Chapter 6. Technological challenges for the digital transition

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6.1. Introduction

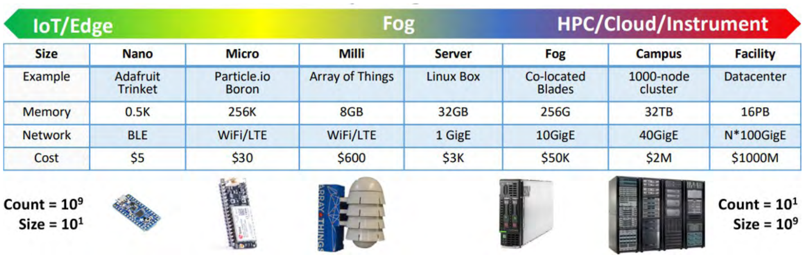
Digital technologies offer enormous growth potential to companies that invest in innovative ICT (Information and Communication Technologies). Indeed, the adoption of digital services can impact business processes in different ways, such as reducing management costs, increasing production, and increasing customer satisfaction. This pushes enterprises to invest in the digital transition, digitalizing data, systems and procedures, optimizing processes and the overall management of resources. Digital Transition integrates digital technology into all the areas of a business, also changing how companies operate and deliver value to customers. It represents a technological but even business, economic and cultural transformation, where new production and delivery models need to be redesigned to address digital advances.

However, to implement a fruitful digital transition, each enterprise must identify the key opportunities, which depends on the real needs of the company itself, the long term objectives and the eligible economic investment. It is essential to identify clearly how technologies can really give added value to business processes.

This chapter aims to show which are the emerging technologies that are enabling the ongoing digital transition of public and private companies. It discusses how such technologies are evolving and why they are becoming so necessary in every application domain. Additionally, it analyses how the combination of such technologies can generate a disruptive potential in creating new solutions and business opportunities, even addressing the setup of innovative value chain models. Finally, it describes the long-term perspective of technological advances and the future direction of digital transition.

6.2 How Information and Communication systems are evolving

Digital transformation is driven by contemporary advances of technologies in different sectors, which unlock their potential whenever combined. First of all, research on microelectronics have brought a high variety of computing devices, with different hardware equipment and computation capabilities. These components range from small, inexpensive devices with limited computer resources (IoT) to modest priced servers with mid-range resources to expensive high-performance computers with extensive computing, storage and network capabilities. Different electronic solutions implement different computation tasks aimed to address specific needs. For example, IoT/Edge devices are primarily used to interact with the environment and users, and to provide time-sensitive responses, such as event alerting, home automation, health status monitoring. In contrast, HCP/Cloud architectures are used to run highly resource-intensive services, such as AI model training, big data analysis, and scientific application execution [2][3].



Size	Nano	Micro	Milli	Server	Fog	Campus	Facility
Example	Adafruit Trinket	Particle.io Boron	Array of Things	Linux Box	Co-located Blades	1000-node cluster	Datacenter
Memory	0.5K	256K	8GB	32GB	256G	32TB	16PB
Network	BLE	WiFi/LTE	WiFi/LTE	1 GigE	10GigE	40GigE	N*100GigE
Cost	$5	$30	$600	$3K	$50K	$2M	$1000M

Figure 6.1 Cyberinfrastructure scale [1]

In telecommunications, wide-bandwidth data transmission enables high-speed internet access worldwide. 5G and 6G networks have great potential to support large volumes of web-based services and real-time and streaming applications, envisioning hyper-connected systems over the internet. The availability of heterogeneous, hyper-connected computing devices has spurred the massive deployment of distributed systems. In these systems, nodes work on a variety of tasks across a network, splitting up the work, balancing workloads and coordinating efforts to complete tasks, even more efficiently than traditional standalone computers [4][5]. However, distributed systems can become highly pervasive and ubiquitous because they can use smart objects to bring computation close to the user, even in a transparent way for the users themselves opportunities to provide new digital services to support users in all their daily activities.

Finally, advances in computer science brought to the development of new key technologies for massive interaction with the environment, storage and processing of huge amounts of complex data through heterogeneous and performing hardware and software infrastructures, e.g. Big data, Internet of Things, Artificial Intelligence and more [6, 7, 8].

On one hand, technology is advancing rapidly. On the other hand, users are evolving in how they interact with these technologies and what they expect from them. Mobile devices, smart apps and automation systems allow users to access data and services quickly and easily. Users expect to have seamless access to customized digital services 24/7 and the provisioning of real-time multimedia communications to address both professional and personal activities. This shift requires a new approach to designing digital solutions, which has to address the fundamental principle that the user is the central focus of the design process itself [9, 10].

6.3 Key technologies for Digital Transformation

Figure 6.2 reports the Gartner Hype Cycle for Emerging Technologies for 2023. It identifies the 25 key technologies that are expected to have a significant impact on business and society over the next two to ten years, in particular enabling digital business transformation.

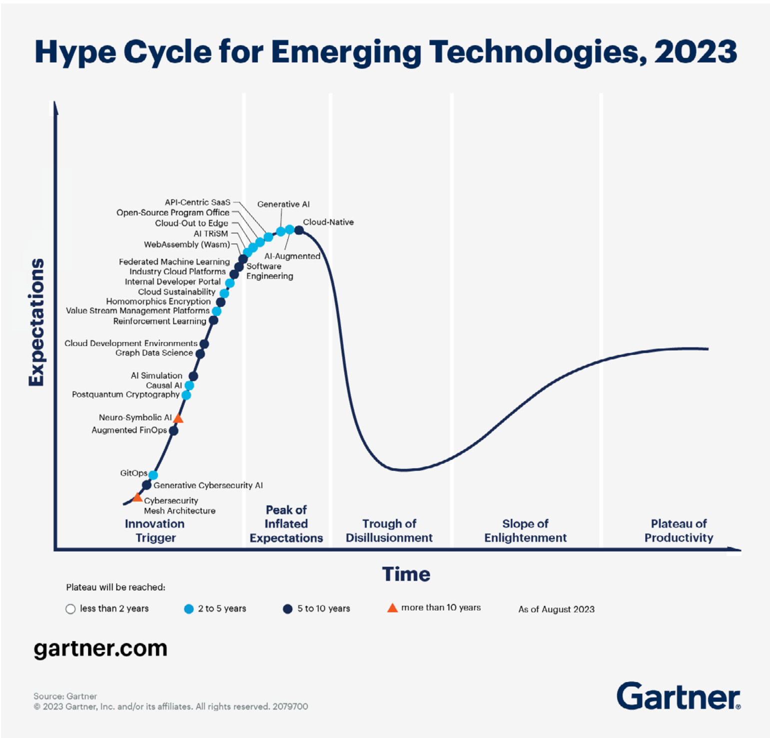


Figure 6.2 2023 Gartner Hype Cycle for Emerging Technologies

In the *Innovation Trigger* and *Peak of inflated expectations* stages there are several Cloud-oriented technologies (e.g., Cloud Development Platform, Industry Cloud Platforms, Cloud-Out to Edge, Cloud-Native...). *Cloud Computing* refers to the delivery of computing services, including storage, processing power, and software, over the Internet [11]. Instead of owning and maintaining physical servers or hardware, users can access these services on-demand from Cloud service providers. This model offers several advantages, including scalability, flexibility, cost-efficiency, and the ability to access resources remotely. Key characteristics of Cloud computing include:

– On-Demand Self-Service: Users can get provision and manage computing resources as needed, without requiring human intervention from the service provider.
– Broad Network Access: Cloud services are accessible over the internet from a variety of devices such as laptops, smartphones, and tablets.
– Resource Pooling: Resources are pooled and shared among multiple users, allowing for more efficient use of computing resources. Users typically don't have direct control over the exact physical location of the resources.
– Rapid Elasticity: Cloud services can be quickly scaled up or down based on demand. This allows users to adapt to changing workloads and only pay for the resources they use.
– Measured Service: Cloud computing resources are metered, and users are billed based on their usage. This pay-as-you-go model is cost-effective and allows for better financial management.

The cloud computing technology can be deployed using to two basic deployment models, each with its characteristics and use cases: public and private models. In a *Public Cloud*, computing resources are owned, operated, and provided by third-party service providers. These providers make resources - such as virtual machines, storage, and applications - available to the general public or multiple organizations over the internet and are typically offered on a pay-as-you-go or subscription basis. Popular Public Cloud service providers include Amazon Web Services (AWS), Microsoft Azure, Google Cloud Platform (GCP), and others. In a *Private Cloud*, computing resources are deployed and used exclusively by a single organization. The infrastructure can be owned and managed by the organization itself or by a third-party provider, but the key characteristic is that the resources are dedicated to the specific organization. Private clouds offer a higher level of control, customization, and security compared to public clouds. Organizations can tailor the environment to meet their specific needs and compliance requirements. Additionally, since resources are not shared with other organizations, private clouds are often selected for their enhanced security and privacy. VMware Cloud, OpenStack, and Microsoft Azure Stack are examples of technologies that enable the creation of private clouds.

Cloud computing is a key technology for enabling the deployment and massive usage of advanced computing solutions. Indeed, scalable Cloud infrastructure and resources allow to store, manage and process massive volumes of data (Big data). Artificial Intelligence (AI) algorithms can then extract valuable insights and patterns from this data, empowering organizations to harness the potential of these technologies without the challenges of managing complex on-premises infrastructures. The integration of cloud computing with AI and Big Data is a powerful combination that can enhance and optimize various business processes, decision-making, and innovation. Big data technologies, like Apache Hadoop or Apache Spark, are used to store, process, and manage these vast datasets across the Cloud data centers. Cloud-based analytics services and platforms, including Amazon Redshift, Google BigQuery, or Azure Analytics, can be leveraged for scalable and efficient data processing, allowing organizations to handle complex analytics tasks.

Significant opportunities for the future of computing are emerging from IoT and edge devices, as discussed in Section 6.2. These devices extend storage and computational resources towards end users. They include physical objects or "things" embedded with sensors, software, connectivity, and other technologies, allowing them to collect and exchange data with other devices and systems over the internet. The goal is to facilitate interactions and communication between devices without human intervention, creating a smart and interconnected environment around the user. IoT, Edge computing and cloud computing are interconnected ecosystems that collaborate to enable efficient data processing, analytics, and decision-making. These technologies work together to handle the vast amounts of data generated by IoT devices across distributed edge and cloud infrastructures [12, 13].

When these technologies work together, they implement an agile and data-driven approach for decision-making and problem-solving, which is central to the current digital transition. Organizations that invest in such technologies will unlock the full potential of their data, gain actionable insights, and build intelligent applications that drive innovation and enhance business processes.

6.4 Enterprise investments for digital transition

The 2020 IDG Cloud Computing Survey [14] asserts that cloud computing represents a third of the ICT cost for enterprises. Most companies surveyed plan to use Cloud services for over half of their infrastructure and applications. In particular, the primary reason for companies to move to the cloud is support in using the essential software, platform and infrastructure quickly and cost-effectively. Another key reason for enterprises to adopt cloud based solutions is the lower cost of IT infrastructure. In a traditional ICT ecosystem, the Total Cost of Ownership (TCO) includes factors like server hardware storage and maintenance, security system maintenance costs, administrative IT costs for systems and databases and more. Cloud services, however, offer a pay-as-you-go subscription model, where costs are proportionate to the effective usage of ICT resources. This approach makes digital transition more accessible, allowing even small enterprises to innovate and enhance their operations without substantial upfront investments. The worldwide enterprise spending on Cloud and data centers shows a significant growth of spending allocation in Cloud services, reaching almost $130 billion. Cloud spending by enterprises has surpassed enterprise spending on on-premises data centers, which has remained relatively stable in recent years. This shift indicates that many enterprises are adopting hybrid and multi-Cloud strategies, leveraging a combination of public and private Clouds to meet specific business requirements. This approach allows organizations to balance factors like performance, security, and compliance effectively.

Eurostat published an analysis on how EU enterprises bought Cloud services. In 2023, 45.2% of EU enterprises purchased Cloud computing services. This marks a 4.2 percentage point (pp) increase compared with 2021. The highest adoption rates were registered in Finland (78.3%), Sweden (71.6%), Denmark (69.5%) and Malta (66.7%). Conversely, less than a quarter of enterprises in Greece (23.6%), Romania (18.4%) and Bulgaria (17.5%) made such purchases.

The Cloud Transformation Observatory reported that Italian companies invested €4.5 billion in cloud services in 2022, marking an 18% increase compared to the previous year.

Additionally, according to the estimate of Statista's Technology Market Outlook, revenues for Italian companies serving as public cloud providers are projected to exceed €8 billion by 2025, up from €3.16 billion in 2020. Notably, about half of this growth is expected to come from the Software as a Service (SaaS) sector (see Figure 6.3).

These statistics prove the ongoing need of enterprises to invest in the cloud, albeit with varying budgets in different countries. These investments have become increasingly crucial for staying competitive, agile, and efficient in today's rapidly evolving business landscape.

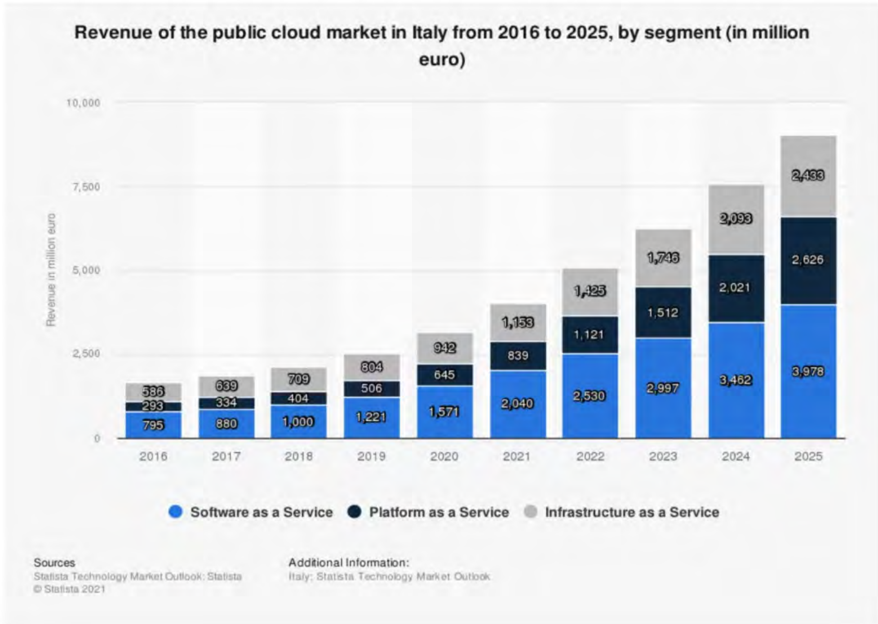


Figure 6.3 Cloud Revenue in Italy

6.5 New digital services

In recent years, cloud technologies provided great support for the deployment of IoT solutions thanks to their high availability of computing and storage resources. However, usually resources in the Cloud are distant from the IoT placement, causing performance degradation, mainly due to network connections. To overcome these problems, a multi-level computing architecture (working at the IoT, edge and cloud levels) can be adopted. In this approach, critical data can be kept and processed close to the environment (e.g., on IoT devices or at the edge of the IoT environment), while the activities that require less responsiveness or more resources run in the cloud (see Figure 6.4). To fully leverage the capabilities of various technologies, complex software applications can no longer be developed as monolithic solutions. Instead, they must be redesigned as a more flexible configuration of components, which implement different and well-defined functionalities. This modular approach allows each component to use the most appropriate resources available within the existing infrastructures. This brings to a new approach in application development, which is based on m*icroservices*. Microservices structure an application as a collection of small, independently deployable services [15]. These services are designed to be highly modular, loosely coupled, and focused on specific business capabilities. Each microservice operates as an independent unit, communicating with other services through well-defined interfaces, commonly referred to as APIs (Application Programming Interfaces).

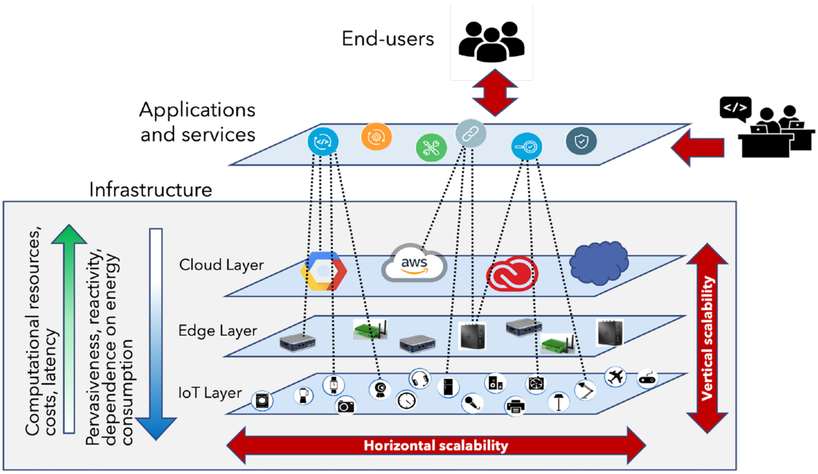


Figure 6.4 Distributed computing opportunities

Innovative principles at the basis of the multi-layer design are as follows:

– Compute Continuum (for vertical scalability): dynamical management of resources (or micro- resources at the IoT and Edge layers) across the different computing layers in a transparent way for the end use and according to several criteria, such as: application/service requirements, infrastructure resource availability, QoS, user QoE, energy consumption [16].
– Collaborative computing at the Edge (for horizontal scalability): IoT and Edge devices do not work in stand-alone mode, but they need to cooperate with each other and with Cloud datacenters for the efficient provisioning of services to the end-user. It implies auto-configurating and self-adaptative strategies for service management, even in presence of mobile nodes (e.g., drones, vehicular equipment...) [17].
– Intelligent orchestration of microservices: orchestration strategies to implement both vertical and horizontal scalability will be developed using AI based solutions, that will allow to predict necessary resources or possible migration of computation, thus to increase the reactivity of the orchestrator to events and to adapt the behavior of the whole system to the specific application-oriented and context- based needs [18].
– Security by design and trust: limits possible system vulnerabilities from the very first phase of creation to be compliant with the principles of lawfulness, fairness and transparency, integrity and confidentiality. In this view, it will integrate secure mechanisms for data integrity, authentication, privacy and trackability. It will safely manage processing workflows and establish

trust among different actors, in particular end-users and/or stakeholders of infrastructure or services [19, 20].
– Environmental sustainability: in line with EU policies to protect the environment, the project will explore strategies to optimize energy consumption in the allocation of computing and storage tasks, thus reducing CO2 emissions. Also, it will define allocation policies that take in consideration green energy sources (e.g. Solar Cells) [21, 22].

6.6 Cloud-based value chains

Value chains represent the full chain of a business's activities in the creation of a product or service based on cooperation, sovereign data sharing and controlled data usage among different organizations.

The value chain in cloud computing involves a series of activities and processes that add value to the delivery of cloud services [23]. It encompasses various stages, from infrastructure and platform provision to the delivery of software and applications, as illustrated in Figure 6.4. However, future value chains can be envisioned as federated ecosystems built on the Compute Continuum. In fact, microservices deployment in the Compute continuum facilitate agile development practices. This approach enables teams to iterate quickly and respond to changing business requirements. The ability to release and update individual services independently supports faster time-to-market for new features and improvements.

The new era of application and services will efficiently articulate opportunities around data spaces, where different Administrations/Country Domains are involved and, hence, need to extend data governance strategies across multi domain data (Figure 6.5). Different tasks in the value chain are modelled as a composition of *Smart Precision Data Services* (i.e. microservices for data-oriented processing) deployed across heterogeneous edge/cloud infrastructures. Each Smart Precision Data Service identifies a computing black box, where input data and metadata are processed to generate new data and metadata. For each Smart Precision Data Service computation, data governance strategies need to be clearly implemented to securely manage the data life cycle (from data generation/collection to the final use and disposal/deletion of data) related to the referred EDS. Value chain management involves both vertical and horizontal collaboration between companies to extract additional value out of data. The horizontal collaboration facilitates interactions among different actors through a well-specified sequence of tasks and rules for controlling the data flows across multidomains. Such interactions can be automatized by using digital components (e.g. triggers, message-based protocols...) or handled by human-based controls (e.g. vocal command, face recognition, sign of a document...). The latter approach puts humans at the center of the data processing flow, further characterizing Data Spaces, which are enriched by human-generated data and metadata. Smart Precision Data Services, which rely on the behavior of the "human in the loop," introduce new challenges for effective data governance strategies. Vertical collaboration, on the other hand, includes the management of Smart Precision Data Services and their execution over the available infrastructure, with a management of the whole data life cycle for involved Data Space(s).

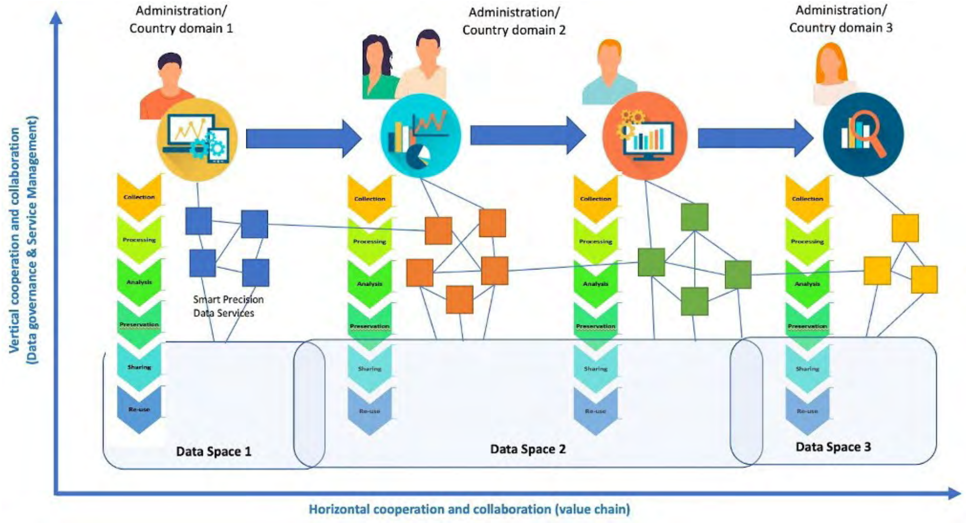


Figure 6.5 Complex Federated systems

6.7 Conclusions

This chapter explores emerging technologies for digital transition, revealing a rich landscape of opportunities and transformative potential. The integration of cloud computing, AI, Big Data, Edge computing and IoT is reshaping the way organizations operate, innovate, and connect with their stakeholders. As we navigate the digital transformation era, it becomes evident that these technologies are not merely tools but catalysts for profound change. However, adopting these emerging technologies is not a one-size-fits-all endeavor. Organizations must meticulously assess their readiness, strategically plan their adoption, and seamlessly integrate these technologies into their existing ecosystems. Change management becomes a critical aspect, recognizing that the successful digital transition is as much about empowering the workforce as it is about deploying cutting-edge tools.

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