THE FUTURE OF SOFTWARE ENGINEERING AND IT OPERATIONS

TREND REPORT FALL 2024

CDTM
CENTER FOR DIGITAL TECHNOLOGY AND MANAGEMENT

The Future of Software Engineering and IT Operations

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A Project of the Center for Digital Technology and Management

The Center for Digital Technology and Management (CDTM) is a joint, interdisciplinary institution for education, research, and entrepreneurship of the Ludwig Maximilians-University (LMU) and the Technical University of Munich (TUM).

It offers the add-on study program "Technology Management" for students from various backgrounds, which provides students with tools and knowledge at the intersection of business and digital technologies.

The entire trend report was written by CDTM students under the close guidance of research assistants.

Visit www.cdtm.de for more information.

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PREFACE OF THE PROJECT PARTNER

The automotive industry is rapidly evolving and driven by the ongoing mobility transition, regulations, and fast-paced technological advancements. Information technology is essential for the success of digital transformation and the advancements of a digital company like the BMW Group. For us, IT is about more than "just" vehicle IT. Far more, BMW Group IT permeates every area of the company, developing and operating digital solutions throughout the BMW value chain and beyond. That's because the digital penetration of every single business process harbors a vast potential for the company's future. However, IT is also changing, and factors like the rise of AI, the need for resilience, and the fast pace influence the entire IT ecosystem's development.

Understanding the future of this environment is highly relevant for BMW Group IT. An unbiased outside-in analysis of the ecosystem and its future developments is vital for generating this foresight and predictions. We are more than pleased that 26 young innovators from various backgrounds started to dive deep into this topic, "The Future of Software Engineering and IT Operations," and created an in-depth analysis of the future of an entire ecosystem. Over seven weeks, 26 CDTM students plunged into the eagerly anticipated topic. Throughout the input lecture and touchpoints, it quickly became apparent how much energy and curiosity the class had in approaching the task. A highlight of the seven weeks was inviting the students to the BMW Group's newest Digital Experience Center—the Future Lab.

After two weeks, the students pre sented the trends throughout technology, social, legal, economic, and environmental dimensions. Even though the topic was broad and could be approached from various fields, the class did a tremendous job of clustering and presenting the key trends and their implications for the BMW Group. As the seminar progressed, the students methodically derived in-depth opportunity spaces. They later developed exciting business models based on them, all done with a stringent reasoning approach that left us stunning. The well-established and methodologically robust framework of the CDTM provided guidance and enabled students to achieve impressive results quickly.

We extend our heartfelt gratitude to the students for their exceptional efforts throughout the trend seminar. Their energetic excitement for the topic, unmatched willingness to challenge existing assumptions, and spot-on analytics of ongoing market situations are highlights of their work. Our team was captivated by the energizing discussions and insights from the seminar. We encourage all the Centerlings to keep up that enthusiasm and leverage it to shape the industries and ecosystems of tomorrow. Also, special thanks to the seminar supervisors, Vera Eger and Sebastian Sartor, for their outstanding work in preparing the seminar content and managing the seminar logistics.

Thank you all for seven intense weeks, 25 trends, five areas of opportunity, and five business models. Your work has significantly contributed to our understanding of the future of software engineering and IT operations, and we are excited to see how these insights will shape the BMW Group's future IT strategy. All the best for your future!

Celine Marie Perrot and Johannes Klepsch

BMW Group IT

Vera Eger 

Sebastian Sartor 

PREFACE OF THE EDITORS

> **Everybody can learn from the past. Today it is important to learn from the future!**
> Herman Kahn

As Herman Kahn, one of the founding fathers of modern scenario planning, nicely states, it is tremendously important for strategy and policymakers to get a deep understanding of possible future developments to be prepared for them.

The CDTM aims to connect, educate, and empower the innovators of tomorrow. It is our mission to equip our students with the tools and knowledge they need to become responsible leaders who actively shape their future environment rather than only react to changes.

This Trend Report is the result of the course Trend Seminar, which is part of the interdisciplinary add-on study program "Technology Management" at CDTM. About 25 selected students of various disciplines, such as Business Administration, Psychology, Medicine, Computer Science, Electrical Engineering work together on a relevant topic of our time. Over the course of seven intense weeks of full-time work during their semester break, the participating students dive deeply into the topic of the Trend Seminar. Working in several interdisciplinary sub-teams, students apply the knowledge of their main studies and learn new perspectives from their team members. They conduct trend research, develop scenarios of the future, generate ideas for innovative products or services, and detail them out into concrete business concepts.

We would like to take the chance to thank everyone who contributed and made this CDTM Trend Report possible:

We want to thank BMW for supporting this Trend Seminar. Particularly, we want to thank Celine Marie Perrot and Florian Novak as well as their colleagues for their collaboration, valuable insights, and feedback throughout the project. We hope our findings support you in driving innovation in the context of The Future of Software Engineering and IT Operations!

In addition, we very much thank all our lecturers, who shared their knowledge and largely contributed to this project's success:

Aaron Defort (BCG)
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Nadine Schmidt (Professional Coach / Alumna)
Nina Feussner (Lakestar VC)
Niko Pallas (CDTM)
Peter van Woerkum (Regulate)
Prof. Alexander Pretschner (TUM)
Raphael Beuter (CDTM)
Silas Alberti (Cognition AI)
Tristan Post (TUM)
Valentin Bertle (BMW)
Zhenya Loginov (Accel)

Last but not least, we would like to thank the CDTM students of the class of Fall 2024. They put great energy and enthusiasm into this project, which made it a pleasure for us to supervise the course and coach the individual teams. Special thanks to the Heads of the editing-, layouting-, and QA-team (Isabel Tscherniak, Aliosha Milsztein, Max Knoll) for finalizing the report.

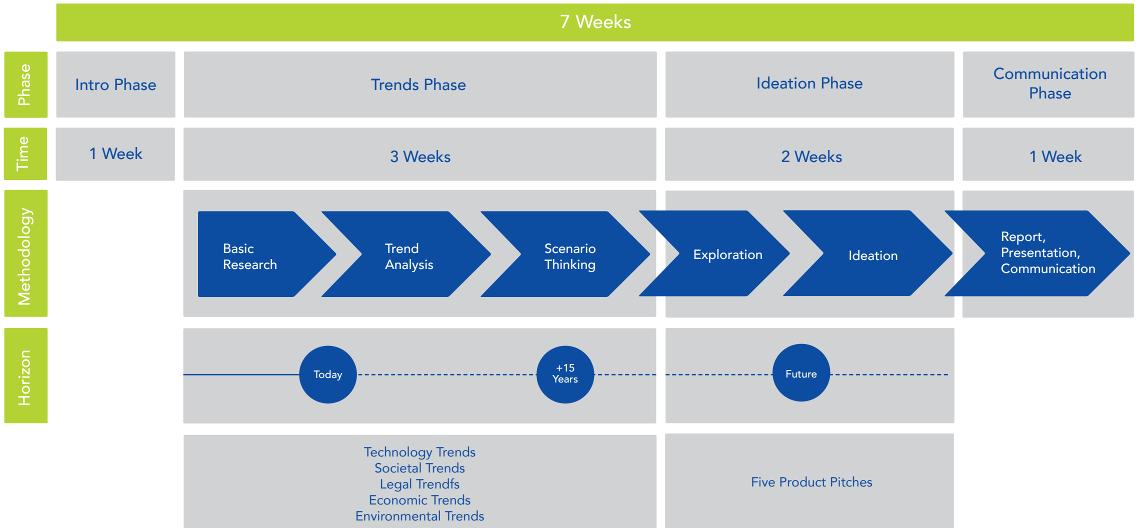
Vera Eger and Sebastian Sartor

Center for Digital Technology and Management

METHODOLOGY

The objective of the Trend Seminar is to provide a methodological approach for diving into a specific subject or industry sector and contemplating its future trajectory. The seminar guides its participants through three phases of trend research: trend, exploration, and ideation. Following this approach, the seminar first analyzes current trends and developments using in-depth desk research, site visits, and interviews with leading experts to establish a shared industry understanding. Next, participants identify areas within the sector where problems and opportunities will likely arise. In the final seminar phase, the students generate future-proof business ideas for products and services, addressing the identified problems and opportunities.

Up to twenty-six students, supervised by two doctoral candidates, pursue the Trend Seminar for seven weeks full-time during their semester break. The sector and framing for the seminar is provided by project partners from within the industry, who share their expertise and feedback, acting as sparring partners to the participants. In each phase, interdisciplinary subteams are formed with students from business, technology, and other disciplines. This interdisciplinarity allows for novel ways of thinking and the development of non-obvious ideas as well as leveraging the students' professional and personal growth throughout the course.



During the introduction week, the participants are prepared for the intense trend research ahead. First and foremost, the students are introduced to the specific industry the seminar is diving into. Project partners and industry experts present past and current industry developments from their individual stakeholder perspectives, engaging in open discussions with the students. Additionally, interactive sessions teach trend research methodologies and refine the participants' communication and teamwork skills.

Following the introduction, the **trends phase** of the seminar covers desk research, expert interviews, and expert lectures, enabling the participants to dive deep into the topic at hand. During the expert interviews, students are empowered to pose specific questions to challenge their initial assumptions on how the industry will develop. Beyond that, site visits at the project partners' facilities complement the students' body of research and allow for further verification of their hypotheses. The derived trends are extrapolated 15 years into the future, providing a long-term perspective.

The first half of the **ideation phase** is about **exploring**. Future opportunities and problems are clustered into specific spaces based on the research done in the preceding phase. The students are reshuffled into new teams and explore these spaces by looking into existing start-ups and projects. Through interviews and discussions with industry experts, the teams validate their hypotheses to identify unmet needs and existing gaps in the industry landscape.

During the second half of the **ideation phase**, students brainstorm **business solutions** addressing the previously identified gaps. To facilitate the ideation process, the students are introduced to structured and unstructured ideation methods. This allows them to generate many ideas before consolidating them and building comprehensive business models. Finally, the research results and the business ideas are pitched to the project partners, industry stakeholders, and the general public.

LIST OF ABBREVIATIONS

AI
Artificial Intelligence

API
Application Programming Interface

AR
Augmented Reality

ARR
Annual Recurring Revenue

AWS
Amazon Web Services

BCI
Brain-Computer Interface

CAGR
Compound Annual Growth Rate

CI/CD
Continuous Integration & Continous Development

CO_2
Carbon Dioxide

DACH
Germany (Deutschland), Austria, Switzerland (Confoederatio Helvetica)

DAX
German Stock Index

DevSecOps
Development, Security, and Operations

EAA
European Accessibility Act

EPB
European Blockchain Partnership

EBSI
European Blockchain Services Infrastructure

EdTech
Education Technology

ESG
Environmental, Social, and Governance

EU
European Union

FPGA
Field Programmable Gate Array

GBP
British Pound Sterling

GDP
Gross Domestic Product

GDPR
General Data Protection Regulation

GenAI
Generative AI

GHG
Greenhouse Gas

GPT
Generative Pre-Trained Transformer

GPU
Graphics Processing Unit

HLS
High-Level Synthesis

ICT
Information and Communications Technology

IDE
Integrated Development Environment

IEEE
Institute of Electrical and Electronic Engineers

IP
Intellectual Property

ISO
International Organization for Standardization

IT
Information Technology

LCNC
Low-code/No-code

LIME
Local Interpretable Model-agnostic Explanations

LLM
Large Language Model

MiCA
Markets in Crypto-Assets

ML
Machine Learning

MR
Mixed Reality

NLP
Neural Language Processing

NPU
Neural Processing Unit

OECD
Organization for Economic Co-operation and Development

OSS
Open-Source Software

QA(s)
Quantum Application(s)

RAAS
Ransomware-as-a-Service

RISC-V
Reduced Instruction Set Computer

SaaS
Software as a Service

SAM
Serviceable Addressable Market

SAST
Static Application Security Testing

SLSA
Supply-chain Levels for Software Artifacts

SME
Small and medium-sized enterprises

SOAR
Security Orchestration, Automation, and Response

SOM
Serviceable Obtainable Market

SPOF
Single Points Of Failure

STEM
Science, Technology, Engineering, and Mathematics

TAM
Total Addressable Market

TPU
Tensor Processing Unit

US
United States

USD
United States Dollar

VEP
Visual Evoked Potentials

VC
Venture Capital

VR
Virtual Reality

WCAG
Web Content Accessibility Guidelines

XR
Extended Reality

TRENDS

The following chapter lists current trends that have a strong influence on the development and long-term strategic orientation of *The Future of Software Engineering and IT Operations*. In accordance with the Trends Phase methodology, trends and related driving forces are structured into five areas: technology trends, societal trends, legal trends, economic trends, and environmental trends.

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TECHNOLOGY TRENDS

INFLUENCING THE FUTURE OF SOFTWARE ENGINEERING AND IT OPERATIONS

AI-Augmented Software Engineering
Progress in Simulation Technologies
Next Generation of User Interfaces
Rising Adoption of Edge Computing
Leveraging Quantum Applications

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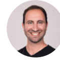
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TECHNOLOGY TRENDS

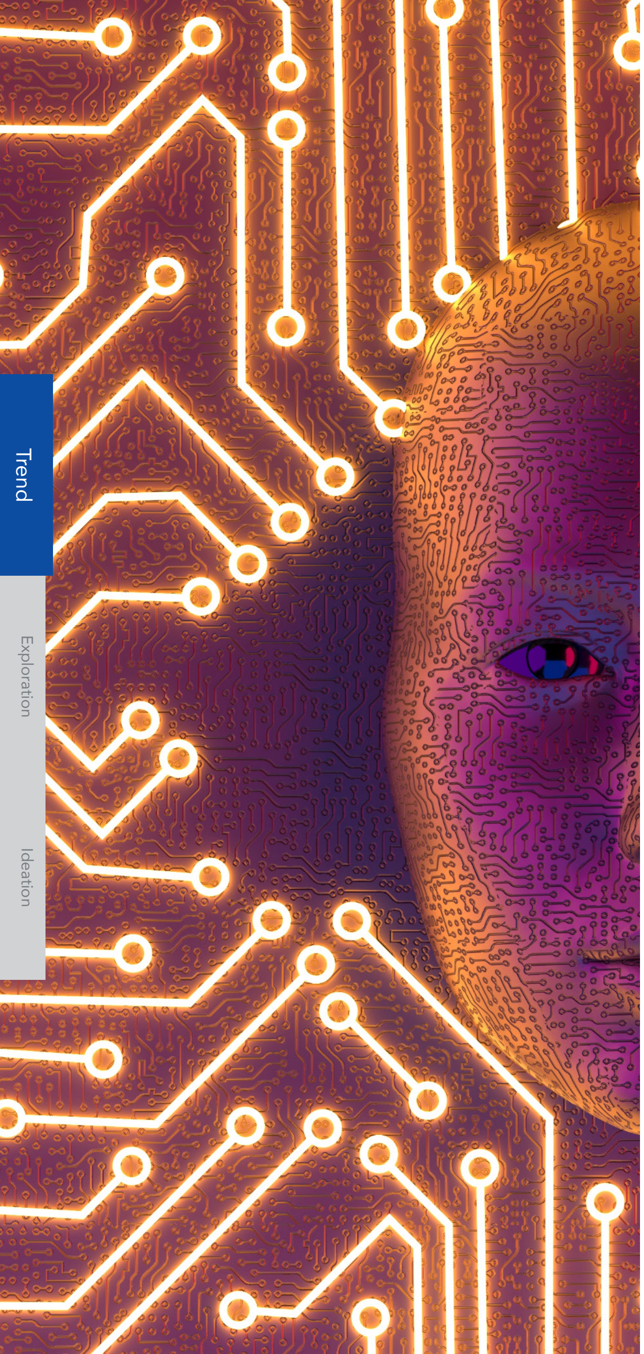
Influencing the Future of Software Engineering and IT Operations

The release of GPT-3.5 in November 2022 ignited a heated public discourse about the future of software development, fundamentally questioning the role of software engineers in the future [1]. While Artificial Intelegence (AI)-encanced software engineering is a significant trend, it is just one of several transformative technological advancements shaping the industry. Understanding these trends is crucial for businesses to anticipate how software will be created, optimized, and managed in the future. It also helps guide conversations in the economic, societal, environmental, and legal domains. Software engineering, therefore, is more than a market segment or business function; it is a discipline that evolves with technological progress. At its core, software engineering involves applying scientific principles, engineering techniques, and technological innovations to software design, development, and maintenance [2].

When defining the scope of technological trends, it is important to recognize the bidirectional relationship between them and software engineering. Both mutually influence the other as technological trends drive software engineering practices, while the software can spur technological breakthroughs. However, the following analysis focuses on technologies currently impacting the practice of software engineering and operations, rather than on how software engineering might drive broader technological applications. For example, the analysis will cover how edge computing influences software engineering practices. In contrast, the development of self-driving cars – an application of these practices – is outside the scope of this discussion.

Several emerging technologies, from AI augmentation to quantum computing, drive significant advancements in software development and computational processes. AI augmentation tools such as copilots and autonomous software engineering agents (e.g., Cognition's Devin AI) are being rapidly adopted [3]. Advances in simulation technologies, notably NVIDIA's Isaac Sim, are revolutionizing robotics training in virtual environments and improving software testing and optimization [4]. On the computational front, edge computing is becoming increasingly significant, enabling real time data processing directly on devices through specialized hardware-software co-design [5]. Another promising technology for the future of computation is quantum computing. While quantum hardware is still limited, its algorithmic potential is being explored by companies like BMW and Airbus, highlighting its potential in various fields [6]. Finally, next-generation interfaces, including Virtual Reality (VR), Augmented Reality (AR), and Brain-Computer Interfaces (BCI), are revolutionizing both user interactions and the software development process [7].

Ultimately, these technological trends promise to transform software engineering and operations by enhancing accessibility, flexibility, and production capabilities. However, implementing these promising technologies comes with notable challenges. Ensuring security, managing data quality, and addressing integration complexities are crucial for maintaining system robustness and reliability. As the industry adapts to these advancements, handling these intricacies will be essential for fully capitalizing on the potential of AI augmentation, edge computing, quantum computing, simulation technologies, and next-generation interfaces.



AI-AUGMENTED SOFTWARE ENGINEERING

AI-Copilots and Autonomous Agents

AI-augmented software engineering integrates AI tools to enhance the productivity of software engineers by automating and optimizing various stages of the development process [8]. These tools assist with code generation, debugging, documentation, testing, deployment, and maintenance. Thereby, they improve efficiency and reduce human cognitive workload. Within this trend, one can differentiate between "in the loop" vs. "out of the loop" systems [9]. "In the loop" refers to AI copilots assisting human developers in performing their tasks more efficiently. GitHub Copilot or Cursor AI are industry examples [10, 11]. They integrate into the code base and give context-based recommendations. On the other hand, Devin AI by Cognition is an example of an "out of the loop" system, as a self-adapting agent that independently performs tasks typically carried out by a human [3].

Facts

- Devin AI achieves a 13.86% success rate in resolving real-world GitHub issues end-to-end on the "SWE-bench" benchmark, significantly outperforming the previous best model's 1.96% success rate [3].
- By 2025, 80% of the software development life cycle will involve Generative AI (GenAI) code generation. By 2028, 75% of enterprise software engineers will use AI coding assistants, compared to less than 10% in early 2023 [12].
- According to a study, 57% of surveyed software engineers anticipate a productivity gain of 20% or more from GenAI use cases over the next two years [13].

Key Drivers

- An anticipated shortage of 4M developers worldwide by 2025 drives the need for AI-driven solutions to enhance productivity and the software development lifecycle [14].
- Breakthroughs in Natural Language Processing (NLP) and Large Language Models (LLMs) combined with hardware innovation enabling model scaling unlock the ability for automated code generation and documentation [15].
- Geopolitical competition in technological innovation for political, military, and economic applications, exemplified in the AI race between China and the US (United States), makes AI-augmented software engineering a national priority [16, 17].

Challenges

- Challenges of GenAI are the lack of training data for specific scenarios, limited contextual understanding leading to incorrect outputs, and AI's difficulty in handling ambiguity [18, 19].
- Code churn (percentage of reverted lines within two weeks) will double in 2024 compared to 2021, reaching over 7% of all code changes, indicating increased instability and maintenance need for AI-generated code [20].
- Samsung's data leak from employees inputting sensitive data into ChatGPT illustrates the need for data security, compliance, and regulatory standards [21, 22].
- The "black-box" nature of GenAI models hinders explainability, endangering transparency, and accountability [16, 23].
- Over-reliance on AI output and automated testing without human reviews increases the likelihood of errors and can reduce original human creativity in complex problem settings [24, 25].

Impact on the Future of Software Engineering and IT Operations

AI-augmented software engineering has the potential to significantly transform software development and operations by automating routines. These tasks include code generation, debugging, testing, accelerating growth, and reducing time-to-market. AI may also enhance code quality and security through advanced error detection and automated code reviews [26]. These capabilities are particularly valuable for managing and maintaining large and legacy codebases [27]. However, as AI takes on more routine tasks, software engineers may need to shift towards higher-level responsibilities such as orchestrating AI tools, strategic planning, and architectural design [19]. Despite these advances, questions still exist about AI's reliability in complex scenarios, its ability to understand context, and how to integrate AI tools effectively into current workflows and different coding environments.

PROGRESS IN SIMULATION TECHNOLOGIES

Modeling and Simulating Complex Systems

Simulation technologies are becoming integral in testing and optimizing complex systems across industries. They offer a controlled environment where scenarios that would be too risky, costly, or impractical to replicate in the real world can be safely analyzed [28]. This ability to simulate and test can provide valuable insights from models, feeding them back into scientific research and practical applications [28]. Their predictive capabilities are beneficial for evaluating risks, costs, operational performance, and potential implementation barriers [29, 30, 31]. Applications of simulation technologies include digital twins (digital replicas of physical systems), 3D worlds, AI-based simulation models, and chaos engineering. Chaos engineering deliberately introduces failures into a system to identify weaknesses and improve resilience [32].

Facts

- A digital twin was first used by NASA for the Apollo program in the 1960s. They created two identical space vehicles to mirror each other, allowing engineers on Earth to diagnose and solve issues by replicating conditions experienced by the spacecraft [33].
- BMW created a fully connected digital twin of a production plant to support production planning, quality assurance, and real time monitoring [34].
- NVIDIA's Isaac Sim, a general-purpose foundation model, provides a comprehensive virtual environment for designing, testing, and training AI-powered robots safely and cost-effectively before deploying them in the real world [4].

Key Drivers

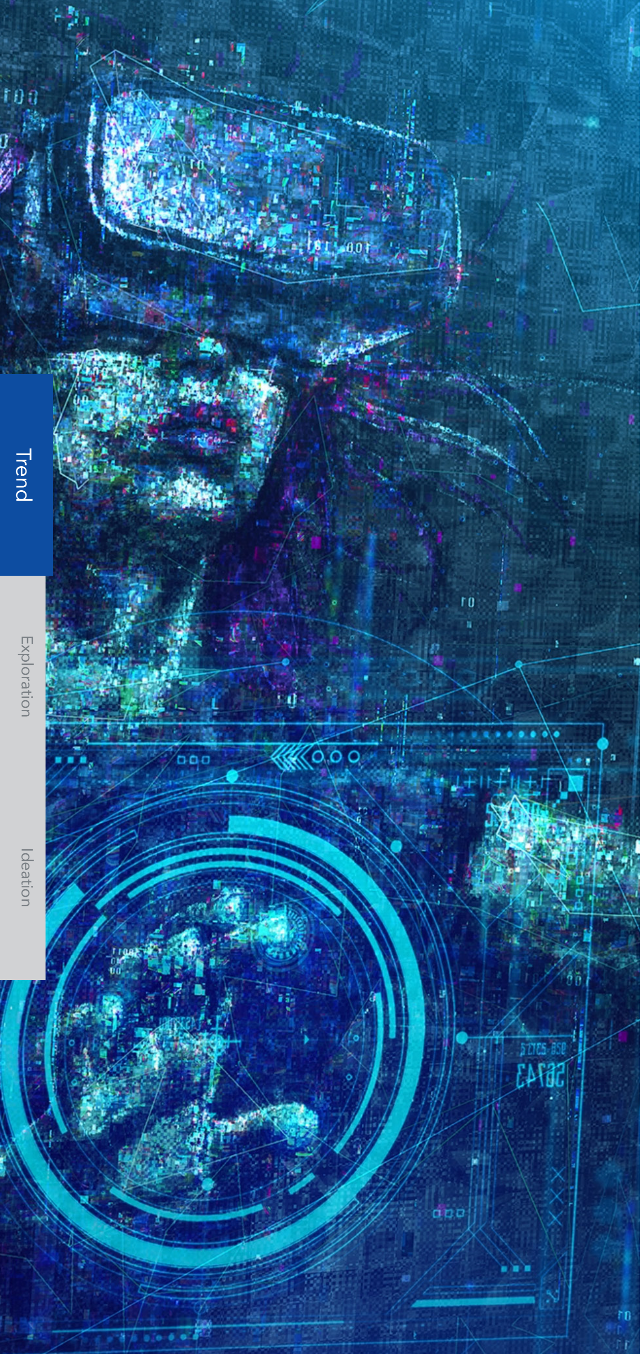
- Virtual simulations can lower design costs by up to 70% and reduce time-to-production by 56% [35, 36].
- The development of synthetic data generation supports simulation technologies by creating diverse scenarios. This includes rare cases that may not be present in historical data or when real-world data is scarce, incomplete, or biased. This data can be generated on demand, allowing for fast and cost-efficient data collection [4, 37, 38, 39, 40].
- Innovations in computation, like NVIDIA's recent Graphics Processing Units (GPUs), offer unprecedented parallel processing power, making real time simulations feasible across various industries such as automobile, manufacturing, healthcare, or urban planning [28, 41, 42, 43].

Challenges

- High-fidelity representation requires heterogeneous and standardized data. Challenges to data preparation arise from incomplete documentation, dark data, and data inaccuracies. Insufficient accuracy can lead to false predictions and decision-making based on the simulation [44, 31].
- Despite hardware advancements that enable simulations of increasingly complex systems, high computational costs limit the level of detail, the complexity of physics, and the number of simulation runs that can be performed. These constraints often lead to simplifying assumptions, which can compromise the accuracy of results, making them unsuitable for practical decision-making [28].
- Simulators are inherently inflexible. They can only simulate what they are explicitly programmed to handle [28].

Impact on the Future of Software Engineering and IT Operations

Simulations enable more accurate, cost-effective, and risk-free testing environments for digital and physical systems. They have the potential to revolutionize how systems are designed, built, and maintained, manifesting in a shift toward predictive and proactive approaches. Potential issues can be identified and addressed long before they appear in real-world scenarios [44]. This evolution enhances the resilience and efficiency of systems and fosters innovation among engineers by allowing them to experiment with complex, high-risk ideas without the traditionally associated physical constraints.



NEXT GENERATION OF USER INTERFACES

Immersive, Intuitive, and Cross-Platform User Interaction Technologies

User interfaces are the components of a software application that enable interaction between the user and the system [45]. Next-generation designs are set to revolutionize software development as these interfaces evolve, making them more accessible, efficient, and engaging [46]. At the forefront of this transformation are holographic interfaces, Extended Reality (XR) programming, voice/conversational interfaces, and BCI. Holographic interfaces provide immersive 3D environments where developers can visualize and manipulate code and data in real time, enhancing understanding and collaboration among teams [47]. XR programming, which includes AR, VR, and mixed reality, enables physical and digital elements to interact in real time. This allows developers to build and test applications in simulated environments, improving accuracy and reducing development time [7]. Voice, conversational interfaces, and BCIs enable developers to interact with development tools using voice commands or their thoughts, making the process more intuitive, accessible, and efficient [48].

Facts

- In 2023, 85% of consumers globally reported using a voice assistant, compared to 51% in 2017. This indicates a substantial increase in adoption over this period [49].
- BCIs based on visual evoked potentials offer the opportunity to reach a communication speed of 100 bits/min. This is equivalent to writing 19.1 error-free letters per minute [50].
- As of 2022, the US had the highest number of BCI publications, followed by China, Germany, and Japan. The United States had over 4.5k publications, while China had around 3.5k [51].
- In a survey about learning programming with AR, 80% of students responded that these systems made learning programming more engaging and efficient than classical programming education [52].

Key Drivers

- The accelerated adoption of XR technologies and holographic interfaces is primarily driven by the growing consumer expectation for seamless integration of virtual and physical environments. This facilitates enhanced interaction and deeper user engagement [53].
- Advancements in AI and NLP substantially augment the functionality and effectiveness of voice-activated systems and conversational user interfaces. This leads to a more sophisticated, responsive, and user-friendly interaction across various digital platforms [54].
- Advancements in signal processing algorithms and increased research funding have significantly contributed to the rise of BCI technology [55].

Challenges

- Ensuring the security and privacy of user data in voice and conversational interfaces remains a significant challenge. As these interfaces become more prevalent, protecting sensitive information is crucial [49].
- The high cost and technical complexity of developing and deploying XR and holographic interfaces can hinder widespread adoption. Companies must invest in specialized hardware and software, which can be expensive and require significant expertise [21].

Impact on the Future of Software Engineering and IT Operations

Next-generation user interfaces, including holographic displays, XR technologies, voice interfaces, and BCI, will revolutionize how developers interact with software. These technologies enable developers to visualize and manipulate code in 3D environments, simulate real-world interactions, and control development tools through voice commands or neural inputs, making the process more immersive, intuitive, and efficient. As software engineering evolves, developers will need to adapt to new tools and methods, redefining the way software is created and operated. With the maturation of these interfaces, they will become vital to the software development lifecycle, driving innovation, improving collaboration, and enhancing the overall user experience.

RISING ADOPTION OF EDGE COMPUTING

The Future of Data Processing Starts At the Edge

Edge computing processes data near its source – such as cameras and radars – using processors in embedded systems. It operates at the intersection of the physical and digital worlds, directly interacting with the environment. Processing data at the edge reduces reliance on centralized data centers, resulting in faster response times and more efficient real time processing [5]. Edge computing's strength comes from technologies like RISC-V, an open-source instruction set architecture, and Field Programmable Gate Arrays (FPGAs), which are reprogrammable hardware [56, 57]. Additionally, neuromorphic computing excels in real time, energy-efficient machine learning by mimicking brain functions. FPGAs can prototype neuromorphic systems or control RISC-V cores [58, 59]. Digital computing has driven much of this progress, but analog computing resurges for ultra-low-power applications. Its efficiency, especially in handling continuous data streams, makes analog ideal for modern challenges [60]. In-memory computing, a specialized subset, reduces energy use and latency by embedding data directly within processing circuits [61]. These technologies are driving innovation across industries. In the industrial Internet of Things (IoT), edge computing detects equipment issues on factory floors. In smart cities, FPGAs optimize traffic light timing and analyze surveillance locally. Autonomous vehicles use RISC-V processors for real time decision-making, ensuring safe navigation [21, 62, 63].

Facts

- The edge computing market size was valued at 16.45B USD in 2023 and is expected to grow anually by 36.9% from 2024 to 2030 [62].
- In-memory computing can boost data-intensive tasks with 435 times faster throughput and 20 times better area efficiency than traditional methods, while minimizing latency [64].
- RISC-V processors and hardware accelerators in edge AI applications achieve an inference latency of 2.12ms, outperforming ARM by delivering half the latency and reducing energy consumption by 20% [65].

Key Drivers

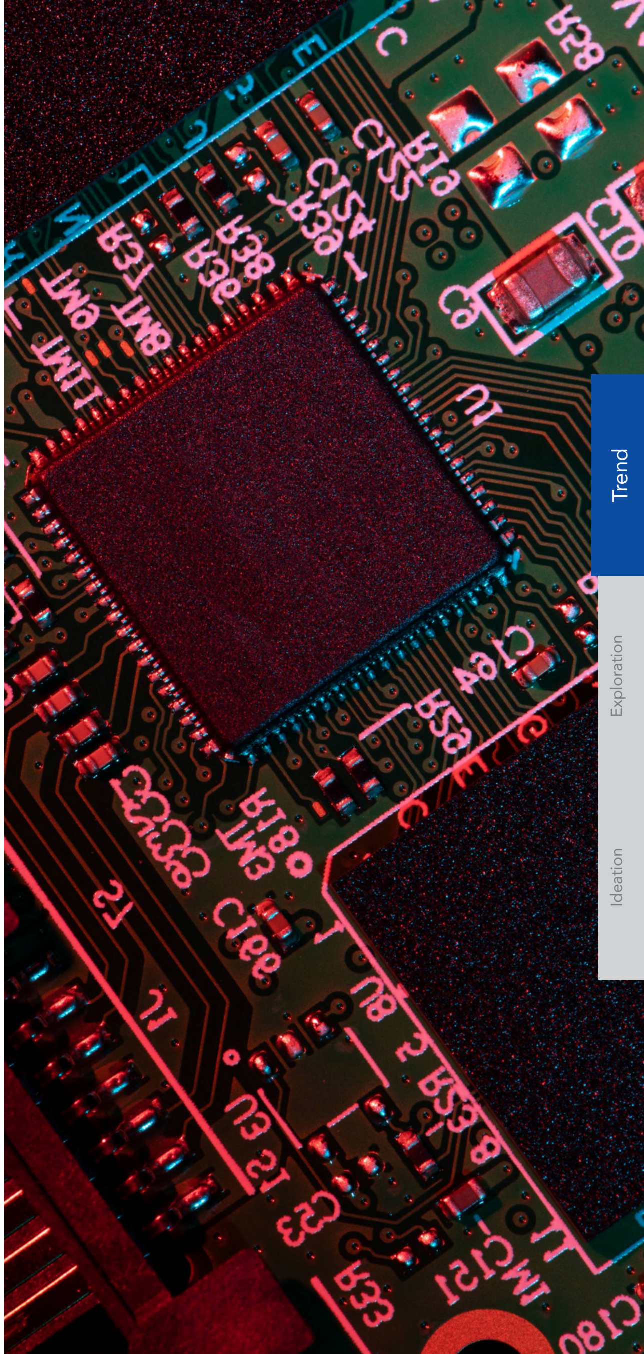
- The rise of IoT devices and 5G technology boosts demand for real time data processing at the edge [66].
- Increased focus on data privacy and security drives the development of edge devices that perform on-device training, keeping private data local [63].
- New developments in non-traditional data processing and non-volatile memory are resulting in faster processes, lower power consumption, and solving data transfer problems, especially in limited resource situations where efficiency is essential [67, 63, 68].

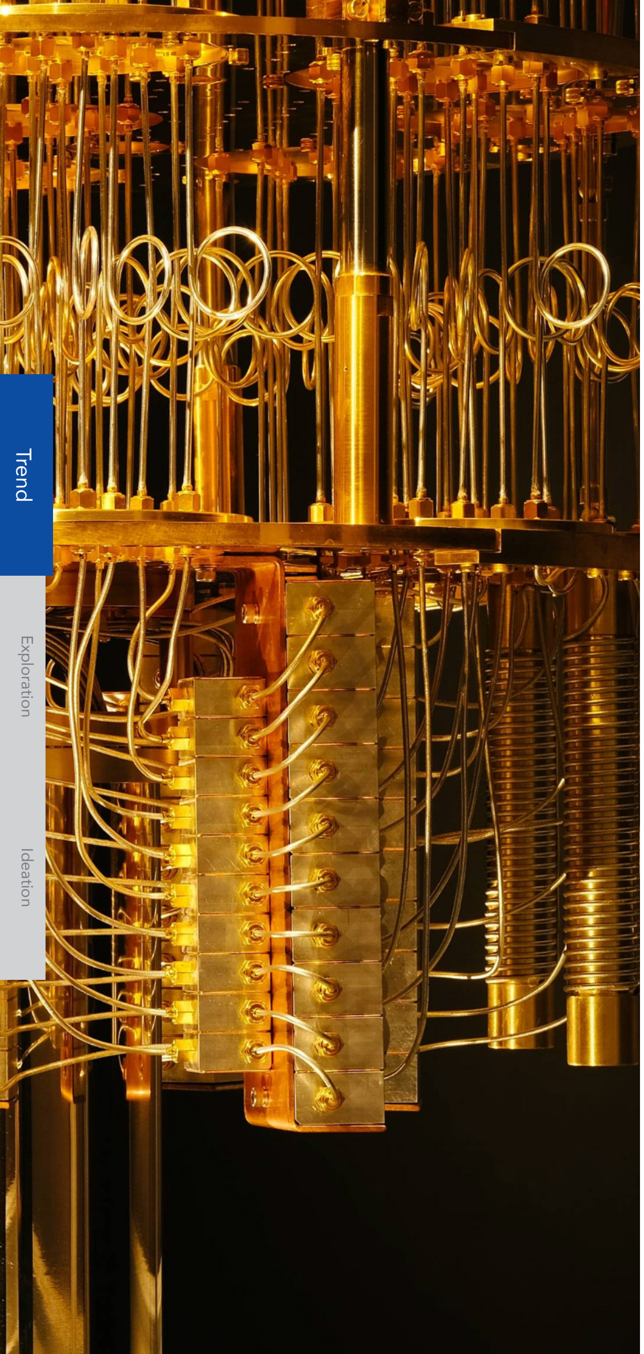
Challenges

- Edge devices face significant security risks due to their decentralized nature and limited defenses. Protecting sensitive data requires strong encryption, secure communication, and monitoring to detect and address threats [66].
- Integrating edge computing with existing IT systems is complex, especially for organizations with outdated technology.
- Legacy systems do not work well with modern edge solutions, often requiering significant upgrades or replacements. Careful planning and execution, possibly through hardware-software co-design, are essential to manage this transition effectively [63].

Impact on the Future of Software Engineering and IT Operations

Edge computing will reshape software engineering and IT operations by requiring applications that run efficiently on edge devices. Technologies like RISC-V processors, FPGAs, and in-memory computing will drive this shift, demanding hardware-software co-design for efficient performance. Engineers will need to develop skills in embedded systems, AI, and cybersecurity as edge devices increasingly process data locally, improving privacy and security through on-device AI training. IT operations must adapt to managing decentralized edge infrastructures and integrating them with cloud services. Real time analytics and decision-making – critical in industries like automotive and healthcare – will require responsive, high-performance systems.





LEVERAGING QUANTUM APPLICATIONS

Utilizing Unique Quantum Properties to Improve Efficiency, Accuracy, and Security

Despite the limitation of current quantum hardware, clever usage of quantum phenomena already enables solutions to problems that are difficult or infeasible for classical computers [6]. For instance, a single quantum bit can generate true random numbers by leveraging the non-deterministic nature of quantum mechanics – which is impossible for any classical computer [69, 70]. Quantum Computers were conceived to simulate quantum systems accurately [71], but the potential of Quantum Applications (QAs) has since broadened significantly [72]. Quantum algorithms promise to complement and outperform their classical counterparts in industry-relevant domains, including optimization, differential equations, and machine learning [73]. Furthermore, quantum information principles have been utilized to develop communication and encryption protocols, revolutionizing data protection and making quantum computing highly relevant to cybersecurity [74]. Companies across diverse industries are beginning to incorporate QAs into their operations, using this cutting-edge technology to address real-world problems and explore new frontiers in computation [75]. As quantum hardware advances, its applications will expand, further driving innovation.

Facts

- Certain problems require an exponential time to solve classically but can be solved in polynomial time with quantum algorithms. Integer factorization is one of the most relevant problems, as many cryptosystems rely on the difficulty of factoring the product of two primes [76].
- Companies like BMW, VW, and Airbus are exploring the potential of QAs to solve engineering problems such as robot scheduling, battery research, and fluid dynamic analysis [73].
- Quantum simulation is being used to investigate chemical processes such as the Haber-Bosch process, which currently uses 1% of global energy production and is responsible for 1.4% of the carbon-dioxide emissions [73].

Key Drivers

- Companies across multiple sectors must optimize recurring activities such as portfolio management, scheduling, and routing [76]. Quantum algorithms pose promising solutions for such problems, as quantum phenomena such as superposition and entanglement can be exploited to explore multiple solutions simultaneously.
- Quantum algorithms can break current cryptography protocols efficiently, leading governments and companies to transition to quantum-resistant encryption [77].
- Accurate simulations of quantum systems in nature are increasingly crucial for fields such as drug discovery and material sciences [78].

Challenges

- The field of QAs faces a talent shortage due to specialized skill requirements, limited educational programs, and a rapidly evolving industry [79].
- QAs are limited by the reliability of quantum hardware. At the same time, quantum properties make classical error correction techniques fundamentally incompatible with quantum hardware [80]. Despite steady progress in quality and the development of error correction methods, quantum hardware is still a significant bottleneck for the effectiveness of QAs [81, 82].

Impact on the Future of Software Engineering and IT Operations

Multiple companies are creating teams dedicated to the research of QAs and their integration into operational activities [83]. This new quantum workforce, including software engineers, must acquire quantum expertise, from theoretical quantum principles to quantum programming languages [79]. Additionally, software engineering practices such as requirements engineering, testing, and verification must be adapted to the quantum paradigm [84].
Besides requiring new competencies and workflows, QAs directly affect the software industry. Quantum encryption is already being set as a cybersecurity standard [77]. In the future, QAs hold the potential to revolutionize software engineering processes, such as resource allocation and network traffic management.

SOCIETAL TRENDS

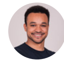
INFLUENCING THE FUTURE OF SOFTWARE ENGINEERING AND IT OPERATIONS

Polarization and Global Fragmentation
Intersectional Accessibility
Evolving Job Markets
Modernization in Education
Increasing Scrutiny of Data Privacy

Antonia Borsutzky

Jakub Skupien

Jonas Seidou

Khadim Fall

Leon Driese


SOCIETAL TRENDS

Influencing the Future of Software Engineering and IT Operations

In our rapidly evolving digital world, the connection between humans and technology grows even stronger. Societal change, driven by demographic shifts, political climate, and cultural differences, fundamentally shapes how technology is designed, developed, and implemented [85, 86, 87, 88]. Societal demands shape the development of technology, while the implementation of technology and the narratives surrounding it also drive societal changes. Understanding societal trends is essential to gain insights into technology's role in addressing the needs and challenges of an increasingly interconnected world.

Societal norms shape the use and perception of technology. Hence, they are crucial in shaping the future of software engineering and IT operations. How do we interact with software? Which parts of our lives are influenced by software? AI-powered development tools, as well as growing sustainability demands, change our ways of interacting with software and drive the adaptation of novel methodologies. These new methods reshape the software development lifecycle from planning to maintenance [89]. As society's expectations evolve, so do the demands on software solutions. For example, the rising significance of digital literacy and education has made user-friendly and accessible software more crucial than ever, as it enables greater participation and promotes inclusive learning. Societal concerns about privacy, security, and the ethical use of technology are also advancing the development of safer and more transparent software solutions.

Moreover, societal trends shape the requirements for how software is developed. The emergence of digital infrastructure in all industries, along with the rise of low-code and no-code platforms, democratizes software development. Thus, more people can contribute to the digital economy [90, 91]. Additionally, political and economic uncertainties are driving a shift towards more resilient development methods. As globalization advances, the demand for software that can operate effectively across diverse cultural, legal, and technical environments becomes ever more critical.

Concluding, software and society are constantly interacting with and shaping each other. The constant change in society and technology promotes innovation, but also presents new challenges. This is because technological progress often outpaces societal adjustments. Software engineers must navigate this complexity while balancing technical excellence and progress with social responsibility.

The following trends examine how societal trends like geopolitical tensions, diversity, education, workforce development, and data security shape the future of software engineering and IT operations.

POLARIZATION AND GLOBAL FRAGMENTATION

Increase of Socio-Political Uncertainty

Socio-Political changes from inflation, elections, war, and declining trust in governments are fragmenting political systems, damaging social cohesion, and influencing public discourse [86, 92, 93]. Economic disparities and rapid technological advancements exacerbate social inequalities and increase discontent. As a result, anti-government protests are emerging, reflecting growing dissatisfaction with political actors [94, 95, 96]. As societies become more divided, reaching a consensus on critical issues such as climate change is increasingly challenging [93]. These shifts reshape institutional structures and policy-making, introducing new dynamics in international relations. In software engineering and IT operations, such instability, especially in relation to supply chains, increases the demand for more resilient, secure, and adaptive software systems, as well as knowledge of hardware dependencies capable of withstanding uncertainties.

Facts

- From 2017 to 2023, around 47% of significant anti-government protests in liberal countries were motivated by instability, high inflation, and rising living costs. Overall trust in governments declined, fueled by unsettled fiscal policies [86, 92, 94, 95, 96].
- The intensifying competition between dominant countries – Russia, China, the US, and Europe – will deepen the struggle for power in the international order, while middle powers such as Saudi Arabia and India increasingly advance their strategic agenda [87]. Ongoing wars have intensified global unpredictability [97, 98].
- In 2024, elections in several countries, representing 60% of the world's Gross Domestic Product (GDP), are expected to increase political and economic uncertainty [86, 87, 88].

Key Drivers

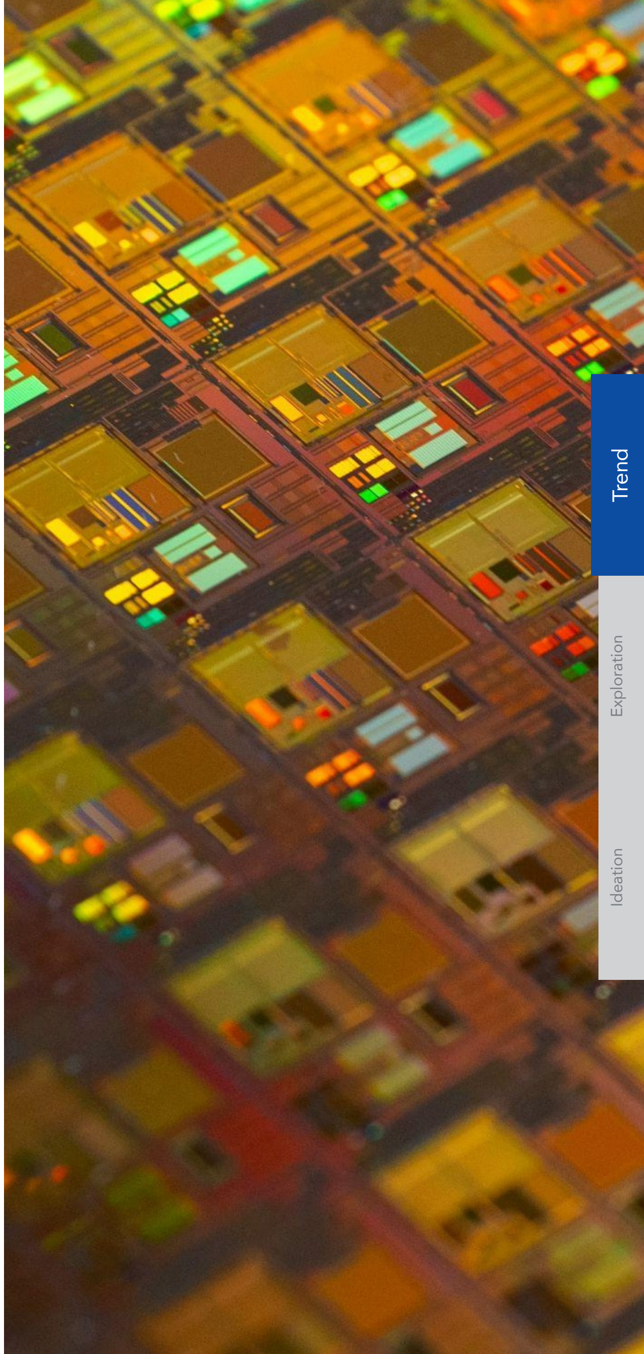
- Rising nationalism promoting national security and technology development increases support for populist leaders globally [87, 99, 100, 101].
- Deglobalization and domestic sourcing, driven by protectionist policies and trade conflicts, are increasing inflation, economic instability, and global tensions [102, 103].
- Taiwan, producing over 60% of the world's semiconductors and 90% of the most advanced chips, is central to geopolitical concerns over potential global supply chain disruptions. In response, the US has limited semiconductor exports to China and boosted domestic production for security reasons [104, 105].
- Growing climate awareness, amplified by social media platforms, fuels environmental protests [107, 108, 109, 110]. Further, conflicts are increased by extreme weather and resource scarcity [93, 106].

Challenges

- Promoting social and cultural integration through education, community engagement, and inclusive policies can reduce societal tensions. Efforts to foster mutual understanding mitigate the drivers of polarization [111, 112].
- Economic stability and inclusive growth can reduce socio-economic shortcomings and inequalities. Reducing unemployment, ensuring equitable distribution of resources, and providing social safety mechanisms can help to create more stability [113].

Impact on the Future of Software Engineering and IT Operations

Geopolitical tensions, such as in Taiwan, have significant implications for future supply chain design in the future, as chips and hardware infrastructure are core to software development. Political agendas influence research agendas, especially in quantum computing. The demand for resilient software will grow significantly, e.g., for energy infrastructure. Emerging technologies like AI can either stabilize societal trust or increase uncertainty, depending on how they are implemented. For instance, by enhancing the reliability of critical infrastructure, people build greater societal trust in these systems. Nationalism influences offshoring and near-shoring practices by pushing companies to favor domestic or allied-region partners, which affects collaboration and increases costs and development timelines.



INTERSECTIONAL ACCESSIBILITY

Diversity is Shaping Technological Development

Intersectionality is a framework that helps understand how different forms of social identities – such as ethnicity, gender, class, sexuality, and ability – intersect and overlap. This framework is crucial in advancing more inclusive and equitable environments, as it enables policymakers and organizations to better address the unique challenges faced by diverse communities. In software development, the application of intersectionality has led to significant progress. Global advancements in infrastructure, open-source software (OSS), and digital services have lowered barriers to entry in the field [114]. As a result, software engineering is becoming more inclusive, with factors like gender, country of origin, and disability becoming less decisive in determining who can participate in the industry [115]. Moreover, progress in accessibility technologies and their adoption allows individuals with disabilities to actively participate as workers and customers in the digital economy [116].

Facts

- Companies with above-average gender diversity have 19% higher innovation turnover than their competitors [117]. However, only 19% of technical roles in software engineering in Europe are taken by women [118].
- New markets are emerging. FemTech focuses on technology-based products for women's health needs, such as reproductive health and menopause. The market is estimated to be worth between 500M and 1B US-Dollar (USD) and is growing at double-digit rates [119].
- 50% of German companies with over 20 employees actively contribute to more accessible software, e.g., considering the needs of disabled people [120].

Key Drivers

- Policy strategies increasingly mandate the inclusion of intersectional considerations [121]. Existing policies do not adequately address the complexities of intersectional identities, leading to gaps in support and services for marginalized groups [122].
- The need for more inclusive and equitable work environments pushes organizations to consider intersectionality in their diversity, equity, and inclusion strategies [123].
- Creating accessible software enlarges the potential user base, ensures compliance with regulations, and improves the company image [116, 124].
- OSS reduces the need for expensive software licenses, shortens development time, and enables customization, making software development more accessible for small businesses and individuals [120, 125].

Challenges

- The increasing need to understand how different forms of inequality overlap in people's lives is driving the demand for intersectional data [126]. Collecting and synthesizing this data from various sources can be complex and resource-intensive [127].
- Only 41% of companies with revenue above 1B USD embed accessibility features into their software for customers and employees, and only about 38% conduct web accessibility audits [128].
- Gender stereotypes, lack of role models, and gender pay gap discourage women from joining Science, Technology, Engineering, and Mathematics (STEM) fields, challenging the efforts to create inclusion in the software industry [118, 129, 124, 130].

Impact on the Future of Software Engineering and IT Operations

The rise of diversity and intersectionality must be accompanied by inclusive work environments and leadership to drive innovation and enhance employee satisfaction. This shift will promote the development of more equitable technologies, ensuring that technological advancements benefit a broader segment of society. As digital services, OSS, and infrastructure continue to evolve, businesses and individuals will be able to develop and deploy software more efficiently. With the increasing availability of intersectional data and greater focus on technology accessibility, new markets will emerge, addressing the needs of diverse societal groups.

EVOLVING JOB MARKETS

New Technologies and a Global Workforce are Reshaping the Job Landscape

The job market is undergoing significant changes due to the emergence of new technologies and the increasing fragmentation of the workforce. There is a development towards more freelance work, remote teams spread across various regions, and an increasing reliance on highly specialized skills. This trend is further accelerated by AI and automation, which are gradually making jobs, such as cashiers, ticket clerks, and administrative positions, obsolete.
Despite an overall decline in global job opportunities, the need for specialized software developers continues to grow, driven by technological advancements [131].

Simultaneously, the hiring market has become more global, with a growing pool of skilled workers from emerging markets [132]. Employment is shifting from permanent to freelance contracts, and many companies are relocating work offshore [133, 134]. Managing a diverse, geographically dispersed workforce requires companies to adopt new strategies for effective cross-border collaboration. While this trend offers individuals more job opportunities worldwide, it also disrupts traditional career paths and weakens job security by promoting short-term contracts over stable, long-term employment.

Facts

- Despite an estimated decrease of 14M jobs until 2027, a substantial growth of 30-35% (equivalent to 1.4M) in data-related jobs and a 40% surge in demand for AI and machine learning specialists is anticipated [131].
- Firms adopt AI mainly to improve product quality (80%), upgrade existing processes (65%), and automate processes (54%) [135].
- In around 60% of the jobs, 30% of the activities have the potential to be automated [136].
- 70% of engineering, research, and development-focused companies report significant talent gaps, particularly in digital engineering capabilities [137].
- Global sales of IT outsourcing services will increase continuously by 248B EUR (+50%) between 2024 & 2029 [138].

Key Drivers

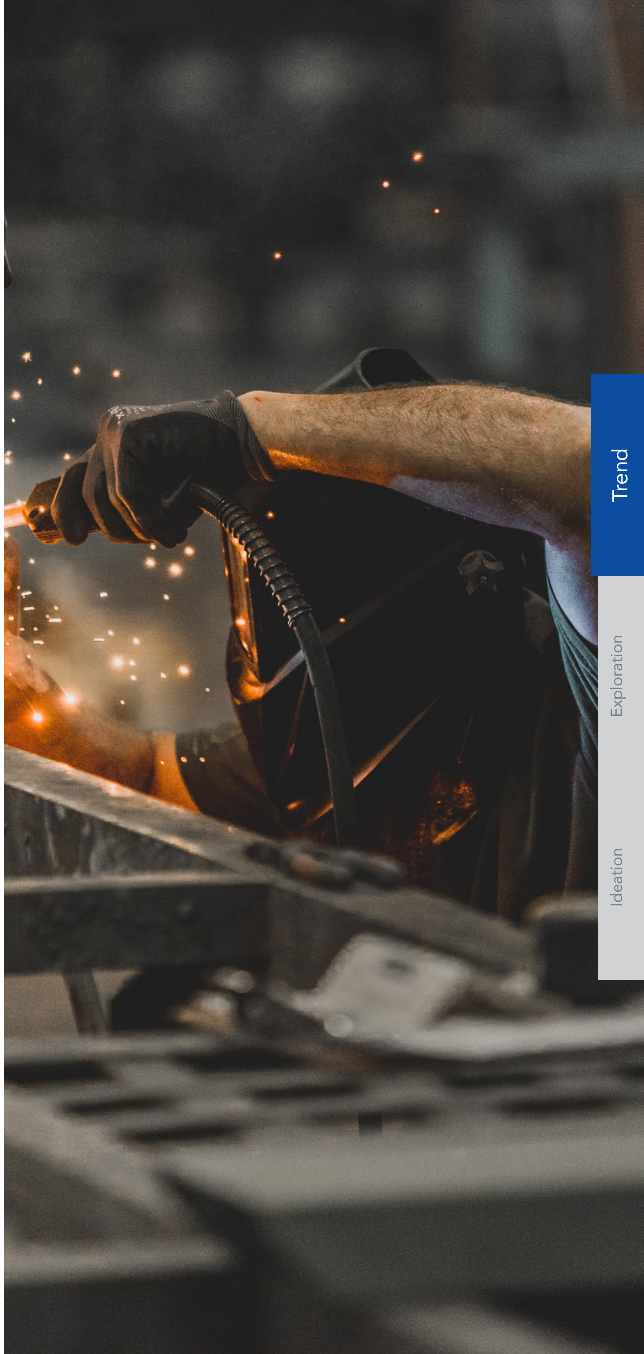
- The increasing number and availability of skilled workers in emerging markets, accessible through novel collaboration channels, enables a global hiring market [132].
- Companies across various industries are increasingly adopting AI to automate processes, boost employee productivity, and reduce operational expenses [139, 140].
- Specialized industry expertise, more robust cost-saving advantages, and better technology expertise are the primary drivers for offshoring [137].

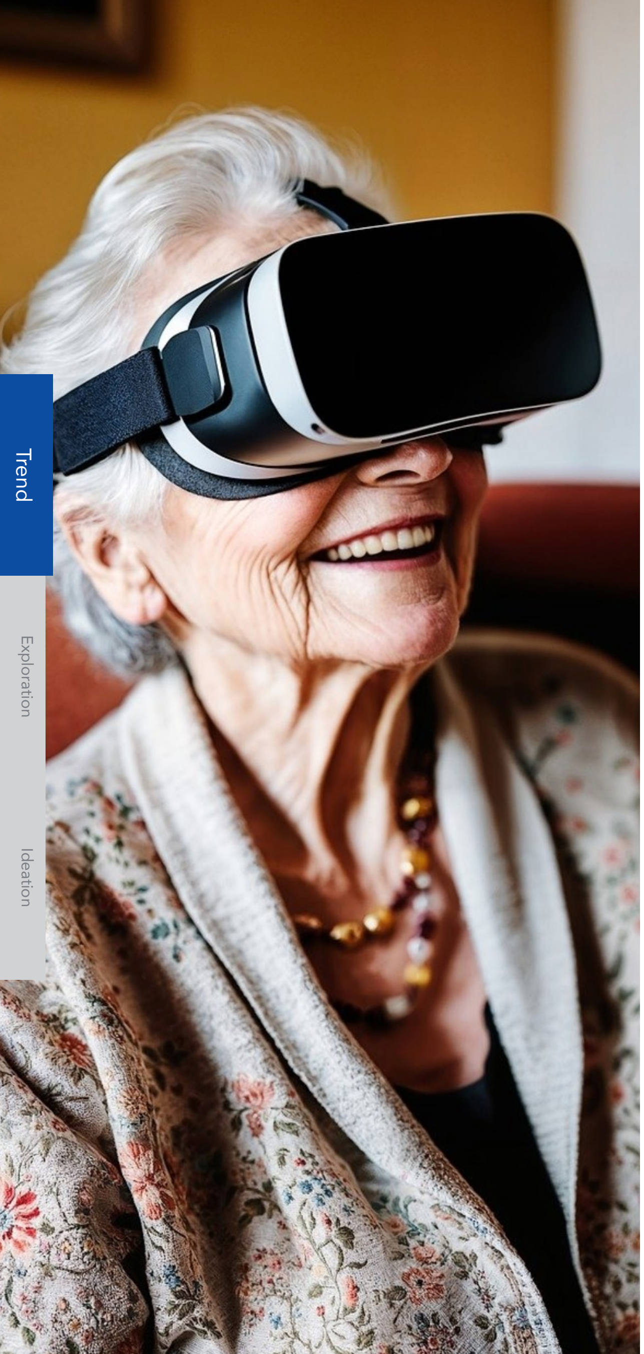
Challenges

- Companies are already recognizing skill gaps as the primary barrier to the evolving job market. Addressing the demand for skilled talent may necessitate external support, which can facilitate innovation and business transformation by providing specialized expertise. While organizations can identify significant skill gaps, they encounter challenges bridging them with local talent [131].
- In response to global events like the COVID-19 pandemic, companies are considering reshoring or bringing operations back to their home countries. This trend is driven by the desire for greater control, reducing dependency on foreign partners, and fostering domestic job creation.

Impact on the Future of Software Engineering and IT Operations

The fast adoption of AI and digital technologies transforms the job market in software engineering and IT. The demand for skilled AI, data, and cybersecurity specialists will rise despite a shrinking global job market. Demographic change only has a minor impact on software engineering, as many professionals are still young and not considering retirement [141].
Subsequently, the talent market has become more global and decentralized. Organizations rely on offshoring, subcontracting, and freelancers to fill critical skill gaps. However, this globalization also introduces challenges, such as managing diverse teams across different time zones and ensuring consistent quality throughout the company.





MODERNIZATION IN EDUCATION

Changes in the Educational Landscape Drive the Skills of Future Software Engineers

Education is crucial in how individuals prepare for and navigate the job market. There is a significant shift in the perception and delivery of education, primarily driven by evolving societal sentiments toward new educational approaches. First, personalized learning and digital fluency are being enhanced by integrating AI and immersive technologies [142]. Secondly, AI-powered tools allow educators to tailor instruction to the unique needs of each learner. At the same time, VR and AR technologies create interactive environments that have the potential to deeply engage students [143, 144]. Additionally, lifelong learning is gaining traction, promoting continuous education beyond traditional school settings. Supported by institutions, governments, and businesses, lifelong learning has become essential in today's rapidly changing landscape [145, 146]. Together, lifelong learning and emerging technologies will enhance digital literacy and adaptability, resulting in a more flexible software engineering workforce.

Facts

- Confidence in fundamental digital literacy can be observed in 72% of students aged between 16 and 18 [145].
- Different initiatives to support lifelong learning, like the World Economic Forum's Reskilling Revolution [145], focus on equipping people with skills in the technological space.
- Lifelong learning initiatives also exist in the private sector. Companies leverage these tools to continuously educate their workforce, even after formal education ends, to keep up with industry trends and skills [146].
- Personalized learning uses digital tools to tailor curricula and assignments to the needs of each student, closing knowledge gaps and considering factors like self-regulation, motivation, and effort [147].

Key Drivers

- Digital transformation reshapes industries, creating new job roles requiring advanced digital skills. Through the rise of AI, the risk of being replaced has emphasized the need to prepare for newly created jobs in the technological space [142].
- Governments and international organizations are prioritizing lifelong learning in their policy agendas. Initiatives like the European Union's (EU) target for 60% of adults to participate in training annually by 2030 reflect this commitment [148].
- For example, Singapore has set new standards for using AI in education with its "Smart Nation" strategy. They use AI on a large scale for personalized learning, special education, and other areas [149].

Challenges

- The cost of education remains a significant obstacle for many individuals, particularly those from low-income backgrounds. Even with financial incentives, the indirect learning costs, such as distance from educational centers and efforts for childcare, are limiting factors [150].
- Digital infrastructure and technology must be more accessible, particularly in rural or disadvantaged areas. This digital divide can limit the ability of some individuals to participate in online learning programs [151].
- The effective integration of new technologies into educational programs requires extensive training, which can challenge teachers [152].

Impact on the Future of Software Engineering and IT Operations

Lifelong learning will shape the future of software engineering by increasing employees' long-term value and improving organizations' adaptability through a more open workforce. Continuous learning fosters a mindset that embraces new technologies and allows organizations to remain competitive in a rapidly evolving industry. Despite that, emerging technologies like AI and VR/AR will bring these modern tools closer to students and increase their future digital literacy, thus enabling the employability of professionals in software engineering and IT operations.

INCREASING SCRUTINY OF DATA PRIVACY

Growing Importance of Data Security and Protection

Current trends in consumer devices, such as wearables and smart home technologies, are significantly increasing the volume of collected data. This data is also becoming more sensitive and personal, particularly in the healthcare sector. Consequently, critical concerns for private and institutional stakeholders arise about data privacy and security. According to recent studies, over 90% of companies stated that their customers would only buy from them if they adequately protected their data [153].

As society increasingly depends on AI for critical tasks, the demand for secure and reliable AI systems is more pressing than ever [154]. Future software development must adhere to stricter regulatory guidelines and implement more robust security measures to ensure safe usage and protect user data. Research shows that most consumers are concerned about how companies utilize and implement AI, making it essential to address these worries, with AI safety playing a pivotal role in future software development [153].

Facts

- 94% of surveyed organizations stated that their customers would only purchase from them if they adequately protected customer data [153].
- 52% of Americans express more significant concern than excitement about AI, with an even more substantial proportion (87%) advocating for stricter government regulations and testing, particularly for autonomous vehicles. Additionally, 75% believe that advancements in AI within healthcare are progressing too rapidly [154].
- An analysis of cyber loss events with more significant damage showed an increase in data exfiltration from 40% in 2019 to 77% in 2022, underlining the growing relevance and value of data [155].

Key Drivers

- The rapid proliferation of IoT sensors, wearables, and mobile devices has substantially increased the volume of personal data collected, intensifying concerns about privacy and security, particularly in the healthcare sector, where the sensitivity and confidentiality of patient data are paramount [156].
- More and more data is collected to train AI models, raising significant privacy concerns. Companies must ensure compliance with global privacy laws and address issues like data accuracy, consent, and transparency to mitigate risks [153].
- There is a significant increase in cyber crime connected to extracting sensitive data, showing an overall trend of data exfiltration issues [155].

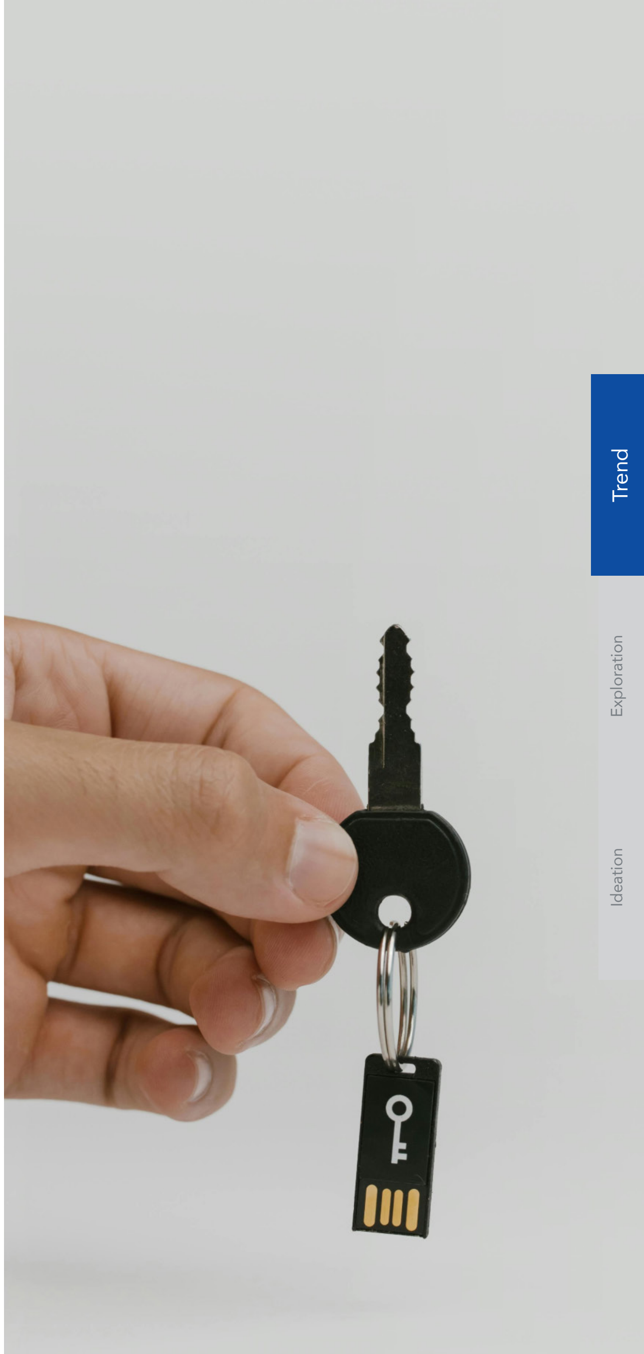
Challenges

- Data liberalization emerges as a trend to accelerate innovation. Both China and the UK are already easing data privacy restrictions to enable more economic growth. China plans to relax cross-border data transfer rules in specific cases, while the UK is adopting a pro-innovation framework to support AI development [157].
- A society's shift towards a technology-critical direction could decrease support for AI. This shift might slow or even stop AI advancements and data collection through technologies like wearables, ultimately impeding the progression of AI integration into everyday life.

Impact on the Future of Software Engineering and IT Operations

Software engineering and IT operations must adapt to increasingly strict regulations and heightened risk management requirements. The growing volume and sensitivity of data place significant responsibility on development teams to integrate security measures throughout the software lifecycle. Cybersecurity has been a significant concern for companies, and it will continue to be so [157].

To address these challenges, software development teams must prioritize secure coding practices, implement encryption, and ensure compliance with data protection laws. Meanwhile, operations teams must maintain robust security protocols, conduct regular vulnerability assessments, and respond swiftly to potential threats.



LEGAL TRENDS

INFLUENCING THE FUTURE OF SOFTWARE ENGINEERING AND IT OPERATIONS

Algorithmic Liability and Transparent AI
Upcoming Intellectual Property Conflicts
Policy-Driven Shift to Decentralized Systems
Navigating International Legal Complexities
Growing Regulatory Lag in IT

Linus Zimmer

Lizzy Stein

Mehmet Uludoğan

Niklas Sindemann

Paul Burkhardt


LEGAL TRENDS

Influencing the Future of Software Engineering and IT Operations

Five legal trends could profoundly influence software engineering and development, highlighting the conflict between rapid technological evolution and conventional regulatory processes.

Algorithmic liability and the need to make AI transparent are pivotal topics shaping AI and its usage. As AI systems take on increasingly critical roles – such as in financial services and autonomous driving – the non-transparency of deep learning models presents significant accountability challenges. The EU's AI Act and the proposed AI Liability Directive are at the forefront of addressing these issues, enforcing transparency in AI decision-making processes and potentially shifting the burden of proof to developers in cases of harm [158, 159]. This regulatory push drives the need for more precise documentation and advanced explainability techniques as businesses strive to balance innovation with legal compliance.

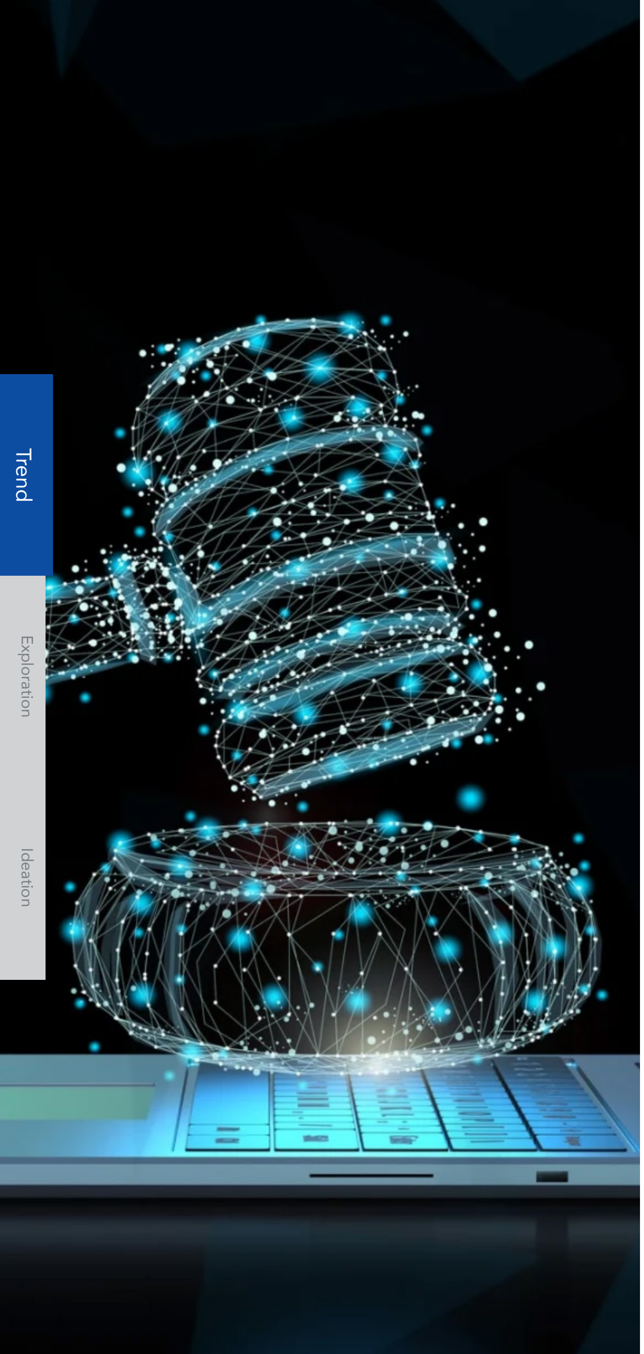
GenAI models require a large amount of training data, which developers often collect from multiple sources in an undisclosed manner. Since this data is usually copyrighted, developers of these models face a growing number of intellectual property (IP) lawsuits [160, 161]. Additionally, AI-generated content, whether text, images, or video, can closely resemble copyrighted works. Meanwhile, enterprises have significantly increased their use of open-source software in recent years, which raises the risk of license infringement due to the resulting complexity [162, 163]. Both trends indicate rising IP conflicts in future software engineering.

Policymakers are increasingly driving the adoption of blockchain-based decentralized systems to enhance technology security and reduce reliance on external tech giants. The EU is leading this shift with regulations like the Markets in Crypto-Assets (MiCA) and initiatives such as the European Blockchain Partnership (EBP), which aim to foster technological sovereignty [91]. Despite challenges like high energy usage and regulatory complexity, higher penetration of decentralized software architectures in software engineering is likely, as governments act as both policymakers and early adopters [164, 165].

Software engineers and organizations must navigate a wide range of international legal complexities. As software operations expand globally, companies must navigate conflicting regulations. The GDPR, the US CLOUD Act, and emerging data localization laws in countries like China and Russia create a fragmented legal landscape [166, 167, 168, 169]. Geopolitical tensions further complicate matters, impacting technology exports and software distribution. To remain compliant and competitive, companies need agile legal strategies that can adapt to these diverse and evolving regulations.

Finally, the growing regulatory lag is relevant as technological advancements often outpace regulatory developments. Rapid advances in AI and blockchain technologies often outpace regulators, creating legal gray areas that make compliance difficult [170, 171]. This lag requires software engineers and legal teams to closely align fast-paced innovation with evolving regulatory frameworks.

These trends reveal the complex link between technology and legal issues in software engineering. Companies must navigate regulations to balance innovation and compliance.



ALGORITHMIC LIABILITY AND TRANSPARENT AI

Algorithm Transparency Can Help to Improve Accountability for AI-Based Decision-Making

Integrating AI in software engineering and IT operations transforms decisions, with AI systems increasingly taking on roles and decisions traditionally made by humans. Pioneering use cases include loan processing in banking and object detection in autonomous vehicles [172, 173]. The trend of relying on decision logic which is not inherently transparent due to the opaque nature of deep learning model design poses several ethical and judicial questions, forming the critical barrier to AI adoption for many businesses [174]. Policymakers aim to define clear legal frameworks and responsibility directives. In 2024, the EU introduced the AI Act, which establishes binding regulations for high-risk AI systems, including transparency requirements, forcing companies to explain how their algorithms work and to keep detailed records for regulatory oversight [175]. Furthermore, explainability techniques can help to approximate how a model determines a specific output [176], though their effectiveness can be limited [19].

Facts

- The EU's AI Liability Directive proposes a fault-based liability regime to alleviate the burden of proof for AI victims through a rebuttable "presumption of causality" against the developer [159].
- The Organisation for Economic Co-operation and Development (OECD) finds that fear of liability for damage caused by AI is the most significant barrier to AI adoption for EU businesses [177]. However, generally, AI can enhance decision-making processes and, thereby, operational efficiency [178].
- GDPR mandates that data controllers of automated systems safeguard data subjects' rights, including the right to human intervention [166]. The EU AI Act requires explainable AI system designs and notification of AI interaction [158, 179].

Key Drivers

- Experts expect AI to play a more prominent role in critical decision-making, with AI assistance projected to be involved in 47% of critical decisions in the life sciences industry within the next five years [178].
- Explainability techniques, such as Local Interpretable Model-agnostic Explanations, help improve model interpretation by examining individual features or local outputs of models [176].
- Increasing regulatory scrutiny and the need for compliance with laws like GDPR, and proposals like the AI Liability Directive are pushing organizations to incorporate transparency into the entire software engineering process [179, 180, 181].

Challenges

- The complexity of deep learning algorithms make it difficult to trace model outputs and decisions back to specific human inputs or technological design, complicating liability determination and stifling transparency [182, 183].
- Ensuring AI transparency requires software engineers to prioritize systematic documentation. This may conflict with practices focused on speed and efficiency [184].

Impact on the Future of Software Engineering and IT Operations

Software engineering, especially in AI, will be strongly influenced by the regulatory need for transparency and oversight, as engineers will potentially be liable for damages resulting from their models. This trend will likely drive changes in documentation, auditing, and development practices, ensuring that AI and software systems remain accountable and trustworthy. As a result, software engineers and IT operation teams will need to adopt new tools (e.g., Beam AI [185], DocuWriter.AI [186]) and methodologies that prioritize transparency without compromising efficiency. Additionally, this focus on transparency may lead to increased collaboration between developers, regulators, and end-users to ensure that AI systems are technically sound and ethically aligned.

UPCOMING INTELLECTUAL PROPERTY CONFLICTS

Navigating the Complexities of GenAI and Open-Source Licensing in Intellectual Property

The rise of GenAI models such as GPT-4o and Midjourney raises many Intellectual Property (IP) issues. First, the development of these models depends on vast amounts of training data, often obtained in undisclosed ways and not owned by the companies developing the models [187]. Second, the AI-generated content may recreate or closely resemble copyrighted works, raising additional copyright issues [160]. As these AI models increasingly find their place in software engineering, both as a development tool and as a technology for building products, these open legal gray areas create a confusing legal environment for software engineers. In addition, companies and institutions' use of OSS has increased significantly in recent years [162]. This results in an increasingly complex landscape of permissive and restrictive licenses, creating the risk of unintentional infringement of IP rights, potential litigation over code use, and challenges in maintaining compliance with different license terms.

Facts

- The New York Times has filed a lawsuit against OpenAI, alleging that ChatGPT infringes on its copyright by scraping and reproducing its articles without permission; however, there is no final judicial verdict yet [160].
- OpenAI and global magazine giant Condé Nast have announced a partnership to allow ChatGPT and its search engine SearchGPT to use their IP and display content from Vogue, The New Yorker, GQ, and other well-known publications [188].
- The US Copyright Office denies copyright protection for GenAI outputs, citing human creativity as a requirement [189].
- There are over 200 different types of OSS licenses, ranging from permissive (e.g., MIT, Apache 2.0) to restrictive (e.g., General Public License), where failure to comply can lead to significant legal liabilities, including forced disclosure of proprietary source code [190, 191].

Key Drivers

- The growing adoption and need for AI training data multiplies legal disputes over ownership and usage rights as it can replicate or closely mimic protected work [161].
- Deep neural networks, like LLMs, need vast amounts of training data, which often has to be obtained by scraping data from the internet or other undisclosed sources [192, 160, 188].
- The use of OSS in companies has been steadily increasing in recent years, and 69% of German companies with at least 20 employees surveyed by Bitkom were using OSS in 2023 [162, 163].

Challenges

- The legal framework governing IP rights for AI-generated content and the permissibility of using scraped data for training purposes remains undefined in some regions and is still evolving. This uncertainty makes it hard for software engineers to navigate the legal complexities of using generative AI [193].
- Companies are under pressure to adopt comprehensive OSS management practices or tools to avoid legal risks from license violations [162].

Impact on the Future of Software Engineering and IT Operations

Future software engineers need to balance the power of AI and OSS while maintaining strict IP compliance. In both the development and use of generative AI, organizations and software engineers must be mindful of legal implications and adapt to changing regulatory frameworks. The growing importance of OSS compliance could also lead to increased investment in tools and processes, such as automated license scanning software. For example, a tool like FOSSA [194] or Mend.io [195] would automatically identify and catalog all open-source components in a project, check for license compliance, and flag potential legal risks.

POLICY-DRIVEN SHIFT TO DECENTRALIZED SYSTEMS

Decentralized Systems for Enhanced Security and Sovereignty

Decentralized systems powered by blockchain technology are being propelled to the forefront of digital infrastructure by policy initiatives, enhancing security, transparency, and resilience while addressing concerns about centralized systems' vulnerabilities. The EU is driving the adoption of decentralized systems to achieve technological sovereignty and reduce dependence on external tech giants [196, 197]. The EU's MiCA regulation provides a clear legal framework for blockchain technologies, reducing the legal uncertainties that previously hampered adoption [165]. Furthermore, individual federal states, such as Bavaria, are driving adoption through policies establishing the region as a leading blockchain hub and promoting practical applications like digital document verification and tax fraud prevention, all while fostering education and trust in blockchain technology through initiatives like Bayern.Trust [198].

Facts

- 27 EU member states, Norway, and Liechtenstein, formed the EBP to develop the European Blockchain Services Infrastructure, leveraging decentralized ledger technologies to improve cross-border digital services, particularly in notarization, digital identity, and data sharing [164].
- The Chinese government launched the Chinese Blockchain Service Network, a global infrastructure promoting decentralized application development on blockchain, integrating decentralized systems within a regulated framework [199, 196].
- New regulations, such as the EU's MiCA regulation, provide a clear legal framework, reducing companies' legal uncertainty when adopting decentralized technologies [165].

Key Drivers

- The EU's push for technology sovereignty directly responds to the region's dependency on non-European tech companies. Decentralized systems, by design, allow for greater control over data and infrastructure, aligning with the EU's broader strategic goals [196].
- The EU supports the development of blockchain skills through initiatives like the CHAISE project to address skill shortages and future needs [200].
- Governments are pushing for more robust cybersecurity measures to protect national security and critical infrastructure, with rising attacks like WannaCry and NotPetya targeting healthcare and other critical sectors [201, 202, 203].

Challenges

- Decentralized systems, particularly those using proof-of-work consensus mechanisms, are criticized for their high energy consumption, raising environmental concerns and practical challenges for widespread adoption [164].
- Over-regulating decentralized systems can undermine their core principles, potentially centralizing control and negating the benefits of decentralization [204].
- Determining liability in decentralized systems is complex, mainly when no central authority exists to take responsibility for failures or breaches, creating legal and operational uncertainties for adopters [205].

Impact on the Future of Software Engineering and IT Operations

The momentum created by policymakers will drive the industry-wide adoption of decentralized systems. In addition, a more mature regulatory environment in the blockchain ecosystem will further accelerate the adoption of decentralized systems. Governments serve not only as policymakers but also as early, significant customers of decentralized software architectures. This dual role will make large-scale business models in blockchain-based software development economically viable and attract a growing number of software engineers. Educational initiatives such as CHAISE have the potential to further strengthen this trend.

NAVIGATING INTERNATIONAL LEGAL COMPLEXITIES

Managing Cross-Border Compliance Amid Fragmented Regulations and Geopolitical Tensions

The rapid evolution of software engineering presents substantial legal challenges, especially in navigating the fragmented landscape of cross-border regulations. Companies must comply with varying data protection laws, such as the EU's GDPR, which imposes strict requirements on handling EU citizens' data, even for companies based outside the EU. In contrast, the US CLOUD Act allows the US government to access data stored by US companies, regardless of where the data is stored [206, 207]. Additionally, rising digital sovereignty movements are prompting countries like China and Russia to enforce strict data localization laws, requiring data to be stored within their borders [208]. "Digital sovereignty refers to the ability to control your digital destiny – the data, hardware and software you rely on and create" [209]. Geopolitical tensions, exemplified by the US-China trade conflicts, have also increased technological export restrictions, further complicating software operations.

Facts

- The GDPR imposes strict data protection requirements on companies handling EU citizens' data, even if the company is not based in the EU [210].
- The US CLOUD Act allows the US government to access data stored by US companies, even if stored abroad, leading to conflicts with foreign data protection laws [207].
- Rising digital sovereignty movements are prompting countries like China and Russia to impose strict data localization laws, requiring data to be stored within their borders [208, 169]. Notably, Russia's 2014 localization law mandates that companies processing data of Russian citizens must store it on Russian soil [208].

Key Drivers

- The global expansion of software companies necessitates compliance with a growing number of diverse and sometimes conflicting international regulations [211].
- Geopolitical tensions, such as US-China trade conflicts, have increased export restrictions on advanced technologies, affecting global supply chains and software operations, as seen with companies like Huawei [211, 212, 213].
- Growing distrust between nations has caused a rise in digital sovereignty [214].

Challenges

- Geopolitical instability causes sudden legal changes, forcing companies to quickly adapt software operations to new export controls to avoid penalties, such as the US restrictions on semiconductor exports to China [212, 215].
- International companies may have to choose which conflicting laws to comply with. For example, the GDPR imposes stringent data protection measures on data transfers outside the EU [216], while the US CLOUD Act mandates data access for US law enforcement even if the data is stored outside the US [207].

Impact on the Future of Software Engineering and IT Operations

Navigating an increasingly complex international legal landscape poses a challenge in the future of software engineering and IT operations. Companies will likely focus on creating more advanced compliance strategies to handle cross-border data flows effectively, navigate diverse regulatory requirements, and adapt to geopolitical changes. This focus on compliance will involve more significant investment in legal expertise and more agile compliance frameworks, even possibly restructuring software operations to localize in key markets. For instance, the OECD highlights the need for mechanisms to facilitate and regulate cross-border data flows, emphasizing the importance of interoperability and harmonized criteria across countries [217].

GROWING REGULATORY LAG IN IT

The Gap Between Technological Innovation and Regulation Widens

Regulatory lag describes the time delay between when a new technology, product, or business model emerges and when regulations are implemented to govern it [218]. Regulatory frameworks have historically struggled to keep pace with technological advances, from the first automobiles to the rapid rise of the internet. However, the gap between technological innovation and regulation is growing unprecedentedly [219]. Rapid developments in fields like AI or blockchain stand in contrast to the relatively slow legislative process designed to ensure thorough consideration of laws and their effects on stakeholders [220]. Regulatory lag can be beneficial, allowing companies to innovate and experiment before regulation is imposed [221]. Furthermore, it can have negative consequences, such as new technologies operating in legal gray areas or facing insufficient oversight [222]. This growing gap in regulatory lag could profoundly affect how software is approached and operated within corporations, as well as how software engineers themselves work.

Facts

- The increasing complexity of regulations in the software field is evident in the significant rise in AI policies, from 5 in 2016 to 77 in 2020 globally [223]. Additionally, multiple state-level privacy laws have been introduced in the US recently, including those in Virginia, Colorado, Utah, and Connecticut, all of which took effect in 2023 [224].
- The legislative process is much slower than the rate at which technology, especially AI, progresses. A policy expert said: "The development of AI technology is currently 2-3 years ahead of regulatory development, and the gap is growing" [225].
- An example of regulatory lag is seen in the cryptocurrency sector, where a boom in emerging platforms outpaced regulators [226]. The collapse of FTX, Celsius Networks, and Voyager highlighted the need for robust regulatory oversight, as inadequate risk management led to significant financial losses [226, 227].

Key Drivers

- The speed of software development has significantly increased due to LLMs and the recent advancements in GenAI.
- Models like GPT-4 vastly outperform their predecessors. Copilots like GitHub Copilot help developers complete coding tasks up to 55% faster [228, 229].
- Legislative processes are not designed to regulate technologies that are developing at such a high pace. Between 2016 and 2020, the average legislative delay was ten months, the longest between 1990 and 2000 [230].

Challenges

- Delays in implementing regulations mean companies and developers operate in legal gray areas. Once rules are introduced, businesses may need to make expensive changes to their products, services, or internal processes to comply, a challenge especially relevant for small and medium-sized enterprises (SMEs) [170, 100].
- Lobbying efforts can influence the decision-making process in regulations like the EU AI Act, potentially delaying or shaping the outcomes [231].

Impact on the Future of Software Engineering and IT Operations

Rapid advances in technologies such as blockchain and AI are changing how software engineers work and driving innovation at an all-time high. However, this progress has outpaced regulatory frameworks, creating a growing gap between innovation and legal governance. In organizations, software development teams focus on innovation, while legal teams ensure compliance – often with conflicting goals. As this gap widens, closer collaboration between these teams is essential to balance innovation and compliance for organizations to remain competitive while navigating the evolving regulatory landscape [232, 233].

ECONOMIC TRENDS

INFLUENCING THE FUTURE OF SOFTWARE ENGINEERING AND IT OPERATIONS

Concentration of Digital Markets
Innovation in Software Automation
Commoditization of Software and IT
Economic Risk Due to Cybercrime
Navigating Talent Shortages

Isabel Tscherniak

Milena Serbinova

Nils Reichardt

Paul Böllhoff

Philipp Hugenroth


ECONOMIC TRENDS

Influencing the Future of Software Engineering and IT Operations

Digital technologies have become an integral part of the modern world. Their growing importance for the global economy is reflected in the stock market, which lists the so-called "Big Tech" companies, such as Google, Apple, Amazon, and Microsoft, as the most valuable in the world. The market capitalization of Microsoft alone is currently at 3T USD [234], which is nearly double the market capitalization of the entire German Stock Index (DAX), which stands at 1.83T USD [235].

Companies invest heavily in innovation to digitize their products and services. The transition towards digitalization shapes how companies design operation processes, drive the development of new business models, enhance customer experiences, and improve overall efficiency. As the software engineering sector is one of the key drivers of digital transformation, trends in the industry significantly impact the broader economy. For instance, innovations in this field can reshape a company's cost and revenue structure by enabling new income streams and business models, such as subscription-based services and data monetization.

However, advancements in digital technologies also bring about significant operational and capital expenditures required to implement, support, and maintain complex digital systems, ensuring their long-term effectiveness and sustainability.

The influence of software engineering and IT services extends beyond innovation and efficiency; it also plays a crucial role in the broader economy. The US tech sector, for instance, contributes roughly 10% of the country's GDP, underscoring its importance as a driver of economic growth and stability [236].

The following section of the trend report explores how economic trends shape the future of software engineering and IT operations. The rising concentration of power among a few tech giants, such as Amazon Web Services (AWS), Microsoft Azure, and Google Cloud, has created a market with fewer competitors, potentially reducing innovation and increasing risks like single points of failure (SPOF). Parallely, advancements in automation and AI-driven tools, such as GitHub Copilot, are boosting efficiency but also bringing challenges like job displacement and rising cybersecurity risks. At the same time, the commoditization of software, driven by the availability of standardized solutions, intensifies price competition, forcing companies to innovate to stay ahead. Cybercrime poses another growing economic risk, with potential losses projected to reach 14T USD by 2028, calling for stronger cybersecurity measures integrated into the software development lifecycle.

In light of these trends, businesses will need to balance innovation, efficiency, and security to remain competitive in an evolving digital landscape.

CONCENTRATION OF DIGITAL MARKETS

Decreasing Competition in the Market Poses Challenges for the Digital Industry

Digital products and services are characterized by high initial investments and low marginal costs [237, 238]. This can lead to a high market concentration, with a few firms dominating the market. Large digital platforms leverage these cost advantages to establish and maintain their dominance in the global economy [239]. However, as companies increasingly depend on these platforms and their cost structures, they face more significant risks of single points of failure, where disruptions in IT systems can cause widespread operational setbacks [240]. These SPOFs arise from the growing reliance of business operations on IT infrastructure, coupled with the increasing number of services produced by a single company. The small number of firms dominating the market determines the direction of the development of a whole industry, significantly influencing research and innovation.

Facts

- With AWS holding 31% of the cloud market share, Microsoft Azure 24%, and Google Cloud 11%, these three giants controlled 66% of the global cloud computing market in 2023 [114].
- The market segment "IT intelligence and analytics" is highly consolidated. For example, Google is the major digital technology and resilience provider, with a market share in the web analytics technologies sector of 74% [241].
- With 45% of Fortune 100 companies reliant on CrowdStrike's cybersecurity platform, the system failure on July 19, 2024, caused over 100B USD in economic damage across healthcare, aviation, finance, and logistics [242].

Key Drivers

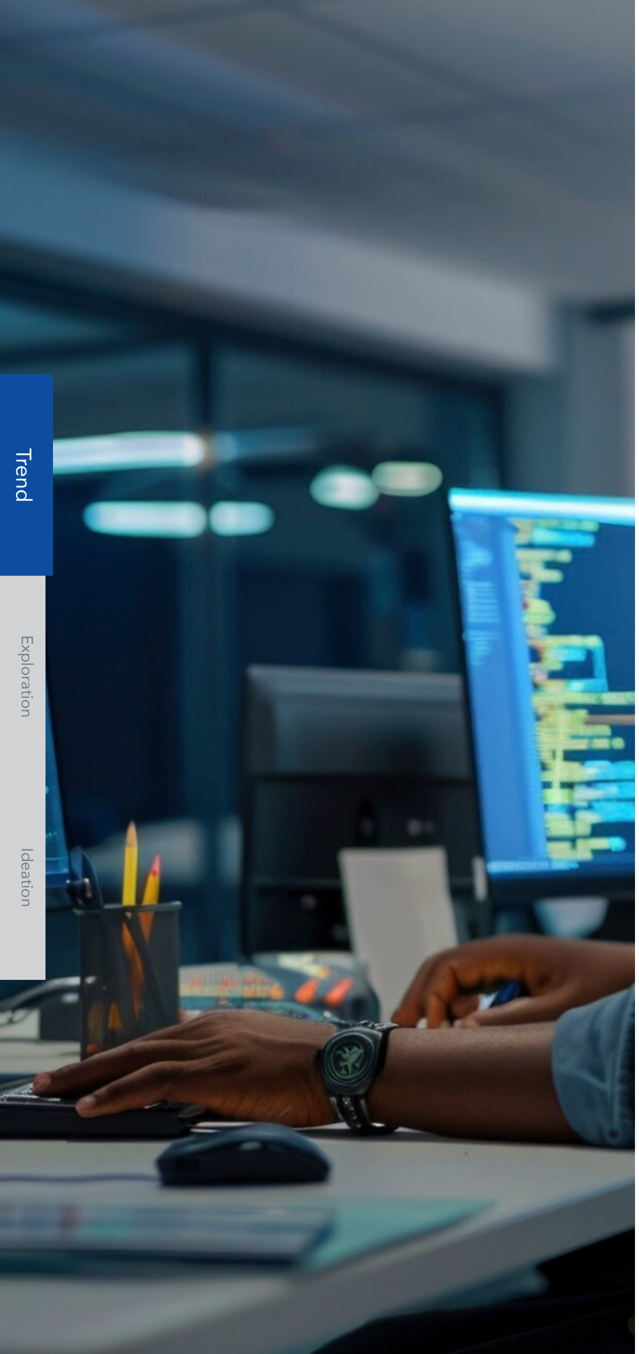
- The non-rival nature of digital goods results in market non-convexity, supporting monopolistic competition, where dominant firms leverage their scale to control market share [243].
- Through vertical integration, established companies can make switching to other solution providers in both software engineering and IT operations difficult and costly [244].
- When products rely on data collection, a self-reinforcing feedback loop can accelerate market dominance. A "virtuous" circle of better data and innovation improves engagement and data sharing. In contrast, a "vicious" circle can emerge when accumulated user data and market power allow a few companies to dominate, potentially stifling competition and limiting consumer choice [245].

Challenges

- Antitrust policies can prevent market concentration. For example, the 10th amendment of the German Competition Act aims to update competition regulations to address modern market abuses and strengthen oversight [246].
- As a result of global internet expansion and the development of accessible AI models, offering new digital products reduces boundaries for entering the market [247]. Therefore, start-ups can compete in niche markets, which larger competitors may overlook due to their "one size fits all" approach [248].

Impact on the Future of Software Engineering and IT Operations

As digital market concentration intensifies, dominant companies may dictate industry standards and technology adoption, limiting variations and creativity in software development. At the same time, more and more experts, attracted by higher salaries and access to vast resources, leave academia to work in these leading tech firms, which can slow down innovation in scientific fields even further [249]. Additionally, the reliance on integrated services from tech giants increases operational dependencies, making it difficult for businesses to switch vendors or adopt alternative solutions. To thrive, the software engineering and operations sectors must focus on fostering open-source innovation and advocating for more inclusive, competitive market environments.



INNOVATION IN SOFTWARE AUTOMATION

Automation and Improved Software Engineering Practices Boost Efficiency

Technological advancements in software engineering and IT operations are increasing the productivity of the labor workforce. The OECD defines workforce or labor productivity as "a ratio between the volume of output and the volume of inputs" [250], where the output is usually measured as the GDP or gross value added. The input can be measured in hours worked and/or the number of employed people. Innovations such as Low-code/No-code (LCNC) and AI-driven coding assistants, such as GitHub Copilot [251], increase software developers' efficiency and decrease the entry barrier for workers with different professional backgrounds and training.

Facts

- Amazon CEO Andy Jassy reported that their GenAI tool for developers saved 4,500 man-years of work for a code migration that now runs more performant and saves 260M USD annually [252].
- In a study of 95 professional developers, the group using GitHub Copilot completed the task of writing a web server 55% faster (1 hour 11 minutes) than the group without GitHub Copilot (2 hours 41 minutes) [253].
- AI's direct impact on software engineering productivity could be 20-45% of current annual spending on the function [254]. Barenkamp et al. point out that AI contributes significantly to cost reduction and efficiency gains in software engineering through the automation of routine tasks and the structured analysis of large data pools [255].

Key Drivers

- It has already been proven that AI increases the productivity of software engineers [256]. This trend is likely to continue in the coming years with the rise of tools such as Cursor, an Integrated Development Environment (IDE)), and Devin (AI Software Engineer) [257, 3].
- The increasing number of new tools aiming to maximize the developer experience like Vercel (platform to easily deploy to the web), Supabase (backend as a service), Codesphere (combines Cloud IDE & DevOps), but also LCNC tools (e.g., DataRobot) boosts the productivity of software engineers [258, 259, 260, 261].
- The widespread automation and adoption of cloud providers have enabled organizations to dynamically and efficiently scale resources [262]. Cloud services provide on-demand infrastructure that allows teams to develop, test, and deploy software without the overhead of manging on premise solutions.

Challenges

- While tools like Vercel can improve the time-efficiency of software engineers, this not necessarily translates to an improvement of overall cost-efficiency [263]. For example, the start-up Cara's web app, powered by Vercel Functions, faced an additional server bill of 98k USD after a surge in usage, compared to development time-saving of a few hours. This illustrates how the efficiency gain compared to costs ended up net negative [263].
- Implementing AI in workplaces raises concerns about job displacement and socioeconomic inequality. The concept of a "Robot Tax", an additional tax for companies using automated systems or AI that replace human workers, is one response to mitigate these effects. Still, it can impact profitability and investments [264].
- The deployment of AI in software engineering also introduces significant data security and compliance challenges, requiring robust measures to manage these risks effectively [265].

Impact on the Future of Software Engineering and IT Operations

The rise of AI-powered tools for software engineers boosts productivity by supporting development processes. This allows teams to achieve more with fewer resources and drives business growth through increased efficiency. Simultaneously, enhanced collaboration tools and methodologies empower larger teams to tackle more ambitious projects, expanding project scope and capacity and further contributing to business growth and innovation. In the long term, these technologies could transform how software engineers work by automating routine tasks and allowing them to focus on more creative and strategic activities.

COMMODITIZATION OF SOFTWARE AND IT

Balancing Commoditization and Standardization in a Software Landscape

"Commoditize" refers to goods or services becoming indistinguishable from rival offerings [266]. This trend is evident in the software industry, where intense competition leads to commoditization as similar features become widespread, reducing differentiation. This results in a supply of standardized solutions and price pressure. A prime example is the LLM space [267], where companies invest heavily but struggle to differentiate [268]. Meanwhile, firms like Meta or Mistral are open-sourcing solutions, increasing competition and lowering prices [269]. Software engineering companies benefit from lower operating costs due to the availability of standardized solutions and accessible infrastructure, accelerating commoditization across the industry.

Facts

- Artificial intelligence is becoming a commodity as more solutions are readily available for end-users [270]. For example, the cost of GPT-4 for 1M tokens has dropped from 180 USD to 0.75 USD in approximately 18 months (240 times cheaper) [271]. Also, the Application Programming Interface (API) cost of other LLMs decreased dramatically [272], and some APIs are even fully open-sourced [269].
- Software as a Service (SaaS) solutions are growing at a compound annual growth rate (CAGR) of 20%, making software solutions a purchasable good [273].
- AI in software engineering can speed up development processes, reduce costs, and boost developers' creative potential by automating routine jobs and analyzing big data [274].

Key Drivers

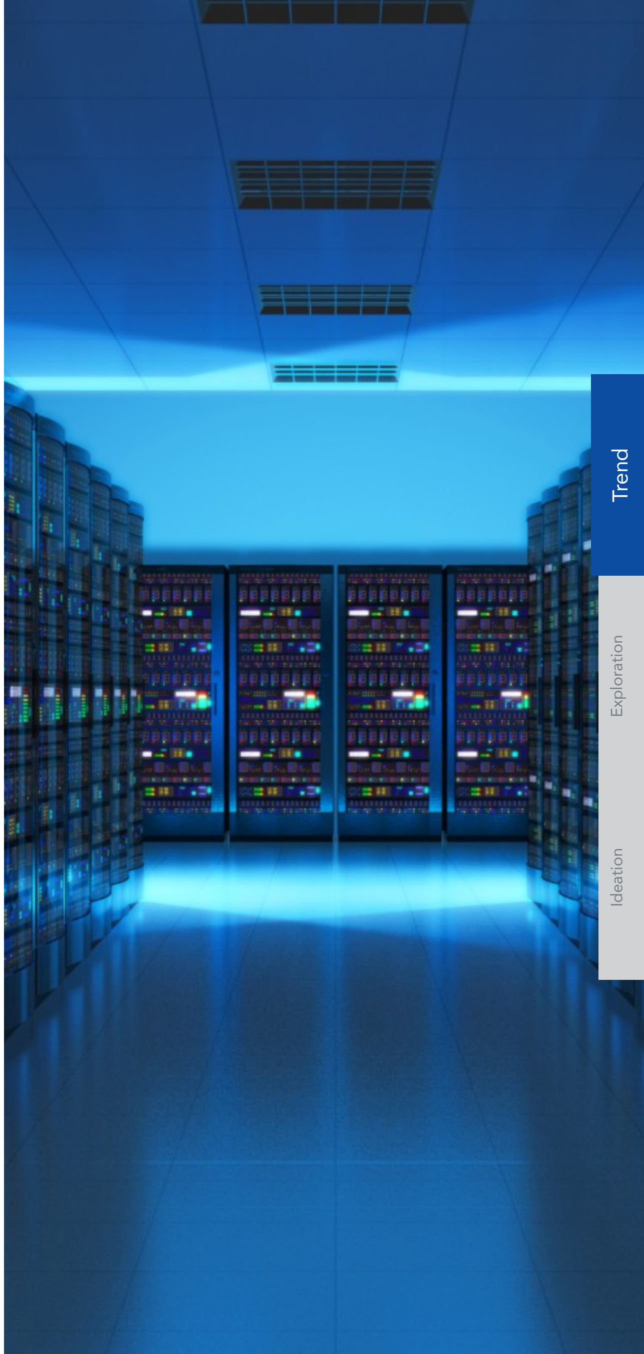
- AI and LCNC tools facilitate the creation of software products, leading to an increased supply that exerts pressure on existing services [275, 66]. Additionally, companies may choose to develop specialized solutions internally.
- The increased investments in data center infrastructure and computing resources drive the availability of computing hardware [276]. An increased availability of undifferentiated hardware drives competition and increases accessibility.
- Software is primarily protected by secrecy rather than IP rights, leading to frequent spillovers, copying, and an increased supply of similar products [277].

Challenges

- As software solutions become increasingly commoditized, vendors face the challenge of differentiating their products to capture positive returns. This drives the need for continuous innovation to stay ahead of competitors and avoid the erosion of value as similar solutions flood the market [278].
- Customer needs for specialized software solutions involving data sovereignty will remain, and standardized solutions will not meet those needs. This challenge is mainly present for multinational companies needing to comply with diverse regional regulations [279].
- The training cost for LLMs rises exponentially [280]. That contradicts the commoditization of best-in-class models but does not, however, contradict the commoditization of undifferentiated standard models [280].

Impact on the Future of Software Engineering and IT Operations

The broader availability of standardized software and computing infrastructure lowers customer costs [281]. Efficiency tools and LCNC platforms also enable software companies to develop their solutions rather than purchase expensive alternatives. However, software companies must continually innovate, build customer loyalty and lock-in, and provide top-quality services to secure sustainable returns. As competitors have similar access to efficiency-enhancing tools, this can increase competition, commoditize specific solutions, and pressure prices and revenues.



ECONOMIC RISK DUE TO CYBERCRIME

Rising Revenue Loss From IT Security Breaches and Cybercrime

Cybercrime refers to illegal activities conducted in cyberspace or utilizing digital devices. Examples of such crimes include phishing, data breaches, identity theft, and fraud [282]. These malicious actions increasingly lead to financial losses for companies, governments, and individuals in two ways: directly through theft of resources or indirectly through reputation damage.

The increase in cybercrime has several causes. First, advances in software engineering and IT operations have enabled more sectors to move into the cyberspace. As more essential services are digitized, the potential attack surface for cybercriminals has expanded. As a result, both the frequency and sophistication of cyberattacks have increased. Finally, technological innovations are making cyberattacks easier and more accessible to a broader range of people.

Facts

- Cybercrime is estimated to have cost businesses over 8T USD in 2023, with projected losses nearing 14T USD by 2028 [283].
- In 2023, 46% of organizations reported reputational damage due to data breaches [283].
- The fear of cybercrime can decrease consumer confidence in online services. This avoidance results in indirect economic costs by reducing the use of these services, thereby impacting business revenues [284].
- The cybersecurity economy grew four times faster than the global economy in 2023 [285].

Key Drivers

- The digital transformation has increased the attack surface for cybercriminals as businesses adopt cloud computing, IoT devices, and remote work technologies. The advancements spread data across different systems, creating more vulnerable points for potential attacks [286].
- The emergence of Ransomware-as-a-Service (RAAS) on the darknet has enabled less-skilled cybercriminals to harm compnies. AI-driven attacks, like deepfakes, present significant challenges for detection and mitigation [287, 288].
- Many organizations struggle with cybersecurity vulnerabilities from underinvestment in tools, personnel, and training, exposing them to significant financial losses amid a global shortage of cybersecurity professionals [289].

Challenges

- IT security and cyber resilience measures, like software maintenance and vulnerability patching, are vital to minimizing potential losses. Advanced strategies such as redundancy planning and AI-driven monitoring are crucial to effectively detecting and responding to threats [290].
- Many companies and governments set aside financial reserves and use cyber insurance to recover from cybercrime-related losses, especially in high-risk sectors like finance and healthcare, where these strategies mitigate long-term economic impacts [285].

Impact on the Future of Software Engineering and IT Operations

The increasing economic risk due to cybercrime impacts Software Engineering and IT operations. Organizations are integrating cybersecurity into all aspects of the software development life cycle to mitigate these growing risks. This "shift-left" approach embeds security practices like threat modeling and Static Application Security Testing/Dynamic Application Security Testing (DAST) tools early in development, reducing vulnerabilities and breaches [291]. Additionally, sophisticated cyberattacks drive IT operations to prioritize continuity planning and rapid response. For example, financial institutions deploy zero-trust architectures and dispersed data centers to safeguard against disruptions [292]. AI-driven monitoring tools, such as security information and event management systems with user and entity behavior analytics, enhance real time threat detection and response, reshaping workflows and resource allocation [293, 294].

NAVIGATING TALENT SHORTAGES

Despite Automation Through AI, the Demand for Software Engineers Continues

Even with current productivity gains from tools like GitHub Copilot, the demand for software engineers continues to significantly outpace the size of the available talent pool [251, 295, 66]. This talent shortage will continue as technological advances in AI change the roles of software engineers and create new areas of responsibility [296]. This task-based technical transformation of work will lead to further growth in the demand for tech talent [297, 298]. An example of this automation is end-to-end AI software engineers, like Devin AI [3]. To retain and attract new talent, companies will need to continue to offer remote and hybrid positions, as telework is especially common among IT specialists [299]. However, the impact of remote working on the productivity of individual software engineers has not been determined yet [300, 301, 302]. A distributed workforce also makes talent location less relevant, allowing companies to scale the workforce flexibly and reduce operational costs by outsourcing clearly defined tasks [303, 304].

Facts

- While tools like GitHub Copilot are widely used and boost productivity, they have not reduced the overall demand for software engineers, which continues to outpace the available talent pool [305].
- Telework was exceptionally common for IT specialists, accelerated through the COVID-19 pandemic [299]. Reports indicate that the percentage of software engineers working entirely remotely can be as high as 60-80% [306, 305].
- Outsourcing jobs in the IT sector is expected to show an annual growth rate of approximately 8% over the next few years [306]. Through outsourcing, companies can directly benefit from lower labor cost markets and maintain high-quality output [307].

Key Drivers

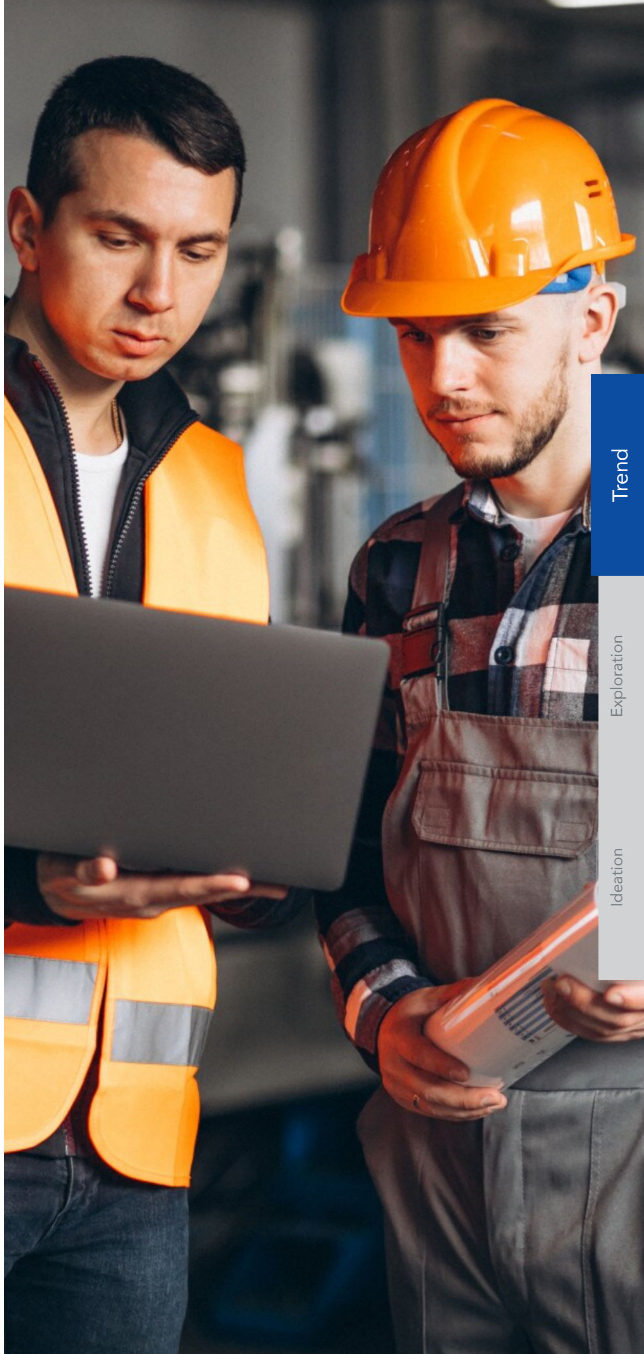
- AI-driven automation in software engineering will transform workflows by redistributing tasks and altering how work is performed. While some current tasks may disappear, new and more complex tasks will emerge that require human expertise [308].
- Given the shortage of software engineers in the labor market, remote work can be another incentive to attract talent. In particular, young professionals now entering the market value remote or hybrid working [309].
- By outsourcing, companies can access a global talent pool and benefit from lower labor costs while maintaining high-quality output [303].

Challenges

- Companies fear outsourcing software engineering to low-cost labor markets due to an expected poorer quality of outcome [310]. At the same time, AI will handle non-core business and low-skilled labor traditionally outsourced, challenging the outsourcing market's growth [311].
- Many companies are requiring employees to return to the office. In particular, large tech companies have made headlines by forcing their employees back to their primary locations [312]. Similarly, software engineering hubs such as San Francisco can still attract a high density of talent and shift towards face-to-face work, especially for startups, challenging the trend towards distributed work [313].

Impact on the Future of Software Engineering and IT Operations

The shortage of software engineers is likely to persist. To attract talent, companies that employ software engineers need to offer flexible working arrangements. Outsourcing can be a short-term solution to the labor shortage, with access to a global talent pool to solve specific problems. In the longer term, automation has the potential to take over this low-skilled labor and change the nature of what software engineers do, leading to more potential jobs in the software engineering landscape. Outsourcing tasks until they can be automated, as Klarna did for customer success, may be a future pattern we will see across the industry [314, 315].



ENVIRONMENTAL TRENDS

INFLUENCING THE FUTURE OF SOFTWARE ENGINEERING AND IT OPERATIONS

Need for Environmental Solutions

Cutting Emissions with Green AI

Improved Resource Efficiency in Digital Infrastruture

Sustainable Software Development

Shift to Circular Economy

Max Knoll

Rudraksha Samdhani

Selin Yildiz

Sophie Tollmann

Teresa Mercedes Maurer


ENVIRONMENTAL TRENDS

Influencing the Future of Software Engineering and IT Operations

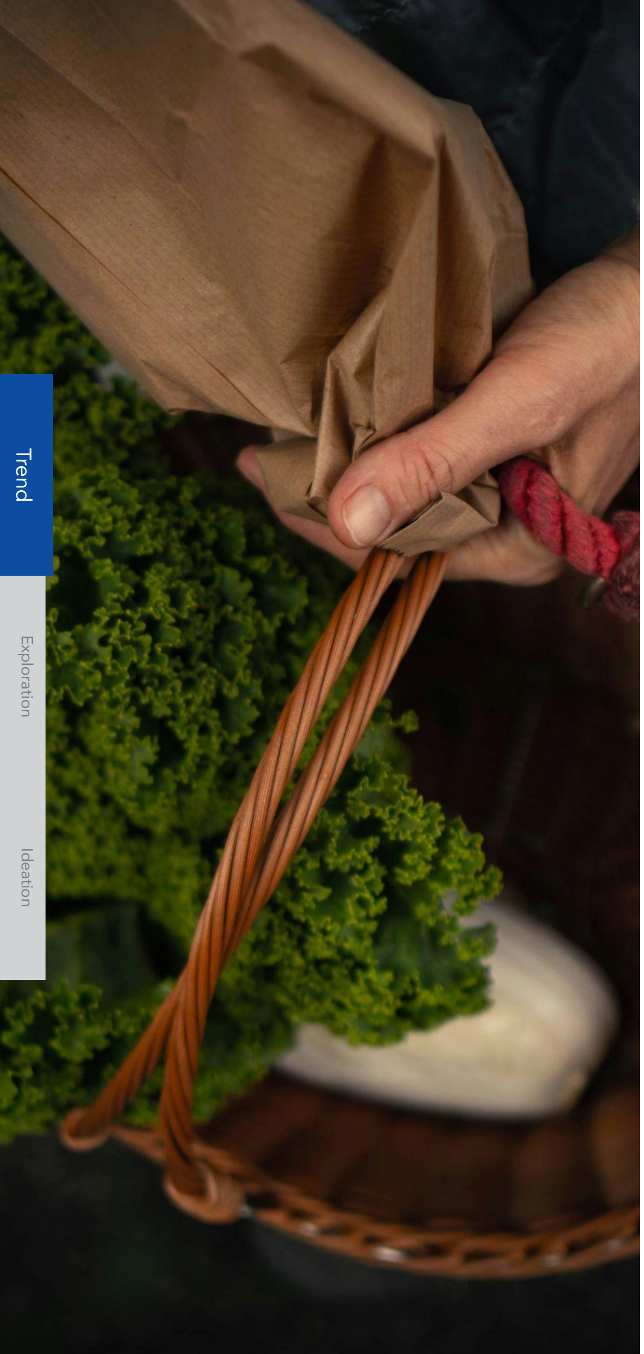
Software engineering and IT operations are central to alost all aspects of modern life – powering industries, businesses, and everyday activities. As the importance of these areas grows, so does their environmental impact. The rapid pace of digital transformation, fueled by advances in cloud computing, AI, and IoT, has led to an unprecedented increase in energy consumption, much of which still stems from non-renewable sources. Data centers, artificial intelligence, and cryptocurrencies currently account for 2% of global energy demand, a figure expected to double by 2026 [316]. This constitutes a significant challenge as companies and governments worldwide strive to achieve ambitious climate targets, such as reaching net-zero emissions by 2050 [317]. Thus, the IT industry is under increased scrutiny by regulators and the public [318]. In response to these challenges, the importance of sustainability in software is increasingly recognized.

One approach to more sustainable IT is adopting computing practices that optimize software and hardware performance while minimizing energy consumption [318]. Additionally, innovations such as advanced cooling technologies for data centers, carbon-conscious software development, and using renewable energy sources are becoming increasingly important [319]. These strategies can potentially reduce costs and improve the organization's reputation by aligning business practices with environmental goals.

Furthermore, shifting to sustainability-focused software practices necessitates the integration of environmental considerations into every stage of the software lifecycle. This includes developing inherently efficient software, minimizing waste through modular and reusable code, and using cloud platforms that provide scalable resources without unnecessary overcrowding [320].

Despite progress, a significant challenge remains: many organizations fail to measure the environmental impact of software, even though standardized metrics like carbon dioxide (CO_2) exist. Without clear benchmarks, companies find it difficult to effectively assess the sustainability of their practices. In addition, there is often a gap between introducing environmental initiatives and the company's commitment to sustainability. Superficial efforts, often seen as greenwashing, can damage trust and undermine the credibility of the industry's sustainability efforts [321].

The software industry stands at a critical crossroads, balancing the pursuit of technological innovation with the urgent need to mitigate its environmental impact. By prioritizing sustainable practices from energy-efficient data centers to carbon-conscious software development, the industry has the potential to make a meaningful contribution to global sustainability goals [320]. This transition is vital for reducing the environmental footprint of digital technologies.



NEED FOR ENVIRONMEN-TAL SOLUTIONS

Empowering Businesses to Achieve Environmental Goals

Sustainability-as-a-Service is an emerging business model that productizes specific sustainability considerations into digital service offerings, such as smart building solutions, Environmental, Social, and Governance reporting, and carbon accounting. These services are part of a broader transformation where traditional products (e.g., sustainability consulting) evolve into digital solutions (e.g., a self-service carbon accounting platform) [322].

Sustainability-as-a-Service solutions offer sustainability as a core business value, thus empowering customers to actively contribute to a sustainable future. However, for customers to fully embrace these solutions, they must address current business needs while preserving resources for future generations, effectively transforming sustainability theory into practical, actionable services [323]. To succeed, Sustainability-as-a-Service solutions must help companies achieve environmental goals while remaining profitable [324]. Balancing environmental responsibility and economic success while implementing such solutions requires the right combination of technological knowledge, organizational capabilities, and a deep understanding of sustainability principles [323, 324].

Facts

- Sustainability-as-a-Service business models leverage cloud computing, IoT, and AI to provide real time monitoring and optimization of IT resources, ensuring environmentally responsible operations [184].
- Only 19% of organizations measure the energy impact of pre-production development and testing [325].
- Historically, sustainability has not been a significant focus of service research. Interest, however, is rising as a sustainable future is unattainable without implementing more sustainable service practices [326].

Key Drivers

- Organizations such as the World Economic Forum emphasize the need for sustainable business strategies with circular economy principles at their core [324].
- Increasing regulatory pressure, such as the EU Corporate Sustainability Reporting Directive, mandates organizations to adopt comprehensive sustainability strategies [327, 328].
- Growing consumer demand for sustainable products and services encourages companies to integrate sustainability into their core operations [327].
- Advances in AI and data science offer powerful tools for industries to reduce greenhouse gas emissions and improve overall sustainability performance [329, 330].

Challenges

- The lack of universally accepted standards for assessing sustainability poses a significant challenge to effective decision-making and implementation processes [330].
- The superficial adoption of sustainability practices without genuine organizational change may result in perceptions of greenwashing, undermining organizational credibility [331].
- Inadequate communication and insufficient incentives within organizations can significantly impede the successful implementation of sustainability strategies [330].

Impact on the Future of Software Engineering and IT Operations

The rise of Sustainability-as-a-Service models is reshaping the future of software engineering and IT operations in two key ways. First, with the growth of AI and other advanced technologies, new solutions are being developed that deeply integrate sustainability into software operations. This allows software operations managers to better account for the environmental impact of their systems. Second, Sustainability-as-a-Service is a technical interface for software engineers, empowering them to incorporate sustainability into their development work. By developing their own Sustainability-as-a-Service solutions, engineers can take on an active role in shaping sustainability strategies, making environmental considerations a fundamental part of software design and operations, and positioning them as key contributors to an organization's sustainability goals.

CUTTING EMISSIONS WITH GREEN AI

Reducing AI's Carbon Footprint Through Computational Efficiency

"Green AI" encompasses the growing commitment to reduce the impact of AI on the environment by improving computational efficiency in development, training, and deployment [332]. Over the past decade, AI has made remarkable progress in areas such as object recognition, gaming, and speech recognition, primarily through increasingly complex and computationally intensive deep learning models [333]. However, these advances have come at a significant environmental cost, as the energy consumption and resources required to train and run these models have increased dramatically [333]. Green AI seeks to address this challenge by incorporating sustainable practices that minimize carbon emissions and energy consumption to make AI development more environmentally friendly. This approach not only reduces the environmental footprint of AI but also has the potential to improve the performance of AI systems. Green AI prioritizes sustainability, ensuring that AI technologies can develop without worsening environmental issues while balancing AI advancements with the responsibility to protect our planet [332].

Facts

- The computational demands of cutting-edge AI research have increased 300k-fold in the last six years [333].
- Training large AI models (e.g., BERT, GPT, and other big LLMs) emit about 280k kg of CO_2, the equivalent of 300 round-trip flights between New York and San Francisco - nearly five times the lifetime emissions of an average car [334].
- Training GPT-3 on a dataset of 500B words consumed 1.29 GWh of electricity. It involved 10k computer chips, comparable to the energy needed to power about 121 homes in the US for a year [332].
- OpenAI researchers report that the computing power required for advanced AI models has doubled every 3.4 months since 2012 [334, 335].

Key Drivers

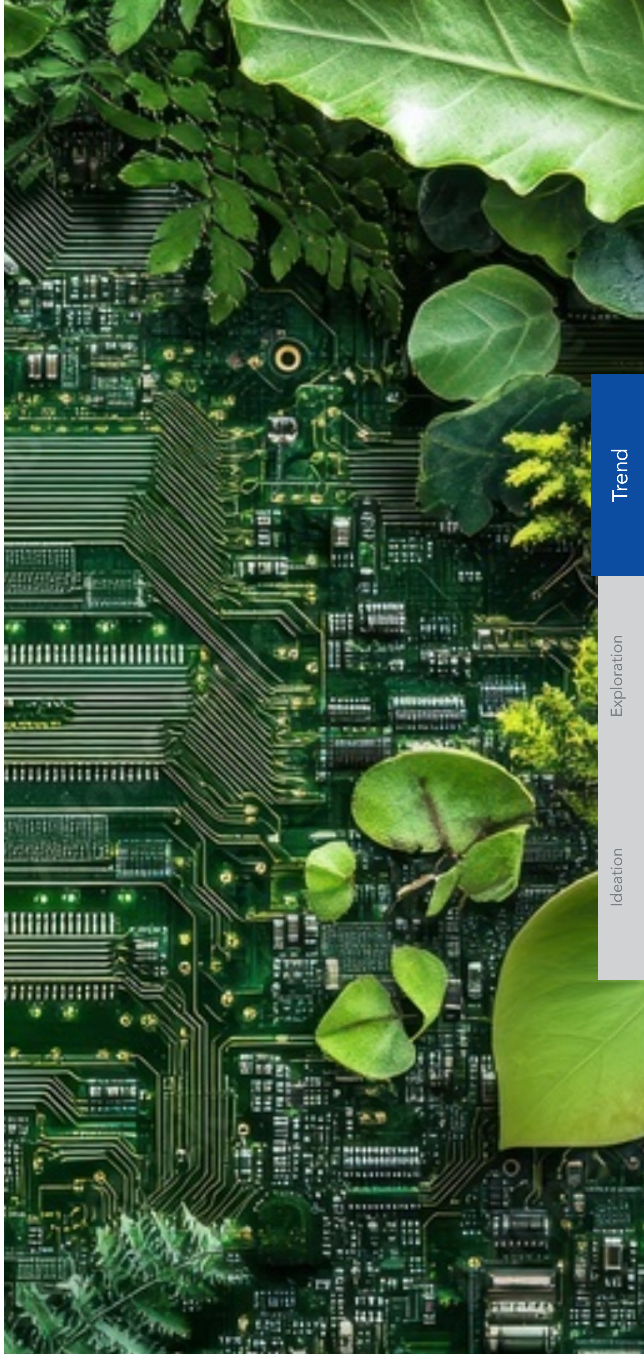
- Reducing power consumption through modern cooling systems, optimized power management, more efficient computing, and support hardware will drive Green AI [336].
- Governments and organizations promote transparency of the environmental impact of AI with reporting guidelines such as the European Code of Conduct for Data Centers and the Spanish National Plan for Green Algorithms [337].
- Supporting green projects strengthens brand reputation and attracts environmentally conscious investors, consumers, and stakeholders, building trust and loyalty [338].
- Modular systems, like modular data centers, and virtualization techniques, such as virtual servers or storage, help meet future demands by enabling scalable, flexible infrastructure without proportionately increasing energy consumption or costs [336].

Challenges

- Green AI relies on high-quality data for accurate decision-making, but limited data infrastructure in some regions can lead to increased energy consumption and less precise results [339].
- Privacy and security are critical concerns for Green AI, as these systems often manage sensitive information such as energy consumption and transportation patterns [340].
- A notable shortage of professionals with the necessary expertise in AI and environmental science hinders progress in Green AI initiatives [339].

Impact on the Future of Software Engineering and IT Operations

Green AI offers a path to cut the carbon footprint of advanced models. Green AI balances performance improvements with ecological responsibility by focusing on sustainable practices such as optimized cooling systems and power management. This approach will increase energy efficiency and transparency in IT operations, aligning technological advancements with environmental sustainability. It also addresses challenges like data quality and expertise shortages, paving the way for more responsible AI development.



IMPROVED RESOURCE EFFICIENCY IN DIGITAL INFRA-STRUCTURE

Minimizing Environmental Impact through Carbon-Aware Computing and Green Data Centers

Digital infrastructure encompasses the facilities and systems involved in collecting, exchanging, storing, processing, and distributing data [341]. As the demand for these activities grows exponentially, so does the energy consumption associated with them [342, 343]. Traditional data centers – the backbone of the internet and cloud services – have historically been significant electricity consumers. They often rely on non-renewable energy sources, contributing to 0.6% of global greenhouse emissions [344]. In addition, vast amounts of water are consumed for cooling systems in data centers [345]. Technological innovations in digital infrastructure range from hybrid cooling systems aimed at reducing water consumption compared to liquid cooling systems for data centers to Green Computing, which refers to practices that lessen the adverse effects of technology on the environment [346, 347]. Sustainable computing and green data centers aim to address these challenges by adopting energy-saving technologies like cloud, spatial, and quantum computing.

Facts

- Between 2015 and 2021, the International Energy Agency reported a 260% increase in the computational tasks handled by data centers, reflecting the increasing adoption of digital technologies [348].
- By 2025, 85% of organizations are expected to embrace a cloud-first principle, with cloud data centers being 80% more energy efficient than traditional data centers [349].
- An average data center uses approximately 300k gallons of water per day for cooling, roughly equivalent to the water usage of 100k homes [350].

Key Drivers

- Data generated at datacenters is expected to double in the next five years. In response, total storage capacity in data centers and endpoint devices will grow from 10.1 zettabytes (ZB) in 2023 to 21.0 ZB in 2027 [351].
- Regulatory requirements, such as the EU Energy Efficiency Directive, require data center operators to adopt more sustainable practices to meet upcoming standards [352, 353, 354].
- Cloud service providers reduce capital expenditures on hardware, which leads to a shift toward operational expense models. This offers the potential for more efficient resource allocation and cost management. This encourages major companies to adopt cloud services, resulting in savings on energy, software, and hardware [355].

Challenges

- Significant upfront investments and infrastructure redesigns are required for implementing sustainable technologies like hybrid cooling and renewable energy integration in data centers [356].
- Companies cannot implement more efficient technologies without expertise in the respective domains, e.g., specialized hardware, quantum computing [357].

Impact on the Future of Software Engineering and IT Operations

The focus on sustainability in digital infrastructure will drive innovation in computing, cooling, and power management solutions, ultimately leading to more resilient and environmentally responsible IT infrastructure [184]. This will require simultaneous advancements in software engineering, including emerging computing methods such as quantum computing, AI-driven development, and edge computing, as well as adjacent technologies that improve resource efficiency [344]. These emerging advancements drive a shift in skills and approaches in both software engineering and IT operations.

SUSTAINABLE SOFTWARE DEVELOPMENT

Leveraging Sustainable Software Practices for Enhanced Resource Efficiency

While the environmental impact of the information and communications technology (ICT) sector is often attributed to hardware [358], software engineering is under-prioritized since it can have a significant environmental impact. For instance, if software developed for a planned data center achieves a 100% efficiency gain, it could halve the required number of servers [359]. CO_2-efficient software consumes less energy, requires fewer resources, and adapts to the availability of clean electricity [360]. These practices not only decrease the energy demand of applications but also reduce operational costs, extend the lifespan of hardware, and enhance compliance with increasingly stringent environmental regulations [361]. By adopting these practices, the industry can develop high-performance software that meets both functional requirements and contributes towards meeting global sustainability goals.

Facts

- Despite increasing awareness of the importance of sustainability, only 28% of organizations measure the environmental impact of their software development, and just 27% have an internal cost of carbon for their software projects [321].
- COP28's website generates 3.69 grams of carbon emissions with each page load. Over the course of a year, with 10k page views per month, this exceeds the emissions of a one-way flight from San Francisco to Toronto [362].
- Google and Electricity Maps developed a carbon footprint calculator for Google Cloud customers, allowing them to choose cloud regions with lower carbon intensities and view their carbon footprint based on grid emissions [363].
- Compiled languages like C, C++, and Rust are 3-4 times more energy-efficient than interpreted languages like Python or Ruby [364].

Key Drivers

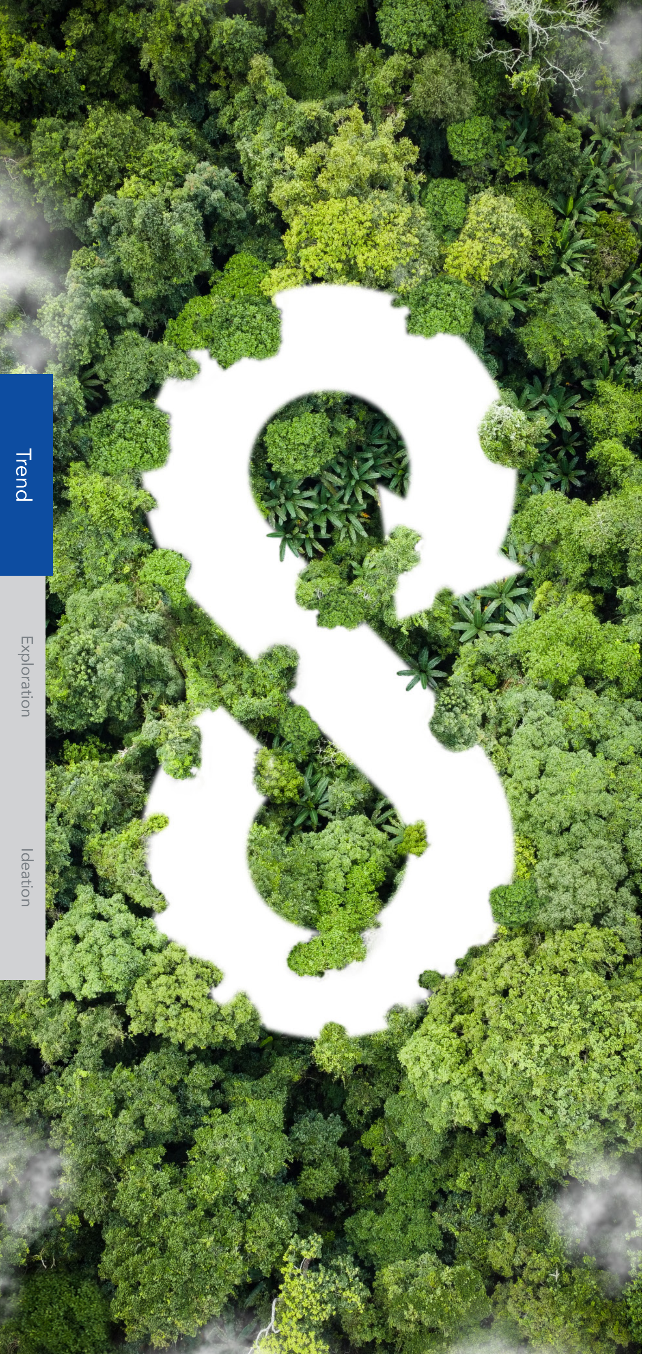
- Frameworks like the Software Carbon Intensity specification or the carbon-aware Software Development Kit tool by the Green Software Foundation are becoming industry standards, helping organizations measure and reduce the carbon footprint of their software [360].
- Legislation like the EU's Corporate Sustainability Reporting Directive mandates that companies disclose their environmental impact, including product-related emissions, thus promoting sustainable practices across various departments [365].
- Rising energy costs and the increasing availability of energy-saving hardware drive demand for energy-efficient software, as environmentally friendly practices help reduce power consumption and operating expenses [184].

Challenges

- The lack of measurement methods and transparency regarding software energy consumption poses a significant challenge in establishing practical norms and standards for sustainable software design [359, 365].
- Despite the availability of tools and techniques for sustainable software development, adoption rates remain relatively low, necessitating substantial training and a cultural shift within organizations to adopt sustainable software practices [184, 366].

Impact on the Future of Software Engineering and IT Operations

Integrating sustainable practices into software development will transform the industry by increasing the focus on energy efficiency and reducing the environmental impact. Establishing new standards for assessing the ecological footprint of software, combined with enhanced data transparency from hyperscalers, will enable organizations to better understand their software's environmental impact [360]. Moreover, integrating sustainable software practices in education will prepare future software engineers to drive the transformation towards reduced carbon emissions, lower costs, extended hardware lifespans, and enhanced organizational reputation. This shift towards sustainable software development is crucial to creating an organizational culture that supports achieving ambitious sustainability goals.



SHIFT TO CIRCULAR ECONOMY

Reducing E-Waste Through Enhanced Software Management

The circular economy aims to extend the lifespan of materials through repairing, refurbishing, and recycling components into new products or materials. Unlike the conventional linear model, which relies on raw materials and generates significant amounts of waste, this approach prioritizes sustainable practices [367]. Integrating circular economy concepts into IT operations promotes the responsible management of data centers, energy consumption, and hardware lifecycles [368]. But also in software development, as businesses increasingly recognize the importance of sustainability, software engineers will likely prioritize circular models, ultimately reshaping how technology is developed, deployed, and maintained. For example, adopting software practices like microservices can reduce the need for constant redevelopment, lowering the required energy and compute [368].

Facts

- By 2025, 75% of large enterprises will adopt circular economy principles, such as automated testing and deployment practices. These approaches will facilitate continuous software improvement and modernize legacy system designs, reducing the need for new software and resulting in “circular software” [369].
- Over-the-air software updates powered by SaaS models reduce e-waste by eliminating the need for physical software distribution and frequent hardware updates [370].
- More than 90% of applications currently contain open-source components, which technically are reusable code and reduce code redundancy [371].

Key Drivers

- Collaboration across the value chain, including partnerships between manufacturers, designers, and recyclers, is essential to promote circularity and ensure the smooth recirculation of materials [372].
- Circular economy practices can lead to cost savings by reducing waste and retaining materials, which can lower production costs and open new markets [373].
- Circular economy principles aim to reduce waste and pollution, optimize resource use, and promote the reuse, repair, and recycling of products [374].

Challenges

- Implementing circular principles in software management requires significant changes to established practices and mindsets, which may provoke resistance. For instance, ERP software customers must adapt to new updates and learn how to use them effectively [375].
- Factors like resource usage optimization require advanced technical solutions, such as new computing methods and AI-driven software, which may not be accessible to emerging companies [375].
- The circularity of software and its environmental impact is hard to quantify, which makes it challenging to assess progress and set clear goals for Corporate Social Responsibility reports [376].

Impact on the Future of Software Engineering and IT Operations

A more circular approach will shift software engineering and IT operations towards more sustainable, efficient, and long-lasting software systems. This, in turn, will drive innovations in software design, development, deployment, and maintenance, creating an industry that prioritizes sustainability alongside technological advancements. As developers strive to minimize e-waste and enhance resource efficiency, software engineering will likely emphasize maintaining open-source software, optimizing resources, and designing new modular software architectures.

EXPLORATION

In the upcoming chapter, the outcomes of the process for validating market hypotheses and problem statements are explored. This phase primarily revolves around the discovery of white spaces and opportunity areas in the established sector of Software Engineering and IT Operations. By clustering the topic, findings are distilled into five key opportunity spaces, and the most critical problems and opportunities within the chosen domain are identified. The exploration phase places a priority on the testing and re-evaluation of hypotheses with expert insights, alongside an examination of the existing landscape to pinpoint key market players.

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COMPUTING RESOURCE EFFICIENCY.........56

OPTIMIZING COLLABORATION....................61

CYBERSECURITY..66

SOFTWARE COMPLIANCE

INFLUENCING THE FUTURE OF SOFTWARE ENGINEERING AND IT OPERATIONS

Monitoring Regulations

Implementing Regulations

Software Certification

Federico Harjes 
Jonas Seidou 
Max Knoll 
Niklas Sindemann 
Nils Reichardt 
Selin Yildiz 

SOFTWARE COMPLIANCE

Understanding, Implementing and Benefiting from Compliance in Software Engineering

Compliance refers to adhering to the applicable regulations to ensure that an organization meets the legally binding criteria for security, safety, and accountability [377]. Software engineering and IT operations have often been subjected to slow regulation and legislation. However, recently, compliance has grown in importance at national and international levels within start-ups, SMEs, and larger corporations [378].

As new technologies continue to emerge, regulators introduce large amounts of legislation, increasing complexity in regulatory frameworks across industries. In the software sector, new rules and requirements are being enacted at an unprecedented rate [379]. Companies must quickly understand regulations and adapt to implement them or face legal consequences. For example, under the EU's GDPR guideline, businesses can face fines of up to 20M EUR or 4% of a firm's annual global revenue for non-compliance [380].

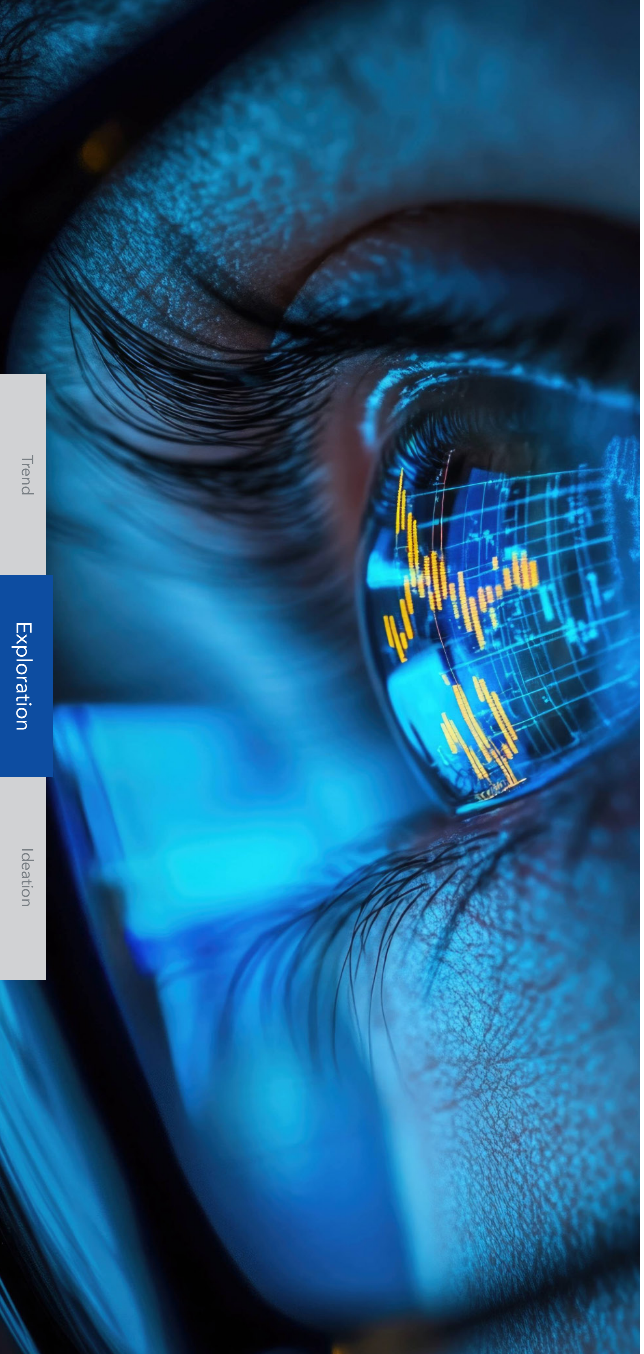
Within software engineering, this growing emphasis on compliance has two primary implications. Firstly, secure, reliable, and compliant software is essential in today's market, but meeting these standards is increasingly difficult due to the rising complexity of laws [381]. Secondly, compliance regulations are becoming more demanding in sectors beyond software, like healthcare, finance, and manufacturing, leading to a rise in tech solutions to help navigate this regulatory maze [382]. As a result, compliance in software engineering is becoming increasingly important to organizations of all sizes.

However, this introduces several challenges. Companies must navigate the complexities of monitoring regulations, implementing them, and ensuring clear communication and certification of their software products. Within software compliance, the following three issues are most prevalent.

First, monitoring, understanding, and interpreting how new and updated regulations impact a business is critical and challenging for companies [383]. Currently, companies rely on legal firms and consultants for assistance, but in the future, these services may be supplemented or replaced by specialized, automated compliance solutions.

The second challenge for companies is acting on and implementing new regulations. SMEs must deal with manual tasks such as documentation to remain compliant, often leading to high costs [384, 385]. AI-driven tools can automate tasks, reduce human error, lower costs, and revolutionize product management and engineering [386]. Compliance departments must constantly enforce product, architecture, and code changes to meet new regulatory requirements [387].

Finally, software certifications are key in building trust and accessing new markets [388, 389]. Certifications from organizations like the International Organization for Standardization (ISO) help establish minimum standards for quality and safety, but incorporating these processes is expensive and time-consuming [390]. Especially start-ups and SMEs struggle as they have limited financial resources [391].



MONITORING REGULATIONS

Identifying, Interpreting, and Assessing Relevant Regulations in the Ever-Changing Legal Landscape

The rapid advancement of technology has triggered a surge in government regulations, creating significant challenges for many companies [392]. In addition to the ever-increasing volume of laws, their constant modification to keep pace with technological progress and the diversity of regulations across various jurisdictions further complicates the ability to maintain oversight of relevant legal requirements [393, 394]. This complexity makes it difficult for companies to identify applicable regulations for their specific products [395].

Once the regulations relevant to the company are identified, the next major challenge is interpreting those with the most stringent compliance requirements [396]. Since regulations are often written in generic terms to accommodate various use cases, issues regarding technical feasibility arise [397]. Additionally, regulations from different jurisdictions can conflict [398]. Therefore, translating these complex regulations into clear, actionable guidelines is necessary to bridge this gap.

Finally, assessing regulatory risks is challenging because enforcement and penalty structures are often unclear, making it difficult for companies to gauge the potential consequences of non-compliance and prioritize their efforts. [399]. However, businesses that adopt advanced monitoring solutions can stay ahead of regulatory changes, reduce costs, and position themselves as trusted, compliant leaders in the market.

> “Many companies have expressed the need for a solution that can accurately identify and extract relevant information from regulations, as determining which laws apply to their specific circumstances is often a complex and challenging task.”

Anna Spitznagel, Co-Founder & CEO of trail [175]

Selected Players

pwc | KIRKLAND & ELLIS LLP | Resolver. A KROLL BUSINESS | DEEPLOY
SCHÜRMANN ROSENTHAL DREYER RECHTSANWÄLTE | COMPLIANCE.AI | credo ai | KPMG

IMPLEMENTING REGULATIONS

Taking Actions to Secure Regulatory Compliance

Managing regulatory compliance in software engineering and IT operations is increasingly challenging due to continuously evolving regulations. These regulations require organizations to integrate compliance measures into their core business and products, affecting stakeholders such as developers, compliance teams, and customers who expect secure software [400]. Achieving compliance is costly and complex. Manual processes often lead to errors, while regulatory bureaucracy diverts focus from core business activities and stifles innovation [401, 402]. Furthermore, fast-advancing technologies and evolving regulations complicate maintaining compliant software products [400].

Compliance implementation involves identifying applicable rules, interpreting requirements, and integrating them into the development lifecycle. While AI and technological solutions can automate tasks like interpreting regulations and conducting audits, concerns remain about the reliability of AI for compliance verification, raising questions about accountability in case of errors [403]. Despite these challenges, the evolving regulatory landscape offers opportunities to implement solutions that streamline compliance, reduce costs, and mitigate risks. However, successfully integrating these solutions can necessitate a substantial investment [404].

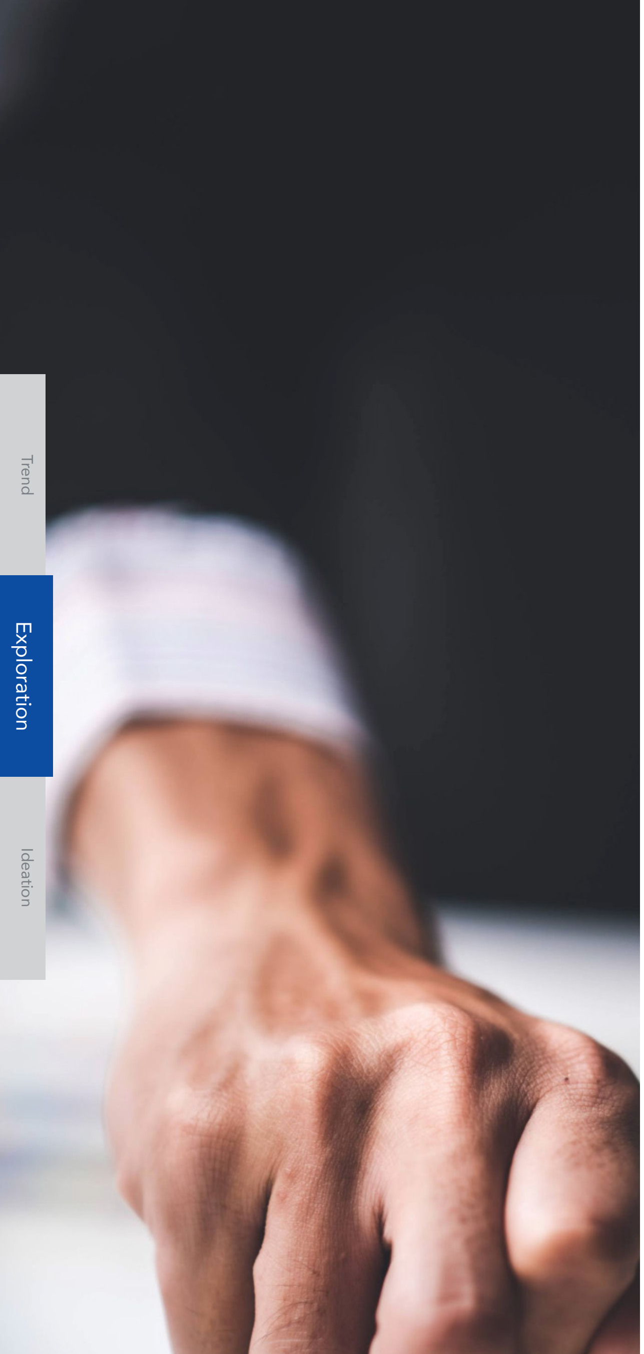
Developing AI-driven tools for compliance implementation and verification can revolutionize how businesses navigate regulations, allowing them to allocate more resources toward innovation while ensuring they meet legal requirements effectively [404, 405].

> "The challenge with using LLMs to comply with regulations lies in their non-deterministic nature and occasional hallucinations. This creates significant difficulties when automating compliance processes."

Andreas Unseld, General Partner at UVC Partners [406]

Selected Players

DRATA, pwc, trail, Thoropass, Checks, KROLL, Deloitte., Vanta, creance.ai, accessiBe



SOFTWARE CERTIFICATION

Proving Compliance Through Certificates

Software certifications are vital in many businesses, especially for companies working with software solutions. Certifications enable entry into new markets by demonstrating compliance with local regulations. Therefore, they enhance the reputation of products and instill trust among potential customers and stakeholders [407].

While certifications help build trust in new products by establishing a minimum standard for quality and safety, they can also discourage companies from pursuing radical innovations as they fear not aligning with current standards. Additionally, the certification process involves third-party verification, which is costly and time-consuming. The associated costs place a heavy financial burden on businesses, particularly on start-ups and SMEs [408]. Furthermore, both struggle to influence the regulations that shape industry standards. Lobbying tends to favor the interests of large companies, such as big tech, leaving the needs of small businesses overlooked [231]. This creates a disconnect between public and private agendas, as regulatory bodies often lack effective feedback mechanisms for incorporating input from diverse stakeholders during the drafting process.

As the tech industry evolves rapidly and the demand for innovative products grows, challenges related to software certification are likely to intensify, undermining the creation and effectiveness of relevant standards.

> “Audits and certifications today are predominantly manual and in-person processes, which often results in inconsistencies in audit findings and certification outcomes.”

Product Manager in the ICT industry [409]

Selected Players

TÜV, KPMG, Deloitte., AUDITBOARD, A-LIGN, Underwriters Laboratories, Delve, DRATA, EY, Vanta

SHORTAGE OF SKILLED LABOR

OVERCOMING THE IT TALENT SHORTAGE

Enlarging the Current Workforce

Immigration of IT Workforce

Efficiency Increase of IT Workforce

Felicia Preuss-Neudorf

Jakub Skupien

Mehmet Uludoğan

Paul Burkhardt

Teresa Mercedes Maurer


SHORTAGE OF SKILLED LABOR

Dealing with the IT Talent Shortage

The labor shortage in the IT sector is caused by a rapid digital transformation, an increasing demand for software engineers, and a lack of sufficient talent. Companies struggle to find qualified specialists, particularly in software engineering and IT operations. There are currently 149k vacant IT positions in Germany alone, and it is estimated that 663k IT specialists will be needed by 2040 [410, 411]. This problem is a widespread trend affecting European and global markets.

Across the EU, around 63% of companies trying to recruit ICT specialists report difficulties filling these positions [412]. This shortage is expected to continue, partly due to high replacement needs as workers retire or leave the profession [411]. The shortage of IT professionals is a significant challenge for organizations, directly impacting their ability to innovate and grow in an increasingly digital world [413].

There are several key factors contributing to this shortage. First, many countries are facing a population decline, reducing the number of potential workers entering the labor market. For instance, Europe's population is estimated to decline by 27.3M people until the year 2100 [414]. Second, the rapid development of technology has led to a shift in the skills required, and many workers are not sufficiently trained to fulfill these new requirements. Finally, IT professions may not appeal to everyone, partly due to gender stereotypes and a shortage of role models. This results in fewer people pursuing education and careers in STEM fields [415].

Countries that fail to attract and retain IT talent risk falling behind in technological progress. In contrast, countries that succeed in addressing the talent shortage will position themselves as hubs of innovation and technological leadership. This talent competition will intensify as companies and governments worldwide recognize the critical importance of a skilled IT workforce for economic growth and competitiveness [416].

Instead of attracting more IT personnel, actors in the software industry could focus on enhancing the productivity of the existing workforce. Several tools and technologies, such as coding assistants like GitHub Copilot, have been proven to increase developer productivity and job satisfaction [417].

The future of the IT sector will be shaped by several factors, including global competition for talent and evolving immigration policies. Countries that create favorable conditions for skilled workers will likely gain a competitive advantage in attracting IT professionals [418]. In addition, there will be increasing pressure on education systems worldwide to produce more graduates with technology-related skills to meet the growing demand for IT professionals [419]. Addressing the IT skills shortage will require a multi-faceted approach, including upskilling, making IT careers more attractive, and reforming immigration and education policies to better meet the needs of a rapidly evolving digital economy.

ENLARGING THE CURRENT WORKFORCE

Education as an Enabler to Attract Talent and Address Skill Gaps

Education is driving innovation. Hence, it is crucial to close the growing gap in the software development workforce [412]. First, many workers do not have the necessary skills for emerging industries, particularly in IT [412]. Transitioning from manual work to highly qualified activities requires considerable efforts to qualify and retrain the workforce. Forecasts show a substantial increase in demand for 12M highly qualified jobs, even as manual and non-manual skilled roles will decline by 3.5M [412]. As a result, more workers need higher education to meet future labor market demands. Second, unemployment intensifies this shortage: over 21% of EU citizens aged 20-64 are not employed [412], including 8M young people who are neither employed nor in education [412]. With adult education underdeveloped in the EU, many potential workers lack the skills to fill labor market gaps [412].

The underrepresentation of women exacerbates the shortage. Women are significantly underrepresented in ICT, with nearly four times as many men employed in these roles in the EU, highlighting a substantial gender gap [412]. This narrows the talent pool needed for skilled labor in key sectors. To address labor shortages and maintain competitiveness, the workforce must be upskilled, and underrepresented groups should be actively recruited through targeted education and diversity initiatives.

> “We need to step up investment in skills, and we need to bring more people into the job market with the skills that are needed for the clean and digital transition.”

Ursula von der Leyen, President of the European Commission [420]

Selected Players

Kodable – Programming basics for kids 5+
CodeMonkey
Outschool
xena
scrimba
codecademy
Start Step
Bloom Institute of Technology
udemy
Code First Girls

IMMIGRATION OF IT WORKFORCE

Removing Complexity and Increasing Transparency in Hiring IT Professionals Globally

Workforce migration can help close the IT labor and skills gap, yet companies struggle to recruit foreign talent. Only 22% of German companies currently recruit IT talent from abroad [411]. Candidate search and selection and visa processing remain key obstacles to overcome [421].

First, companies struggle to search and filter the right talent due to information asymmetries. Local companies struggle with for e.g. unfamiliar with educational backgrounds, certifications, or work experiences from abroad [422]. Second, visa processing is another significant barrier to recruiting talent [421]. 75% of German companies that recruited foreign IT workers complained about a lack of clear information about the immigration process, and 67% about excessive bureaucracy [411]. Additionally, 44% reported that visa processing took too long, delaying important projects [411].

To address the labor shortage, governments and businesses could simplify visa and work permit procedures for highly skilled workers, especially in high-demand sectors such as IT, while promoting global talent mobility and public-private collaboration. The EU is already exploring fast-track immigration options for tech talent, such as the Blue Card scheme [412]. Platforms that match companies with talent streamline visa processing, and can validate skills and credentials to unlock access to a global pool of IT professionals.

> "The brain waste of migrants is a real problem for European governments."

Friedrich Poeschel, Senior Research Fellow at the Migration Policy Centre of the European University Institute [423]

Selected Players

WBS RECRUITING INTERNATIONAL
boundless
airswift
ENVOYGLOBAL
Allen Recruitment
LIONSTEP

EFFICIENCY INCREASE OF IT WORKFORCE

Unleashing Software Engineers' Full Potential by Automating Repetitive Tasks

To effectively address the current labor shortage, it is crucial to enhance the productivity of individual software engineers. Around 30% of their day-to-day work is consumed by repetitive tasks, such as writing tests, documenting code, and deploying software [424]. The routine tasks are often seen as mentally exhausting and unproductive and detract from the creative and technical aspects of development that drive innovation [425, 417]. By automating these tasks, not only is employee satisfaction elevated, but efficiency is also markedly improved. Numerous studies have drawn a clear connection between higher job satisfaction and increased productivity among software engineers [426, 417]. Furthermore, automation of repetitive tasks tends to have up to 40% more effect on developer speed than automation of high-complexity tasks [424].

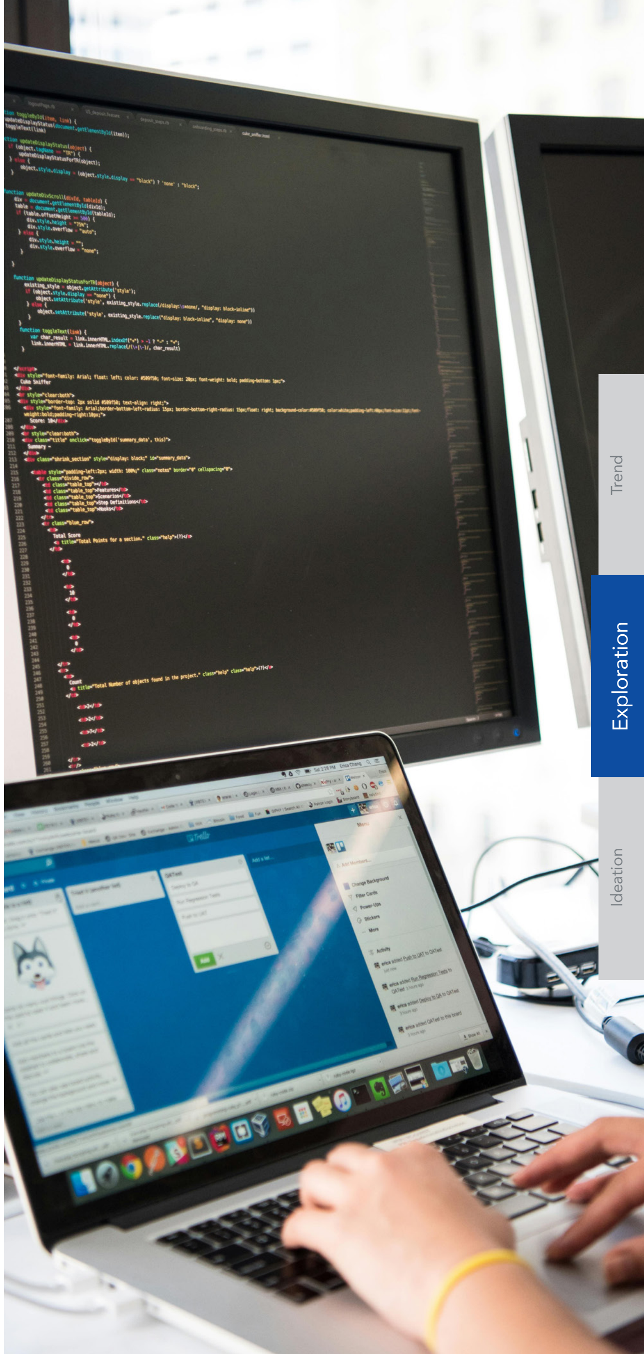
Recent advances in generative AI have introduced a new set of developer tools to automate many of these repetitive processes, thereby improving individual performance [427]. These include copilot solutions like Github Copilot, autonomous agents like Devin, documentation tools like Mintlify, and many more. However, adoption remains low, especially in the corporate world, mainly due to difficulties with system integration and the need to retrain developers [428].

> "We need to have a way to increase the productivity of developers while also helping in their developer experience in their day-to-day because this is an important part of the developer's journey."

João Batista Cordeiro Neto, Product Manager at StackSpot at the AWS re:invent Conference 2023 [429]

Selected Players

codium ai, Grafana, Cognition, Framer, Jira, GitLab, HashiCorp Terraform, SENTRY, PC, GitHub Copilot, Mintlify, Vercel



COMPUTING RESOURCE EFFICIENCY

INFLUENCING THE FUTURE OF SOFTWARE ENGINEERING AND IT OPERATIONS

Energy Supply and Infrastructure for Compute
Specialized Computing
Computational Workload Distribution

Agustin Coppari Hollmann

Aliosha Milsztein

Benedikt Wieser

Leon Driese

Milena Serbinova


COMPUTING RESOURCE EFFICIENCY

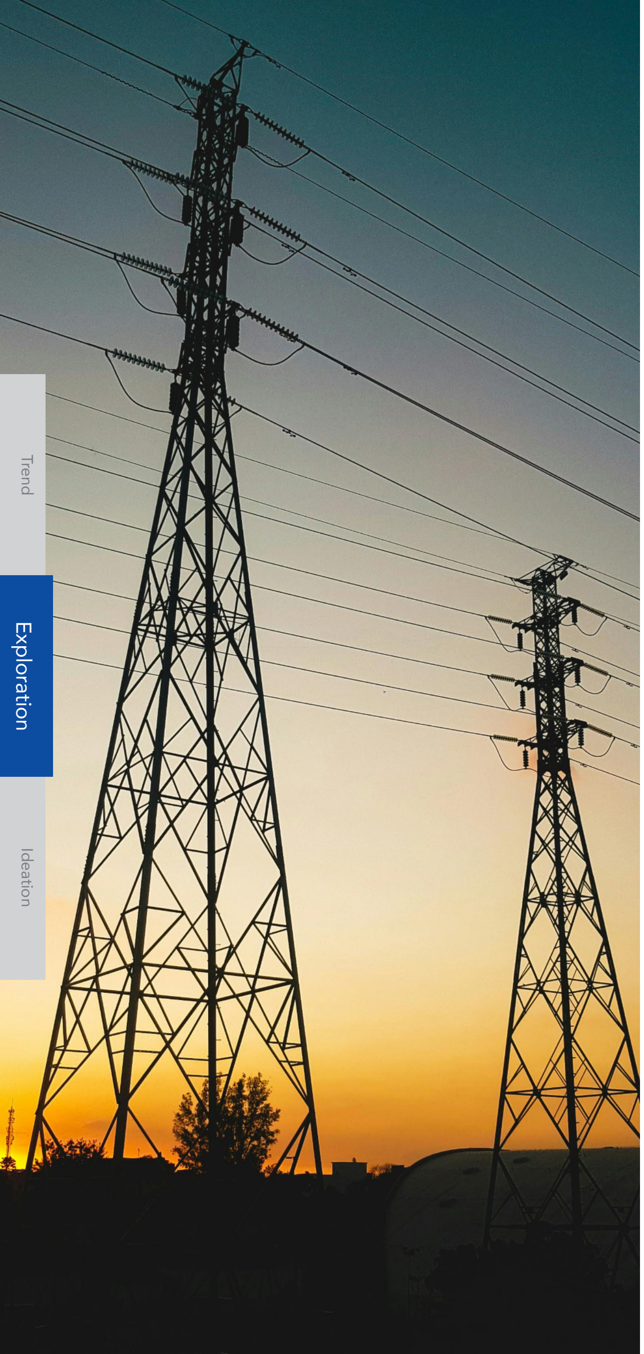
Optimizing Energy and Cost in Modern Computing

The training of GPT-4 alone required 25k NVIDIA A100 GPUs for 90-100 days and consumed an estimated 52-62 GWh of energy – roughly the equivalent of powering 1k average US households for 5-6 years [430]. In addition, the energy used for inference, generating outputs from a trained model based on user inputs, must be considered [431]. A single ChatGPT query is estimated to consume around 3 Wh, ten times the energy of a typical Google search [432]. While architectural improvements in AI models may reduce energy consumption over time, the overall demand for computing resources and energy is projected to increase significantly, making computing resource efficiency a critical concern for the future of software engineering [433, 434].

As energy, computing, and costs are inherently interconnected, resource efficiency in computing is essential not only for environmental reasons but also for economic viability and innovation [435]. At an organizational level, companies are under increasing pressure to optimize their use of computational resources to reduce costs and stay competitive [436]. Meanwhile, at a national level, the issue of energy efficiency is becoming a priority, as evidenced by the growing strategic importance of data center locations [437]. Here, the efficiency of energy supply and cooling systems is essential, to the point where ambitious projects like space-based data centers are now a viable option [438].

To fully capture the opportunity space of computing resource efficiency, we first examine the foundational infrastructure and energy supply required to power data centers. This involves energy generation, storage, and grid balancing – increasingly critical processes due to the growing share of renewable energy sources. Second, we consider the evolution of computing hardware [439]. In recent years, the field has experienced a shift from traditional CPUs to general-purpose GPUs. Today, a trend towards more custom-designed chips like Tensor Processing Units (TPUs) or Neural Processor Units, specifically for machine learning application, is seen [440]. In this context, the current success of NVIDIA's GPUs is a testament to the trade-off of current hardware design as general-purpose GPUs. While not as energy-efficient as specialized hardware, they outperform specialized hardware because of their longer life cycle ability to cater to ever-changing model architectures [441]. The third component of computing resource efficiency is workload management and distribution, which focus on optimizing the utilization of available resources [442]. Studies show that despite the enormous capacity of modern data centers, only 30% of the servers are fully utilized [443]. Efficiently orchestrating workloads and maximizing resource usage are vital to reducing waste and increasing cost-effectiveness across the computing ecosystem.

Optimization and innovation are needed across the entire computing resource value chain to cater to the continuous growth of AI models, software capabilities, and computing resource demand. For businesses and research, this opens up an attractive opportunity space.



ENERGY SUPPLY AND INFRA-STRUCTURE FOR COMPUTE

Addressing Energy Challenges and Opportunities for Sustainable AI Growth

The number of computational tasks handled by data centers increased by 260% between 2012 and 2015 [444]. Computing is energy-intensive, with a single GPU consuming up to 3.74 MWh per year [445]. Increased usage leads to a substantial increase in power demand. When computing demand scales faster than the energy infrastructure, the energy capacity limit might be reached, thus limiting technological progress [446]. In response to this scarcity, power-generating start-ups that offer innovative solutions must emerge to enable further energy consumption growth.

In tackling the energy generation problem, renewables such as wind and solar are increasingly relevant, representing a 57.1% share of Germany's energy generation mix in 2022 [447]. Nevertheless, this also comes with challenges, as supply variability resulting from daytime and weather dependencies of renewable energy make a stable energy supply challenging. Maintaining a consistent, 24/7 power supply for data center operations will become critical, driving the demand for balancing and storage solutions.

Lastly, the resource-intensive operations of existing cooling techniques (e.g., energy-demanding air cooling, water-dependent systems, and expensive liquid immersion) will increase the need for more effective alternatives [448].

> "This type of collaboration [nature-based and technology-based carbon removal solutions] is essential as we continue to progress towards our ambition to run on 24/7 carbon-free energy on every grid where we operate every hour of every day."

Amanda Peterson Corio, Google's Global Head of Data Energy Center [449]

Selected Players

KITE// KRAFT	OOLU	MOXION	Entrix	Fuse
Reach Labs	terralayr	MarvelFusion	ENERVENUE	Vestas

SPECIALIZED COMPUTING

Revolutionizing Efficiency and Performance in Specialized Compute Workloads

With general-purpose hardware such as GPUs struggling to meet low latency and energy efficiency demands, specialized computing is becoming increasingly relevant. Specialized computing hardware, such as FPGAs, offers significant performance gains for specialized tasks, but deployment can be challenging [450]. Tools like High-Level Synthesis, which enable developers to design hardware directly in C++ or Python, simplify this process [451]. This allows the smooth deployment of workloads onto FPGAs, making specialized hardware more accessible and efficient.

In robotics, the need for tightly integrated systems is critical. Compute and control systems must work together efficiently, where the robot's decision-making and mechanical actions are optimized in real time [452]. Integrated systems require specialized hardware to handle complex calculations and control tasks while minimizing energy consumption [453].

Limitations in data transfer between memory and processors, known as the Von Neumann bottleneck, continue to be a significant challenge for hardware performance. This bottleneck pushes the industry towards innovations like 3D memory stacking and in-memory computing [454, 455].

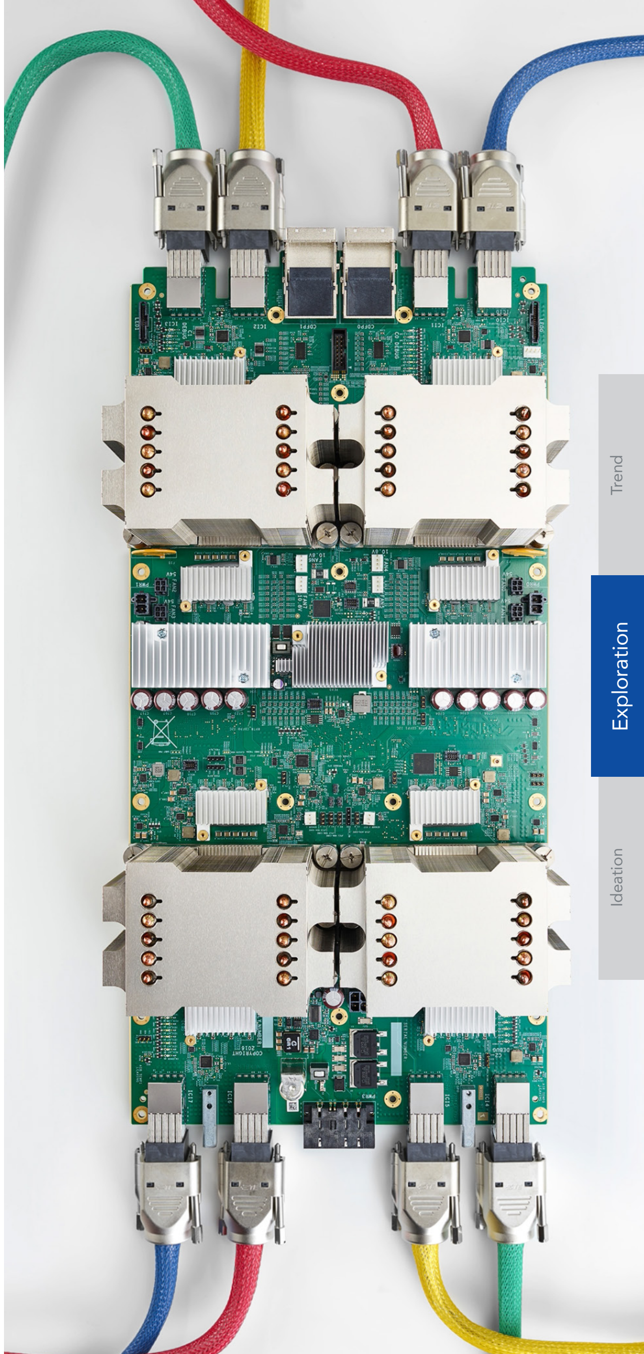
Furthermore, rapidly evolving fields like AI need faster hardware iteration cycles. This is crucial to adapt to the growing demand for specialized computing solutions. Start-ups in this space can create adaptable, high-efficiency hardware tailored to specific use cases [456, 457].

> "I think this ushers in a golden age for compute architectures. [...] We're prepared to make trade-offs to accelerate AI compute by not trying to be good at other things. [...] We will attack this vast demand for compute by building dedicated hardware for AI work."

Andrew Feldman, CEO of Cerebras Systems [458]

Selected Players

aws, Infineon, Zeetta, GRAPHCORE, AMD
cadence, NVIDIA, SambaNova Systems, Microsoft, NXP



COMPUTATIONAL WORKLOAD DISTRIBUTION

Inefficient Workload Management Leading to Resource Waste and Increased Costs

In recent years, software engineering has experienced a significant shift towards sustainable resource allocation [459]. Two factors drive this trend: growing recognition of the environmental impact associated with software engineering and increasing resource costs (e.g., energy, water, and labor). However, developers are building many applications without considering computing resource consumption, highlighting the urgent need for optimization [460]. In combination with inefficient scheduling and tiling techniques, resource waste is becoming ubiquitous, emphasizing the importance of innovation in this field [461].

The increasing costs of cloud computing services challenge SMEs, forcing them to weigh the complexity of on-premise solutions against the risk of cloud lock-in at high prices [462]. Companies may own their hardware or adopt on-premise software to reduce these expenses. However, this adds operational overhead, including hardware maintenance, infrastructure management, and the need for specialized in-house expertise [463].

As demand for computational power grows, applications require the ability to dynamically scale up or down. Over-provisioning leads to resource waste, while under-provisioning results in poor performance [461]. However, this challenge presents a significant market opportunity for solutions integrating advanced scaling algorithms, improved coding standards, and more efficient orchestration systems. This offers a hopeful outlook for the future.

> “Estimates project artificial intelligence algorithms will require ten times more computing power annually for the foreseeable future. This is in addition to traditional computing workloads. Data center computing is already gated today by the available power, and this trend will present an inevitable stress on the global energy supply.”

Mark Papermaster, CTO at AMD [464]

Selected Players

Thunder Compute, kubernetes, Google Cloud, Aptible, Outerport, DigitalOcean, cerebrium, linode, Félafax, vmware

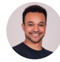
OPTIMIZING COLLABORATION

INFLUENCING THE FUTURE OF SOFTWARE ENGINEERING AND IT OPERATIONS

Bridging Gaps between Remote Collaboration and Well-Being

Disjointed Team Collaboration

Coordination of Software Engineering Teams

Isabel Tscherniak 
Khadim Fall 
Lizzy Stein 
Paul Böllhoff 
Sophie Tollmann 

OPTIMIZING COLLABORATION

Overcoming Collaboration Challenges in Global Software Engineering Teams

The software engineering industry is experiencing a significant labor shortage, driven by the ever-growing demand for skilled engineers in industries across the globe [465]. Although advancements in automation, LCNC tools, and AI-driven copilots have improved efficiency, the gap between the supply and demand of software engineers continues to widen. This shortage is particularly problematic for companies that rely heavily on talented engineers to drive innovation and maintain competitiveness [466]. Many organizations increasingly adopt a distributed workforce model to address this shortfall, leveraging global talent pools through remote and hybrid work setups. This trend enables companies to access a broader range of expertise while benefiting from potential salary benefits through geo-arbitrage [467].

Distributed teams, however, introduce new challenges in maintaining effective collaboration and communication across time zones and cultures. Studies have shown that geographical and cultural distances can hinder team coordination, impacting overall productivity [468]. Despite these obstacles, the shift towards remote work offers a promising solution to the labor shortage by broadening access to skilled professionals worldwide.

While expanding the global workforce helps mitigate the labor gap, companies must also focus on maximizing the potential of their existing software engineers. This raises the question of how organizations can optimize team collaboration and task management to fully leverage their current talent. Optimizing teamwork and task distribution is essential to boost productivity and ensure the well-being and motivation of employees – which ultimately translates into better-performing teams [469]. Effective collaboration, particularly in remote settings, has been shown to reduce the need for excessive management overhead and improve overall team output [470].

Modern software engineering teams can be optimized on three levels: engagement and mental health, collaboration, and management. First, the rise of remote and hybrid work has profoundly impacted engagement and mental health in software engineering teams [471]. Remote work limits spontaneous interactions essential for mentorship, feedback, and knowledge sharing. This lack of face-to-face communication widens the gap between senior and junior developers, slowing the development of skills and innovation [471]. Trust and team collaboration suffer due to the absence of regular, in-person contact, diminishing the potential for effective problem-solving [115]. In addition, despite modern tools, software engineering teams face barriers related to outdated or incomplete documentation, particularly in legacy systems [472]. Updating these systems and automating processes can unlock better collaboration and long-term sustainability. Moreover, effective onboarding and product management are critical for maximizing the potential of software engineers. Poor onboarding, especially in complex projects, causes underutilized talent and burdens senior developers with training tasks. Similarly, miscommunication between product managers and developers can lead to inefficiencies and wrong product focus, highlighting the importance of clear task structuring and technical oversight.

In conclusion, while the global labor shortage in software engineering is a pressing issue, optimizing how existing teams work can contribute to the solution. By refining remote collaboration strategies, companies can unlock the full potential of their current workforce and future hires, fostering a productive and supportive environment for software engineers worldwide.

BRIDGING GAPS BETWEEN REMOTE COLLABORATION AND WELL-BEING

Remote and Hybrid Work Affecting Engagement and Mental Health

The shift to remote and hybrid work arrangements has significantly impacted engagement and mental health in software engineering teams. Remote work reduces opportunities for spontaneous interactions, which are crucial for knowledge sharing and mentorship. This creates a widening gap between senior and junior developers, as junior engineers miss out on valuable on-the-job learning and feedback [473].

Limited face-to-face contact in remote work weakens team trust, making employees less likely to collaborate and support each other effectively [474]. Engineers are less involved in brainstorming sessions and collaborative problem-solving, which are crucial for driving innovation [473]. Furthermore, many remote software engineers find it challenging to connect with their company's culture and values, leading to lower levels of engagement and decreased motivation [474].

Additionally, the blurred boundaries between personal and professional life in remote settings lead to mental fatigue from extended screen time and a constant feeling of being "always on", which increases the risk of burnout [475]. The lack of physical separation between work and home life makes it difficult for engineers to disconnect, exacerbating stress and mental health issues [476].

The opportunity lies in continuously improving remote collaboration tools, such as better videoconferencing and cloud-based knowledge management, facilitating more effective communication and coordination among dispersed teams [473].

> Employee engagement tends to be negatively affected by (...) remote collaboration and long distance and off-shore team split.
>
> Celine Marie Perrot, Stream Lead Innovation & AI at BMW Group [477]

Selected Players

Modern Health, slack, poppulo, workvivo by zoom, oliva, lyra, skype

DISJOINTED TEAM COLLABORATION

Increasing Efficiency of Team Collaboration Across Distance and Time

Distributed teams frequently encounter fragmented collaboration. Software engineering teams face increasing coordination challenges, especially with complex, evolving code bases, large product development pipelines, and changing software engineering practices. The challenge of replicating real time activities, such as pair programming in remote environments, often results in delays and interpersonal issues [478]. New technologies could offer valuable solutions. For example, a recent study suggests that VR environments can enable programmers to fix more bugs and reduce issue resolution times compared to traditional screen-sharing setups [479]. This suggests that enhancing real time collaboration with immersive tools could help mitigate delays and coordination issues associated with remote pair programming [479].

Legacy systems, often written in outdated languages like COBOL, exacerbate these collaboration issues [480, 481]. Despite their foundational importance in industries like finance, the lack of documentation and personal experience of younger software engineers in these languages makes updating these systems extremely challenging [482]. Incremental approaches, such as encapsulating, rehosting, and refactoring, offer solutions by optimizing or migrating legacy systems without altering their core functionality. Automating these processes is essential for improving long-term sustainability and security, helping teams overcome barriers to efficient collaboration across distance and time [483].

> “Efficient software engineering requires rethinking collaboration and modernizing legacy systems to overcome documentation gaps and sustain long-term productivity.”

Razvan Ion Radulescu, CEO at bevel [484]

Selected Players

Bitbucket, Azure DevOps, GitHub, swimm, GitLab, Sphinx

COORDINATION OF SOFTWARE ENGINEERING TEAMS

Onboarding and Product Management as Challenges in Software Engineering Teams

Management teams must match the right talent with strategically essential tasks. Even the most capable developers can fall short if not directed toward solving critical business challenges or delivering features that drive business value. With precise alignment between skills and priorities, the organization's overall effectiveness and ability to innovate will improve.

One major challenge companies face is the lengthy onboarding process for developers joining complex projects. Monolithic legacy systems and tightly coupled interdependencies require new developers to invest substantial time before they can contribute effectively. These onboarding cycles can stretch up to six months [485], which leads to underutilized developer capacity and pulls senior staff away from their core responsibilities to provide training. The real issue, therefore, lies not just in the onboarding duration but in how it affects overall team productivity and project timelines. Addressing this challenge may require rethinking system architecture to decouple components and simplify onboarding, as well as investing in knowledge-sharing frameworks that reduce the reliance on senior team members for training.

Another challenge is managing developers and software projects effectively. Product managers must translate diverse stakeholder input into actionable tasks while maintaining a solid technical product understanding. Without this balance, miscommunication and misalignment can occur, leading to inefficiencies in development [486, 487]. Ensuring managers have both technical and communication skills can help mitigate these risks.

> "Often it takes developers up to six months of onboarding until they push their first line of code."

Zhenya Loginov, Partner at Accel [505]

Selected Players

Trello
Notion
wrike
awork
asana
monday.com
Linear

CYBERSECURITY

INFLUENCING THE FUTURE OF SOFTWARE ENGINEERING AND IT OPERATIONS

Identity and Access Management
Security Operations
Post-Breach Response and Disaster Recovery

Antonia Borsutzky

Linus Zimmer

Philipp Hugenroth

Philipp Wahler

Rudraksha Samdhani


CYBERSECURITY

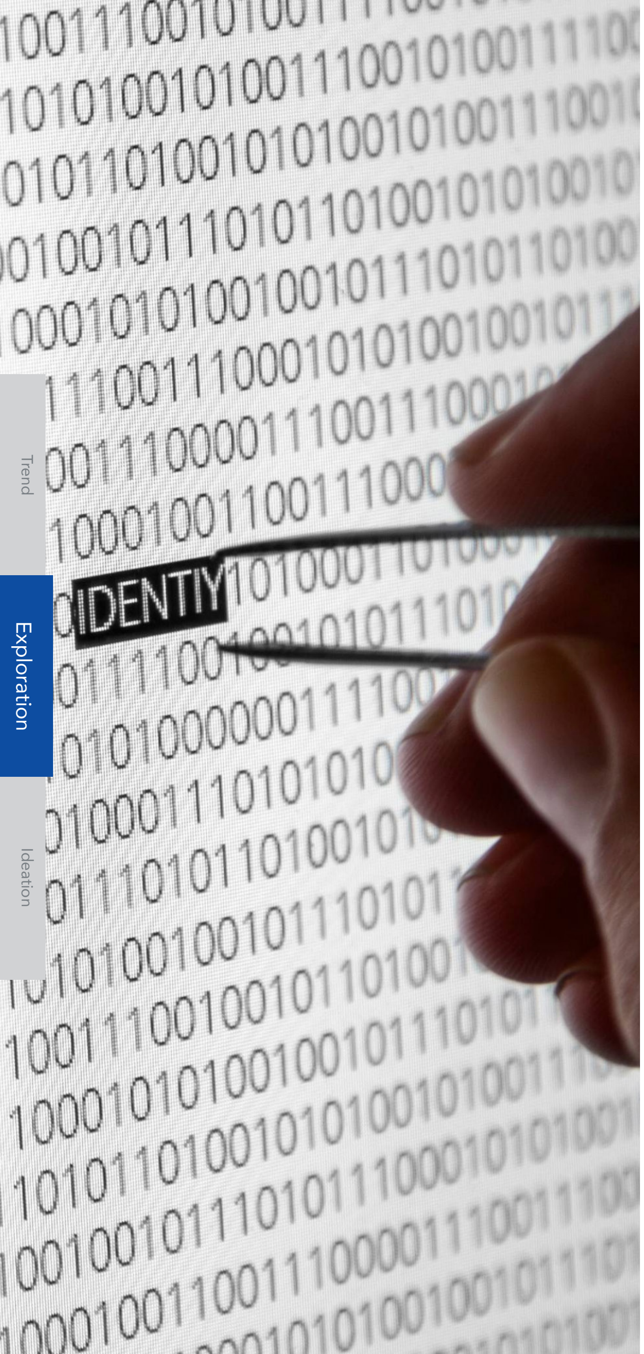
Building Resilience Against Rising Cybercrime and Ransomware Attacks

At first glance, many enterprises and start-ups seem to fully cover the cybersecurity space. However, there are still blind spots and challenges for companies created by new technologies such as artificial intelligence. Expert interviews and discussions with several venture capital funds have highlighted three promising market areas with room for innovation: identity and access management, security operations, and post-breach responses.

Cybersecurity protects sensitive data, systems, and networks from unauthorized access, attacks, and damage. Driven by geopolitical tensions, rising attacks, regulations, and costs, cybersecurity is increasingly crucial to companies and governments [488]. The global cybersecurity market is estimated at approximately 150B USD in 2024 and is projected to grow over 10% within the next five years [489]. Cybercrime costs businesses over 8T USD in 2023, expected to increase by 70% to nearly 14T USD by 2028 [178]. Emerging technologies such as blockchain are being explored for their potential to provide more secure and transparent methods of protecting data, further illustrating the dynamic nature of the cybersecurity field. Additionally, the rapid adoption of IoT devices in consumer and industrial sectors presents new security challenges, necessitating more advanced protective measures.

Developments in cybersecurity directly impact how software is written and how companies can provide secure services to their customers. For software engineers, following the Development, Security, and Operations principles promotes shift-left security, embedding security early in the software development lifecycle to identify vulnerabilities before they reach production [490, 491]. Automated security testing in Continuous Integration and Continuous Deployment (CI/CD) pipelines continuously scans code and third-party dependencies, ensuring more secure deployments. Identity and access management are especially highly relevant on the IT operations site. Integrating machine learning (ML) and AI in threat detection systems is becoming increasingly prevalent, enhancing the ability to predict and mitigate potential cyber threats in real time [492].

Small businesses are especially vulnerable to cyberattacks, with a significant gap in resilience compared to larger organizations. While cyber audits and insurance have become more and more relevant, cyber inequity between SME and large enterprises is an expanding global problem [493]. Over 50% of SMEs lack cyber resilience to meet critical operational requirements [493]. State-of-the-art cyberattacks leverage ransomware, a method that infiltrates an IT system through a trojan virus, subsequently encrypting vital data and demanding a ransom payment to decrypt it [494]. Ransomware attacks have increased by 151% in 2021 globally [495]. Additionally, the interconnectedness of AI systems creates vulnerabilities in data privacy and confidentiality [496]. Even though prevention measures have become more common in large organizations, new breaches across the industry show the need to secure companies at risk further.



IDENTITY AND ACCESS MANAGEMENT

Human and Non-human Identification Will Advance Through Artificial Intelligence and Biometric Data

In access management, zero-trust architectures are increasingly adopted industry-wide [497]. Zero-trust architectures operate under the assumption that networks are compromised, prompting the need for tighter control and monitoring [498]. For identity management, the rise of AI challenges existing solutions, e.g., through advancements in voice cloning and video deep fakes [499].

While AI poses a cybersecurity risk, it can also help identify unconventional behavior from users and suspicious activities on the server side automatically [500]. This is especially interesting for fraud detection [501] and anomaly detection in data streams [502]. As a result, biometric technologies like fingerprints and iris scans are spreading, aiming to improve access control and enhance identity verification across multiple modalities [503, 504]. Business-to-government and business-to-consumer models are currently underserved due to a lack of solutions, thus constituting a promising white space. Furthermore, both are highly threatened because of their sensitive data and value to supply chains, creating an even greater need for solutions.

> "Building a pan-European SME go-to-market strategy is tough, with just a few good examples. While new approaches exist, the US offers a more homogenous market, making scaling easier. However, non-human identity management is a green field, especially for SMEs."

Zhenya Loginov, Partner at Accel [505]

Selected Players

feedzai, CrowdStrike, Fortinet, Ping Identity, yubico, kasada, Cloudflare, Cisco Duo, Oasis

SECURITY OPERATIONS

Mitigating Alert Fatigue and Infrastructure Fragmentation in Security Operations Through AI

Security Operations teams face a shortage of security analysts, driving many organizations to rely on threat detection tools for vulnerability monitoring [506]. However, these tools frequently generate false positives, overwhelming security teams, leading to alert fatigue and making vulnerability prioritization difficult [507, 508, 509]. External integrations, microservice sprawl, and interoperability requirements fragment the software supply chain, expanding the attack surface for malicious actors [510]. Integration challenges within Security Operations often lead to misconfigurations, unmonitored dependencies, or unpatched vulnerabilities. Poorly integrated and manual Security Orchestration, Automation, and Response workflows add complexity [511], hindering the adoption of best practices like Reproducible Builds or Supply-chain Levels for Software Artifacts [512, 513]. As a result, vulnerabilities are more likely to occur, and during incident responses it is harder to reliably identify safe and unsafe components [514].

AI has significant potential to automate Security Operations, yet many current solutions are not mature enough to cover the entire software supply chain [515]. This gap presents a substantial opportunity for emerging companies to automate critical steps in the exposure management lifecycle, including vulnerability tracking, trust verification, or incident response mechanisms.

> "AI and LLMs in security operations could effectively address expanding attack surfaces from interoperability issues."

Nina Feussner, Investor at Lakestar [516]

Selected Players

CADO, perimeter 81, VECTRA, WIZ, uptycs, expel, SentinelOne, GreatHorn, snyk, ENGINSIGHT

POST-BREACH RESPONSE AND DISASTER RECOVERY

SMEs Are Increasingly at Risk of Ransomware Attacks, Lacking Response Strategies

SMEs are less protected against cyber-attacks than larger enterprises, and the vulnerability is growing [517, 285]. Often, attacks begin with phishing, increasingly aided by GenAI, which infiltrates a network through a 'trojan' virus. The virus then encrypts data and demands a ransom for decryption [518, 519]. Hardware is also affected at times, necessitating replacement [514]. Restoring IT systems to full functionality is called "disaster recovery" [520]. Alternatively, attackers may steal sensitive data to sell, e.g., customer credit card information.

On average, firms need 21 days to recover from a ransomware attack; however, this time can increase further if the hardware is affected [520, 514]. This interruption in business continuity often involves the business itself, third-party suppliers, and customers. For example, a ransomware attack on Maersk using the software "Petya" caused an estimated 300M USD of damages to the firm alone and 10B USD in the entire supply chain [521]. Many SMEs underestimate ransomware protection, often believing that on-premise server solutions are more secure than cloud-based systems. This holds, especially in more traditional industries [514]. SMEs lack both knowledge and resources to address ransomware protection, but with the rise of ransomware-as-a-service, resilience becomes a competitive necessity.

> "SMEs are underserved in ransomware resilience. They often lack knowledge and resources to prepare for ransomware attacks and disaster recovery."

Reinhard Zimmer, Disaster Recovery Expert at Zerto (HPE) [520]

Selected Players

Zerto, NovaBackup, Dell, Acronis, NovaStor, Barracuda, Hewlett Packard Enterprise, Veeam, datto

IDEATION

The following chapter describes five novel business models of great relevance for *The Future of Software Engineering and IT Operations*, especially in view of the identified future trends. Each of the business models is developed to solve a specific problem in the identified problem spaces.

Complion **72**

TechTiger **76**

Inferlynx **80**

Product Panther **84**

Reino **88**

Federico Harjes 
Jonas Seidou 
Max Knoll 
Niklas Sindemann 
Nils Reichardt 
Selin Yildiz 

COMPLION

Creating an Accessible and Inclusive Digital Experience for Millions of Users

Around 30% of the German population lives with a disability, yet digital accessibility remains a widespread issue [522]. Essential features like alternative texts, color contrast, easy-to-understand language, and voice-only controls are crucial to making the digital world accessible. However, 96% of the top one million websites still have accessibility issues, failing to meet the Web Content Accessibility Guidelines (WCAG) 2.1 standards [523]. To address this, the EU is introducing the European Accessibility Act (EAA), which mandates strict accessibility standards for digital products, websites, and other services starting in 2025 [524].

This new regulation presents a significant challenge for software engineers who must ensure accessibility across all website configurations, browsers, and operating systems. Many companies are struggling to adapt to the changes proposed. A recent audit of Fortune 100 company websites uncovered 815k accessibility issues [523]. Current approaches to ensuring accessibility heavily rely on manual human testing, driving up costs and limiting scalability.

Complion aims to change that, empowering software developers to make the internet a more inclusive space for millions of people worldwide. Complion streamlines accessibility checks, turning a challenge into a seamless step in the development workflow. Its mission is simple yet ambitious: an accessible internet for everyone. At the heart of Complion is an autonomous agent that interacts with applications just like a human user would. Powered by an LLM trained on accessibility norms and best practices, the agent ensures that all interactions comply with established guidelines. Through reinforcement learning from human accessibility testers, the agent can identify flaws and reduce false negatives.

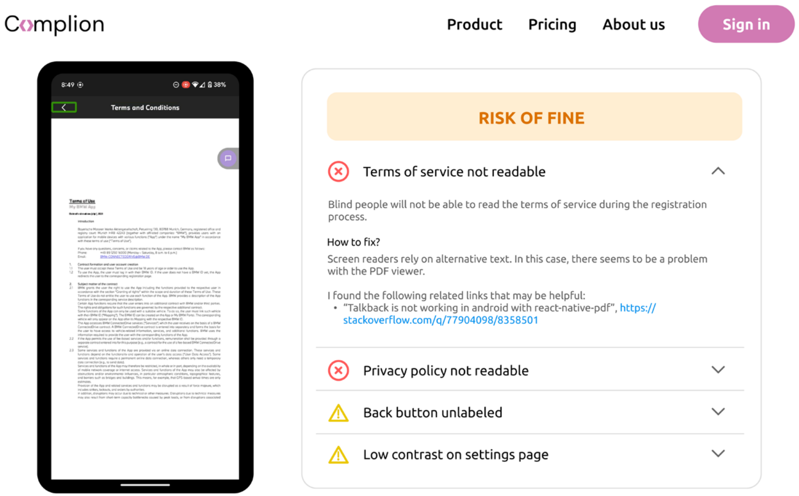
Complion's multi-platform approach guarantees compatibility across all browsers and operating systems, eliminating the complexities traditionally associated with accessibility testing. Furthermore, it can be seamlessly integrated into the CI/CD pipeline, allowing automatic end-to-end testing of every new feature or update. Compliance checks are thus fully embedded within the development process, lifting the burden of software developers and ensuring that digital products are accessible upon their creation.

With Complion, digital accessibility is no longer an afterthought – it is an integral part of the development journey, making the web a better, more inclusive place for everyone.

Problem

- Nearly 10% of Germans live with a severe disability, with around 4% affected by visual impairment [522]. In total, 30% of the German population has some form of disability. Across the EU, 27% of citizens aged 16 and above have a disability [526].
- As of 2023, over 96% of the top one million websites were still inaccessible, showing a high need for better accessibility in software development [527].
- The EAA, set to be enforced by 2025, will impose fines of up to 100k EUR on companies in Germany for non-compliance with accessibility standards [528]. Other EU member states like the Netherlands even propose penalties of up to 900k EUR or 10% of the annual turnover [529].
- In 2020, businesses lost nearly 20B EUR in revenue due to inaccessible services, preventing disabled customers from engaging [530].
- Implementing EAA standards is projected to reduce market costs due to divergent requirements by 45-50% for companies and EU member states [530].

Upcoming regulations, coupled with the significant economic value of customers with disabilities, will turn accessibility into a business priority.



Solution

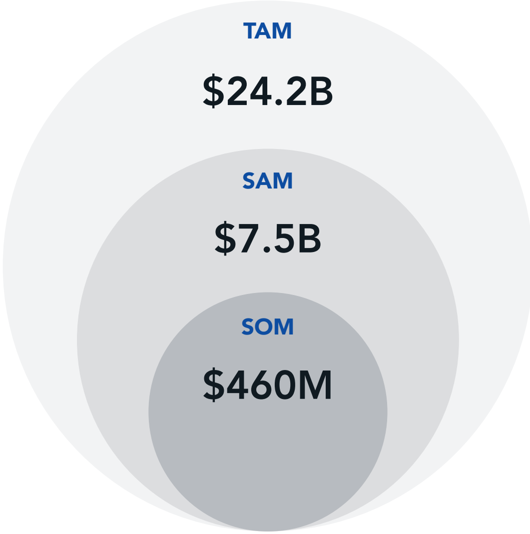
- Complion is an automated accessibility tester designed to ensure compliance with the EAA.
- Developers trigger the automated scanning process by uploading websites and apps, agnostic of their platform.
- During the scan, an autonomous agent navigates through the application, employing user interface testing tools to interact with it like a human expert would.
- The agent's logic is dictated by an LLM, which has previously been trained on accessibility standards and best practices. The agent's ability to detect anomalies is ensured by a fine-tuning process based on reinforcement learning from a human accessibility tester.
- A standardized graph representing the app helps the model find every human-accessible screen. This graph can be constantly updated as developers add features to the app, enabling a continuous testing process with Complion.
- By integrating Complion into the CI/CD pipeline, each new feature can be automatically tested for accessibility before it is merged.

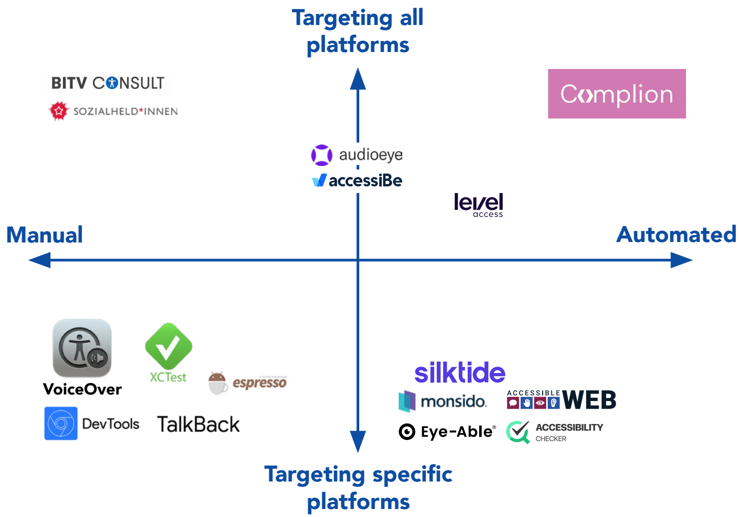
Complion is a fully autonomous, seamlessly integrated solution that enables developers to create accessible software across all platforms.

Market

- Globally, 1.4B people live with disabilities, yet 96% of the top one million websites remain inaccessible [523].
- 4M users abandoning websites because of accessibility barriers costed UK retailers 17.1B British Pound Sterling (GBP) in lost business in 2019. This was up from 11.75B GBP in 2016, showing a lack of progress [531].
- Accessibility is relevant for SMEs and large corporations, as a WCAG 2.1 accessibility audit of the Fortune 100 corporate websites revealed 815k accessibility issues [523].
- With 16M web stores across the EU and US and assuming 10k visitors per day on average [532], a 2% conversion rate [533], 2.5 USD average purchasing volume [534], and 10% of the population suffering from accessibility barriers results in 300B EUR in losses due to accessibility annually. Assuming that 7% of disabled people refuse to purchase due to accessibility barriers results in a TAM of 24.4B EUR.

The market for accessibility-enabling solutions is strongly driven by regulation push and leads to a SOM of 460M EUR.





Competition

- Existing solutions struggle to offer comprehensive compliance verification across web, mobile, and desktop applications.
- Market-leading tools like LevelAccess and Audioeye provide partial automation. However, those tools rely heavily on manual testing, especially for dynamic interfaces, which drives operational costs [535, 536].
- On the market, automated accessibility checkers, such as EyeAble, Accessibility Checker, and Monsido, currently cover only 20-30% of potential issues found, necessitating inefficient and costly manual testing for dynamic interfaces to achieve full compliance [537, 538, 539, 540, 541, 542].
- BITV Consult, Be Inclusive, and APPT target a wider range of platforms yet still operate only manually [543, 544, 545].
- Complion's AI-driven solution offers real time compliance checks that fully integrate into CI/CD pipelines, clearly differentiating from current competitors.

Existing solutions focus on specific platforms or require manual checking, leaving a gap for multi-platform compliance automation.

Assumption Tree

Accessibility Awareness Deficit

With the variety of accessibility requirements for software – spanning visual, auditory, motor, and cognitive areas – it is difficult for developers to be constantly aware of a user's individual needs. The complexity of these requirements, lack of accessibility training, and fast development cycles often result in software that is not accessible.

Reliance on Manual Testing

Accessibility compliance tools often require human intervention due to the complexity of modern applications, making testing time-consuming, costly, and challenging to integrate. Manual checks on various operating systems and browsers worsen the issue. This can cause delayed reports, slowing down the process by weeks.

Lost Business Opportunities

Companies miss out on billions in revenue by overlooking disabled customers, who often turn to more accessible competitors. This shift results in lost market share and reduced customer loyalty for those neglecting accessibility. Firms prioritizing accessibility capture growth opportunities from this underserved segment, while those that do not risk missing out on a significant market.

Cost of Non-Compliance

Failure to comply with the EAA will have serious consequences, which vary by country, including fines, product or service withdrawal, and temporary business suspension. For example, in 2023, over 4k organizations were sued in the US for non-compliance with WCAG guidelines, highlighting the growing importance of accessibility standards [525].

Automated Accessibility Integration

Reliance on manual accessibility testing creates significant barriers to maintaining software accessibility due to human error and resource-intensiveness. With advancements in AI, there is a clear opportunity to automate accessibility testing, ensuring consistent compliance while reducing errors and costs associated with manual intervention.

Accessibility Compliance as a Profit

Companies increasingly recognize accessibility as a profit lever due to two key drivers: lost revenue from neglected disabled customers and legal costs from non-compliance with accessibility laws. By prioritizing accessibility, businesses tap into a broader customer base and mitigate legal risks, enhancing their bottom line and brand reputation.

Multiplatform Accessibility Compliance

The EAA will make fully automated, end-to-end compliance testing across all platforms essential. Manual processes are inefficient, and organizations risk significant legal penalties and lost revenue. Automated AI-driven solutions, such as Complion, will be critical to ensuring compliance and meeting these requirements effectively.

Felicia Preuss-Neudorf

Jakub Skupien

Mehmet Uludoğan

Paul Burkhardt

Teresa Mercedes Maurer


TechTiger

Making Personalized Computer Science Education Accessible to Every Student

Traditional education systems struggle to modernize as the demand for digital literacy and coding skills accelerates in today's tech-driven economy. In Germany, the obstacle is the critical shortage of computer science teachers [546]. This hinders enough students from entering the IT education pipeline [546]. TechTiger is an AI-powered educational platform designed to revolutionize computer science education for students aged 12 to 18. It offers a scalable, personalized learning experience, allowing teachers of other backgrounds to facilitate computer science lessons. Furthermore, it helps to democratize access to quality education, especially in rural or underserved areas where resources are limited, ensuring no student is left behind.

The platform dynamically adjusts the curriculum to each student's learning style and progress, helping them master fundamental concepts in computer science. In addition to foundational knowledge, students work on practical projects – building games, websites, or applications – giving them a hands-on experience that solidifies the acquired theoretical concepts. This immersive approach keeps students engaged and deepens their understanding of complex concepts, fosters critical thinking, and enhances problem-solving skills, all essential for success in tech. Designed for broad general education, this approach enables every student to engage with computer science, regardless of their interests or prior knowledge.

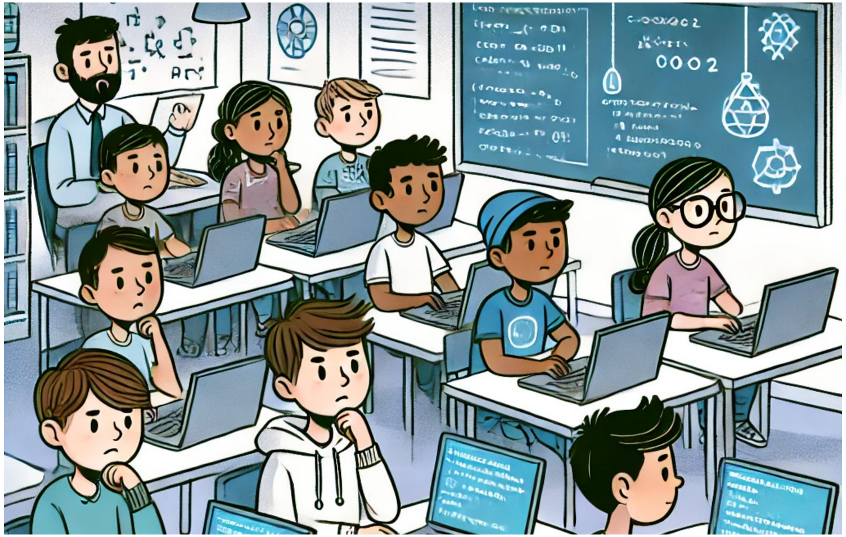
TechTiger offers students an AI-powered "learning buddy" as a chatbot, which allows them to ask unlimited questions and receive immediate answers, providing instant support beyond the limitations of a traditional classroom where a single teacher often has to manage 30 students. This learning companion also supports voice interactions, offering an intuitive experience that closely resembles engaging with a traditional teacher. Additionally, an AI-powered dashboard helps teachers maintain an overview of student progress, offering detailed performance analytics to track learning outcomes and identify areas where additional support is needed, giving teachers more time to focus on guidance and mentoring. The platform's adaptability also means it can be easily integrated into existing school systems, offering a cost-effective solution for institutions struggling to provide specialized computer science instruction.

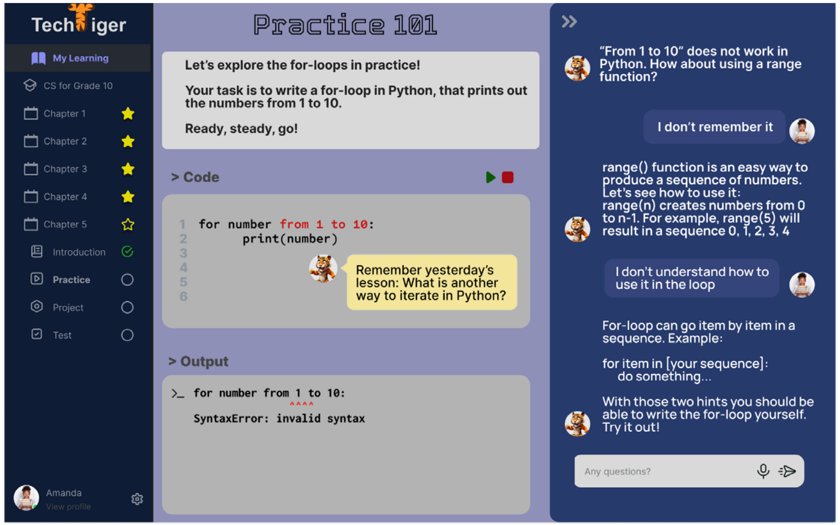
By combining personalized AI technology with general education frameworks, TechTiger addresses the growing shortage of skilled IT workforce by giving students access to the digital competencies necessary and providing them the opportunity to explore the promising path of computer science in the modern economy.

Problem

- The IT sector in Germany faces a labor shortage with 149k vacant positions. This issue is partially rooted in the educational system. Computer science courses account for only 2% of upper secondary school offerings, indicating that only a very limited number of students enters the IT pipeline [546, 411].
- Although national and EU policymakers acknowledge the importance of digital education, as demonstrated by initiatives like the "Digital Education Action Plan (2021-2027)" and "EU Code Week", these efforts have yet to see widespread implementation [548].
- Implementation is hindered by a severe shortage of qualified teachers, with only 10k computer science teachers available for 13.5k secondary schools in Germany [546, 549]. This gap is expected to widen as the number of computer science graduates with teaching degrees remains stagnant, further exacerbating this shortage.

Schools must find a way to teach computer science despite a lack of trained teachers.





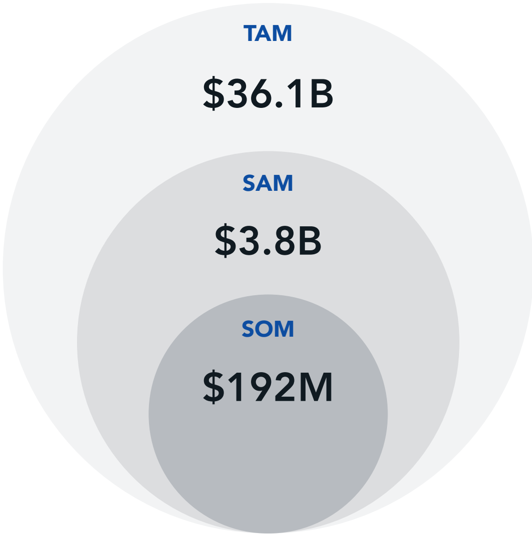
Solution

- Our AI-powered platform transforms IT education for students aged 12 to 18 by providing a highly personalized experience. It adapts each student's learning journey in real time to their learning style and performance. Centralized curriculum planning makes it easy to ensure content is always up-to-date with the latest industry trends and technologies.
- Students create tangible end products, such as downloadable games or websites, making their learning experience practical and engaging while fostering peer learning through collaborative projects.
- TechTiger enables teachers without a technical background to supervise computer science courses. Detailed performance summaries are provided to the teachers to track student progress and highlight improvement areas. Integrated AI-powered chatbots handle course-related technical questions and troubleshooting, allowing students to progress.

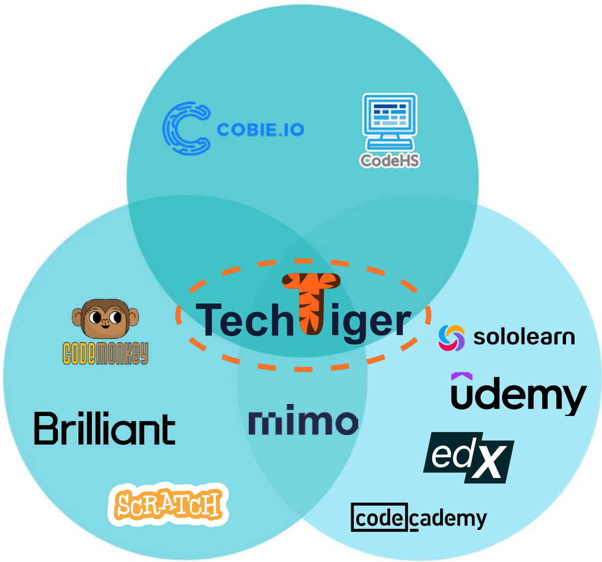
TechTiger combines curriculum-focused education with AI-personalized learning, making computer science accessible to every student.

Market

- Global spending on overall education is expected to increase to 8T USD by 2030, compared to 6T USD in 2022 [550].
- Spending on Education Technology (EdTech) is expected to grow faster than the overall education sector, from 250B USD in 2022 to 620B USD in 2030 [550].
- TechTiger will be available for an annual price of 60 USD per student, approximately 0.6% of the average yearly cost per student in Germany, which currently is around 8.5k EUR [551].
- With 602M students in secondary education globally, the TAM is 36.1B USD [552, 553].
- Focusing on European and US students, the Serviceable Addressable Market (SAM) is 3.8B USD [554, 555].
- TechTiger will initially be deployed in German-speaking countries. The product is expected to be roughly 5% of the SAM. This translates to a SOM of 192M USD.



TechTiger taps into the rapidly expanding EdTech market worth 36.1B USD.



Competition

- Numerous self-learning platforms, such as Codecademy and Sololearn, are designed for self-driven, independent learners [556, 557].
- CodeHS and CobieAI focus on supporting computer science teachers in facilitating their classes [558, 559]. TechTiger does not require a computer science teacher.
- Intuitive coding tools like Scratch and CodeMonkey simplify computer science education by teaching coding as abstractions.
- ANTON and Bettermarks have successfully sold math and language learning licenses in over half of Germany's states, but no similar solution is used for computer science [560].
- Traditional schoolbook publishers such as Westermann and Cornelsen are increasingly developing interactive digital materials, pushed partly by state policies like those in Rhineland-Palatinate [561, 562, 563].

TechTiger offers an intuitive, self-guided computer science curriculum that empowers teachers of any background to easily teach coding.

Assumption Tree

Shortage of Teachers

There is a need for more qualified ICT teachers, which presents a substantial challenge for the education sector. This shortage impacts the quality of IT education, leaving many students needing proper instruction. This hypothesis can be tested by analyzing student performance across regions with and without sufficient IT teachers.

High Costs of Teachers

Training teachers is costly and time-intensive. This makes scaling up IT education using traditional teacher-based models unsustainable and unaffordable, especially in rural areas. This hypothesis can be tested by collecting cost and time data from training institutions.

Policy Push for IT Education

The EU provides general guidelines for IT training but no binding, standardized specifications. However, they promote the integration of digital competencies into the member states' education systems. This hypothesis can be tested by reviewing the EU guidelines, recommendations, and directives related to IT education and digital competencies.

Demand for Computer Science Skills

Demand for digital literacy and coding skills grows as the economy becomes more tech-focused. STEM job opportunities are rising, and students exposed to technology in school are more likely to pursue such careers [547]. Tracking student outcomes after exposure to coding programs could test how well this training prepares them for future job markets.

Need for IT Education

General education teachers often lack sufficient IT expertise to effectively teach digital literacy and coding. Schools need flexible systems to deliver high-quality IT lessons using modern technologies. This hypothesis can be tested through focus groups with schools to identify challenges and assess the need for technical solutions.

Requirement of Adaptable Education

As digital and coding skills become increasingly important, the education system must adapt quickly. The growing demand for STEM skills will exacerbate labor shortages in the tech industry if it is not met. This hypothesis can be tested with the help of labor market forecasts and reports, such as the OECD or the World Economic Forum.

High-Quality Computer Science Education

AI-powered platforms offer a scalable, cost-effective solution to the IT education crisis by providing personalized learning under the supervision of general education teachers. This can reduce reliance on specialist IT teachers and counteract labor shortages. The trial will utilize AI in schools and compare the results with traditional methods.

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INFERLYNX

Inferlynx

Inference-as-a-Service

As AI and ML technologies rapidly evolve, organizations increasingly face inefficient use of computing resources [564]. Building an AI-driven system presents numerous obstacles, from initial infrastructure setup to ongoing maintenance and scalability. While trying to leverage the potential of ML, companies frequently face issues caused by complex deployment structures and vendor lock-in [565].

One of the significant yet often overlooked aspects of ML deployment is inference. In the context of AI, this term refers to using a trained ML model to make predictions or decisions based on new data [566]. For example, after training a model to recognize patterns in customer behavior, inference is when the model uses real time input to predict customer preferences.

The market for inference solutions is expanding rapidly as industries across the board – from finance and healthcare to retail and logistics – seek to incorporate machine learning into their operations. With businesses increasingly relying on AI for tasks ranging from predictive analytics to automation, the demand for flexible, cost-efficient, and scalable ML deployment solutions has never been greater.

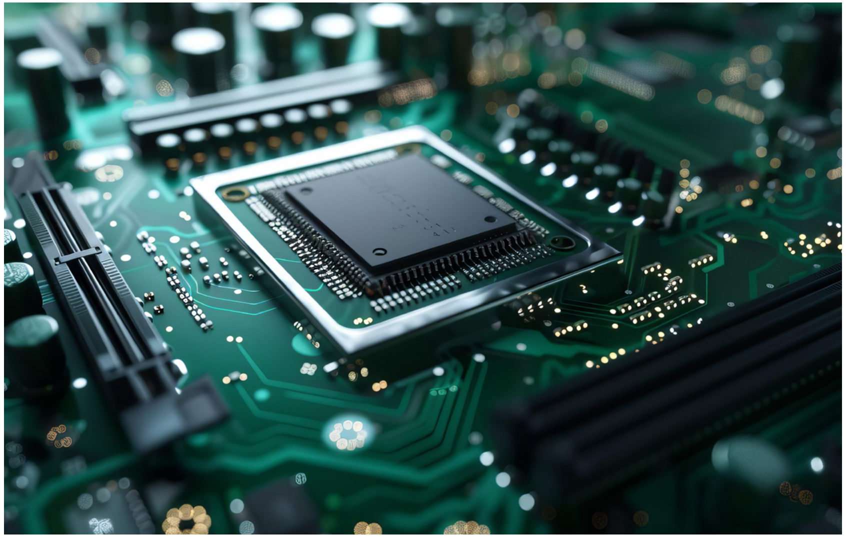
Inferlynx offers a breakthrough solution through its Inference-as-a-Service platform. It is designed to simplify the deployment of ML models, abstracting the complexities associated with infrastructure management and allowing companies to focus on extracting value from their data. Moreover, by providing businesses access to a broad array of hardware resources, Inferlynx allows them to optimize the usage of their specialized equipment, reducing the need for frequent hardware replacements and thus lowering the capital expenditure typically associated with AI infrastructure and hardware refresh cycles.

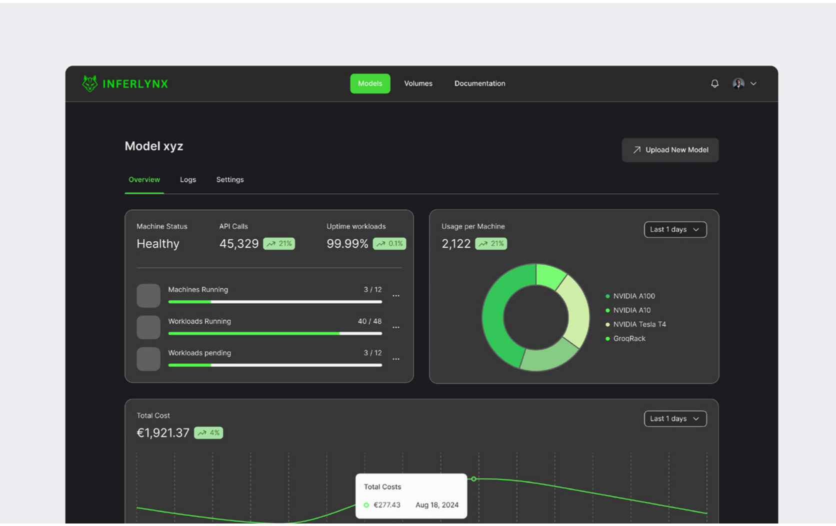
Inferlynx is well-positioned to capture the growing ML deployment market, offering a solution that not only reduces the friction associated with AI adoption but also empowers organizations to unlock the full potential of their data-driven strategies.

Problem

- AWS's Elastic Inference and On-Demand GPU models charge for "attachment time", meaning that costs are accumulated even when the hardware is not fully utilized. Organizations end up paying for idle resources, making it cost-inefficient, especially for intermittent inference tasks that do not require continuous GPU usage [570].
- 65% of companies lack specialized personnel for AI deployment [571], and managing GPU resources on platforms like AWS is complex. Businesses must manually manage entire instances, often leading to resource waste.
- Limited access to specialized hardware like Groq or Cerebras limits flexibility, forcing reliance on less optimal general-purpose hardware for specific AI models [572].
- Especially for companies like tech, healthcare, and fintech start-ups, these complexities introduce overhead in resource management, leading to inefficient utilization of GPUs and driving up operational costs. For example, the average AI model deployment time was 121 days in 2021 [573].

Break free from costly idle GPU usage – switch to smarter, cost-efficient inference solutions that only charge for active usage.





Solution

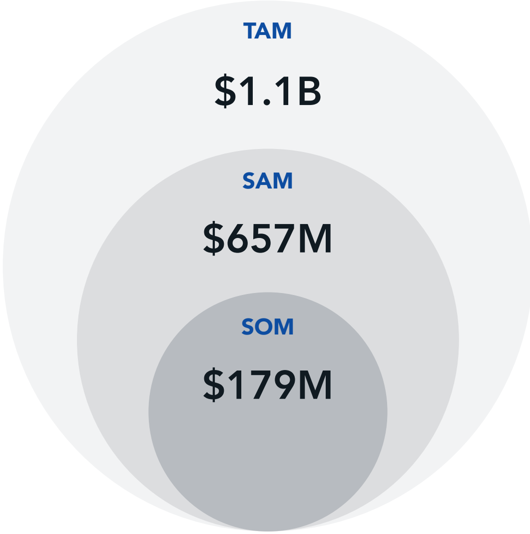
- The platform offers a pay-per-inference model, which means that customers only pay for the time the AI runs. This allows companies with intermittent workloads to pay less than for continuous usage.
- Multiple users can share a single compute unit, ensuring optimal resource usage and lowering costs even further. Intelligent resource allocation optimizes usage, ensuring that only the necessary resources are utilized.
- Simplified management is a central part of the offering. From easy integration to end-to-end deployment, it eliminates the need for manual management.
- The platform provides access to specialized hardware like Groq, which is unavailable through traditional cloud providers like AWS, letting companies leverage hardware tailored to their AI models.
- Whether one requires dedicated or shared GPU resources, Inferlynx delivers a seamless experience with reduced management complexity and greater flexibility in hardware selection.

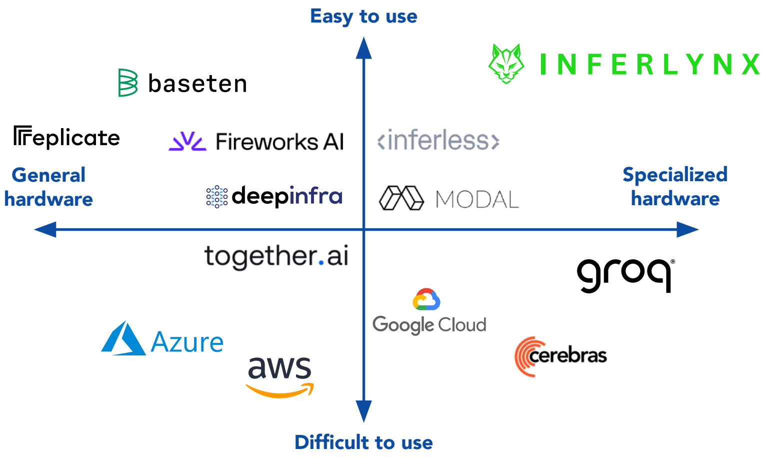
Inferlynx unlocks the full potential of AI with efficient, scalable, and cost-effective inference solutions tailored to customer needs.

Market

- Inferlynx is targeting tech start-ups and software-based SMEs as primary customers with a pay-as-you-go model.
- An annual revenue of 38.65k USD per customer is estimated on average usage patterns. This calculation assumes the average GPU rates, with customers running 5-10 instances for 8 hours per day throughout the year, leading to an approximate yearly cost of 38.65k USD per customer.
- Worldwide, 30k SaaS companies are operating in a diverse range of industries. An estimated average annual revenue per customer of 38.65k USD results in a TAM of 1.16B USD [574].
- In the United States alone, 17k SaaS companies operate, accounting for a significant market share. This leads to a SAM of 657M USD, indicating the specific opportunity for Inferlynx within the US [575].
- There are 4,633 AI-focused SaaS companies in the US, a rapidly growing sector with increasing demand. These companies contribute to a SOM of 179M USD [576].

Inferlynx specifically targets AI SaaS companies in the US to solve the problem of work-intensive model deployment and inference.





Competition

- The inference market can be mapped across two dimensions: ease of use and hardware specialization.
- Companies such as Modal, Inferless, and Baseten prioritize simplifying AI model deployment, making their platforms user-friendly [577, 578, 579]. However, they mainly rely on general-purpose hardware, which limits performance and resource efficiency for specialized tasks.
- Providers like Cerebras or Groq offer advanced, specialized hardware optimized for demanding AI workloads [580, 581].
- Major cloud providers like AWS and Azure are indirect competitors, offering general-purpose cloud infrastructure. However, they offer less tailored optimization, making them less efficient for users needing specialized AI inference.
- Overall, Inferlynx stands out by combining specialized hardware with a user-friendly design. Therefore, Inferlynx provides optimized performance without the complexity of high-end infrastructure.

Inferlynx not only provides the best user experience for deploying AI models frictionless but also enables specialized hardware to scale.

Assumption Tree

AI Models Requiring Specialized HW

Advanced AI models require specialized hardware due to the high computational demands of tasks such as deep learning. Efficient training and inference depend on high-performance computing resources, including GPUs, TPUs, and custom accelerators, which optimize the processing of large datasets and complex operations [567, 568].

Short Lifetime Value of Specialized HW

Specialized hardware for AI may have a short lifetime value due to rapid technological advancements. As AI models and algorithms evolve, hardware quickly becomes outdated, requiring frequent upgrades or replacements. Short life cycles increase costs and limit AI infrastructure's long-term efficiency and scalability.

Strong Lock-In by Hyperscalers

Vendor-lock-in by hyperscalers such as AWS limits companies' flexibility, restricting their ability to adjust to evolving business requirements. AWS customers may face higher computing costs due to specific services or infrastructure constraints.

Complexity of AI Model Deployment

Once an AI model is trained, it must only be deployed for inference. However, this deployment process includes steps such as model packaging, infrastructure setup, and monitoring, making it very complex. 65% of organizations engaged in digital transformation report a shortage of skilled professionals needed for AI model deployment [569].

Difficulty in Accessing Specialized HW

Specialized hardware poses challenges due to the high costs, short hardware lifecycles, and rapid technological advancements. Companies face risks when investing in such hardware, as frequent upgrades are required to remain competitive. As a result, maintaining access to cutting-edge AI infrastructure is costly and inefficient for many companies.

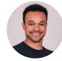
Inefficient Resource Utilization

Due to the vendor lock-in of hyperscalers like AWS, as well as complex deployment, computing resources are often underutilized. Despite the enormous capacity of today's data centers, servers are only utilized at an average of 30% capacity [443]. Efficiently orchestrating workloads is vital to reducing waste and increasing cost-effectiveness.

Inference-as-a-Service

Deploying AI comes with high costs, limited hardware options, and complex management. Inference-as-a-Service solves these issues by offering a pay-per-use model, optimizing resources, and providing access to specialized hardware. This lowers costs, simplifies management, and enables scalable AI without infrastructure limitations.

Isabel Tscherniak 

Khadim Fall 

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Product Panther

Full-Context AI Copilot for Product Management

Software engineering and IT companies face enormous challenges in attracting, retaining, and managing software engineers. On the one hand, there is a lack of skilled software professionals. On the other hand, remote and distributed work makes it more difficult to efficiently use the workforce that companies already have. Hence, companies must optimize the productivity of their existing development teams to maximize both input efficiency and output quality.

A better product development process could significantly improve how software engineering teams collaborate and operate. The product manager is at the heart of this process and central to orchestrating the development cycle. They are responsible for integrating input from sales, marketing, and customers, and translating it into precise product requirements that can be implemented by developers. This role is particularly challenging as product managers must manage large teams and tight deadlines while channeling all business and customer-related information into actionable work packages for software engineers.

Moreover, as the complexity of software projects grows, the need for effective cross-functional collaboration becomes increasingly crucial. Product managers frequently act as intermediaries between multiple teams working asynchronously across different time zones. This fragmented communication creates opportunities for misunderstandings, which can lead to delays that ultimately reduce productivity. To thrive in such an environment, companies must equip their product managers with advanced tools that enable them to seamlessly coordinate complex workflows.

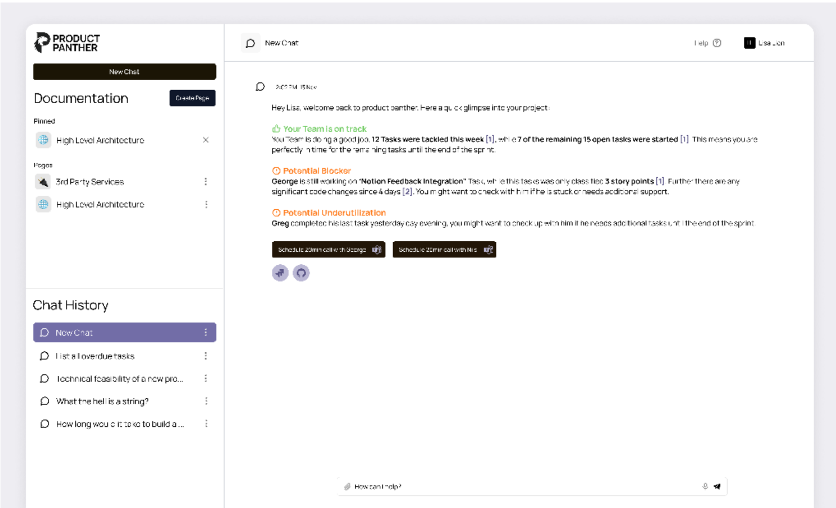
Tools like Jira, Notion, and GitHub are already in place to support product managers in task management, communication, and version control. Yet, managing and maintaining every task and project, while fully understanding the respective technical requirements, remains a significant challenge. This is particularly amplified by the sheer volume of explicit, implicit, and tacit information that must be considered during product management.

Product Panther offers an elegant solution to these challenges in the form of a full-context AI copilot that integrates data from the existing tool landscape. This provides product managers and developers a single source of truth for all relevant information. It scopes, generates, and structures tasks for product managers, thereby providing a concise overview of the current project status, road blockers, and the team's over- or underutilization. By doing so, Product Panther turns 1x product managers into 10x Product Panthers and enables software engineers to focus on what they are best at: Writing software.

Problem

- Product managers face the difficult task of translating customer and business needs into products. With numerous tasks and information sources to manage simultaneously, it can be challenging to maintain a clear overview of the team's activities as well as the product's technical requirements. This complexity leads to bottlenecks in development cycles, resulting in delays, missed deadlines, and reduced revenue potential [583].
- Product managers' daily struggles directly translate into their teams' productivity and quality. As a result, software engineers spend 21% of their time with non-technical overhead tasks [582], such as documentation, task coordination in long meeting cycles, and onboarding themselves and colleagues into projects. The onboarding process for large software projects often takes up to six months [505].
- Companies could save up to 27k USD per developer per year if they eliminated developer's non-technical overhead tasks, allowing them to focus purely on software development [584].

Product development teams need an assistant to make sense of all the existing information while increasing accessibility.



Solution

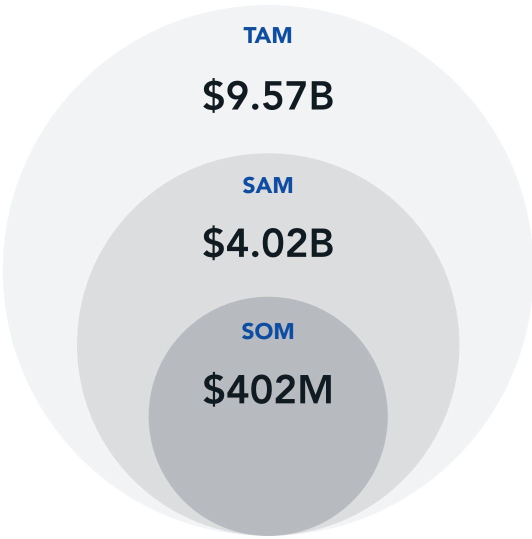
- Product Panther is a full-context AI copilot for product teams that integrates information from various tools. It is a constant assistant for product managers and developers to boost their collaborative efficiency. It does not replace a company's current tool landscape but rather makes the data in existing tools more accessible and brings them into context.
- Product Panther helps with scoping, generating, and structuring tasks for product managers. It provides a concise overview of the current project status and identifies potentially blocked tasks and underutilization of developers.
- Product Panther allows project managers and developers to efficiently locate necessary information within various tools, consolidating relevant data from multiple sources into a central hub. Furthermore, it acts as a sparring partner for product managers and developers for technical questions, helping them to understand technical details and and enabling easier access to the project.

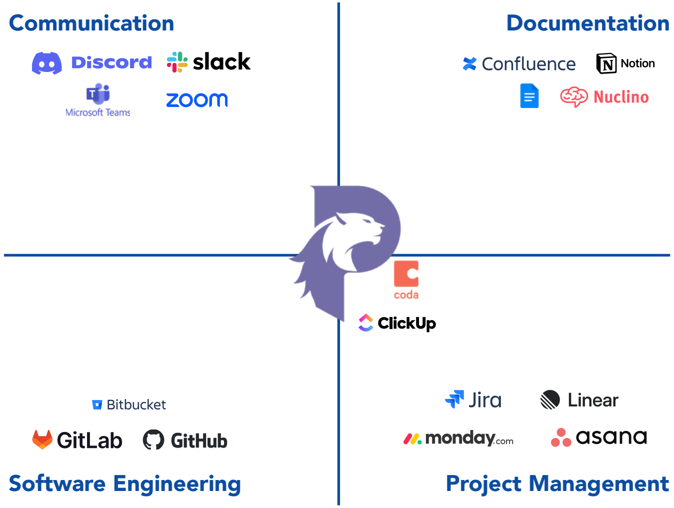
Everyone talks about 10x developers; Product Panther creates 10x product managers.

Market

- Product Panther caters to complex, distributed software development teams in large corporations and fast-growing scale-ups, especially those utilizing digital workflows and AI. Companies employing software development teams with more than 20 engineers can benefit from the product, as they need to streamline project management and collaboration across multiple platforms.
- Product Panther operates a SaaS model, offering licenses at 500 USD per year.
- With an estimated 17.4M software engineers working in companies with 20 or more engineers worldwide, along with approximately 1.74M product managers in software engineering, the TAM is projected to be around 9.57B USD [585].
- Focusing on regions with high AI adoption (e.g., Europe, North America, Asia) and an AI readiness rate above 40% [586], the SAM is calculated at 4.02B USD [587].
- With a 10% market penetration target [588], the SOM amounts to 402M USD in annual recurring revenue (ARR).

Product Panther taps into a 400M USD market opportunity by enabling seamless collaboration between product managers and developers.





Competition

- Software product teams are already supported by a variety of tools for project management and tasks (e.g., Jira, Asana, Trello), communication (e.g., Slack, Teams, Zoom), software engineering (e.g., GitHub, Bitbucket), or documentation (e.g., Notion, Confluence).
- Product Panther does not compete directly with those or aims to replace a company's existing tools, but integrates and enhances them. Customers can continue using their current tool stack while Product Panther consolidates the existing information, making it more accessible and valuable for product managers and developers.
- Direct competitors, such as Coda, have a similar integrative approach to Product Panther. However, these competitors require more complex onboarding and integrations, while Product Panther offers a lean customer onboarding and does not require changes in the current tool stack.
- Product Panther fully integrates all tools, offering real time, full-context insights that enhance collaboration, streamline workflows, and boost efficiency without replacing existing systems.

Product Panther eliminates fragmented systems, streamlines communication, reduces inefficiencies, and unifies project data in one platform.

Assumption Tree

Product Management Misalignment

Product managers struggle to translate business requirements into actionable development tasks. This leads to miscommunication, unfulfilled expectations, and project delays as developers work on tasks that do not align with broader business goals.

Developer Overload

Developers are frequently responsible for non-technical administrative tasks such as updating documentation or managing responsibilities. These tasks consume around 21% of their time [582], reducing the focus they can dedicate to actual coding and technical problem-solving, resulting in slower development cycles.

Inefficient Onboarding

Onboarding new developers into projects is complex and time-consuming, often taking months, which decreases productivity and adds unnecessary costs. Incomplete or outdated documentation further complicates the process, requiring senior team members to step in, distracting them from their work.

Lack of Seamless Tool Integration

Software engineering projects are unique, with teams using tailored tools and workflows. Forcing developers and project managers into rigid, standardized tool sets hampers productivity. Existing tools often fail to integrate seamlessly across platforms (e.g., Jira, Notion, GitHub), leading to fragmented workflows and reduced efficiency.

Collaboration Mismatch

The combination of misalignment between project managers and developers and the high volume of non-technical tasks developers face leads to significant issues in collaboration. This results in slower decision-making, task mismanagement, and delayed product development timelines, ultimately reducing team productivity.

Performance Impact

Inefficiencies in onboarding and a lack of flexible tool integration hinder smooth project execution. This negatively impacts team performance, which measurably extends project delivery timelines.

AI Copilot for Efficient Collaboration

Product Panther can help overcome these challenges. An AI copilot that enhances collaboration between project managers and developers, reduces non-technical overhead, streamlines onboarding, and integrates seamlessly with existing tools. Product Panther will drive team efficiency, reduce delays, and enable faster development cycles.

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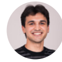
Rudraksha Samdhani 

Reino

Operational Cybersecurity Response for SMEs

Cyberattacks are increasing in frequency and cost, with business interruptions due to ransomware rising by 40% in recent years and overall cybercrime losses more than doubling [589]. SMEs are particularly vulnerable: in 2019, 58% of all cyberattacks targeted SMEs, with the UK Federation of Small Businesses reporting 10k daily attacks [590, 591]. The financial toll is severe, as the average breach cost has surged to 4.88M USD [592]. This is due to a lack of preparation among SMEs, which results from a combination of low-risk perception, insufficient investment in cybersecurity, poor cybersecurity literacy, and a general lack of awareness of the threats they face [593, 591, 594].

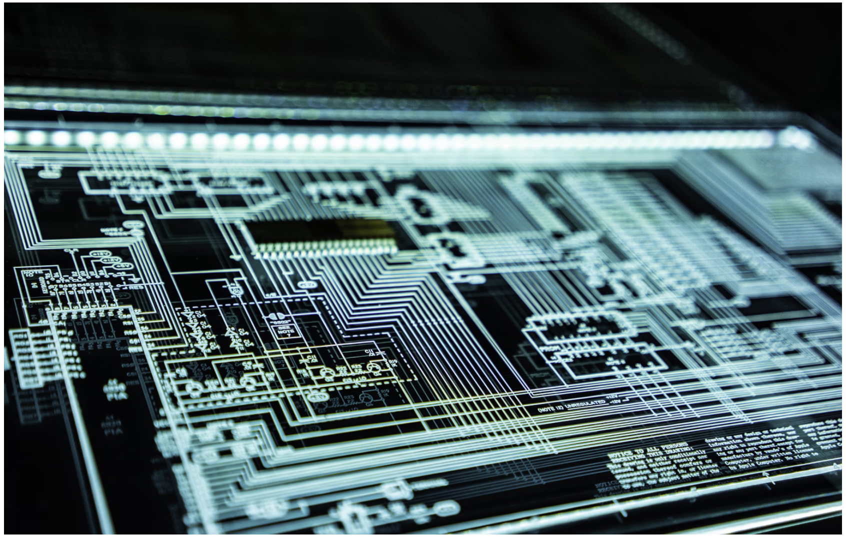
A slow and disorganized breach response is another key factor driving the high costs. On average, it takes 25 days to restore operations after a successful attack [595], with full recovery often stretching to 300 days [592]. The extended downtime costs from ransom payments, data breaches, and third-party service fees can devastate start-ups and smaller enterprises. SMEs often prepare only outdated emergency response plans, if any [596]. Likewise, 53% of businesses struggle with a shortage of cybersecurity professionals [592]. Reino is designed to help organizations cooperate faster during cyber-interruptions to ensure business continuity. The solution supports businesses throughout the journey, from pre-breach preparation to emergency response. Like an emergency plan for real-world fire drills, Reino provides businesses with the tools and workflows to efficiently address cyber breaches, minimizing recovery time and maintaining business continuity. Thus, Reino aims to reduce the length of business interruption by 60%, from 25 to 10-12 days, and to provide the best possible support by reducing organizational overhead [592].

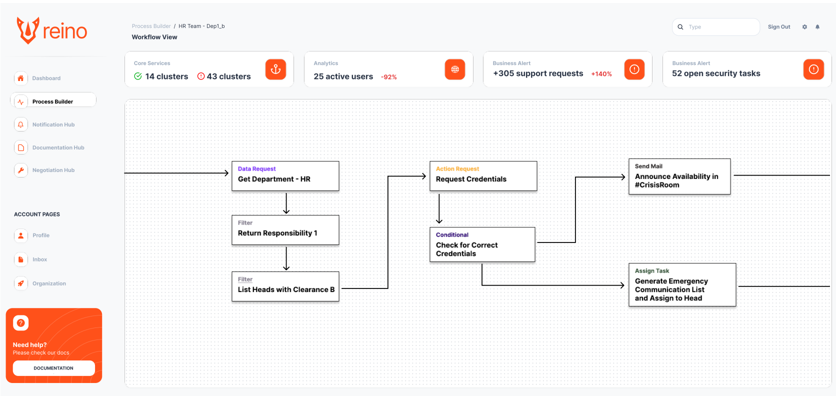
The aim is to smoothly integrate Reino with SMEs' existing standard systems and enable the creation of response plans and protocols that comply with international standards before a breach occurs. In case of a successful breach, Reino excels in optimizing post-breach operations. It enables the parallel management of essential tasks, such as notifying authorities, overseeing data recovery, and negotiating with stakeholders like insurers or consultancies. This reduces recovery time, minimizes reputational damage, and mitigates potential penalties. Reino helps leaders focus on what matters.

Problem

- Financial losses due to cybercrime have more than doubled in the last three years, significantly increasing the economic burden on companies [589].
- Business interruptions caused by ransomware attacks now last significantly longer on average, leading to considerable losses in productivity and revenue [494].
- SMEs are particularly vulnerable, making up 58% of breach victims and often lacking sufficient resources for effective incident management [591].
- Security incident response is often inefficient. A lack of coordination, communication, and negotiation during a cyber attack leads to high operational overheads, increasing financial losses [593].
- Only 27% of companies have automated breach response systems, leaving many reliant on slow, manual processes that increase recovery times over 25 days [592].

Safeguarding companies from cyber attacks is crucial for survival in a digital world.





Solution

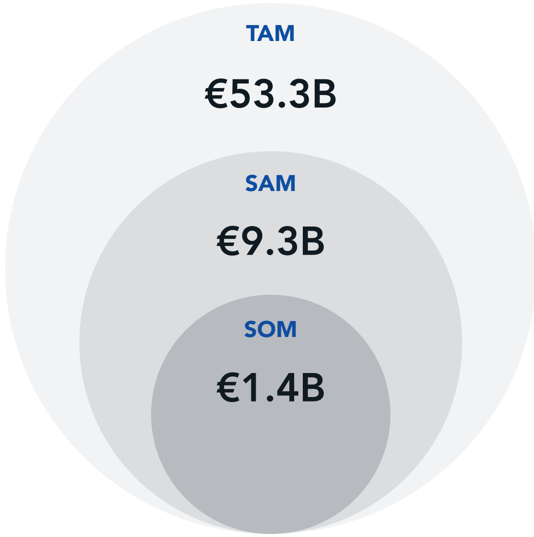
- Reino is a flexible workflow builder tailored to the individual needs of organizations that provides straightforward and actionable steps to effectively manage security breaches. No-code templates allow for customization and set up workflows for various attack scenarios.
- During an attack, the automated, predefined workflows notify the responsible person before executing and managing the whole process in parallel workstreams. Parallelization in areas such as negotiations, documentation, and communication increases the efficiency and effectiveness of incident response. Recovery time is reduced by up to 60% by minimizing the time of operational overhead.
- The workflow builder supports the simultaneous management and optimization of various processes, such as negotiating with insurers or hackers and adhering to compliance requirements.
- Reino reduces financial losses through quick operations and decision-making, minimizing downtime after cyberattacks.

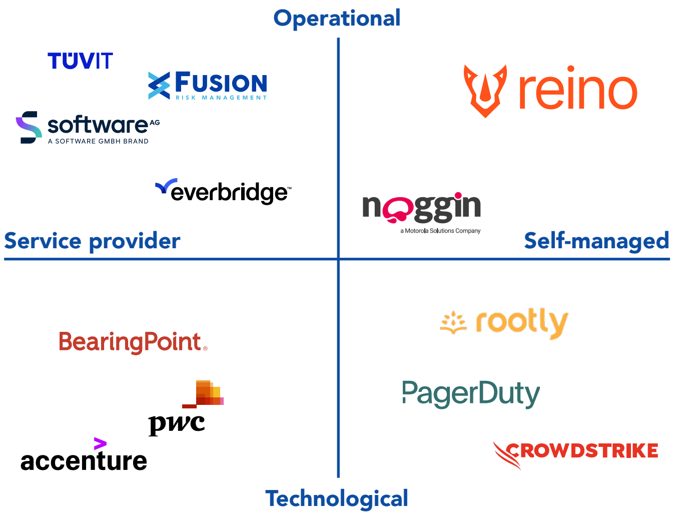
Enabling teams to cooperate more effectively during cyber-interruptions to ensure business continuity through prepared and automated workflows.

Market

- Reino aims to capture a significant share of the available market through customized solutions for European SMEs due to similar compliance laws and colossal business advantages.
- With 24.4M SMEs in the EU as of 2024 [597], taking into account the size of the IT infrastructure of the enterprise and the pricing in the European market, the TAM amounts to 53.3B EUR.
- This market is developing with a CAGR of 2.7% [597], increasing the market window.
- Since 15.5% of SMEs in the total EU market are from the DACH region [598, 599], this creates a huge potential addressable market for Reino with an ARR of 9.3B EUR.
- Considering the current market dynamics, Reino aims for a 15% market share and a potential 1.4B EUR in ARR from the addressable market. The targeted focus on SMEs in the DACH region offers considerable growth opportunities.

Tapping into a 1.4B EUR opportunity through workflow optimization during cyberattacks with Reino.





Competition

- Technological service providers like PwC, Accenture, or BearingPoint provide cybersecurity consulting services supporting the recovery of data and systems. However, they are neglecting the operational side of recovery.
- Operational service providers like TÜVIT, Fusion Risk Management, SoftwareAG, and Everbridge focus on understanding the operational structure and helping companies tackle auditing and compliance, but they lack technological support and customized solutions.
- Technological self-managed solutions like PagerDuty, Rootly, and CrowdStrike give clients full control over processes like backup restoration but do not extend to managing overall company operations.
- Reino bridges the gap between operational and self-managed solutions by offering customized, flexible workflows and strategies, especially for SMEs.

Protecting businesses with a customizable, self-managed cyber security solution and minimizing financial loss.

Assumption Tree

Growing Attack Intensity

As more companies digitize their processes, a cyberattack can stop operations longer. This is reflected in the growing damage per successful attack – for individual companies higher downtimes put them at risk of running out of business.

Increasing Number of Cyberattacks

Cyberattacks, especially on SMEs and governments, are increasing worldwide. Ransomware attacks have become more common as attackers use "Ransomware-as-a-service" solutions, commoditizing crime. Organizations maintaining legacy services are especially at risk as known vulnerabilities stay longer in the codebase.

Cybersecurity Talent Shortage

The increasing frequency and complexity of cyberattacks create a high demand for cybersecurity specialists in all industries. Especially for SMEs in the DACH region (Germany, Austria, and Switzerland), it is difficult to find and retain talented employees. Current education programs do not provide enough graduates with the required skills to meet market demand.

Dependence on Digital Supply Chains

Supply chains depend on digital systems for tracking and management, with third-party providers increasing disruption risks from cyber incidents. Greater connectivity heightens vulnerability to hacks, causing delays, losses, and reputational damage. Global risks like trade restrictions and climate disruptions also affect data flow and coordination.

Missing Business Continuity Plan

Small and medium-sized companies are unprepared for cyberattacks and the operational chaos that comes with them. There is a need for business continuity plans to address individual needs to minimize downtime and financial loss. Unique business risks and regulatory requirements make it necessary to customize responses for each organization.

Decrease of Recovery Time

To minimize business disruption, the downtime of services has to be decreased. Yet, the cybersecurity talent shortage increases recovery time. The existing technical staff and external cybersecurity consultants need to be empowered to focus on solving the technical impact. Communication and coordination should not be another burden.

Reduction of Expected Loss

Organizations can reduce the financial impact of cyberattacks by optimizing post-breach response parallelization. Minimizing downtime through better coordination lowers expected losses. Tailored continuity plans and continuous monitoring ensure faster recovery and limit escalating damage.

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THE FUTURE OF SOFTWARE ENGINEERING AND IT OPERATIONS

From managing finances via mobile apps and scheduling appointments to controlling home lighting with smart devices, software is now embedded in nearly every aspect of our lives. Given its undeniable importance, it is essential to explore how the underlying systems of software development and maintenance meet the demands of a digital world.

Just as Moore's Law describes the trend of shrinking transistor sizes, a similar phenomenon can be observed in software engineering. Emerging technologies in both software engineering and underlying hardware performance drive down the time and cost of software development but at the same time, increase its complexity and capabilities. This raises two critical questions: How will software engineering evolve to meet the arising complexities, and how will we effectively monitor and manage the expanding IT systems?

These questions shape the focus of this report: The future of software engineering and IT operations.

Besides technological dimensions, broader societal, environmental, legal, and economic factors also play a critical role in this regard. For instance, how will increasing concerns about sustainability affect software development practices? What legal frameworks need to be updated to regulate AI and data privacy? And how will economic shifts and global labor shortages impact the talent pool for software engineers?

The transformation of software engineering and IT operations brings new challenges that demand innovative business models. For example, improving the accessibility of digital products will require solutions that bridge technology and regulation. Furthermore, post-breach response strategies will be redefined and assessed in novel ways. Additionally, the education of computer science students must evolve to align with the future needs of the workforce.

This report organizes these considerations into three sections: trends, exploration, and ideation. First, current trends across technical, societal, environmental, regulatory, economic, and legal domains are examined, analyzing their potential future impact on the IT industry. Building on this, key problems and opportunities are identified and thoroughly analyzed. The final section translates these insights into five innovative business ideas, addressing critical areas such as accessibility compliance, education, AI inference, product management, and post-breach response.

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The Center for Digital Technology and Management (CDTM) is a joint interdisciplinary institution of education, research, and entrepreneurship of the Ludwig Maximilian University (LMU) and the Technical University of Munich (TUM).

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