NESSI

Software and Artificial Intelligence

Executive Summary

Artificial Intelligence (AI) is a domain currently receiving a lot of attention. Availability of technology, successes in some use cases, foreseen impacts on society and economy, and global investments promise a new era of AI applications. There is a lot of focus on data and AI, because the latest AI algorithms and applications are typically data hungry. However, without software there is no AI. It is important to identify both the specificities of AI software and what AI can bring to software engineering. This paper presents the challenges identified by NESSI[1] to successfully integrate AI in the smart software systems required to advance the digital transformation of Europe.

We identify four primary research challenges: governance of self-adapting software; explainable AI; appropriate data; and legal, ethical and societal challenges. We identify the need to re-engineer software technologies, and to address: software composability; software and data lifecycles; quality assurance; socio-technical challenges; and dedicated hardware.

Software technologies must feature strongly in an ambitious shared and agreed AI research and innovation roadmap. We recommend dedicated research programmes in Horizon Europe to develop the core technologies and tools to support new sophisticated AI-based systems, and to introduce and validate the use of AI in sectorial research and innovation programmes. To compete with the USA and China, and to collaborate with them as equals, Europe should conduct ambitious research programs in all aspects of AI.

Europe's ambition and investment in AI software research and innovation should be on par with the transformative potential of the technology.

Introduction

Software is transforming society, defining the behaviour of the ever growing number of digital systems in all sectors, including eHealth, smart transport (e.g. smart driving, autonomous cars, connected cars, the digital railway, and avionics), smart cities, homes and buildings, smart grids, smart agriculture, industry 4.0, and trade and commerce in general.

Artificial Intelligence (AI) is a domain currently receiving a lot of attention. Availability of technology, successes in some use cases, foreseen impacts on society and economy, and global investments promise a new era of AI applications. There is a lot of focus on data and AI, because the latest AI algorithms and applications are typically data hungry. However, without software there is no AI. It is important to identify both the specificities of AI software and what AI can bring to software engineering.

In a previous paper "Next Generation Software Technologies Empowering the Digital Transformation of Europe - Recommendations on Software Technology Research for Horizon Europe"[2] NESSI considered the fundamental role that software is playing in the digitalisation of society and economy. AI is one aspect of

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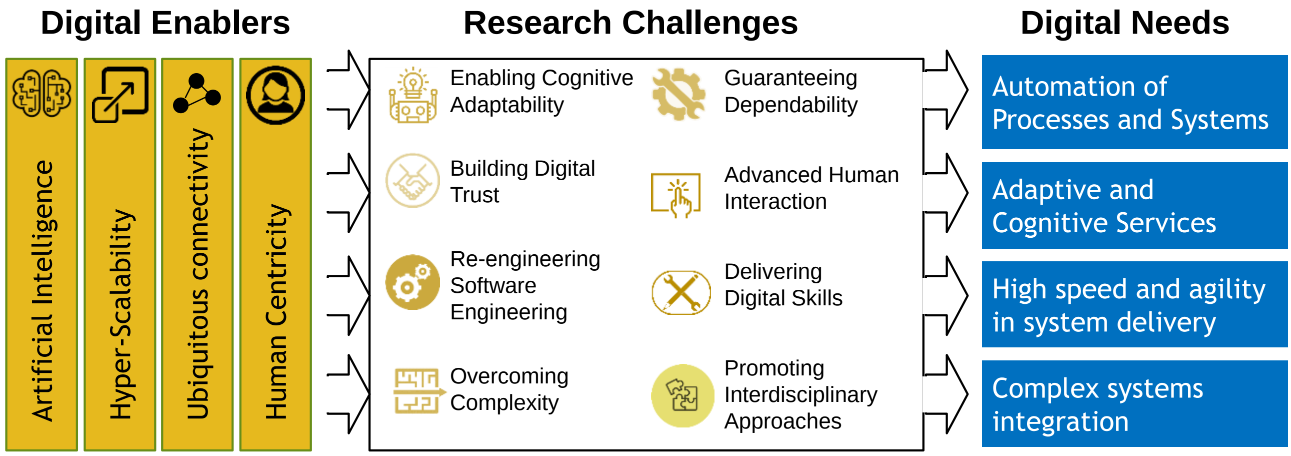
[1] NESSI (Networked European Software and Services Initiative), the European Technology Platform (ETP) dedicated to software, data and services; http://www.nessi.eu/.

[2] NESSI - Software Empowering the Digital Transformation of Europe; http://www.nessi.eu/Files/Private/NESSI%20-%20Software%20Empowering%20the%20Digital%20Transformation%20of%20Europe%20-%20final%20version%2009-2018%20v1.pdf

software and will be a major digital enabler, along with hyper-scalability, ubiquitous connectivity and human centricity (see figure below), and as such should be addressed in Horizon Europe as a major software topic.



Artificial Intelligence delivers automated analysis, cognition, and decision making based on several approaches, such as knowledge representation, multi-agent systems, planning, and machine learning. In particular, there has been a recent and remarkable boost of AI impact enabled by the usage of advanced machine learning technologies, access to big data assets, and the availability of software tools and libraries implementing AI-based algorithms. AI can be used for building smarter and more adaptive software systems, as well as supporting more efficient software development and construction processes.

Artificial Intelligence can enhance the quality of analysis and prediction and reduce their cost[3]. It means that AI can play an important role in economic sectors in which human cognitive capabilities are involved, and is a transformative factor, not just a technology that improves existing processes.

Artificial Intelligence helps to solve the digital needs of the current society and the economy:

- **Automation** of processes and entire systems, thereby increasing productivity and delivering new digital business models;
- **Implementation of adaptive and cognitive services** to better meet customer demands and enable new functionalities, increasing customer satisfaction and enabling innovative digital services;
- **Agility** in providing new system functionality and adaptability to exploit market opportunities, technology trends, and ever-increasing data availability; and
- **Complex systems of systems**, integrating AI and classical software to achieve smarter solutions.

Artificial Intelligence is a key digital enabler that contributes to help address the key software challenges identified by NESSI[4]:

- **Building digital trust** by analyzing behaviors and automating decisions to preserve security and privacy;
- **Overcoming complexity** by providing high-level insight on the characteristics of complex systems and thus helps manage difficult problems created by scale, dependencies, or heterogeneity;

[3] Agrawal, A, A Goldfarb and J Gans (2018), Prediction Machines: the Simple Economics of Artificial Intelligence, Harvard Business Review Press.
[4] NESSI - Software Empowering the Digital Transformation of Europe; http://www.nessi.eu/Files/Private/NESSI%20-%20Software%20Empowering%20the%20Digital%20Transformation%20of%20Europe%20-%20final%20version%2009-2018%20v1.pdf

- **Guaranteeing dependability** by helping implement smart autonomic loops to control the behavior of critical digital systems;
- **Advancing human interactions** by enabling the adaptation of systems to human behaviors and improving of the machine understanding of human intent; and
- **Promoting interdisciplinary approaches** as AI requires synergies between technologies, domain knowledge, and understanding of cognitive or social impacts.

Promises and challenges

The importance and impact of software is increasing with the emergence of AI. AI algorithms are able to closely imitate and augment human cognition and decision making, as well as model complex organizations and entire societies, or automate complex processes or systems. There will be a new generation of software systems with embedded AI capabilities providing self-awareness, enabling systems to be self-organized, self-optimized, self-protected, self-healing and beyond. AI-based tools can master the complexity of future systems, and improve the effectiveness and productivity of software and systems engineering. Next-generation programs develop by 'learning' from every interaction with their surroundings. These programs are built using novel machine learning (ML) including deep learning techniques, which have significantly different characteristics compared to today's programming tools and algorithms.

AI capabilities and characteristics imply two key opportunities and challenges with respect to software engineering:

- Enabling cognitive adaptability; and
- Re-engineering software engineering.

Enabling cognitive adaptability of software systems

Anticipating all relevant situations in which software operates is seldom possible due to uncertainty regarding the circumstances in which a software system may be used and the challenges it may face at run-time. Examples of such challenges include cyber-physical or IoT-systems operating in ever changing environments such as smart cities, or digital business processes that face unpredictable usage patterns. An emerging solution to address this uncertainty is to furnish software systems with self-adapting cognitive capabilities. Breakthroughs in machine learning paradigms, such as deep learning or reinforcement learning, provide new ways to embed cognitive adaptability within software and systems. This will allow software to self-adapt and self-improve based on awareness of its environment, its goals, and its constraints.

We identify four primary research challenges: governance of self-adapting software; explainable AI; appropriate data; and legal, ethical and societal challenges.

Governance of self-adapting software

Anticipating the possible changes that a self-adaptive system may encounter at run time requires identifying the situations the system should be able to handle. Since all relevant situations cannot be anticipated at design time, due to incomplete knowledge and uncertainty about the system environment, a self-adaptive evolving system may encounter situations that have not been fully understood or anticipated. This may lead to ineffective adaptations whereas AI-based cognitive intelligence allows a software system to self-improve its self-adaptation mechanisms. Underpinning this is a need to guarantee the predictability and governability of self-adapting software system and architectures, improving the speed of convergence of AI-based cognitive intelligence and coping with ineffective or hazardous actions that may be executed by self-adaptive systems. Similarly, ML algorithms and software development activities need to be properly connected, to ensure that knowledge about the changes made by developers (e.g. new features, new configurations) are fed to the ML algorithms in a timely fashion. One option of governance today is to use human oversight; in future, AI systems may be required to use automated failsafe mechanisms, which will rely on monitoring systems that can detect failure modes, and will execute remedial actions to restore safe operations even in situations that have not been previously defined and analysed.

Explainable Artificial Intelligence

Cognitive adaptability can be used to master the complexity, dynamicity and uncertainty of future software systems. However, this can create difficulty when developing, debugging and testing systems that can self-adapt, e.g. determining causality and liability for autonomous actions and decisions. The lack of transparency regarding how a system works, and who or what is responsible for the resulting output, can raise concerns. Explainable AI, including algorithmic transparency, should allow verification, even by non-experts, and can contribute to discovering errors or biases that otherwise would have been left unnoticed. The interpretability of ML models is a particular current concern, and requires a multidisciplinary approach. Another major challenge is the cognitive overhead required when trying to understand complex processes. Effective clues and safeguards are topics of research to uncover and characterize possible unwanted effects of algorithms, and the circumstances under which they may occur, e.g. preventing adversarial attacks on ML algorithms. Limitations to the observability of all inputs and outputs of an algorithm, for security or legal reasons, can be a challenge when trying to validate or prove its behaviour.

Appropriate data

The effectiveness of much AI depends on access to sufficient high-quality data to train the algorithms. As an example, for supervised learning, labelled data is required, but labelling can be expensive or impossible in practice. Establishing effective techniques for generating labelled training datasets will remove a significant bottleneck in producing high quality ML systems. The data used as input for AI capabilities should be carefully scrutinized in order to avoid potential bias or noise in the data, involving dedicated software. Additionally, algorithms may be so widespread that they may even come to regulate individuals or society as a whole, and e.g. influence health decisions, modify human relations or impact legislation and the delivery of justice. Possible biases hidden in the datasets that train algorithms need to be more readily discoverable and addressable to maintain/enhance fairness and preserve human values and principles. In some domains, unsupervised learning is a key research challenge.

Legal, ethical and societal challenges

In applying the law to fast developing technologies such as AI, regulation may lag behind technical development, making it difficult to anticipate how systems might be treated judicially. Recent discussions of legal personhood for robots and AI are clearly a long-term approach, but for the foreseeable future humans will have ultimate responsibility for the decisions taken by AI systems. This implies the need for a framework of software and systems engineering requirements for determinable legal liability. It is also important that developers of AI systems have a means to assess the ethical dimensions of their design choices, given the potential for such systems to disrupt and damage the legitimate interests of citizens. AI systems need to be considered as complex multi-stakeholder systems in which the designers as well as system operators and end-users are moral agents who must share the legal and ethical responsibility for the outcomes.

The socio-economic impact of AI systems may also raise ethical or moral issues. AI systems can contribute to create new positive societal models, where the societal roles may evolve, and thus benefit workers e.g. by taking over monotonous or dangerous tasks; they may also cause harm by deskilling or destroying employment opportunities, or by undermining human or societal values. In general the governance of intelligent (cognitive) systems and their impacts will be a major new concern in society.

Cognitive adaptation offers these systems the ability to continuously adapt and evolve to meet the needs of their new context - becoming ever more efficient and effective. For the software developer or designer, cognitive adaptability alleviates the burden of software optimization, configuration, quality assurance, repair, evolution and adaptation[5]. Moreover, cognitive adaptability can be a key enabler of 'citizen software'. Such software may be automatically generated based on users describing their needs in terms of 'intents' or 'system goals', by customizing, orchestrating and even creating software services.

Re-engineering software technologies

We identify the need to address the following challenges, as AI components get frequently introduced in modern digital systems: software composability, software and data lifecycles, quality assurance, socio-technical challenges, and dedicated hardware.

Software composability

Composability of systems involving AI-based components will introduce a new layer of complexity that should be qualified and researched, introducing new functional and non-functional constraints. Symbolic AI and knowledge based systems may help simplify the task of building complex digital systems based on multiple software components and sub-systems, helping with architecture, consistency, adaptability and dependencies.

Software and data lifecycles

ML components are dependent on data. System changes to code, data and models are interdependent and are likely to require new types of source and dependency control. As the number of possible ML hyper-parameters is exponential, difficulties may arise in maintenance and updates. AI-based techniques to support software development, delivery, maintenance, and the design of automated ML methods are necessary to overcome many of these challenges. A stepwise way towards automated software development is to integrate the AI-based software development activities into the currently human-centric software processes. For example, bug-fixing bots can submit automatically generated software patches as pull requests to a project, waiting for human developers to approve.

Quality assurance

AI-enabled software systems introduce a host of new quality assurance and security challenges (e.g. AI/ML components may introduce vulnerabilities that cybercriminals can exploit). This new situation is likely to require a new programming paradigm that will enable the smooth integration of e.g. non-deterministic ML components and interfaces in a readable and debug-able manner.

Today, it is hard to anticipate in advance if a data pipeline used for ML will produce high-quality models, thus requiring repeated iterations through the data resulting in major inefficiencies (e.g. resampling of data and manual labelling, computationally intensive process). These iterative cycles need addressing through novel tooling and methodologies.

AI/ML techniques could support software development with new validation and formal verification methods, helping create high-quality, less vulnerable and more secure code.

[5] NESSI - SOFTWARE CONTINUUM Recommendations for ICT Work Programme 2018+; http://www.nessi.eu/Files/Private/NESSI_Input_for_WP18_RELEASE2_to_EC.PDF

Socio-technical challenges

Addressing the disruptive socio-technical challenges raised by deploying AI-based systems will require multidisciplinary legal and ethical impact assessment, incorporating expertise in technology, law, economics, psychology and sociology, during design, implementation, testing and maintenance.

Energy efficiency

AI techniques sometimes consume a lot of energy (e.g. deep learning algorithms based on training phases that require large amounts of data and intensive processing). If applied inappropriately or for insignificant incremental results, the global cost/benefit ratio may be too high compared to using more efficient methods. Improving the energy efficiency of AI in general would help in making ICT sustainable in the long term.

Dedicated hardware

Specialized processor architectures are emerging (neuromorphic chips, tensor processing units). They will offer unprecedented computing capabilities, but software engineering challenges must be addressed to enable these new computing units to be integral parts of new generation computers.

Recommendations for Horizon Europe

Recent advances in AI have renewed the interest in this domain and created new promises to benefit EU society and economy. However, these raise a number of technical and ethical challenges which call for immediate actions for AI to fully deliver a positive impact.

Built on software and data, AI is every bit as cross-cutting and ubiquitous as these key domains. AI will help manage complex digital domains such as highly distributed systems, security, robotics, and next generation digital services (often grouped under the term "Next Generation Internet"). Dedicated research programmes in Horizon Europe are required to develop the core technologies and tools to support new sophisticated AI-based systems. Additional support is needed to introduce and validate the use of AI in sectorial research and innovation programmes. In some cases, promoting research on specialized AI-based domains may be necessary to achieve new smart behaviours of digital systems that require a close interrelation between technologies, semantics and applications.

Software technologies must feature strongly in an ambitious shared and agreed AI research and innovation roadmap. This will help position, compare, map, assess and evaluate the research and innovation projects and their use in vertical sectors. Such a roadmap should be regularly updated to take account of achievements made and to re-evaluate future priorities based on different perspectives (i.e. research, technology, business and societal needs).

The USA and China have developed comprehensive roadmaps for AI leadership and are the most active countries in this field, concentrating a higher level of investment for research and development. They could potentially grab most of the economic impact derived from AI. Therefore, Europe should conduct ambitious research programs in all aspects of AI, and promote research collaboration between European entities developing AI-based services and leading actors in the Chinese and American AI-based services market

Artificial Intelligence is a conjunction of major domains including mathematics, cognitive sciences, data science, data engineering, computer science and software engineering. Its algorithms have the potential to deeply impact all aspects of our lives. Artificial intelligence is part of a software continuum that supports people, business and society. Europe's ambition and investment in AI software research and innovation should be on par with the transformative potential of the technology.