic segments (TES) analytical approach developed by the EC JRC to the AI field (Samoili et al., 2020b). Through the TES approach we will identify the most representative keywords of each domain of the taxonomy of AI.

The TES methodology is developed to map technological (and non-technological) domains that do not correspond to standard classifications (e.g. industries, products), and that are pervasive and cross-sectoral. It is conceived as an analytical framework and replicable methodology to analyse and describe the dynamics of specific TES ecosystems, by exploiting different types of factual data including non-official heterogeneous sources. The initial stages of the TES analytical approach are presented in Samoili S., Righi R., Lopez-Cobo M., Cardona M., and De Prato G. (2019), and a first application to the AI domain is shown in De Prato et al. (2019) and Samoili et al. (2020b). The first step of the TES methodology addresses the definition of a techno-economic segment, e.g. AI, followed by its operationalisation through a list of keywords. The keywords are used in text queries to identify activities and economic agents relevant to the technology under study, AI in this case, for further analysis.

### 4.3.1 Construction process

The domains and subdomains that are selected as characterising AI are represented by a list of keywords. These, as the AI subdomains, cover different aspects, such as methods, algorithmic approaches, applications, products, research areas, etc., but also address aspects such as ethics and philosophy, not as an intrinsic part of AI, but rather as an application of ethical principles and philosophical concerns to AI. The list of keywords is built in a multi-step process combining a semi-automatic text mining approach, desk research and domain experts' involvement:

1. **Identification of top keywords in the research domain**

(a) Seed articles: First we conduct a selection of a seed subset of scientific articles where the term "artificial intelligence" is present in the title, keywords or abstract of the publication. This first step is run on all articles available in the Scopus Database in three different years (2005, 2009 and 2017). The consideration of the time dimensions allows capturing recently coined terms, as well as others that are consolidated, or even some that fell into disuse but that were important terms in the past.

(b) Expansion to cover articles not triggered by the technology term: In view of expanding the set of investigated documents, and not limiting the analysis to the papers containing the keyword "artificial intelligence", we consider all articles published in the journals in which the articles identified in step 1.(a) are found. In this step, 137 specialised journals are considered, while generalist journals and the

ones centred in other scientific fields are ignored. For instance, the journal "Engineering Applications of Artificial Intelligence" would be selected, while "Physics of Life Reviews" would not, even if the latter has published some AI related articles.

(c) First draft list of keywords: We consider all papers published in the journals selected in step 1.(b) during the three referred years. The selected AI related articles amount to 25 600: 2 907 published in 2005, 12 706 in 2009 and 9 987 in 2017. The number of different keywords included in these papers totals 57 850. The first draft list of keywords is composed by a selection from the 300 most frequent author's keywords per year, from which generic terms are removed.

**2. Identification of keywords in the industrial dimension of the technology**

In order to cover terms reflecting the recent industrial developments and AI applications, we also take into consideration sources of industrial activity. To that end, we have analysed and extracted relevant terms from companies' activities descriptions. Since an equivalent to author's keywords is not available from firms' descriptions, we obtain the most frequent terms (unigrams, bigrams and trigrams) and manually inspect their relevancy in order to incorporate them to the draft list built in step 1.

**3. Initial keyword selection**

The list of candidate terms, sorted by relevance based on their frequency of occurrence, is then reviewed by in-house researchers and a short selection is made. Terms are grouped when synonyms, very similar terms and different spellings are found, then the groups are reduced to a single term per groups. Terms appearing in both sub-lists are prioritised.

**4. Selection of keywords through topic modelling**

We consider the most representative terms from the six AI subdomains identified from topic modelling on a corpus of 64 thousand documents of R&D and industrial activity. The subdomains are identified by applying semantic clustering with the Latent Dirichlet Allocation (LDA) model, a generative hierarchical mixed-membership model for discrete data (Blei & Laerty, 2009; Blei et al., 2003; Papadimitriou et al., 2000). The model returns the most probable topics that best represent the corpus, without the involvement of any expert to avoid unintentional bias. Only the labelling of topics is done manually. The most relevant keywords of each of the six topics are also considered, and redundancies with terms already included in the list, removed.

**5. Validation by a panel of experts in several AI subdomains**

An in-house pool of researchers made a selection that was reviewed by external domain experts in several AI areas. The advice for improvement targeted the expansion of the frontiers considered, namely the inclusion of domains and related terms not so well captured by the research and industrial sources analysed so far.

**6. Final review and selection of list of keywords per domain**

As a consequence of the review in step 5, areas such as Knowledge representation and reasoning or AI ethics and their corresponding related terms were introduced. The final taxonomy was then depicted and the final keyword list defined. Valuable inputs in this process were: the terms describing the submission groups in top AI conferences, the term frequencies observed in AITopics, and the terms produced by the Spanish Working Group on AI responsible for the drafting of the Spanish strategy.

### 4.3.2 List of Keywords

Table 2 presents the keywords identified as most relevant within each AI subdomain comprising the taxonomy. This list of keywords is designed to map and model AI activities in a broad sense. The keywords are presented grouped in the broad categories identified in the taxonomy, which, as explained in detail in subsection 0, are not mutually exclusive. This keyword list is intended to be dynamically updated according to new technological developments in core and transversal domains, and to agree with alternative proposals.

The rationale for building the list of keywords is to determine, in a practical way, the boundaries of the ecosystem of economic agents active in AI. In practical terms, the list of keywords will be used taking into account additional considerations. For instance, in order to avoid as much as possible the occurrence of false positives, i.e., the incorrect identification as AI of activities that are not AI related, a reduced list of intrinsic-AI keywords is used to query the data sources to identify the relevant active agents in the TES ecosystem. Furthermore, some of the remaining keywords are considered only after conditioning its co-occurrence with some of the core AI terms (these are the non-intrinsic AI keywords). Examples of intrinsic-AI terms used as standalone terms to identify activities are: deep learning, face recognition, swarm intelligence and

unsupervised learning. Terms that are only used in combination with intrinsic-AI terms include, for instance: accountability, classification, clustering, cognitive system, industrial robot, service robot and social robot, since these non-intrinsic terms could be used in a non-AI context.

**Table 2. Most relevant keywords within each AI domain**

| AI domain | AI subdomain | Keyword | |
|---|---|---|---|
| **Reasoning** | **Knowledge representation;**<br>**Automated reasoning;**<br>**Common sense reasoning** | case-based reasoning | inductive programming |
| | | causal inference | information theory |
| | | causal models | knowledge representation & reasoning |
| | | common-sense reasoning | latent variable models |
| | | expert system | semantic web |
| | | fuzzy logic | uncertainty in artificial intelligence |
| | | graphical models | |
| **Planning** | **Planning and Scheduling;**<br>**Searching;**<br>**Optimisation** | Bayesian optimisation | hierarchical task network |
| | | constraint satisfaction | metaheuristic optimisation |
| | | evolutionary algorithm | planning graph |
| | | genetic algorithm | stochastic optimisation |
| | | gradient descent | |
| **Learning** | **Machine learning** | active learning | feature extraction |
| | | adaptive learning | generative adversarial network |
| | | adversarial machine learning | generative model |
| | | adversarial network | multi-task learning |
| | | anomaly detection | neural network |
| | | artificial neural network | pattern recognition |
| | | automated machine learning | probabilistic learning |
| | | automatic classification | probabilistic model |
| | | automatic recognition | recommender system |
| | | bagging | recurrent neural network |
| | | Bayesian modelling | recursive neural network |
| | | boosting | reinforcement learning |
| | | classification | semi-supervised learning |
| | | clustering | statistical learning |
| | | collaborative filtering | statistical relational learning |
| | | content-based filtering | supervised learning |
| | | convolutional neural network | support vector machine |
| | | data mining | transfer learning |
| | | deep learning | unstructured data |
| | | deep neural network | unsupervised learning |
| | | ensemble method | |
| **Communication** | **Natural language processing** | chatbot | natural language generation |
| | | computational linguistics | machine translation |
| | | conversation model | question answering |
| | | coreference resolution | sentiment analysis |
| | | information extraction | text classification |
| | | information retrieval | text mining |
| | | natural language understanding | |
| **Perception** | **Computer vision** | action recognition | object recognition |
| | | face recognition | recognition technology |
| | | gesture recognition | sensor network |
| | | image processing | visual search |
| | | image retrieval | |
| | **Audio processing** | computational auditory scene | sound synthesis |

| AI domain | AI subdomain | Keyword | |
|---|---|---|---|
| | | music information retrieval | speaker identification |
| | | sound description | speech processing |
| | | sound event recognition | speech recognition |
| | | sound source separation | speech synthesis |
| **Integration and Interaction** | **Multi-agent systems** | agent-based modelling | negotiation algorithm |
| | | agreement technologies | network intelligence |
| | | computational economics | q-learning |
| | | game theory | swarm intelligence |
| | | intelligent agent | |
| | **Robotics and Automation** | cognitive system | robot system |
| | | control theory | service robot |
| | | human-ai interaction | social robot |
| | | industrial robot | |
| | **Connected and Automated vehicles** | autonomous driving | self-driving car |
| | | autonomous system | unmanned vehicle |
| | | autonomous vehicle | |
| **Services** | **AI Services** | ai application | intelligence software |
| | | ai benchmark | intelligent control |
| | | ai competition | intelligent control system |
| | | ai software toolkit | intelligent hardware development |
| | | analytics platform | intelligent software development |
| | | big data | intelligent user interface |
| | | business intelligence | internet of things |
| | | central processing unit | machine learning framework |
| | | computational creativity | machine learning library |
| | | computational neuroscience | machine learning platform |
| | | data analytics | personal assistant |
| | | decision analytics | platform as a service |
| | | decision support | tensor processing unit |
| | | distributed computing | virtual environment |
| | | graphics processing unit | virtual reality |
| **AI Ethics and Philosophy** | **AI Ethics** | accountability | safety |
| | | explainability | security |
| | | fairness | transparency |
| | | privacy | |
| | **Philosophy of AI** | artificial general intelligence | weak artificial intelligence |
| | | strong artificial intelligence | narrow artificial intelligence |

Source: Authors' elaboration

# 5 Summary of AI definitions and subdomains

Table 3 presents a summary of the definitions collected and analysed in this report. The domains included in the summary table are mentioned in the collected documents as categories or applications. The documents are ordered in descending chronological order and then by alphabetical order within each section of: policy and institutional (EU level, national level and international organisations), research and market. For longer descriptions of the AI definitions, explanations, context, etc., see the individual subsections of the Annex.

**Table 3. Summary of definitions and subdomains or applications referred to in the collected documents.**

| Source | AI Definition | Reasoning; Planning | Learning | Communication | Perception | Integration and Interaction | Services | Ethics and Philosophy | Other/ NA |
|---|---|---|---|---|---|---|---|---|---|
| **AI reference definition for AI Watch** | | | | | | | | | |
| EC AI HLEG, 2019a | "Artificial intelligence (AI) systems are software (and possibly also hardware) systems designed by humans[3] that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information, derived from this data and deciding the best action(s) to take to achieve the given goal. AI systems can either use symbolic rules or learn a numeric model, and they can also adapt their behaviour by analysing how the environment is affected by their previous actions." | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ |
| **Policy and institutional approaches** | | | | | | | | | |
| **EU Level** | | | | | | | | | |
| AI Act (EC, 2021) | "'Artificial intelligence system' (AI system) means software that is developed with one or more of the techniques and approaches listed in Annex I and can, for a given set of human-defined objectives, generate outputs such as content, predictions, recommendations, or decisions influencing the environments they interact with".<br><br>The techniques and approaches in Annex I are: "(a) Machine learning approaches, including supervised, unsupervised and reinforcement learning, using a wide variety of methods including deep learning; (b) Logic- and knowledge-based approaches, including knowledge representation, inductive (logic) programming, knowledge bases, inference and deductive engines, (symbolic) reasoning and expert systems; (c) Statistical approaches, Bayesian estimation, search and optimization methods." | ✓ | ✓ | | | | | | ✓ |

| Source | AI Definition | Reasoning; Planning | Learning | Communication | Perception | Integration and Interaction | Services | Ethics and Philosophy | Other/ NA |
|---|---|---|---|---|---|---|---|---|---|
| EPRS, 2020 | The study adopts the European Commission's Communication of 2018 definition of AI, "which is both accessible and typical of contemporary definitions.<br>AI refers to systems that display intelligent behaviour by analysing their environment and taking action – with some degree of autonomy – to achieve specific goals." | | ✓ | ✓ | ✓ | | | | ✓ |
| White paper on AI<br>EC, 2020b | Mentions the European Strategy on AI (EC, 2018a) and the AI HLEG (2019a) definitions, and report that AI is a "collection of technologies that combine data, algorithms and computing power", for which the "advances in computing and the increasing availability of data are therefore key drivers of the current upsurge of AI". No specific definition is adopted. | | | | | | | | |
| EC, Ipsos and iCite (by DG CNECT), 2020 | Three definitions are developed:<br>"Artificial Intelligence: is technology that tries to automate one or more (human) cognitive functions or processes. It provides predictions, recommendations or decisions to achieve specific objectives. It does so by continuously learning about its environment or results from its actions."<br>"Artificial Intelligence system: is a system having an artificial intelligence as one of its components. It provides information about the environment as input for the artificial intelligence and uses the predictions, classifications, recommendations or decisions produced by this component to act on its environment."<br>"Cognitive functions: are the intellectual processes by which one becomes aware of, perceives, or comprehends ideas. It involves all aspects of perception, language, remembering, reasoning and learning." | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| Eurostat, 2020 | "Artificial intelligence refers to systems that use technologies such as: text mining, computer vision, speech recognition, natural language generation, machine learning, deep learning to gather and/or use data to predict, recommend or decide, with varying levels of autonomy, the best action to achieve specific goals." | | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| European Defence Agency (EDA), 2019 | "Artificial Intelligence (AI) is the capability provided by algorithms of selecting optimal or sub-optimal choices from a wide possibility space in order to achieve specific goals by applying different strategies, including learning from knowledge or data, externally supplied or self-generated, and surrounding changing conditions." | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ |
| Coordinated Plan on AI, 2018<br>(EC, 2018b) | "Artificial Intelligence refers to systems that display intelligent behaviour by analysing their environment and taking action — with some degree of autonomy — to achieve specific goals." | | | | ✓ | | | | ✓ |

| Source | AI Definition | Reasoning; Planning | Learning | Communication | Perception | Integration and Interaction | Services | Ethics and Philosophy | Other/ NA |
|---|---|---|---|---|---|---|---|---|---|
| European AI Strategy: Communication "Artificial Intelligence for Europe" (EC, 2018a) | "Artificial intelligence (AI) refers to systems that display intelligent behaviour by analysing their environment and taking actions – with some degree of autonomy – to achieve specific goals." | | | | ✓ | | | | ✓ |
| EC JRC Flagship report on AI: Artificial Intelligence. A European Perspective, 2018 | "AI is a generic term that refers to any machine or algorithm that is capable of observing its environment, learning, and based on the knowledge and experience gained, taking intelligent action or proposing decisions. There are many different technologies that fall under this broad AI definition. At the moment, ML techniques are the most widely used." | | ✓ | ✓ | ✓ | ✓ | | | |
| **National level: European Union Member States** | | | | | | | | | |
| AI4Belgium Report, 2019 | Reference to the European AI Strategy definition:<br>'According to the European Commission: "AI refers to systems that display intelligent behaviour by analysing their environment and taking actions – with some degree of autonomy – to achieve specific goals. AI-based systems can be purely software-based, acting in the virtual world (e.g. voice assistants, image analysis software, search engines, speech and face recognition systems) or AI can be embedded in hardware devices (e.g. advanced robots, autonomous cars, drones or Internet of Things applications)." ' | | ✓ | ✓ | ✓ | ✓ | | | |
| AI National Strategy: Denmark, 2019 | "Artificial intelligence is systems based on algorithms (mathematical formulae) that, by analysing and identifying patterns in data, can identify the most appropriate solution. The vast majority of these systems perform specific tasks in limited areas, e.g. control, prediction and guidance. The technology can be designed to adapt its behaviour by observing how the environment is influenced by previous actions." | | ✓ | ✓ | ✓ | ✓ | | | |
| AI National Strategy: France. Monitoring report, 2019 | Unofficial translation:<br>A theoretical and practical interdisciplinary field, with objective the understanding of the cognitive and thinking mechanisms, and their imitation by a material and software device, for assistance or substitution purposes of human activities.<br>The AI definition used is reported to be the one of Russel and Norvig, 1995. | ✓ | ✓ | ✓ | | ✓ | | | ✓ |
| Spanish RDI Strategy in Artificial Intelligence, 2019 | "AI can be defined as the Science and Engineering that allows the design and programming of machines capable of carrying out tasks that require intelligence. Rather than achieving general intelligence, current AI focuses on what is known as specific AI, which is producing very important results in many fields of application | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |

| Source | AI Definition | Reasoning; Planning | Learning | Communication | Perception | Integration and Interaction | Services | Ethics and Philosophy | Other/ NA |
|---|---|---|---|---|---|---|---|---|---|
| | such as natural language processing or artificial vision; however, from a scientific and basic and applied research point of view, general AI remains the major objective to be achieved, that is, creating an ecosystem with intelligent multitasking systems." | | | | | | | | |
| Latvian Information Report, 2019 | Unofficial translation:<br>AI systems are man- made software and hardware systems that, depending on the intended purpose, operate in a physical or digital dimension, perceiving the environment from data , interpreting structured or unstructured data collected, making causal relationships or processing information derived from that data, and making decisions on the best course of action to be taken to achieve the objective pursued. AI systems can use rules or learn a numerical model, and they can adapt their behaviour by analysing how the environment affects their past actions. | ✓ | ✓ | ✓ | ✓ | ✓ | | | |
| National Strategy: Luxembourg, 2019 | "...we are defining artificial intelligence as a machine's ability to mimic human behavior and, to an extent, human intelligence. This broad spectrum encompasses single tasks (think chess playing, translating or categorizing images) and complex activities (e.g. autonomous driving). General AI will remain a topic to be monitored as technology evolves." | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Osservatorio Artificial Inteligence, 2019 | Unofficial translation:<br>Artificial Intelligence is the branch of computer science that studies the development of HW and SW systems endowed with typical human skills (interaction with the environment, learning and adaptation, reasoning and planning), capable of independently pursuing a defined purpose,<br>making decisions that, until then, were usually left to people. | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| AI National Strategy: France (Villani Mission), 2018 | "AI has always been envisioned as an evolving boundary, rather than a settled research field. Fundamentally, it refers to a programme whose ambitious objective is to understand and reproduce human cognition; creating cognitive processes comparable to those found in human beings. Therefore, we are naturally dealing with a wide scope here, both in terms of the technical procedures that can be employed and the various disciplines that can be called upon: mathematics, information technology, cognitive sciences, etc. There is a great variety of approaches when it comes to AI: ontological, reinforcement learning, adversarial learning and neural networks, to name just a few." | ✓ | ✓ | ✓ | | ✓ | | | ✓ |
| AI National Strategy: | "In highly abstract terms, AI researchers can be assigned to two groups: "strong" and "weak" AI. "Strong" AI means that AI systems have the same intellectual | ✓ | ✓ | | ✓ | ✓ | | | |

| Source | AI Definition | Reasoning; Planning | Learning | Communication | Perception | Integration and Interaction | Services | Ethics and Philosophy | Other/ NA |
|---|---|---|---|---|---|---|---|---|---|
| Germany, 2018 | capabilities as humans, or even exceed them. “Weak” AI is focused on the solution of specific problems using methods from mathematics and computer science, whereby the systems developed are capable of self-optimisation. To this end, aspects of human intelligence are mapped and formally described, and systems are designed to simulate and support human thinking." | | | | | | | | |
| Artificial Intelligence Mission Austria 2030 (AIM AT 2030), 2018 | “Artificial intelligence (AI) comprises computer systems that exhibit intelligent behaviour.”<br>“Systems based on artificial intelligence analyse their environment and autonomously act to achieve certain goals. They work through expert-generated rule knowledge or based on data-derived statistical models (machine learning or deep learning). AI includes both pure software systems that set actions in virtual environments and hardware such as robots.” | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| National Industrial Strategy: UK, 2018; 2017 | - | | ✓ | | | ✓ | | | |
| AI National Strategy: Sweden, 2018 | "There is no one single, clear-cut or generally accepted definition of artificial intelligence, but many definitions. In general, however, AI refers to intelligence demonstrated by machines." | | | | | | | | ✓ |
| Report of the Steering Group of the AI Programme: Finland, 2017 | "Artificial intelligence refers to devices, software and systems that are able to learn and to make decisions in almost the same manner as people. Artificial intelligence allows machines, devices, software, systems and services to function in a sensible way according to the task and situation at hand." | | | | | | | | ✓ |
| **National level: outside the EU** | | | | | | | | | |
| Australia’s Ethic Framework, 2019 | "A collection of interrelated technologies used to solve problems autonomously and perform tasks to achieve defined objectives without explicit guidance from a human being " | | ✓ | | | ✓ | | | |

| Source | AI Definition | Reasoning; Planning | Learning | Communication | Perception | Integration and Interaction | Services | Ethics and Philosophy | Other/ NA |
|---|---|---|---|---|---|---|---|---|---|
| US Congressional Research Service, 2019 | - | | ✓ | | ✓ | ✓ | | | ✓ |
| Working Paper for AI National Strategy: India, 2018 | "AI refers to the ability of machines to perform cognitive tasks like thinking, perceiving, learning, problem solving and decision making. Initially conceived as a technology that could mimic human intelligence, AI has evolved in ways that far exceed its original conception. With incredible advances made in data collection, processing and computation power, intelligent systems can now be deployed to take over a variety of tasks, enable connectivity and enhance productivity." | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| US National Defense Authorization Act, 2018 | "1. Any artificial system that performs tasks under varying and unpredictable circumstances without significant human oversight, or that can learn from experience and improve performance when exposed to data sets.<br>2. An artificial system developed in computer software, physical hardware, or other context that solves tasks requiring human-like perception, cognition, planning, learning, communication, or physical action.<br>3. An artificial system designed to think or act like a human, including cognitive architectures and neural networks.<br>4. A set of techniques, including machine learning that is designed to approximate a cognitive task.<br>5. An artificial system designed to act rationally, including an intelligent software agent or embodied robot that achieves goals using perception, planning, reasoning, learning, communicating, decision-making, and acting." | | | | | | | | ✓ |
| US Department of Defense, 2018 | - | | ✓ | ✓ | ✓ | | ✓ | | ✓ |
| AI National Strategy: Japan, 2017 | - | | | ✓ | ✓ | ✓ | | | ✓ |

| Source | AI Definition | Reasoning; Planning | Learning | Communication | Perception | Integration and Interaction | Services | Ethics and Philosophy | Other/ NA |
|---|---|---|---|---|---|---|---|---|---|
| AI National Strategy: China, 2017 | - | ✓ | | ✓ | | ✓ | ✓ | | ✓ |
| AI National Strategy: Canada, 2017 | - | | | | | | | | ✓ |
| US Artificial Intelligence, Automation, and The Economy, 2016 | - | | ✓ | | | ✓ | | ✓ | |
| **International Organisations** | | | | | | | | | |
| OECD, 2019a | AI definition adopted from Russel and Norvig, 2013 (initial edition 1995), which is four categories of AI and eight definitions of earlier literature. The categories are regarding thought processes, reasoning, human and rational behaviour. "An AI system is a machine-based system that is capable of influencing the environment by making recommendations, predictions or decisions for a given set of objectives. It does so by utilising machine and/or human-based inputs to: i) perceive real and/or virtual environments; ii) abstract such perceptions into models manually or automatically; and iii) use model interpretations to formulate options for outcomes." | ✓ | ✓ | | ✓ | | | | |
| OECD, 2019b | "An AI system is a machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations, or decisions influencing real or virtual environments. AI systems are designed to operate with varying levels of autonomy." | | | | | | | | |
| UNESCO, 2019 | - | | | | | ✓ | | | ✓ |

| Source | AI Definition | Reasoning; Planning | Learning | Communication | Perception | Integration and Interaction | Services | Ethics and Philosophy | Other/ NA |
|---|---|---|---|---|---|---|---|---|---|
| StandICT.eu project, 2019 | - | | ✓ | | | | | | ✓ |
| OECD, 2018 | "AI can make business more productive, improve government efficiency and relieve workers of mundane tasks. It can also address many of our most pressing global problems, such as climate change and wider access to quality education and healthcare…This combination of interdisciplinary origins, wavering trajectories, and recent commercial success make "artificial intelligence" a difficult concept to define and measure…The term itself is used interchangeably both as the still-faraway goal of true machine intelligence and as the currently available technology powering today's hottest startups" | | ✓ | ✓ | ✓ | | | | |
| ETSI, 2018 | "Computerized system that uses cognition to understand information and solve problems."<br>NOTE 1: ISO/IEC 2382-28 "Information technology -- Vocabulary" defines AI as "an interdisciplinary field, usually regarded as a branch of computer science, dealing with models and systems for the performance of functions generally associated with human intelligence, such as reasoning and learning".<br>NOTE 2: In computer science AI research is defined as the study of "intelligent agents": any device that perceives its environment and takes actions to achieve its goals.<br>NOTE 3: This includes pattern recognition and the application of machine learning and related techniques.<br>NOTE 4: Artificial Intelligence is the whole idea and concepts of machines being able to carry out tasks in a way that mimics the human intelligence and would be considered "smart". | ✓ | | | | | | | |
| OECD, 2017 | "Artificial Intelligence (AI) is a term used to describe machines performing human-like cognitive functions (e.g. learning, understanding, reasoning or interacting). It has the potential to revolutionise production as well as contribute to tackling global challenges related to health, transport and the environment." | | ✓ | | ✓ | | | | ✓ |
| World Economic Forum, 2017 | "Artificial intelligence (AI) is the software engine that drives the Fourth Industrial Revolution. Its impact can already be seen in homes, businesses and political processes. In its embodied form of robots, it will soon be driving cars, stocking warehouses and caring for the young and elderly. It holds the promise of solving some of the most pressing issues facing society, but also presents challenges such | | | | | | | | ✓ |

| Source | AI Definition | Reasoning; Planning | Learning | Communication | Perception | Integration and Interaction | Services | Ethics and Philosophy | Other/ NA |
|---|---|---|---|---|---|---|---|---|---|
| | as inscrutable "black box" algorithms, unethical use of data and potential job displacement. As rapid advances in machine learning (ML) increase the scope and scale of AI's deployment across all aspects of daily life, and as the technology itself can learn and change on its own, multistakeholder collaboration is required to optimize accountability, transparency, privacy and impartiality to create trust."<br>"Artificial intelligence (AI) or self-learning systems is the collective term for machines that replicate the cognitive abilities of human beings. Within the broader technological landscape, predictive maintenance in the cognitive era has the potential to transform global production systems." | | | | | | | | |
| ISO, 1993; 1995; 2015; 2020 | "Branch of computer science devoted to developing data processing systems that perform functions normally associated with human intelligence, such as reasoning, learning, and self-improvement" (2121393: ISO, AI: term, abbreviation and definition standardized by ISO/IEC (ISO/IEC 2382-1:1993))<br>"Interdisciplinary field, usually regarded as a branch of computer science, dealing with models and systems for the performance of functions generally associated with human intelligence, such as reasoning and learning" (2123769: term, abbreviation and definition standardized by ISO/IEC (ISO/IEC 2382-28:1995))<br>"Capability of a functional unit to perform functions that are generally associated with human intelligence such as reasoning and learning" (2123770: term, abbreviation and definition standardized by ISO/IEC (ISO/IEC 2382-28:1995))<br>"…systems providing or using AI, called hereafter artificial intelligence (AI) systems." AI: "capability of an engineered system (3.38) to acquire, process and apply knowledge and skills. Note 1 to entry: Knowledge are facts, information (3.20) and skills acquired through experience or education." (ISO/IEC TR 24028:2020) | | | | | | | | ✓ |
| IEC, 2019 | "AI, <discipline>: branch of computer science devoted to developing data processing systems that perform functions normally associated with human intelligence, such as reasoning and learning" (IEC 60050-171:2019 171-09-16)<br>"AI, <capability>: capability of a functional unit to perform functions that are generally associated with human intelligence, such as reasoning and learning" (IEC 60050-171:2019 171-09-17) | | | | | | | | ✓ |
| **Research approach** | | | | | | | | | |

| Source | AI Definition | Reasoning; Planning | Learning | Communication | Perception | Integration and Interaction | Services | Ethics and Philosophy | Other/ NA |
|---|---|---|---|---|---|---|---|---|---|
| Osservatorio Artificial Inteligence, 2019 | Unofficial translation:<br>Artificial Intelligence is the branch of computer science that studies the development of HW and SW systems endowed with typical human skills (interaction with the environment, learning and adaptation, reasoning and planning), capable of independently pursuing a defined purpose, making decisions that, until then, were usually left to people. | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | : |
| Tsinghua University, 2018 | "AI machines do not necessarily have to obtain intelligence by thinking like a human and that it is important to make AI solve problems that can be solved by a human brain. Brain science and brainlike intelligence research and machine-learning represented by deep neural networks represent the two main development directions of core AI technologies, with the latter referring to the use of specific algorithms to direct computer systems to arrive at an appropriate model based on existing data and use the model to make judgment on new situations, thus completing a behavior mechanism…In general, the artificial intelligence we know today is based on modern algorithms, supported by historical data, and forms artificial programs or systems capable of perception, cognition, decision making and implementation like humans." | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ |
| Kaplan and Haenlein, 2018 | "Artificial intelligence (AI)—defined as a system's ability to correctly interpret external data, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation." | | ✓ | | ✓ | | | | ✓ |
| Poole et al., 2017; 2010; 1998 | "Artificial intelligence (AI) is the established name for the field we have defined as computational intelligence (CI), Computational intelligence is the study of the design of intelligent agents. An agent is something that acts in an environment—it does something. Agents include worms, dogs, thermostats, airplanes, humans, organizations, and society. An intelligent agent is a system that acts intelligently: What it does is appropriate for its circumstances and its goal, it is flexible to changing environments and changing goals, it learns from experience, and it makes appropriate choices given perceptual limitations and finite computation."<br><br>"Artificial intelligence, or AI, is the field that studies the synthesis and analysis of computational agents that act intelligently.<br>An agent is something that acts in an environment; it does something. Agents include worms, dogs, thermostats, airplanes, robots, humans, companies, and countries." | | ✓ | | ✓ | | | ✓ | ✓ |

| Source | AI Definition | Reasoning; Planning | Learning | Communication | Perception | Integration and Interaction | Services | Ethics and Philosophy | Other/ NA |
|---|---|---|---|---|---|---|---|---|---|
| Kaplan, 2016 | "There is little agreement about what intelligence is. …there is scant reason to believe that machine intelligence bears much relationship to human intelligence, at least so far."<br>"There are many proposed definitions on AI …most are roughly aligned around the concept of creating computer programs or machines capable of behavior we would regard as intelligent if exhibited by humans." | | | | | | | | ✓ |
| Stone et al.: AI100, 2016 | ""Intelligence" remains a complex phenomenon whose varied aspects have attracted the attention of several different fields of study, including psychology, economics, neuroscience, biology, engineering, statistics, and linguistics. Naturally, the field of AI has benefited from the progress made by all of these allied fields. For example, the artificial neural network, which has been at the heart of several AI-based solutions was originally inspired by thoughts about the flow of information in biological neurons." | | ✓ | ✓ | ✓ | ✓ | | | ✓ |
| Russel and Norvig, 2010 (3rd edition); 1995 | Four categories of AI are presented and eight definitions of earlier literature.<br>The categories are regarding thought processes, reasoning, human and rational behaviour. For more detailed information please refer to subsection 2.7. | | | | | | | | ✓ |
| Bruner, 2009 | "…any and all systems that process information must be governed by specifiable "rules" or procedures that govern what to do with inputs. It matters not whether it is a nervous system, or the genetic apparatus that takes instruction from DNA and then reproduces later generations, or whatever. This is the ideal of artificial intelligence (AI), so-called." | | | | | | | | ✓ |
| McCarthy, 2007 | "It is the science and engineering of making intelligent machines, especially intelligent computer programs. It is related to the similar task of using computers to understand human intelligence, but AI does not have to confine itself to methods that are biologically observable."<br>"Intelligence is the computational part of the ability to achieve goals in the world. Varying kinds and degrees of intelligence occur in people, many animals and some machines." | ✓ | ✓ | ✓ | ✓ | | | | ✓ |
| Gardner, 1999 | "A biopsychological potential to process information that can be activated in a cultural setting to solve problems or create products that are of value in a culture." | | | | | | | | ✓ |

| Source | AI Definition | Reasoning; Planning | Learning | Communication | Perception | Integration and Interaction | Services | Ethics and Philosophy | Other/ NA |
|---|---|---|---|---|---|---|---|---|---|
| Nakashima, 1999 | "Intelligence is the ability to process information properly in a complex environment. The criteria of properness are not predefined and hence not available beforehand. They are acquired as a result of the information processing." | | | | | | | | ✓ |
| Nilsson, 1998; 2010 | "Artificial Intelligence (AI), broadly (and somewhat circularly) defined, is concerned with intelligent behavior in artefacts. Intelligent behavior, in turn, involves perception, reasoning, learning, communicating, and acting in complex environments." (1998)<br>"Artificial intelligence is that activity devoted to making machines intelligent, and intelligence is that quality that enables an entity to function appropriately and with foresight in its environment." (2010) | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ |
| Neisser et al., 1996 | The article introduces in the AI definition the notions of adapting to the environment, reasoning, learning etc. through a human intelligence definition, with multiple dimensions, due to biologically inspired processes.<br>"Individuals differ from one another in their ability to understand complex ideas, to adapt effectively to the environment, to learn from experience, to engage in various forms of reasoning, to overcome obstacles by taking thought.<br>Concepts of intelligence are attempts to clarify and organise this complex set of phenomena." | ✓ | ✓ | | ✓ | | | | ✓ |
| Fogel, 1995 | "Any system…that generates adaptive behaviour to meet goals in a range of environments can be said to be intelligent." | | | | ✓ | | | | ✓ |
| Wang, 1995 | Intelligence is "the ability for an information processing system to adapt to its environment with insufficient knowledge and resources." | | | | | | | | ✓ |
| Albus, 1991 | "…the ability of a system to act appropriately in an uncertain environment, where appropriate action is that which increases the probability of success, and success is the achievement of behavioral subgoals that support the system's ultimate goal." | | | | | | | | ✓ |
| Schank, 1991; 1987 | "AI suffers from a lack of definition of its scope. One way to attack this problem is to attempt to list some features that we would expect an intelligent entity to have. None of these features would define intelligence, indeed a being could lack any one of them and still be considered intelligent. Nevertheless each attribute would be an integral part of intelligence in its way. …They are communication, internal knowledge, world knowledge, intentionality, and creativity."<br>"AI's primary goal is to build an intelligent machine. The second goal is to find out | | | | | | | | ✓ |

| Source | AI Definition | Reasoning; Planning | Learning | Communication | Perception | Integration and Interaction | Services | Ethics and Philosophy | Other/ NA |
|---|---|---|---|---|---|---|---|---|---|
| | about the nature of intelligence."<br>"Intelligence means getting better over time." | | | | | | | | |
| McCarthy, 1988 | "The goal of artificial intelligence (A.I.) is machines more capable than humans at solving problems and achieving goals requiring intelligence. There has been some useful success, but the ultimate goal still requires major conceptual advances and is probably far off.<br>There are three ways of attacking the goal. The first is to imitate the human nervous system. The second is to study the psychology of human intelligence. The third is to understand the common sense world in which people achieve their goals and develop intelligent computer programs. This last one is the computer science approach." | | | | | | | ✓ | ✓ |
| Gardner, 1987 | AI "seeks to produce, on a computer, a pattern of output that would be considered intelligent if displayed by a human being".<br><br>Schlinger (1992) mentions that this book also refers that "AI is viewed as a way of testing a particular theory of how cognitive processes might work. That theory is the popular information-processing model of cognition. Where AI researchers disagree, according to Gardner, is how literally to interpret the thinking metaphor. For example, some take what John Searle calls the "weak view" of AI, wherein computer programs are simply a means for testing theories of how humans might carry out cognitive operations. The weak view of AI is synonymous with modern cognitive psychology." | | | | | | | | ✓ |
| Gardner, 1983 | "Artificial intelligence is commonly defined by referencing definitions of human intelligence, as in Minsky's definition.<br>In contrast to the standard approach of measuring one kind of intelligence (as in standard IQ tests), Gardner (cognitive scientist) offers an eight-dimensional definition to disentangle the oversimplification of intelligence's measurement.<br>In particular, he proposed multiple conceptions of intelligence, not only logical-mathematical, linguistic, but also spatial, musical, bodily-kinaesthetic, personal." | | | | | | | | ✓ |

| Source | AI Definition | Reasoning; Planning | Learning | Communication | Perception | Integration and Interaction | Services | Ethics and Philosophy | Other/ NA |
|---|---|---|---|---|---|---|---|---|---|
| Newell and Simon, 1976 | "By "general intelligent action" we wish to indicate the same scope if intelligence as we see in human action: that in any real situation behavior appropriate to the ends of the system and adaptive to the demands of the environment can occur, within some limits of speed and complexity." | | | | | | | | ✓ |
| Minsky, 1969 | AI is "the science of making machines do things that would require intelligence if done by men". | | | | | | | | ✓ |
| McCarthy, 1959 | The author, one of the founding father of AI, proposes that common sense reasoning ability is key to AI.<br>"A program has common sense if it automatically deduces for itself a sufficiently wide class of immediate consequences of anything it is told and what it already knows." | | | | | | | | ✓ |
| McCarthy et al., 1955 | "..every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it. An attempt will be made to find how to make machines use language, form abstractions and concepts, solve kinds of problems now reserved for humans, and improve themselves.<br><br>...the artificial intelligence problem is taken to be that of making a machine behave in ways that would be called intelligent if a human were so behaving." | | | | | | | | ✓ |
| **Market approach** | | | | | | | | | |
| CB Insights, 2019 | - | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ |
| Statista, 2017 | "Artificial Intelligence (AI) essentially refers to computing technologies that are inspired by the ways people use their brains and nervous systems to reason and make decisions, but typically operate quite differently." | | | | | ✓ | ✓ | | ✓ |
| McKinsey, 2017 | - | | ✓ | ✓ | ✓ | ✓ | ✓ | | |

Source: Authors' elaboration.

# 6 Conclusions

In 2018, when our work on AI Watch started, the absence of a commonly agreed one-fits-all AI definition called for the development of a process to establish a reference AI operational definition to be adopted in the AI Watch framework and used in its mapping and monitoring activities, especially in what concerns the definition and analysis of an AI landscape. Today, while the recent adoption of a legal AI definition within the proposed AI Act has specific regulatory purposes, an operational definition is still very useful for the mentioned monitoring goal, as a concrete and objective operational definition would help us define and identify AI activities and map them in the AI Watch AI landscape. The proposed iterative process includes three perspectives: policy and institutional, research, and market, in order to acquire a comprehensive overview about the AI domain. The AI definition adopted by the EC High Level Expert Group on AI is used as a baseline definition. It was selected following the review of 65 relevant documents covering AI policy and institutional reports (including standardisation efforts, national strategies, and international organisations reports), research publications and market reports. An exhaustive list of the collected documents can be found in the report. The proposed operational definition is composed by a concise taxonomy characterising the core domains of the AI research field and transversal topics; and a list of keywords representative of such taxonomy. As AI is a dynamic field, we propose an iterative method that can be updated over time to capture the rapid AI evolution.

Whilst the baseline definition is used as a starting point, the operational definition has a more functional use. Both the taxonomy and the list of keywords are essential to identify, map and characterise the worldwide AI landscape, one of the monitoring goals of AI Watch. The keywords are used in the initial phase to capture the relevant AI activities and the economic agents behind them. The main utility of the taxonomy is to classify AI activities, and assists in the mapping of the AI landscape and the classification of economic agents' areas of specialisation. Different uses of the keyword list are possible. A narrow use of the list, i.e. selecting only intrinsic-AI terms, allows to identify relevant AI activities, with an expected low proportion of false positives. When the objective is the categorisation of AI-related activities, a more comprehensive list is more suitable, in order to classify activities in their corresponding taxonomy domains.

In addition to the proposed operational definition, which has a precise objective in the scope of AI Watch activities, there are other alternative approaches to studying AI, which may be useful for conducting studies with other specific objectives. These, which show certain level of overlap with the AI Watch one and also between them, are briefly described in the report, and their corresponding classifications outlined. The approaches presented, complementary to the taxonomy used for the analysis of the AI international landscape, are also useful to gain a wider understanding of the AI domain.

Valuable contributions of this work are: the collection of definitions developed between 1955 and 2021; the summarisation of the main features of the concept of artificial intelligence as reflected in the relevant literature; and the development of a replicable process that can provide a dynamic operational definition and taxonomy of AI for the purposes of an AI landscape analysis or similar activities.

New developments in AI as a research field and its practical applications will continue to be monitored.

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## List of tables

# Annex: AI definitions and subdomains in: policy documents, research and market reports

## 1 Policy and institutional perspective: Commission Services; National; International

### 1.1 EU level

#### 1.1.1 Reference for the development of the operational definition and taxonomy: High Level Expert Group on Artificial Intelligence (AI HLEG), 2019a

| | |
|---|---|
| Source | AI HLEG Definition of AI |
| Text of the definition | "Artificial intelligence (AI) systems are software (and possibly also hardware) systems designed by humans[3] that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information, derived from this data and deciding the best action(s) to take to achieve the given goal. AI systems can either use symbolic rules or learn a numeric model, and they can also adapt their behaviour by analysing how the environment is affected by their previous actions."<br><br>[3] Humans design AI systems directly, but they may also use AI techniques to optimise their design. |
| Subdomains | As a scientific discipline, AI includes several approaches and techniques, such as machine learning (of which deep learning and reinforcement learning are specific examples), machine reasoning (which includes planning, scheduling, knowledge representation and reasoning, search, and optimisation), and robotics (which includes control, perception, sensors and actuators, as well as the integration of all other techniques into cyber-physical systems). |
| Context | The High-Level Expert Group on Artificial Intelligence (AI HLEG) has been appointed by the European Commission, with main aim to support the implementation of the European AI Strategy. This includes the elaboration of recommendations on future-related policy development and on ethical, legal and societal issues related to AI, including socio-economic challenges.<br>The AI HLEG is composed by 52 representatives from academia, civil society and industry.<br>The first two outputs of the AI HLEG are the Ethics Guidelines for Trustworthy Artificial Intelligence, and the definition on AI presented here, developed as a supporting document for the AI HLEG's deliverables. |
| Date of publication/ release | 8 April 2019 |
| Comments | This definition builds on the definition used in the EC Communication 'Artificial Intelligence for Europe'.<br>A disclaimer warns about the oversimplification undergone for the development of the definition and the consideration of AI capabilities and research areas. |

### 1.1.2 AI Act (EC, 2021)

| | |
|---|---|
| Source | Proposal for a Regulation of the European Parliament and of the Council Laying down harmonised rules on artificial intelligence (Artificial Intelligence Act) and amending certain Union legislative acts" COM(2021) 206 final, 21.4.2021 |
| Text of the definition | "'Artificial intelligence system' (AI system) means software that is developed with one or more of the techniques and approaches listed in Annex I and can, for a given set of human-defined objectives, generate outputs such as content, predictions, recommendations, or decisions influencing the environments they interact with". |
| Subdomains | The techniques and approaches in Annex I are: "(a) Machine learning approaches, including supervised, unsupervised and reinforcement learning, using a wide variety of methods including deep learning; (b) Logic- and knowledge-based approaches, including knowledge representation, inductive (logic) programming, knowledge bases, inference and deductive engines, (symbolic) reasoning and expert systems; (c) Statistical approaches, Bayesian estimation, search and optimization methods." |
| Context | As announced by the White Paper on AI, the AI Act proposes regulatory principles for the development of an ecosystem of trust, by proposing a legal framework for trustworthy AI. The proposal lays down a methodology to define "high-risk" AI systems that pose significant risks to the health and safety or fundamental rights of persons. |
| Date of publication/ release | 2021 |
| Comments | |

### 1.1.3 EC, Ipsos and iCite (DG CNECT), 2020

| | |
|---|---|
| Source | European enterprise survey on the use of technologies based on artificial intelligence |
| Text of the definition | Three definitions are developed:<br>"Artificial Intelligence: is technology that tries to automate one or more (human) cognitive functions or processes. It provides predictions, recommendations or decisions to achieve specific objectives. It does so by continuously learning about its environment or results from its actions."<br>"Artificial Intelligence system: is a system having an artificial intelligence as one of its components. It provides information about the environment as input for the artificial intelligence and uses the predictions, classifications, recommendations or decisions produced by this component to act on its environment."<br>"Cognitive functions: are the intellectual processes by which one becomes aware of, perceives, or comprehends ideas. It involves all aspects of perception, language, remembering, reasoning and learning." |
| Subdomains | "The resulting taxonomy and therefore the AI technologies included in the survey to explore awareness and application of in European enterprises are:<br>1. Speech recognition, machine translation or chatbots, also known as natural language processing.<br>2. Visual diagnostics, face or image recognition, also known as computer vision.<br>3. Fraud detection or risk analysis, also known as anomaly detection.<br>4. Analysis of emotions or behaviours, also known as sentiment analysis.<br>5. Forecasting, price optimisation and decision-making using machine learning algorithms.<br>6. Process or equipment optimisation using artificial intelligence.<br>7. Recommendation and personalisation engines using artificial intelligence to produce customised recommendations, via matching algorithms or information retrieval.<br>8. Process automation using artificial intelligence, including warehouse automation or robotics process automation (RPA).<br>9. Autonomous machines, such as smart and autonomous robots or vehicles.<br>10. Creative and experimentation activities, such as virtual prototyping, data generation, artificial music or painting." |
| Context | Analysis of the EU-wide collected data on the "uptake of AI technologies as part of the project "Collecting quantitative data on the state of play of artificial intelligence and other new technologies" commissioned by DG Connect." |
| Date of publication/ release | 2020 |
| Comments | |

### 1.1.4 Eurostat, 2020

| | |
|---|---|
| Source | Model Questionnaire for the Community Survey on ICT Usage and e-commerce in Enterprises 2021. |
| Text of the definition | "Artificial intelligence refers to systems that use technologies such as: text mining, computer vision, speech recognition, natural language generation, machine learning, deep learning to gather and/or use data to predict, recommend or decide, with varying levels of autonomy, the best action to achieve specific goals." |
| Subdomains | The following are mentioned: text mining, computer vision, speech recognition, natural language generation, machine learning, business virtual assistants, chatbots, machine learning, autonomous drones and robots. |
| Context | "The aim of the European ICT usage surveys is to collect and disseminate harmonised and comparable information on the use of Information and Communication Technologies in enterprises and e-commerce at European level." |
| Date of publication/ release | 2020 |
| Comments | One of the modules focuses on artificial intelligence. |

### 1.1.5 European Defence Agency (EDA), 2019

| | |
|---|---|
| Source | Artificial Intelligence In Defence - A Definition, Taxonomy and Glossary, Annexes to EDA SB 2019/065 |
| Text of the definition | "Artificial Intelligence (AI) is the capability provided by algorithms of selecting optimal or sub-optimal choices from a wide possibility space in order to achieve specific goals by applying different strategies, including learning from knowledge or data, externally supplied or self-generated, and surrounding changing conditions." |
| Subdomains | The taxonomy presented includes a comprehensive description of numerous AI subdomains per algorithms, functions, features and more. |
| Context | The annexes of the report present a definition of AI in defence, and an AI taxonomy with a glossary of commonly used terms, so as to establish "a harmonised understanding of AI in defence." |
| Date of publication/ release | 2019 |
| Comments | |

### 1.1.6 EC Coordinated Plan on AI, 2018

| | |
|---|---|
| Source | EC, Coordinated Plan on AI, COM(2018) 795 |
| Text of the definition | "Artificial Intelligence refers to systems that display intelligent behaviour by analysing their environment and taking action — with some degree of autonomy — to achieve specific goals. We are using AI on a daily basis, for example to block email spam or speak with digital assistants.<br>Growth in computing power, availability of data and progress in algorithms have turned AI into one of the most important technologies of the 21st century." |
| Subdomains | "Medicine (…improve diagnoses and develop therapies for diseases for which none exist yet)<br>Environment (…reduce energy consumption by optimising resources; it can contribute to a cleaner environment by lessening the need for pesticides; it can help improve weather prediction and anticipate disasters)<br>Finance & employment (AI will be the main driver of economic and productivity growth and will contribute to the sustainability and viability of the industrial base in Europe)" |
| Context | After the adoption of the European AI Strategy in April 2018, the Coordinated Action Plan proposes joint actions for closer and more efficient cooperation between Member States, Norway, Switzerland and the Commission in four key areas: increasing investment, making more data available, fostering talent and ensuring trust. Its main aim is to foster the development and use of AI in Europe. |
| Date of publication/ release | 07 December 2018 |
| Comments | "The Commission is increasing investments in AI under the research and innovation framework programme Horizon 2020 to EUR 1.5 billion in the period 2018-2020, constituting a 70% increase compared to 2014-2017."<br>"For the next MFF, the Commission has proposed to dedicate at least EUR 1 billion per year from Horizon Europe and the Digital Europe Programme to AI."<br>The definition is the same as in the European AI Strategy. |

### 1.1.7 EC Communication: Artificial Intelligence for Europe, 2018

| | |
|---|---|
| Source | EC Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. Artificial Intelligence for Europe. COM(2018) 237 {SWD(2018) 137}. |
| Text of the definition | "Artificial intelligence (AI) refers to systems that display intelligent behaviour by analysing their environment and taking actions – with some degree of autonomy – to achieve specific goals.<br>AI-based systems can be purely software-based, acting in the virtual world (e.g. voice assistants, image analysis software, search engines, speech and face recognition systems) or AI can be embedded in hardware devices (e.g. advanced robots, autonomous cars, drones or Internet of Things applications).We are using AI on a daily basis, e.g. to translate languages, generate subtitles in videos or to block email spam.<br>Many AI technologies require data to improve their performance. Once they perform well, they can help improve and automate decision making in the same domain. For example, an AI system will be trained and then used to spot cyber-attacks on the basis of data from the concerned network or system." |
| Subdomains | - |
| Context | EC AI COMM is prepared in order to set a European initiative on AI. In particular the aims are (i) to promote EU's technological and industrial capacity and AI uptake across the economy, (ii) anticipate socio-economic changes driven by AI and adapt accordingly, (iii) form a suitable ethical and legal framework |
| Date of publication/ release | 25 April 2018 |
| Comments | |

### 1.1.8 EC JRC Flagship report on AI: Artificial Intelligence. A European Perspective, 2018

| | |
|---|---|
| Source | Craglia M. (Ed.), Annoni A., Benczur P., Bertoldi P., Delipetrev P., De Prato G., Feijoo C., Fernandez Macias E., Gomez E., Iglesias M., Junklewitz H, López Cobo M., Martens B., Nascimento S., Nativi S., Polvora A., Sanchez I., Tolan S., Tuomi I., Vesnic Alujevic L., Artificial Intelligence - A European Perspective, EUR 29425 EN, Publications Office, Luxembourg, 2018, ISBN 978-92-79-97217-1, doi:10.2760/11251, JRC113826 |
| Text of the definition | "AI is a generic term that refers to any machine or algorithm that is capable of observing its environment, learning, and based on the knowledge and experience gained, taking intelligent action or proposing decisions. There are many different technologies that fall under this broad AI definition. At the moment, ML techniques are the most widely used." |
| Subdomains | Machine learning methods; Connected and automated vehicles (CAVs); Speech recognition & NLP; Face recognition |
| Context | |
| Date of publication/ release | 2018 |
| Comments | |

## 1.2 National level: European Union

### 1.2.1 AI 4 Belgium Report, 2019

| | |
|---|---|
| Source | AI 4 Belgium Coalition, AI 4 Belgium Report |
| Text of the definition | Reference to the European AI Strategy definition:<br>'According to the European Commission: "AI refers to systems that display intelligent behaviour by analysing their environment and taking actions – with some degree of autonomy – to achieve specific goals. AI-based systems can be purely software-based, acting in the virtual world (e.g. voice assistants, image analysis software, search engines, speech and face recognition systems) or AI can be embedded in hardware devices (e.g. advanced robots, autonomous cars, drones or Internet of Things applications)." ' |
| Subdomains | A structured taxonomy is not presented, although some AI subdomains are mentioned: machine learning, NLP, chatbots, automation.<br>Identification of application domains: healthcare, environment, mobility, autonomous driving, smart cities, fraud detection, |
| Context | The report is drafted with manifold objectives: bringing AI to the top of the political agenda and public debate, stimulate a human-centred approach to AI, and providing a first version of an overarching Belgian AI Strategy.<br>It provides a number of recommendations covering areas such as: education and skills, innovation, data strategy, boost AI adoption by the private and public sectors. |
| Date of publication/ release | 2019 |
| Comments | The report declares the need of an investment of at least EUR 1 billion by 2030. |

### 1.2.2 AI National Strategy: Denmark, 2019

| | |
|---|---|
| Source | Danish Government: Ministry of Finance and Ministry of Industry, Business and Financial Affairs. Strategy for Denmark's Digital Growth.<br>Larosse J. (Vanguard Initiatives Consult&Creation) for DG CNECT. Analysis of National Initiatives on Digitising European Industry. Denmark: Towards a Digital Growth Strategy - MADE. |
| Text of the definition | "Artificial intelligence is systems based on algorithms (mathematical formulae) that, by analysing and identifying patterns in data, can identify the most appropriate solution. The vast majority of these systems perform specific tasks in limited areas, e.g. control, prediction and guidance. The technology can be designed to adapt its behaviour by observing how the environment is influenced by previous actions.<br>Artificial intelligence is used in a number of areas, e.g. search engines, voice and image recognition, or to support drones and self-driving cars. Artificial intelligence can be a crucial element to increase productivity growth and to raise the standard of living in the years to come."<br>Danish center for artificial intelligence (DCKAI), part of the Alexandra Institute-Center for artificial intelligence:<br>"Artificial intelligence is an experimental science: You use your customer data to build a model, but you test the model continuously to see if there are alternative and better algorithms. It will be improved, the more it is being used and the larger the database it has.<br>Artificial intelligence requires that you have access to large datasets, which will be provided by the centre. Since Denmark consists of mainly small and medium-sized companies, you could fear that they will lose the race, as they do not have the same opportunities for developing new solutions. Lack of data does not pose the same problem for large organisations such as IBM, Google and Amazon." |
| Subdomains | Priority areas of AI use are reported on: healthcare, energy and utilities, agriculture, transport, with focus also on big data, cybersecurity, cloud technologies.<br>AI applications are mentioned as language understanding, voice and image recognition, machine learning methods, ethics, cybersecurity, robotics, drones, self-driving cars. |
| Context | National Strategy: Denmark<br>The strategy's objectives are: (i) to introduce common ethical and human-based principles of AI, (ii) to promote Denmark's AI attractiveness through research and development on AI, (iii) to increase Danish businesses growth with AI use and development, and (iv) improve significantly public services through AI use. |
| Date of publication/ release | March 2019 |
| Comments | Three AI institutes in DK:<br>- The Alexandra Institute – Center for artificial intelligence.<br>- DELTA (part of FORCE Technology from 01.01.2017)<br>- Danish Technological Institute (Ibiz-center)<br><br>1 billion DKK from 2018 to 2025, and afterwards 75 million DKK per year. More Investment numbers available in the report. |

### 1.2.3 AI National Strategy: France. Monitoring report, 2019

| | |
|---|---|
| Source | Commission des affaires européennes. Gattolin A., Kern C., Pellevat C., Ouzoulias P. Rapport d'information sur la stratégie européenne pour l'intelligence artificielle. Intelligence artificielle : l'urgence d'une ambition européenne. |
| Text of the definition | Unofficial translations follow:<br>- Annexe 3:<br>"Champ interdisciplinaire théorique et pratique qui a pour objet la compréhension de mécanismes de la cognition et de la réflexion, et leur imitation par un dispositif matériel et logiciel, à des fins d'assistance ou de substitution à des activités humaines.<br>Attention : Cette publication annule et remplace celle du Journal officiel du 22 septembre 2000."<br>A theoretical and practical interdisciplinary field, with the objective of understanding the cognitive and thinking mechanisms, and their imitation by a material and software device, for assistance or substitution purposes of human activities.<br>Attention: This publication cancels and replaces this of the Journal officiel of September 22nd 2000.<br><br>- Première Partie I.A.:<br>The AI definition used is reported to be one of Russel and Norvig, 1995:<br>"...l'étude des méthodes permettant aux ordinateurs de se comporter intelligemment... l'IA inclut des tâches telles que l'apprentissage, le raisonnement, la planification, la perception, la compréhension du langage et la robotique... ces technologies visent à réaliser par l'informatique des tâches cognitives réalisées traditionnellement par les êtres humains."<br>...the study of methods allowing to the computer to behave intelligently...AI includes tasks as learning, reasoning, planning, perception, language comprehension and robotics...these technologies aim to achieve with computer science cognitive tasks that are traditionally achieved by human beings.<br><br>" Ce qu'on appelle intelligence artificielle est donc plus aujourd'hui un prolongement de l'intelligence humaine qu'une forme autonome d'intelligence. C'est pourquoi Charles-Édouard Bouée, PDG du cabinet Roland Berger, préfère parler d'intelligence humaine augmentée plutôt que d'intelligence artificielle."<br>What it is called AI today is more an extension of human intelligence than an autonomous form of intelligence.<br>This is why Charles-Édouard Bouée, CEO of Roland Berger consultancy firm, prefers to talk about augmented human intelligence than AI. |
| Subdomains | The subdomains defined by Russel and Norvig, 1995:<br>learning, reasoning, planning, perception, understanding, language comprehension, robotics |
| Context | Monitoring technical report of the French Senate to follow the objective set by the national plan "AI for Humanity". |
| Date of publication/ release | 31 January 2019 |
| Comments | Annexe 2 (budget) from La stratégie nationale de recherche en intelligence artificielle, 28.11.2018<br>- From EU: 1'5 billion € in the framework of the H2020 programme until 2020, and for the next MFF 1 billion € per year are proposed in research on AI, as part of the H2020, with objective to release 20 billion € of investments each year over 2020-2030.<br>- From France: 1'5 billion € in AI, from which 700 million for research.<br>- 5'000 researchers in AI, 250 research groups, 35 master degrees specialised in AI, 300 start-ups specialised in AI [Ministère de l'Enseignement supérieur, de la Recherche et de l'Innovation, date accessed 07.03.2019]<br><br>Six axis of the AI strategy:<br>1. Interdisciplinary AI institutes |

2. Attract and keep talents
3. Support AI projects (100 million € until 2022. Since 2018 22 million € to 61 projects.)
4. Reinforce the computation means (HPC) (170 million € until 2022)
5. Reinforce private-public research partnerships (65 million € will be invested by the state by 2022 to bring the total volume of projects to at least 130 million €, 65 millions € additional to other programs and institutes.)
6. Reinforce bilateral, European, international collaborations with Germany, Europe, and the world.

### 1.2.4 Spanish RDI Strategy in Artificial Intelligence, 2019

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|---|---|
| Source | Spanish Ministry of Science, Innovation and Universities, Spanish RDI Strategy in Artificial Intelligence |
| Text of the definition | "AI can be defined as the Science and Engineering that allows the design and programming of machines capable of carrying out tasks that require intelligence. Rather than achieving general intelligence, current AI focuses on what is known as specific AI, which is producing very important results in many fields of application such as natural language processing or artificial vision; however, from a scientific and basic and applied research point of view, general AI remains the major objective to be achieved, that is, creating an ecosystem with intelligent multitasking systems." |
| Subdomains | Listing the areas that the Spanish academic and scientific communities are active, the following AI areas are mentioned:<br>machine learning, heuristic optimisation, planning, automatic deduction, ontologies, logic and reasoning, big data, natural language processing, artificial vision, robotics, multi-agent systems, recommender systems, man-machine cooperation, agent-based modelling.<br><br>Moreover the following applications are mentioned in the strategic sectors of:<br>health, agriculture, creative industry, industry based on experience, services, energy and environmental sustainability, as part of the AI for society.<br><br>AI ethics are also among the strategy's priorities, in order to avoid discrimination. |
| Context | AI RDI Strategy: Spain<br>The priorities of the strategy are to: (i) achieve organisational structure, (ii) establish strategic areas, (iii) facilitate knowledge transfer, (iv) plan actions in AI education/training, (v), develop a digital data ecosystem, (vi) analyse AI ethics. |
| Date of publication/ release | 2019 |
| Comments | |

### 1.2.5 Latvian Information Report, 2019

| | |
|---|---|
| Source | Polityka Rozwoju Sztucznej Inteligencji w Polsce: na lata 2019 – 2027 |
| Text of the definition | Unofficial translation:<br>AI systems are man- made software and hardware systems that, depending on the intended purpose, operate in a physical or digital dimension, perceiving the environment from data , interpreting structured or unstructured data collected, making causal relationships or processing information derived from that data, and making decisions on the best course of action to be taken to achieve the objective pursued. AI systems can use rules or learn a numerical model, and they can adapt their behaviour by analysing how the environment affects their past actions. |
| Subdomains | KRR, planning and decision making, machine learning, computer vision, natural language processing, robotics |
| Context | Information report that provides an insight into AI, the current situation with the use of AI solutions worldwide and in the country. Furthermore, the report describes growth potential and risks, and promotes the introduction of Ai technologies in public administration and the Latvian economy. |
| Date of publication/ release | 2019 |
| Comments | |

### 1.2.6 National Strategy: Luxembourg, 2019

| | |
|---|---|
| Source | The Government of the Grand Duchy of Luxembourg: Artificial Intelligence: a strategic vision for Luxembourg. |
| Text of the definition | "…we are defining artificial intelligence as a machine's ability to mimic human behavior and, to an extent, human intelligence. This broad spectrum encompasses single tasks (think chess playing, translating or categorizing images) and complex activities (e.g. autonomous driving). General AI will remain a topic to be monitored as technology evolves." |
| Subdomains | Mentions the following as technologies under the umbrella of AI: robotics, automation, natural language processing, computer vision, optimisation, machine learning, AI-enabled apps and automated driving. It also includes ethics issues. |
| Context | To present a strategic vision for AI for the country. The publication includes Luxembourg's ambitions, focus areas and current situation of AI in the country. |
| Date of publication/ release | 2019 |
| Comments | |

### 1.2.7 AI National Strategy: France (Villani Mission), 2018

| | |
|---|---|
| Source | Parliamentary Mission (Villani Mission): Villani C., Schoenauer M., Bonnet Y., Berthet C., Cornut A.-C., Levin F., Rondepierre B. For A Meaningful Artificial Intelligence Towards A French And European Strategy (Donner un sens à l'intelligence artificielle : pour une stratégie nationale et européenne). |
| Text of the definition | "AI has always been envisioned as an evolving boundary, rather than a settled research field. Fundamentally, it refers to a programme whose ambitious objective is to understand and reproduce human cognition; creating cognitive processes comparable to those found in human beings. Therefore, we are naturally dealing with a wide scope here, both in terms of the technical procedures that can be employed and the various disciplines that can be called upon: mathematics, information technology, cognitive sciences, etc. There is a great variety of approaches when it comes to AI: ontological, reinforcement learning, adversarial learning and neural networks, to name just a few."<br>"…this technology [AI] represents much more than a research field: it determines our capacity to organize knowledge and give it meaning, it increases our decision-making capabilities and our control over these systems and, most notably, it enables us to capitalize on the value of data."<br>"A meaningful AI finally implies that AI should be explainable: explaining this technology to the public so as to demystify it—and the role of the media is vital from this point of view—but also explaining artificial intelligence by extending research into explicability itself. AI specialists themselves frequently maintain that significant advances could be made on this subject." |
| Subdomains | APIs; Text Data Mining (including computer processes that "involve extracting knowledge from texts or databases according to criteria of novelty or similarity"); CAVs; Health (pre-diagnosis); Robotics; Components Industry Adapted to AI |
| Context | This report was assigned as a parliamentary mission by the Prime Minister É. Philippe, and led by C. Villani, with aim to create a national strategy that, among other aims, will make France a leader in AI. The report analyses different AI aspects: political, economic, research, employment, ethics, social cohesion. There are separate annexes for each of the domains of particular interest for France: education, health, agriculture, transport, defense and security.<br>The AI definition presented in this fiche is used for the national strategy. |
| Date of publication/ release | 29 March 2018 |
| Comments | The French Strategy for AI is also called as the "AI for Humanity" plan. The world AI leaders are mentioned:<br>"The current colossi of artificial intelligence—the United States and China—and the emerging economies in that field (Israel, Canada and the United Kingdom in particular) have sometimes developed or are still developing in radically different ways. France and Europe will not necessarily need to launch their own 'European style Google' to secure a place on the international stage.<br>The United States and China are at the forefront of this technology and their investments far exceed those made in Europe. Canada, the United Kingdom and, especially, Israel hold key positions in this emerging ecosystem. Considering that France and Europe can already be regarded as "cybercolonies" in many aspects, it is essential that they resist all forms of determinism by proposing a coordinated response at European level."<br>The role of Europe in robotics is discussed as having all the necessary to lead in this subdomain, "whether in terms of industrial robotics, for example, or agricultural robotics."<br>Budget: 1.5 billion euros on AI during the next 5 years. More funding details are mentioned in the report. |

### 1.2.8 AI National Strategy: Germany, 2018

| | |
|---|---|
| Source | Federal Government. Artificial Intelligence Strategy. |
| Text of the definition | It is stated that a generally valid or consistently used by all stakeholders AI definition does not exist. The AI definition used for the Federal Government's AI Strategy is based on the following understanding of AI:<br>"In highly abstract terms, AI researchers can be assigned to two groups: "strong" and "weak" AI. "Strong" AI means that AI systems have the same intellectual capabilities as humans, or even exceed them. "Weak" AI is focused on the solution of specific problems using methods from mathematics and computer science, whereby the systems developed are capable of self-optimisation. To this end, aspects of human intelligence are mapped and formally described, and systems are designed to simulate and support human thinking." |
| Subdomains | "Weak" AI approach:<br>deductive reasoning systems; knowledge-based systems methods and software; pattern analysis and recognition; robotics (autonomous systems); multimodal human-machine interaction |
| Context | National Strategy: Germany<br>The aims of the strategy are: (i) to promote Germany's and Europe's leading role in AI, (ii) ensure a responsible AI development and use, (iii) integrate AI in society. In the framework of science and innovation promotion, an organisation specialised in AI is established (German Research Center of Artificial Intelligence - DFKI). |
| Date of publication/ release | November 2018 |
| Comments | It is mentioned that Germany's Government will use AI to solve specific problems, namely the "weak" approach will be adopted. (For examples of "weak"/ "narrow", "strong"/ "general" AI see OECD, 2018; McCarty, 2007; Gardner, 1987)<br><br>Budget:<br>500 million € in the AI strategy for 2019 and the following years, up to 3 billion € by 2025.<br>100 additional professorships in AI.<br><br>In the last 30 years, the German government has provided just €500 million in state aid for AI-related research. [Handelsblatt, 07.2018, date accessed 07.03.2019] |

### 1.2.9 Artificial Intelligence Mission Austria 2030 (AIM AT 2030), 2018

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|---|---|
| Source | Federal Ministry for Transport, Innovation and Technology and Federal Ministry for Digital and Economic Affairs. Artificial Intelligence Mission Austria 2030. |
| Text of the definition | In the report AI is more described than defined. AI applications and certain areas are also presented.<br>"Artificial intelligence (AI) comprises computer systems that exhibit intelligent behaviour."<br>"Systems based on artificial intelligence analyse their environment and autonomously act to achieve certain goals. They work through expert-generated rule knowledge or based on data-derived statistical models (machine learning or deep learning). AI includes both pure software systems that set actions in virtual environments and hardware such as robots." |
| Subdomains | Larger areas of AI applications as mentioned. |
| Context | First steps towards an official strategy for AI. |
| Date of publication/ release | October 2018 |
| Comments | Seven priority areas are mentioned to be the ones that will assist the development of AI in Austria:<br>1. qualification and training<br>2. research and innovation<br>3. AI in the economy<br>4. AI in the public sector<br>5. society, ethics and labour market<br>6. AI governance, security and legal aspects<br>7. infrastructure for industrial leadership positions<br><br>The following application areas of AI are mentioned to be multiple, in the areas of perception, understanding, action, learning etc. AI and ethics is also raised. |

### 1.2.10 AI National Strategy: Sweden, 2018

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|---|---|
| Source | Government Offices of Sweden: Ministry of Enterprise and Innovation. National Approach to AI (N2018.36). |
| Text of the definition | Sweden's innovation strategy approach to the AI definition is used:<br>"There is no one single, clear-cut or generally accepted definition of artificial intelligence, but many definitions. In general, however, AI refers to intelligence demonstrated by machines. Vinnova (Sweden's innovation agency) (2018) (Artificiell intelligens i svenskt näringsliv och samhälle. (Artificial intelligence in Swedish business and society). Interim report 12 February 2018, Reg. no 2017-05616."<br>Moreover the breadth of the field is recognised, which "encompasses many technologies, not least machine learning and deep learning." |
| Subdomains | - |
| Context | National Strategy: Sweden<br>The strategy's goal is promote the Sweden's role as an AI leader using AI, in order to strengthen the country's welfare and competitiveness. |
| Date of publication/ release | 2018 |
| Comments | |

### 1.2.11 Report of the Steering Group of the AI Programme: Finland, 2017

| | |
|---|---|
| Source | Ministry of Economic Affairs and Employment. Finland's Age of Artificial Intelligence. |
| Text of the definition | "Artificial intelligence refers to devices, software and systems that are able to learn and to make decisions in almost the same manner as people. Artificial intelligence allows machines, devices, software, systems and services to function in a sensible way according to the task and situation at hand."<br>The absence of a widely accepted definition is stated. |
| Subdomains | - |
| Context | Second interim report of the Steering Group of the Artificial Intelligence Programme appointed by the Ministry of Economic Affairs and Employment.<br>The Finnish government is expected to implement the recommendations as government policy.<br>Eight key actions are mentioned that are expected to promote Finland to leader in AI:<br>"1. Enhancement of business competitiveness through the use of AI<br>2. Effective utilisation of data in all sectors<br>3. Ensure AI can be adopted more quickly and easily<br>4. Ensure top-level expertise and attract top experts<br>5. Make bold decisions and investments<br>6. Build the world's best public services<br>7. Establish new models for collaboration<br>8. Make Finland a frontrunner in the age of AI" |
| Date of publication/ release | 18 December 2017 |
| Comments | US companies and innovation hubs are found to be leading in AI applications.<br>Chinese government is promoting AI development.<br>A SWOT analysis for Finland is provided. It is found that in Finland the use of AI: will improve public sector's efficiency, society and education will be significantly affected, as well as other sectors. Moreover enterprise-driven ecosystems are promoted to improve AI implementation. |

## 1.3 National level: non-EU

### 1.3.1 Australia's Ethic Framework, 2019

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|---|---|
| Source | Dawson, D. and Schleiger, E., Horton, J., McLaughlin, J., Robinson, C., Quezada, G., Scowcroft, J., Hajkowicz S. Artificial Intelligence: Australia's Ethics Framework. Data61 CSIRO, Australia. |
| Text of the definition | "A collection of interrelated technologies used to solve problems autonomously and perform tasks to achieve defined objectives without explicit guidance from a human being."<br>"This definition of AI encompasses both recent, powerful advances in AI such as neural nets and deep learning, as well as less sophisticated but still important applications with significant impacts on people, such as automated decision systems."<br>The categorisation between "narrow" and "general" AI is mentioned. The "narrow AI" performs specific functions. The "general AI" "is comparable to human intelligence across a range of fields".<br><br>In the country's plan on innovation and science (Innovation and Science Australia 2017, Australia 2030: prosperity through innovation, Australian Government, Canberra), AI is defined as follows in the acronyms, abbreviations and glossary part:<br>"Computer systems that are able to perform tasks normally requiring human intelligence." |
| Subdomains | Algorithms; mechanical systems (robots, autonomous vehicles, etc.)<br><br>The following ethical principles that should be applied in AI are mentioned:<br>1. The benefits of any AI systems are greater that its costs.<br>2. Minimise negative harmful and deceitful outcomes to humans.<br>3. Regulatory and legal compliance to all relevant obligations, regulations and laws national and international.<br>4. Peoples' private data protection.<br>5. Ensure fair treatment of human individuals, communities or groups.<br>6. For transparency reasons, people will be informed when an algorithm is applied, and which information it uses for decision-making.<br>7. In the case that an algorithm affects a person, an efficient process should be ensured, so that the person can "challenge the use or output of the algorithm".<br>8. People and organisations that create and implement an AI algorithm are accountable for its impact.<br>These could be considered as potential subdivisions of the AI ethics subdomain. |
| Context | Governmental discussion paper on AI ethics to ensure a responsible development and application of AI in Australia. The focus is set on "narrow AI", as "general AI" is not seen as a likely prospect by 2030. |
| Date of publication/ release | 4 March 2019 |
| Comments | Australia does not presently have an AI national strategy. A Technology Roadmap, a Standards Framework, and a national Ethics Framework are planned. An AU$29.9 million investment was announced to promote AI development in Australia. Currently AI and automation are included in the national Innovation Strategy (Australia 2030: Prosperity Through Innovation, 2017), in the Victorian All-Party Parliamentary Group on Artificial Intelligence (VAPPGAI, March 2018), and the Digital Economy Strategy (September 2017). |

### 1.3.2 US Congressional Research Service, 2019

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|---|---|
| Source | US Congressional Research Service. Artificial Intelligence and National Security. |
| Text of the definition | The absence of a commonly accepted definition is again stated. Among the reasons are the numerous and diverse approaches of research in AI. The report is using NDAA, 2018 definition of AI. |
| Subdomains | Narrow AI notion is used, with all current AI systems being assigned to this category. This includes:<br>machine learning, image recognition, IoT, autonomous/ human-supervises/semi-autonomous weapon system, robot.<br>Automated systems are defined as the superset that includes AI, robots and autonomous systems, which intersect each other. |
| Context | Report prepared for the US Congress. |
| Date of publication/ release | 30 January 2019 |
| Comments | A US AI national strategy is not yet signed, but on February 2019 an executive order was signed to establish the *American AI Initiative*. This is expected to include aims to promote to AI research, R&D and workforce development, while proposing an international engagement.<br>Older reports are the following:<br>- *Preparing for the Future of Artificial Intelligence*. October 2016: Recommendations on AI regulations, automation, ethics, fairness, security and publicly funded R&D.<br>- National Artificial Intelligence Research and Development Strategic Plan. October 2016: Strategic plan outline for publicly funded R&D in AI.<br>- *Artificial Intelligence, Automation, and the Economy*. December 2016: The impact of automation, the benefits and the costs of AI were studied, in order to provide policy recommendations. |

### 1.3.3 Working Paper for AI National Strategy: India, 2018

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|---|---|
| Source | National Strategy for Artificial Intelligence #AIFORALL |
| Text of the definition | "AI refers to the ability of machines to perform cognitive tasks like thinking, perceiving, learning, problem solving and decision making. Initially conceived as a technology that could mimic human intelligence, AI has evolved in ways that far exceed its original conception. With incredible advances made in data collection, processing and computation power, intelligent systems can now be deployed to take over a variety of tasks, enable connectivity and enhance productivity."<br><br>Three different ways of categorising AI are also offered:<br>(a) weak vs. strong AI: "weak AI describes "simulated" thinking", namely "a system which appears to behave intelligently, but doesn't have any kind of consciousness about what it's doing",<br>(b) narrow vs. general AI: "narrow AI describes an AI that is limited to a single task or a set number of tasks"<br>(c) superintelligence: "often used to refer to general and strong AI at the point at which it surpasses human intelligence, if it ever does". |
| Subdomains | Three main categories of AI technologies are identified:<br>(i) sense: computer vision; audio processing;<br>(ii) comprehend: natural language processing; knowledge representation<br>(iii) act: machine learning; expert systems<br><br>Virtual agents, cognitive robotics, speech and identity analytics, recommendation systems, and data visualisation are presented as AI solutions. |
| Context | National strategy: India, Discussion Paper<br>Healthcare, agriculture, education, smart cities and infrastructure, smart mobility and transportation, are identified as the areas that AI would be beneficial in covering societal needs. The report is intended as an initiator of an evolving AI national strategy. |
| Date of publication/ release | June 2018 |
| Comments | |

### 1.3.4 US National Defense Authorization Act, 2018

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|---|---|
| Source | US National Defense Authorization Act for Fiscal Year 2019. |
| Text of the definition | In section 238 it is mentioned:<br>"1. Any artificial system that performs tasks under varying and unpredictable circumstances without significant human oversight, or that can learn from experience and improve performance when exposed to data sets.<br>2. An artificial system developed in computer software, physical hardware, or other context that solves tasks requiring human-like perception, cognition, planning, learning, communication, or physical action.<br>3. An artificial system designed to think or act like a human, including cognitive architectures and neural networks.<br>4. A set of techniques, including machine learning that is designed to approximate a cognitive task.<br>5. An artificial system designed to act rationally, including an intelligent software agent or embodied robot that achieves goals using perception, planning, reasoning, learning, communicating, decision-making, and acting." |
| Subdomains | - |
| Context | Federal Law that specifies the policies, budget and expenditure of the US Department of Defense for 2019. |
| Date of publication/ release | 3 January 2018 |
| Comments | |

### 1.3.5 US Department of Defense, 2018

| | |
|---|---|
| Source | US Department of Defense, Govini. Artificial intelligence, big data and cloud taxonomy. |
| Text of the definition | - |
| Subdomains | Learning and Intelligence: modeling and simulation, DL, ML, NLP, data mining;<br>Advanced Computing: super-computing, neuromorphic engineering, quantum computing;<br>AI systems: virtual reality, computer vision, virtual agents<br><br>Cloud service models are also mentioned (IaaS, PaaS, SaaS). |
| Context | US Department of Defense (DoD) report to analyse the critical to AI technologies critical, and the vendor landscape and performance within the 25 sub-segments that are found. |
| Date of publication/ release | 2018 |
| Comments | Govini is a US big data and analytics firm contracted by the DoD. DoD considers AI as a “technological cornerstone” for its Third Offset Strategy. |

### 1.3.6 National Industrial Strategy: United Kingdom, 2018; 2017

| | |
|---|---|
| Source | [1] HM Government: Department for Business, Energy & Industrial Strategy, Department for Digital, Culture, Media & Sport. Industrial Strategy. Artificial Intelligence Sector Deal.<br><br>[2] HM Government: Department for Business, Energy & Industrial Strategy. Industrial Strategy. Building a Britain fit for the future. |
| Text of the definition | - |
| Subdomains | Machine learning and robotics are mentioned as parts of examples for the uses that the strategy aims to achieve, without further indications of AI subdomains. |
| Context | National Strategy: UK<br>The strategy's aims are to position UK as global leader in AI based on ideas, people, infrastructure, business environment, communities across the UK. |
| Date of publication/ release | [1] April 2018<br>[2] November 2017 |
| Comments | Budget:<br>- £20 million in AI applications for the services sector<br>- £93 million for robotics with multiple uses<br>- £20 million to stimulate among other ways the AI uptake<br>- £300 million for AI research funding, £83 million for AI grants, £42 million for the expansion of the Alan Turing Institute, with £30 million from private funding. |

### 1.3.7 AI National Strategy: Japan, 2017

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|---|---|
| Source | Strategic Council for AI Technology. Artificial Intelligence Technology Strategy. |
| Text of the definition | - |
| Subdomains | Vision; virtual reality (VR); autonomous driving; robots; natural language processing; image recognition; voice recognition/synthesis; prediction |
| Context | National Strategy: Japan<br>AI is seen a set of valuable services with a roadmap for its development in three phases: (i) the use and application of data-driven AI, (ii) the public use of AI and data, (iii) the creation of ecosystems through multi-domains connections.<br>A strong focus is set on the data management, the academia-industry collaborations, the technological and system development and system development for AI start-ups and their matching with large corporations or financial institutions |
| Date of publication/ release | 31 March 2017 |
| Comments | Japan was among the first countries that developed a national AI strategy. The strategy presents AI's development phases for Japan. The strategy combines US and Chinese aims. |

### 1.3.8 AI National Strategy: China, 2017

| | |
|---|---|
| Source | China's State Council. Next Generation Artificial Intelligence Development Plan (AIDP). Original report. Translated report. |
| Text of the definition | - |
| Subdomains | Knowledge computing engines and knowledge service technology;<br>Cross-medium analytical reasoning technology;<br>Swarm intelligence technology;<br>Autonomous unmanned systems;<br>Intelligent virtual reality modelling technology;<br>Intelligent computing chips and systems;<br>Natural language processing technology;<br>Support platforms of the aforementioned (Autonomous Unmanned System Support Platforms, AI Basic Data and Security Detection Platforms, etc.) |
| Context | National Strategy: China |
| Date of publication/ release | 20 July 2017 |
| Comments | China shows a significant interest in the foreign AI developments and among the conclusions of the strategy is the focus that is set on achieving world-leading levels in AI and reduce foreign dependence [China State Council. Made in China 2025].<br>"AI has become a new focus of international competition. AI is a strategic technology that will lead in the future; the world's major developed countries are taking the development of AI as a major strategy to enhance national competitiveness and protect national security…"<br>"…by 2030, China's AI theories, technologies, and applications should achieve world leading levels, making China the world's primary AI innovation center…"<br><br>Budget:<br>"…the intelligent application of a complete industrial chain and high-end industrial clusters, with AI core industry scale exceeding 1 trillion RMB, and with the scale of related industries exceeding 10 trillion RMB." |

### 1.3.9 AI National Strategy: Canada, 2017

| | |
|---|---|
| Source | Pan-Canadian Artificial Intelligence Strategy |
| Text of the definition | - |
| Subdomains | - |
| Context | National strategy: Canada.<br>It has four goals:<br>1. to increase the number of AI researchers and graduates in Canada,<br>2. to form three AI centres of scientific excellence (Alberta Machine Intelligence Institute (AMII, Edmonton), Vector Institute (Toronto), Mila (Montreal)),<br>3. to develop thought leadership on the economic, ethical, policy, and legal implications of AI,<br>4. to support Canada's AI research community.<br><br>Part of the strategy is the collaboration of the Canadian Institute for Advanced Research (CIFAR), which leads the strategy, with the Canadian government and the three new AI centres of scientific excellence. |
| Date of publication/ release | 2017 |
| Comments | Canada was the first country that released an AI national strategy.<br>Budget: $125-million investment in AI research and innovation in Canada.<br>On 7th of June 2018 Canada and France published a joint statement on AI. The announcement included their common aim, namely to encourage the development of AI while anticipating any impacts with coordinated efforts. The materialisation of this aim would be an international study group consisted of internationally recognised experts in science, industry and civil society, together with policymakers. It is set to identify opportunities and challenges ensuing from AI, and provide an inclusive mechanism "for sharing multidisciplinary analysis, foresight and coordination capabilities in the area of artificial intelligence". |

## 1.4 International Organisations

### 1.4.1 OECD, 2019a

| | |
|---|---|
| Source | Scoping the OECD AI principles Deliberations of the expert Group on Artificial Intelligence at the OECD (AIGO). |
| Text of the definition | AI definition adopted from Russel and Norvig, 2013 (initial edition 1995), which is four categories of AI and eight definitions of earlier literature. The categories are regarding thought processes, reasoning, human and rational behaviour.<br>Russel and Norvig present four categories of AI and eight definitions of earlier literature. The categories are regarding thought processes, reasoning, human and rational behavior, and more explicitly are: 1) systems that think as humans, 2) systems that act as humans, 3) systems that think rationally, 4) systems that act rationally (Russel and Norvig, 1995 first edition, 2010 3rd edition).<br><br>The definition of an AI system is also given: "An AI system is a machine-based system that is capable of influencing the Environment by making recommendations, predictions or decisions for a given set of Objectives. It does so by utilising machine and/or human-based inputs/data to: i) perceive real and/or virtual environments; ii) abstract such perceptions into models manually or automatically; and iii) use Model Interpretations to formulate options for outcomes." |
| Subdomains | Ethics and related principles, as well as biases. |
| Context | |
| Date of publication/ release | November 2019 |
| Comments | The same definition of AI was also used by the French AI National Strategy monitoring report (French National Strategy monitoring report, 2019). The AI system description meant to be "understandable, technically accurate, technology-neutral, and applicable to short and long-term time horizons" (OECD, 2019a).<br><br>The OECD principles are: 1) inclusive and sustainable growth and well-being, 2) human-centred values and fairness, 3) transparency and explainability, 4) robustness and safety, 5) accountability. These principles are set based on the following characteristics: "specific to AI, facilitating innovation and trust in AI, implementable, flexible to stand the test of time, and conducive to increased co-operation".<br><br>The study takes into account four potential biases in an AI system, namely "perception bias, technical bias, modelling bias and activation bias". |

### 1.4.2 OECD, 2019b

| | |
|---|---|
| Source | OECD, Recommendation of the Council on Artificial Intelligence, OECD/LEGAL/0449 |
| Text of the definition | "An AI system is a machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations, or decisions influencing real or virtual environments. AI systems are designed to operate with varying levels of autonomy." |
| Subdomains | Ethics: inclusive growth, sustainable development and well-being; human-centered values and fairness; transparency and explainability; robustness, security and safety; accountability |
| Context | Under the OECD Legal instruments, this document presents a number of recommendations to promote innovation on AI based on ethical principles and respecting human rights and democratic values. |
| Date of publication/ release | 22 May 2019 |
| Comments | |

### 1.4.3 UNESCO, 2019

| | |
|---|---|
| Source | UNESCO. Principles for AI: Towards a Humanistic Approach? A Global Conference |
| Text of the definition | - |
| Subdomains | Rapid technological advancements in artificial intelligence (AI) – as well as other evolving technologies such as robotics, big data analytics, and the Internet of Things – are changing the way we learn, work and live together. |
| Context | Conference on AI principles |
| Date of publication/ release | 04 March 2019 |
| Comments | Presently no definition is found reported by UNESCO. |

### 1.4.4 StandICT.eu project, 2019

| | |
|---|---|
| Source | Supporting European Experts Presence in International Standardisation Activities in ICT (StandICT.eu). ICT standards and ongoing work at International level in the AI field – a Landscape analysis |
| Text of the definition | - |
| Subdomains | Themes/challenges/areas:<br>personalised AI; trustworthiness; ethics; AI security; transparency of autonomous systems; AI usage; wellbeing metrics; big data; AI foundational standards; AI governance; computational approaches; health; transparency of data processing; conceptualisation and specification of domain knowledge |
| Context | Project funded by H2020 for ICT standardisation, ICT Technical specifications, cloud computing, 5G communications, IoT, cybersecurity, data technologies.<br>Aim: description of the ICT standards, ongoing work at international level and landscape analysis. |
| Date of publication/ release | 24 February 2019 |
| Comments | "End of 2018 two sub committees" (JTC1 SC42, JTC1 SC27 WG4) "with 6 working groups" (JTC1 SC42 JWG1, JTC1 SC42 WG1, JTC1 SC42 WG2, JTC1 SC42 WG3, JTC1 SC42 WG4, JTC1 SC42 WG5) "and 1 study group" (JTC1 SC42 Study Group 1) "with the goal to develop 10 AI standards are active in ISO/IEC."<br>More details on each expected standard: p. 39.<br>3 standards are published (2 are stated in the report):<br>**1.** ISO/IEC 20546:2019 Information technology -- Big data -- Overview and vocabulary. ISO/IEC JTC1/SC42 working groups for standardisation in the area of AI published on 28.02.2019 the ISO/IEC 20546:2019. It requires a fee to be downloaded, however from the preview it can be seen that it is an overview and vocabulary only on "Information technology – Big data", without any mention to AI definitions.<br>**2.** ISO/IEC TR 20547-2:2018 Information technology -- Big data reference architecture -- Part 2: Use cases and derived requirements<br>Until 03.05.2019 the ISO/IEC WD 22989 on Artificial Intelligence -- Concepts and terminology *Standard and/or project under the direct responsibility of ISO/IEC JTC1/SC42* is reported "*under development*", and more specifically in the "Preparatory" phase.<br>**3.** ISO/IEC TR 20547-5:2018 Information technology -- Big data reference architecture -- Part 5: Standards roadmap<br>ISO/IEC JTC1/SC42 is the *first international standards committee* looking *at the entire AI ecosystem.* JTC1's scope for SC42 is to become *a systems integration entity to work with other ISO, IEC and JTC 1 committees looking at AI applications.*<br>Among the reported community and industrial activities are mentioned (some involved in ISO/IEC JTC1/SC42):<br>- the multi-stakeholder platform on ICT standardisation (MSP)<br>- European AI Alliance steered by High-Level Expert Group on AI (AI HLEG)<br>- Fraunhofer Cluster of Excellence "Cognitive Internet Technologies" (CCIT)<br>- Big Fata Value Association (BDVA)<br>More projects are mentioned for the development of standards on other aspects of AI (e.g. P7006 - Standard for Personal Data Artificial Intelligence (AI) Agent, P7008 Standard for Ethically Driven Nudging for Robotic, Intelligent and Autonomous Systems, P7010 - Wellbeing Metrics Standard for Ethical Artificial Intelligence and Autonomous Systems, IEEE Ethically Aligned Design version 2, et. al.) |

### 1.4.5 OECD, 2018

| | |
|---|---|
| Source | OECD Directorate for Science, Technology and Innovation, Committee on Industry, Innovation and Entrepreneurship. Identifying and Measuring Developments in Artificial Intelligence. DSTI/CIIE/ WPIA(2018)4 |
| Text of the definition | "AI is neither science fiction nor a science project. There was universal agreement that artificial intelligence already provides beneficial applications that are used every day by people worldwide. Going forward, conference participants suggested that the development and uses of AI systems should be guided by principles that will promote well-being and prosperity while protecting individual rights and democracy.<br>A consensus emerged that the fast-paced and far-reaching changes from AI offer dynamic opportunities for improving the economic and social sectors. AI can make business more productive, improve government efficiency and relieve workers of mundane tasks. It can also address many of our most pressing global problems, such as climate change and wider access to quality education and healthcare.<br>…<br>This combination of interdisciplinary origins, wavering trajectories, and recent commercial success make "artificial intelligence" a difficult concept to define and measure.<br><br>The term itself is used interchangeably both as the still-faraway goal of true machine intelligence and as the currently available technology powering today's hottest startups" (p.5) |
| Subdomains | Machine learning (including deep learning); statistics, mathematics and computational methods; specific fields and applications such as: text mining; image recognition; biology machine vision; speech recognition; machine translation (weak AI or Artificial Narrow Intelligence) (pp.4-5) |
| Context | Policy Document that proposes an approach to identify and measure AI developments in science, technological developments, and software. |
| Date of publication/ release | 12 October 2018 |
| Comments | Methods used: topic modelling to subdivide AI-codes, and find key development fields and applications.<br>Among other sources used: GitHub, patents, Scopus. |

### 1.4.6 ETSI, 2018

| | |
|---|---|
| Source | ETSI GR ENI 004 v.1.1.1. Experiential Network Intelligence (ENI); Terminology for Main Concepts in ENI |
| Text of the definition | "Computerized system that uses cognition to understand information and solve problems."<br>NOTE 1: ISO/IEC 2382-28 "Information technology -- Vocabulary" defines AI as "an interdisciplinary field, usually regarded as a branch of computer science, dealing with models and systems for the performance of functions generally associated with human intelligence, such as reasoning and learning".<br>NOTE 2: In computer science AI research is defined as the study of "intelligent agents": any device that perceives its environment and takes actions to achieve its goals.<br>NOTE 3: This includes pattern recognition and the application of machine learning and related techniques.<br>NOTE 4: Artificial Intelligence is the whole idea and concepts of machines being able to carry out tasks in a way that mimics the human intelligence and would be considered "smart". |
| Subdomains | Mention of only two fields:<br>"Knowledge reasoning: field of artificial intelligence that uses a set of knowledge bases and a given knowledge representation to reason about the information available<br>NOTE: Typically, this is used to validate data as well as predict or infer new information from existing information.<br>Knowledge representation: field of artificial intelligence that represents data and information in a form that a computerized system can use." |
| Context | The Experiential Networked Intelligence (ENI) ETSI Industry Specification Group (ISG) of the European Telecommunications Standards Institute (ETSI) published a document on the main concepts in ENI. |
| Date of publication/ release | June 2018 |
| Comments | European Telecommunications Standards Institute (ETSI) is the recognized regional standards body addressing telecommunications, broadcasting and other electronic communications networks and services. It is a not-for-profit organization, part of the European Standards Organization (ESO).<br>It uses the ISO/IEC 2382-28 AI definitions, and works on the standardised use of AI applications. |

### 1.4.7 OECD, 2017

| | |
|---|---|
| Source | OECD. Science, Technology and Industry Scoreboard 2017. The Digital Transformation. |
| Text of the definition | "Artificial Intelligence (AI) is a term used to describe machines performing human-like cognitive functions (e.g. learning, understanding, reasoning or interacting). It has the potential to revolutionise production as well as contribute to tackling global challenges related to health, transport and the environment." |
| Subdomains | Technologies that embed AI; large capacity analysis and storage; information communication devices; mobile communication; imaging and sound technology; ICT security; measurement; high-speed computing and network; medical technology |
| Context | Policy document with indicators regarding the impact of digital transformation on science, innovation, the economy, work and society. |
| Date of publication/ release | 2017 |
| Comments | Global rankings and technological map are available in the report. |

### 1.4.8 World Economic Forum, 2017

| | |
|---|---|
| Source | World Economic Forum<br>WEF. 2017. Impact of the Fourth Industrial Revolution on Supply Chains. |
| Text of the definition | "Artificial intelligence (AI) is the software engine that drives the Fourth Industrial Revolution. Its impact can already be seen in homes, businesses and political processes. In its embodied form of robots, it will soon be driving cars, stocking warehouses and caring for the young and elderly. It holds the promise of solving some of the most pressing issues facing society, but also presents challenges such as inscrutable "black box" algorithms, unethical use of data and potential job displacement. As rapid advances in machine learning (ML) increase the scope and scale of AI's deployment across all aspects of daily life, and as the technology itself can learn and change on its own, multistakeholder collaboration is required to optimize accountability, transparency, privacy and impartiality to create trust."<br>"Artificial intelligence (AI) or self-learning systems is the collective term for machines that replicate the cognitive abilities of human beings. Within the broader technological landscape, predictive maintenance in the cognitive era has the potential to transform global production systems." |
| Subdomains | - |
| Context | Policy conference and white paper on how production and supply chain will be affected by new technological developments, including AI. |
| Date of publication/ release | 2017 |
| Comments | Prepared in collaboration with the German logistics association BVL International. |

### 1.4.9 ISO, 1993; 1995; 2015; 2020

| | |
|---|---|
| Source | ISO/IEC 2382:2015; ISO/IEC TR 24028:2020 |
| Text of the definition | "Branch of computer science devoted to developing data processing systems that perform functions normally associated with human intelligence, such as reasoning, learning, and self-improvement" (2121393: ISO, AI: term, abbreviation and definition standardized by ISO/IEC (ISO/IEC 2382-1:1993))<br>"Interdisciplinary field, usually regarded as a branch of computer science, dealing with models and systems for the performance of functions generally associated with human intelligence, such as reasoning and learning" (2123769: term, abbreviation and definition standardized by ISO/IEC (ISO/IEC 2382-28:1995))<br>"Capability of a functional unit to perform functions that are generally associated with human intelligence such as reasoning and learning" (2123770: term, abbreviation and definition standardized by ISO/IEC (ISO/IEC 2382-28:1995))<br><br>"…systems providing or using AI, called hereafter artificial intelligence (AI) systems." (ISO/IEC TR 24028:2020)<br><br>"capability of an engineered system (3.38) to acquire, process and apply knowledge and skills. Note 1 to entry: Knowledge are facts, information (3.20) and skills acquired through experience or education." (ISO/IEC TR 24028:2020) |
| Subdomains | - |
| Context | International Organization for Standardization (ISO) |
| Date of publication/ release | 2015 |
| Comments | The definitions imply the "general" AI classification; they refer to performance of human functions: reasoning, learning etc. |

### 1.4.10 IEC, 2019

| | |
|---|---|
| Source | IEC 60050-171:2019 171-09-16 171-09-17 |
| Text of the definition | "AI, <discipline>: branch of computer science devoted to developing data processing systems that perform functions normally associated with human intelligence, such as reasoning and learning" (171-09-16)<br>"AI, <capability>: capability of a functional unit to perform functions that are generally associated with human intelligence, such as reasoning and learning" (171-09-17) |
| Subdomains | - |
| Context | International Electrotechnical Commission (IEC) |
| Date of publication/ release | 2019 |
| Comments | |

# 2 Research perspective

## 2.1 Osservatorio Artificial Inteligence, 2019

| | |
|---|---|
| Source | Osservatorio Artificial Intelligence, Politecnico di Milano, Dipartimento di Ingegneria Gestionale: Artificial Intelligence on your marks! |
| Text of the definition | Unofficial translation:<br>Artificial Intelligence is the branch of computer science that studies the development of HW and SW systems endowed with typical human skills (interaction with the environment, learning and adaptation, reasoning and planning), capable of independently pursuing a defined purpose, making decisions that, until then, were usually left to people. |
| Subdomains | The document presents applications that are considered as AI based on the conducted survey. These applications are related to automation and robotics, natural language processing, computer vision, machine learning, searching and optimisation. Moreover, in the section that discusses the AI worldwide, mentions the ethical and legal implications that are raised by many national and institutional projects. |
| Context | The report gives insights on AI by analysing the results of a survey, which was addressed to large Italian organizations, by identifying the main points of interest (in AI) of these organisations, by analysing the AI market, and by providing the current state of AI worldwide. |
| Date of publication/ release | February, 2019 |
| Comments | |

## 2.2 Tsinghua University, 2018

| | |
|---|---|
| Source | China Institute for Science and Technology Policy at Tsinghua University. AI Development Report. |
| Text of the definition | "AI machines do not necessarily have to obtain intelligence by thinking like a human and that it is important to make AI solve problems that can be solved by a human brain. Brain science and brainlike intelligence research and machine-learning represented by deep neural networks represent the two main development directions of core AI technologies, with the latter referring to the use of specific algorithms to direct computer systems to arrive at an appropriate model based on existing data and use the model to make judgment on new situations, thus completing a behavior mechanism.<br>While only limited progress has been made in the first direction, tremendous strides have been taken in the second direction so much that machine learning has not only become the main paradigm of AI technology but been equated by some with AI itself. In general, the artificial intelligence we know today is based on modern algorithms, supported by historical data, and forms artificial programs or systems capable of perception, cognition, decision making and implementation like humans." |
| Subdomains | Technical Dimensions of AI Enterprise Identification:<br>- Speech: speech recognition, speech synthesis, speech interaction, speech evaluation, human-machine dialogue, voiceprint recognition<br>- Vision: biometrics (face recognition, iris recognition, fingerprint recognition, vein recognition, etc.) affective computing, emotion recognition, expression recognition, behavior recognition, gesture recognition, body recognition, video content recognition, object and scene recognition, mobile vision, optical character recognition (OCR), handwriting recognition, SLAM, spatial recognition, 3D reconstruction etc.<br>- Natural Language Processing: natural language interaction, natural language understanding, semantic understanding, machine translation, text mining (semantic analysis, semantic computing, classification, clustering), information extraction, human-machine interaction<br>- Basic algorithm and platform: machine learning, deep learning, open source framework, open platform<br>- Basic hardware: chips, lidars, sensors, etc.<br>- Basic enabling technology: cloud computing, big data<br><br>Product and Industry Dimensions:<br>- Intelligent robotics: industrial robotics, service robotics, personal/ home robotics<br>- Smart driving: Intelligent driving, driverless driving, autonomous driving, assisted driving, advanced driver assistance system (ADAS), laser radar, ultrasonic radar, millimetre wave radar, GPS positioning, high-precision map, vehicle chip, human-car interaction, etc.<br>- Drone: consumer drones, professional drones<br>- AI+: Finance, insurance, judiciary administration, entertainment, tourism, healthcare, education, logistics and warehousing, smart home, smart city, network security, video surveillance, commerce, human resources, corporate services |
| Context | The report captures in multiple dimensions the Chinese and worldwide AI ecosystem. It was firstly presented during the World Peace Forum. |
| Date of publication/ release | July 2018 |
| Comments | Budget:<br>150 billion dollars by 2030, more than 50 billion euros in AI research by 2025 |

## 2.3 Kaplan and Haenlein, 2018

| | |
|---|---|
| Source | Kaplan, A. and Haenlein, M. Siri, Siri, in my hand: Who's the fairest in the land? On the interpretations, illustrations, and implications of artificial intelligence |
| Text of the definition | "Artificial intelligence (AI)—defined as a system's ability to correctly interpret external data, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation." |
| Subdomains | - |
| Context | The article states that AI is different from concepts as IoT and big data.<br>It introduces in the definition the notions of interpretation of the environment (external data), learning, achievement of goals/tasks etc.<br>Refers to AI through stages: artificial narrow/general/super intelligence. |
| Date of publication/ release | 2018 |
| Comments | |

## 2.4 Poole et al., 2017; 2010; 1998

| | |
|---|---|
| Source | Poole, D., Mackworth, A., and Goebel, R. (1998). Computational Intelligence: A Logical Approach. Oxford University Press, New York.<br>Poole, D., Mackworth. A. (2010). Artificial Intelligence Foundations of Computer Agents<br>Poole, D., Mackworth A. (2017). Artificial Intelligence: Foundations of Computational Agents, second edition |
| Text of the definition | 1998: "Artificial intelligence (AI) is the established name for the field we have defined as computational intelligence (CI), Computational intelligence is the study of the design of intelligent agents. An agent is something that acts in an environment—it does something. Agents include worms, dogs, thermostats, airplanes, humans, organizations, and society. An intelligent agent is a system that acts intelligently: What it does is appropriate for its circumstances and its goal, it is flexible to changing environments and changing goals, it learns from experience, and it makes appropriate choices given perceptual limitations and finite computation."<br><br>2010, 2017: "Artificial intelligence, or AI, is the field that studies the synthesis and analysis of computational agents that act intelligently.<br>An agent is something that acts in an environment; it does something. Agents include worms, dogs, thermostats, airplanes, robots, humans, companies, and countries."<br>"We are interested in what an agent does; that is, how it acts. We judge an agent by its actions…<br>An agent acts intelligently when:<br>• what it does is appropriate for its circumstances and its goals, taking into account the short-term and long-term consequences of its actions<br>• it is flexible to changing environments and changing goals<br>• it learns from experience<br>• it makes appropriate choices given its perceptual and computational limitations"<br>"A computational agent is an agent whose decisions about its actions can be explained in terms of computation. That is, the decision can be broken down into primitive operations that can be implemented in a physical device. This computation can take many forms. In humans this computation is carried out in "wetware"; in computers it is carried out in "hardware." Although there are some agents that are arguably not computational, such as the wind and rain eroding a landscape, it is an open question whether all intelligent agents are computational.<br>All agents are limited. No agents are omniscient or omnipotent. Agents can only observe everything about the world in very specialized domains, where "the world" is very constrained. Agents have finite memory. Agents in the real world do not have unlimited time to act."<br>The central scientific goal of AI "is to understand the principles that make intelligent behavior possible in natural or artificial systems. This is done by:<br>• the analysis of natural and artificial agents<br>• formulating and testing hypotheses about what it takes to construct intelligent agents and<br>• designing, building, and experimenting with computational systems that perform tasks commonly viewed as requiring intelligence.<br>As part of science, researchers build empirical systems to test hypotheses or to explore the space of possible designs. These are quite distinct from applications that are built to be useful for an application domain."<br>"The definition is not for intelligent thought alone. We are only interested in thinking intelligently insofar as it leads to more intelligent behavior. The role of thought is to affect action."<br>"The central engineering goal of AI is the design and synthesis of useful, intelligent artifacts. We actually want to build agents that act intelligently. Such agents are useful in many applications." |
| Subdomains | - |
| Context | Book |
| Date of publication/ release | 2017; 2010; 1998 |

| | |
|---|---|
| Comments | Endorsed by McCarthy (among the founders of AI in McCarthy, J. What is Artificial Intelligence. (2007))<br>It equals AI to computational intelligence, and it is focused on the definitions of agents, actions, reaction to the environment, learning.... |

## 2.5 Kaplan, 2016

| | |
|---|---|
| Source | Kaplan, J. Artificial Intelligence What everyone needs to know. |
| Text of the definition | "There is little agreement about what intelligence is. …there is scant reason to believe that machine intelligence bears much relationship to human intelligence, at least so far."<br>"There are many proposed definitions on AI …most are roughly aligned around the concept of creating computer programs or machines capable of behavior we would regard as intelligent if exhibited by humans."<br>He suggests that McCarthy's definition, although sensible, is deeply flawed [section 1 Defining AI, p.1], as it is difficult to define and/or measure human intelligence.<br>"Our cultural predilection for reducing things to numeric measurements that facilitate direct comparison often creates a false patina of objectivity and precision." |
| Subdomains | - |
| Context | The book offers a definition of AI based on the juxtaposition between human and computer intelligence. It is highlighted that the mono-dimensional quantification of human intelligence and other simplified approaches to define AI are inadequate. |
| Date of publication/ release | 2016 |
| Comments | The author is a Lecturer and Research Affiliate at Stanford University.<br>To disentangle the oversimplification of intelligence's quantification, a proposal was made by a cognitive scientist [Gardner H., 1999] to approach intelligence in eight dimensions. |

## 2.6 Stone et al.: AI100, 2016

| | |
|---|---|
| Source | Stone, P., Brooks, R., Brynjolfsson, E., Calo, R., Etzioni, O., Hager, G., Hirschberg, J., Kalyanakrishnan, S., Kamar, E., Kraus, S., Leyton-Brown, K., Parkes, D., Press, W., Saxenian, A.L, Shah, J., Tambe, M., and Teller, A. Artificial Intelligence and Life in 2030. One Hundred Year Study on Artificial Intelligence: Report of the 2015-2016 Study Panel, Stanford University, Stanford, CA. |
| Text of the definition | ""Intelligence" remains a complex phenomenon whose varied aspects have attracted the attention of several different fields of study, including psychology, economics, neuroscience, biology, engineering, statistics, and linguistics. Naturally, the field of AI has benefited from the progress made by all of these allied fields. For example, the artificial neural network, which has been at the heart of several AI-based solutions[1,2] was originally inspired by thoughts about the flow of information in biological neurons[3]."<br>The definition of AI of Nilsson, 2010 is also mentioned.<br>[1] Gerald Tesauro, "Practical Issues in Temporal Difference Learning," Machine Learning, no. 8 (1992): 257—77.<br>[2] David Silver, Aja Huang, Chris J. Maddison, Arthur Guez, Laurent Sifre, George van den Driessche, Julian Schrittwieser, Ioannis Antonoglou, Veda Panneershelvam, Marc Lanctot, Sander Dieleman, Dominik Grewe, John Nham, Nal Kalchbrenner, Ilya Sutskever, Timothy Lillicrap, Madeleine Leach, Koray Kavukcuoglu, Thore Graepel, and Demis Hassabis, "Mastering the game of Go with deep neural networks and tree search," Nature 529 (2016): 484—489.<br>[3] W. McCulloch and W. Pitts, W., "A logical calculus of the ideas immanent in nervous activity," Bulletin of Mathematical Biophysics, 5 (1943): 115—133. |
| Subdomains | Trends: large scale machine learning, deep learning, reinforcement learning, robotics, computer vision, natural language processing, collaborative systems, crowdsourcing and human computation, algorithmic game theory and computational social choice, IoT, neuromorphic computing.<br>Applications in domains: transportation, home service robots, healthcare, education, low-resource communities, public safety and security, employment and workplace, entertainment |
| Context | Investigation of the AI field, started publishing periodic reports in 2014. Analysis of AI impact on "people, their communities and society", in view of other fields that can affect the AI evolution (science, engineering, computing systems). |
| Date of publication/ release | September 2016 |
| Comments | Policy projections in the report available.<br>There is not a definition per se, but a reference to different disciplines interested in and interrelated with AI. |

## 2.7 Russel and Norvig, 2010 (3rd edition); 1995

Source

Russel, S. and Norvig, P. Artificial Intelligence. A Modern Approach.

Text of the definition

In Figure 1.1 of the book eight definitions are mentioned:

| **Thinking Humanly** | **Thinking Rationally** |
|---|---|
| "The exciting new effort to make computers think . . . *machines with minds*, in the full and literal sense." (Haugeland, 1985)<br>"[The automation of] activities that we associate with human thinking, activities such as decision-making, problem solving, learning . . ." (Bellman, 1978) | "The study of mental faculties through the use of computational models." (Charniak and McDermott, 1985)<br>"The study of the computations that make it possible to perceive, reason, and act." (Winston, 1992) |
| **Acting Humanly** | **Acting Rationally** |
| "The art of creating machines that perform functions that require intelligence when performed by people." (Kurzweil, 1990)<br>"The study of how to make computers do things at which, at the moment, people are better." (Rich and Knight, 1991) | "Computational Intelligence is the study of the design of intelligent agents." (Poole *et al.*, 1998)<br>"AI . . . is concerned with intelligent behavior in artifacts." (Nilsson, 1998) |

**Figure 1.1** Some definitions of artificial intelligence, organized into four categories.

"Eight definitions of AI, laid out along two dimensions. The definitions on top are concerned with thought processes and reasoning, whereas the ones on the bottom address behavior. The definitions on the left measure success in terms of fidelity to human performance, whereas the ones on the right measure against an ideal performance measure, called rationality. A system is rational if it does the "right thing," given what it knows.

Historically, all four approaches to AI have been followed, each by different people with different methods. A human-centered approach must be in part an empirical science, involving observations and hypotheses about human behavior. A rationalist approach involves a combination of mathematics and engineering. The various groups have both disparaged and helped each other. Let us look at the four approaches in more detail."

Subdomains

-

Context

Leading book in the AI field. Introduces the idea of a human-centered approach to AI versus a pragmatic computational approach.

Date of publication/ release

1995
2010 (3rd edition http://aima.cs.berkeley.edu/)

Comments

Endorsed by McCarthy (among the founders of AI in McCarthy, J. What is Artificial Intelligence. (2007))
Norvig is an AI leading researcher, Director of Research at Google Inc. He is also an AAAI Fellow and councillor of the Association for the Advancement of Artificial Intelligence. He was head of the Computational Sciences Division (now the Intelligent Systems Division) at NASA Ames Research Center, for research and development in the areas of autonomy and robotics, automated software engineering and data analysis, neuro-engineering, collaborative systems research, and simulation-based decision-making.

## 2.8 Bruner, 2009

| | |
|---|---|
| Source | Bruner J. Culture, Mind and Education. Contemporary theories of learning. |
| Text of the definition | "...any and all systems that process information must be governed by specifiable "rules" or procedures that govern what to do with inputs. It matters not whether it is a nervous system, or the genetic apparatus that takes instruction from DNA and then reproduces later generations, or whatever. This is the ideal of artificial intelligence (AI), so-called." |
| Subdomains | - |
| Context | The book chapter offers an AI definition relating it to human intelligence. This definition includes the notion of having rules or procedures leading to decisions. |
| Date of publication/ release | 2009 |
| Comments | |

## 2.9 McCarthy, 2007

| | |
|---|---|
| Source | McCarthy, J. What is Artificial Intelligence. |
| Text of the definition | "It is the science and engineering of making intelligent machines, especially intelligent computer programs. It is related to the similar task of using computers to understand human intelligence, but AI does not have to confine itself to methods that are biologically observable."<br>"Intelligence is the computational part of the ability to achieve goals in the world. Varying kinds and degrees of intelligence occur in people, many animals and some machines." |
| Subdomains | Branches:<br>logical AI; search; pattern recognition; representation; inference; common sense knowledge and reasoning; learning from experience; planning; epistemology; ontology; heuristics; genetic programming<br>Applications: game playing; speech recognition; understanding natural language; expert systems; heuristic classification |
| Context | The article uses the notion of the achievement of goals. Refers to different kinds of intelligence. Implicit reference to general AI / strong AI. |
| Date of publication/ release | 2007 |
| Comments | McCarthy is among the founding fathers of AI. |

## 2.10 Gardner, 1999

| | |
|---|---|
| Source | Gardner H. Intelligence Reframed: Multiple Intelligences for the 21st Century, pp.33-34 |
| Text of the definition | "A biopsychological potential to process information that can be activated in a cultural setting to solve problems or create products that are of value in a culture." |
| Subdomains | - |
| Context | Book revisiting the multiple human intelligences. |
| Date of publication/ release | 1999 |
| Comments | This book is the revision of the 1983 book. |

## 2.11 Nakashima, 1999

| | |
|---|---|
| Source | H. Nakashima. AI as complex information processing. Minds and machines, 9:57–80. |
| Text of the definition | "Intelligence is the ability to process information properly in a complex environment. The criteria of properness are not predefined and hence not available beforehand. They are acquired as a result of the information processing." |
| Subdomains | - |
| Context | The article presents a definition that includes the notions of information processing and complex environment. |
| Date of publication/ release | 1999 |
| Comments | |

## 2.12 Nilsson, 1998; 2010

| | |
|---|---|
| Source | Nilsson, N.J. Artificial intelligence: a new synthesis. Morgan Kaufmann Publishers, Inc.<br>Nilsson, N.J. The Quest for Artificial Intelligence: A History of Ideas and Achievements. Cambridge University Press. |
| Text of the definition | "Artificial Intelligence (AI), broadly (and somewhat circularly) defined, is concerned with intelligent behavior in artifacts. Intelligent behavior, in turn, involves perception, reasoning, learning, communicating, and acting in complex environments."<br>"Artificial intelligence is that activity devoted to making machines intelligent, and intelligence is that quality that enables an entity to function appropriately and with foresight in its environment." |
| Subdomains | - |
| Context | The book of 1998 introduces in the definition the notions of complex environment, reasoning, learning, communicating etc., and in 2010 the |
| Date of publication/ release | 1998; 2010 |
| Comments | "AI has as one of its long-term goals the development of machines that can do these things as well as humans can, or possibly, even better. Another goal of AI is to understand this kind of behavior whether it occurs in machines or in humans or other animals."<br><br>Endorsed by McCarthy (among the founders of AI in McCarthy, J. What is Artificial Intelligence. (2007)). |

## 2.13 Neisser et al., 1996

| | |
|---|---|
| Source | Neisser U., Boodoo G., Bouchard T.J., Boykin A.W., Brody N., Ceci S.J., Halpern D.F., Loehlin J.C., Perloff R., Sternberg R.J., and Urbina S. Intelligence: Knows and Unknowns |
| Text of the definition | On human Intelligence:<br>"Individuals differ from one another in their ability to understand complex ideas, to adapt effectively to the environment, to learn from experience, to engage in various forms of reasoning, to overcome obstacles by taking thought.<br>Concepts of intelligence are attempts to clarify and organise this complex set of phenomena." |
| Subdomains | - |
| Context | The article introduces in the AI definition the notions of adapting to the environment, reasoning, learning etc. A human intelligence definition is used to approach AI, due to biologically inspired processes. Multiple intelligences approach. |
| Date of publication/ release | 1996 |
| Comments | Cited among others by Yang, 2013 |

## 2.14 Fogel, 1995

| | |
|---|---|
| Source | D. B. Fogel. Review of computational intelligence: Imitating life. Proc. of the IEEE, 83(11).<br><br>Evolutionary Computation: Toward a New Philosophy of Machine Intelligence. |
| Text of the definition | "Any system…that generates adaptive behaviour to meet goals in a range of environments can be said to be intelligent." |
| Subdomains | - |
| Context | The article includes the notions of adaptive behaviour, environment, and achieving goals. |
| Date of publication/ release | 1995 |
| Comments | He is a pioneer in evolutionary computation.<br>He is currently Chief Scientist at Trials.ai, and holds other founding positions at Natural Selection, Inc., Color Butler, Inc., and Effect Technologies, Inc., the maker of the patented EffectCheck sentiment analysis software tool. Advisor for several AI companies in the areas of B2B lead generation, logistics, and employee retention, as well as other areas. |

## 2.15 Wang, 1995

| | |
|---|---|
| Source | Wang P. On the working definition of intelligence. Center for Research on Concepts and Cognition, Indiana University. |
| Text of the definition | Intelligence is “the ability for an information processing system to adapt to its environment with insufficient knowledge and resources.” |
| Subdomains | - |
| Context | Technical Report.<br>The definition includes the notions of information processing, adaptation to the environment, and insufficiency of knowledge/resources. |
| Date of publication/ release | 1995 |
| Comments | |

## 2.16 Albus, 1991

| | |
|---|---|
| Source | J. S. Albus. Outline for a theory of intelligence. IEEE Trans. Systems, Man and Cybernetics, 21(3):473–509. |
| Text of the definition | "…the ability of a system to act appropriately in an uncertain environment, where appropriate action is that which increases the probability of success, and success is the achievement of behavioral subgoals that support the system's ultimate goal." |
| Subdomains | - |
| Context | article |
| Date of publication/ release | 1991 |
| Comments | From Wikipedia:<br>He was an American engineer, Senior NIST Fellow and founder and former chief of the Intelligent Systems Division of the Manufacturing Engineering Laboratory at the National Institute of Standards and Technology (NIST). Albus made contributions to cerebellar robotics, developed a two-handed manipulator system known as the Robocrane (a crane-like variation on the Stewart platform idea), among other contributions.<br>The definition includes the notions of environment, actions and achieving goals. |

## 2.17 Schank, 1991; 1987

| | |
|---|---|
| Source | Schank R.C. What is AI, Anyway? AI Magazine, 8 (4), aaai.org<br>R. Schank. Where's the AI? AI magazine, 12(4):38–49, 1991 |
| Text of the definition | "AI suffers from a lack of definition of its scope. One way to attack this problem is to attempt to list some features that we would expect an intelligent entity to have. None of these features would define intelligence, indeed a being could lack any one of them and still be considered intelligent. Nevertheless each attribute would be an integral part of intelligence in its way. ...They are communication, internal knowledge, world knowledge, intentionality, and creativity."<br><br>"AI's primary goal is to build an intelligent machine. The second goal is to find out about the nature of intelligence."<br><br>"Intelligence means getting better over time." |
| Subdomains | - |
| Context | article |
| Date of publication/ release | 1987 |
| Comments | Roger Carl Schank is an American artificial intelligence theorist, cognitive psychologist, learning scientist, educational reformer, and entrepreneur. Beginning in the late 1960s, he pioneered conceptual dependency theory and case-based reasoning, both of which challenged cognitivist views of memory and reasoning. |

## 2.18 McCarthy, 1988

| | |
|---|---|
| Source | McCarthy, J. The Logic and Philosophy of Artificial intelligence |
| Text of the definition | "The goal of artificial intelligence (A.I.) is machines more capable than humans at solving problems and achieving goals requiring intelligence. There has been some useful success, but the ultimate goal still requires major conceptual advances and is probably far off.<br><br>There are three ways of attacking the goal. The first is to imitate the human nervous system. The second is to study the psychology of human intelligence. The third is to understand the common sense world in which people achieve their goals and develop intelligent computer programs. This last one is the computer science approach." |
| Subdomains | - |
| Context | |
| Date of publication/ release | 1988 |
| Comments | McCarthy is among the founding fathers of AI. |

## 2.19 Gardner, 1987

| | |
|---|---|
| Source | Gardner, H. The mind's new science: A history of the cognitive revolution. Basic books. |
| Text of the definition | AI “seeks to produce, on a computer, a pattern of output that would be considered intelligent if displayed by a human being”.<br><br>Schlinger (1992) mentions that this book also refers that “AI is viewed as a way of testing a particular theory of how cognitive processes might work. That theory is the popular information-processing model of cognition. Where AI researchers disagree, according to Gardner, is how literally to interpret the thinking metaphor. For example, some take what John Searle calls the "weak view" of AI, wherein computer programs are simply a means for testing theories of how humans might carry out cognitive operations. The weak view of AI is synonymous with modern cognitive psychology.” |
| Subdomains | - |
| Context | book |
| Date of publication/ release | 1987 |
| Comments | |

## 2.20 Gardner, 1983

| | |
|---|---|
| Source | Gardner, H. Frames of Mind; The Theory of Multiple Intelligences. New York, NY: basic Books. |
| Text of the definition | Artificial intelligence is commonly defined by referencing definitions of human intelligence, as in Minsky's definition.<br>In contrast to the standard approach of measuring one kind of intelligence (as in standard IQ tests), Gardner (cognitive scientist) offers an eight-dimensional definition to disentangle the oversimplification of intelligence's measurement.<br>In particular, he proposed multiple conceptions of intelligence, not only logical-mathematical, linguistic, but also spatial, musical, bodily-kinaesthetic, personal. |
| Subdomains | - |
| Context | book |
| Date of publication/ release | 1983 |
| Comments | This definition of intelligence is more used to approximate the definition of AI in terms of aim and processes.<br><br>Gardner is a cognitive developmental psychologist, among the pioneers trying to quantify human intelligence in more than one dimension (another is Robert Sternberg), introducing the notion of multiple intelligences.<br>Before his study, human intelligence was mono-semantic and was quantified as such in intelligence quotient (IQ) points.<br>The multiple intelligences approach is a better fit to the oversimplification of one intelligence, and is used to describe why the definition of AI is not easy. (see J. Kaplan 2016, Artificial Intelligence What everyone needs to know, section 1 Defining AI) |

## 2.21 Newell and Simon, 1976

| | |
|---|---|
| Source | Newell, A., Simon, H. A. Computer science as empirical enquiry: Symbols and search. Communications of the ACM 19, 3:113–126. |
| Text of the definition | "By "general intelligent action" we wish to indicate the same scope if intelligence as we see in human action: that in any real situation behavior appropriate to the ends of the system and adaptive to the demands of the environment can occur, within some limits of speed and complexity." |
| Subdomains | - |
| Context | article |
| Date of publication/ release | 1976 |
| Comments | Simon was a pioneer in the field of artificial intelligence, creating with A. Newell the Logic Theory Machine (1956) and the General Problem Solver (GPS) (1959) systems. The GPS system is considered as the first knowledge representation approach [Newell and Simon, 1961].<br><br>Newell was a researcher in computer science and cognitive psychology at the RAND Corporation and at Carnegie Mellon University's School of Computer Science, Tepper School of Business, and Department of Psychology.<br><br>They founded an artificial intelligence laboratory at Carnegie Mellon University and produced a series of important programs and theoretical insights throughout the late fifties and sixties.<br>The definition includes the notions of real situation, goal (ends of the system), adaptation to the environment, and complexity. |

## 2.22 Minsky, 1969

| | |
|---|---|
| Source | Minsky, M. L. Semantic information processing. Cambridge, MA: MIT Press |
| Text of the definition | AI is “the science of making machines do things that would require intelligence if done by men”. |
| Subdomains | - |
| Context | PhD Thesis of one of the first cognitive scientists approaching AI as human intelligence. |
| Date of publication/ release | 1969 |
| Comments | Marvin Minsky was Toshiba Professor of Media Arts and Sciences and Donner Professor of Electrical Engineering and Computer Science at MIT.<br>He was a cofounder of the MIT Media Lab and a consultant for the One Laptop Per Child project.<br>Definition based on general intelligence. |

## 2.23 McCarthy, 1959

| | |
|---|---|
| Source | McCarthy, J. Programs with Common Sense. |
| Text of the definition | Proposes that common sense reasoning ability is key to AI.<br>"A program has common sense if it automatically deduces for itself a sufficiently wide class of immediate consequences of anything it is told and what it already knows." |
| Subdomains | - |
| Context | |
| Date of publication/ release | 1959 |
| Comments | "Probably the first paper on logical AI, i.e. AI in which logic is the method of representing information in computer memory and not just the subject matter of the program. It may also be the first paper to propose common sense reasoning ability as the key to AI."<br><br>McCarthy is among the founding fathers of AI and it is cited as the one who coined the term "artificial intelligence".<br>AI used for deductive reasoning. |

## 2.24 McCarthy et al., 1955

| | |
|---|---|
| Source | McCarthy, J., Minsky, M. L., Rochester, N., Shannon, C.E. A Proposal For The Dartmouth Summer Research Project On Artificial Intelligence |
| Text of the definition | "..every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it. An attempt will be made to find how to make machines use language, form abstractions and concepts, solve kinds of problems now reserved for humans, and improve themselves.<br><br>...the artificial intelligence problem is taken to be that of making a machine behave in ways that would be called intelligent if a human were so behaving." |
| Subdomains | - |
| Context | Founding proposal and conference for initiation of AI studies |
| Date of publication/ release | 31 August 1955 |
| Comments | Founding fathers and conference of AI.<br>AI as a machine that does what humans do (strong AI concept) |

# 3 Market perspective

## 3.1 CB Insights, 2019

| | |
|---|---|
| Source | CB Insights. Artificial Intelligence Trends |
| Text of the definition | - |
| Subdomains | AI trends are reported:<br>conversational agents, cyber threat hunting, drug discovery, predictive maintenance, e-commerce search, medical imaging & diagnostics, edge computing, facial recognition, open source frameworks, synthetic training data, back office automation, language translation, anti-counterfeit, check-out free retail, auto claims processing, advanced healthcare biometrics, clinical trial enrolment, next-gen prosthetics, capsule networks, GANs, federated learning, network optimization, reinforcement learning, autonomous navigation, crop monitoring,<br>with the following applications:<br>computer vision, natural language processing/synthesis, predictive intelligence, architecture, infrastructure |
| Context | market report |
| Date of publication/ release | 2019 |
| Comments | Clustering method for figure p.3 is not extensively presented.<br>The trends are reported using the CB Insights NexTT framework, which is explained as:<br>INDUSTRY ADOPTION (y-axis): Signals include momentum of startups in the space, media attention, customer adoption (partnerships, customer, licensing deals).<br>MARKET STRENGTH (x-axis): Signals include market sizing forecasts, quality and number of investors and capital, investments in R&D, earnings transcript commentary, competitive intensity, incumbent deal making (M&A, strategic investments). |

## 3.2 Statista, 2017

| | |
|---|---|
| Source | Statista Report. Artificial Intelligence |
| Text of the definition | "Artificial Intelligence (AI) essentially refers to computing technologies that are inspired by the ways people use their brains and nervous systems to reason and make decisions, but typically operate quite differently." |
| Subdomains | Applications:<br>Automotive (autonomous driving, cloud computing).<br>Healthcare (early diagnosis and preventing healthcare, surgical assistance, recovery and rehabilitation, drug discovery, precision medicine and personal genetics, healthcare robotics: direct patient care robots(surgical robots, exoskeletons, prosthetics), indirect patient care robots(pharmacy, delivery, disinfection), home healthcare robots).<br>Education (intelligent tutoring, science simulation, personalised learning, resources/courses, educational games).<br>Finance (Wealth Management, Insurance, Fraud Detection, Banking, Personal Finance Management).<br>Entertainment (Movies, Games, Advertising, Personalised Content, Music). |
| Context | Market report with definitions for machine learning, robotics (including subcategories), artificial neural networks. |
| Date of publication/ release | 2017 |
| Comments | |

## 3.3 McKinsey, 2017

| | |
|---|---|
| Source | McKinsey Global Institute. Artificial Intelligence. The next digital Frontier? |
| Text of the definition | - |
| Subdomains | Computer vision; natural language; machine learning; autonomous vehicles; smart robotics; virtual agents |
| Context | Discussion Paper on AI landscape, investment and expenditures in AI |
| Date of publication/ release | June 2017 |
| Comments | The global AI landscape, expenditure and investment are discussed, with analysis by technological subcategories, affected sectors in the value chain (leaders, followers, adopters etc.). More detailed information is provided for leading countries. |

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KJ-NA-30873-EN-N

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doi:10.2760/019901
ISBN 978-92-76-42648-6