CHAPTER 2. Cloud computing; a historical and technical overview

a. Introduction – scope of this chapter

Cloud computing technologies have been rapidly expanding over the past ten to fifteen years to be today the standard enabling technology for most of the applications and aspects of the internet as we know it. Cloud-based systems and cloud computing, as such, were not an invention, nor a pioneering discovery when they started to be widely commercialized in the beginning of 2000s. They had actually been around long before, as technically feasible arrangements for the handling of data and the execution of computational tasks. However, the growing appetite for processing power that an increasing e-economy necessitated, the commoditization of more and more internet-based services related to data handling and the equally fast rate at which consumers adopted these services led to a rapid commercialization of cloud technologies[46]. Yet, despite the fact that the cloud, as a technical feasibility, had been around since long before, its true meaning and the ways in which it did things differently than before had not been adequately realized or examined for many years after its popularization as a commodity. In order to understand what cloud computing is all about and, eventually, demonstrate what it does differently in comparison to previous technical arrangements for data handling tasks, a review of the history of the cloud is the first step.

Getting familiar with the essence of the technical aspects of cloud computing is the aim of this chapter of the study.

46 For more information on the history and technical evolution of cloud computing refer to: M. Arif, A history of cloud computing, available at: http://www.computerweekly.com/feature/A-history-of-cloud-computing (18 February 2015); Hongji Yang & Xiaodong Liu, Software reuse in the emerging cloud computing era (2012); Thomas Erl, Richardo Puttini & Zaigham Mahmood, Cloud computing. Concepts, technology, & architecture (2013); Antonio Regalado, Who Coined 'Cloud Computing'?, available at: https://www.technologyreview.com/s/425970/who-coined-cloud-computing/ (11 January 2017); Inc. Gartner, Cloud Computing Confusion Leads to Opportunity (2008).

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b. A brief history of the cloud

Cloud computing has evolved to be the technology that we so extensively use today through a number of phases that included concepts like client-server arrangements[47], grid[48] and utility computing[49], application service provision (ASP)[50] and, more recently, Software as a Service (SaaS)[51].

On a visionary level, the idea of an "intergalactic computer network"[52] was for the first time formulated in the 1960s by Joseph Carl Rob-

47 The client–server model of computing is a distributed application structure that partitions tasks or workloads between the providers of a resource or service, called servers, and service requesters, called clients. At most times, clients and servers communicate over a computer network on separate hardware, but both client and server may reside in the same system. (https://www.techopedia.com/definition/18321/client-server-model; last accessed on 01/11/2017.)

48 Grid computing is a collection of computer resources from multiple locations that are dedicated to reaching a common goal. The grid can be thought of as a distributed system with non-interactive workloads that involve a large number of files. (https://www.techopedia.com/definition/87/grid-computing; last accessed on 01/11/2017.)

49 Utility computing is a service provisioning model in which a service provider makes computing resources and infrastructure management available to the customer as needed, and charges them for specific usage rather than a flat rate. (https://www.techopedia.com/definition/14622/utility-computing; last accessed on 01/11/2017.)

50 Application Service Provisioning (ASP) is the business of providing computer-based services to customers over a network, such as access to a particular software application using a standard protocol (such as HTTP). (https://www.techopedia.com/definition/2476/application-service-provider-asp; last accessed on 01/11/2017.)

51 Software as a service (SaaS) is a software licensing and delivery model in which software is licensed on a subscription basis and is centrally hosted. (https://www.techopedia.com/definition/155/software-as-a-service-saas; last accessed on 01/11/2017.)

52 Intergalactic Computer Network or Galactic Network was a computer networking concept similar to today's Internet. The term was used for the first time in the early 1960s to refer to a networking system as an electronic commons open to all, ‘the main and essential medium of informational interaction for governments, institutions, corporations, and individuals.’ (https://en.wikipedia.org/wiki/Intergalactic_Computer_Network; last accessed on 01/11/2017.)

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nett Licklider[53], who was responsible for facilitating the development of ARPANET[54] in 1969.

Licklider's vision was for everyone to be interconnected and able to access programs and data hosted at any site, from anywhere. "It is a vision that sounds a lot like what we are calling cloud computing"[55].

Another popular view is that the cloud concept was first envisaged by computer scientist John McCarthy who proposed the idea of computation being delivered as a public utility[56].

From a technical point of view, several decades went by with the know-how related to today's cloud-based systems already existing. Literally, cloud technologies were no invention and did not come as a result of a ground-breaking discovery. They were simply the outcome of better or, at least, different exploitation of existing knowledge related to IT systems[57]. One of the first milestones in cloud computing history was the arrival of

53 Joseph Carl Robnett Licklider was an American psychologist and computer scientist who is considered one of the most important figures in computer science and general computing history. He is particularly remembered for being one of the first to foresee modern-style interactive computing and its application to all kinds of activities; and also as an Internet pioneer with an early vision of a worldwide computer network long before it was built. (https://en.wikipedia.org/wiki/J._C._R._Licklider; last accessed on 01/11/2017.)

54 The Advanced Research Projects Agency Network (ARPANET) was an early packet switching network and the first network to implement the protocol suite TCP/IP. Both technologies became the technical foundation of the Internet. ARPANET was initially funded by the Advanced Research Projects Agency (ARPA, later Defense Advanced Research Projects Agency, DARPA) of the United States Department of Defense. (https://www.techopedia.com/definition/2381/advanced-research-projects-agency-network-arpanet; last accessed on 01/11/2017.)

55 J. Locke, The Roots of Cloud Computing, available at: http://www.servercloudcanada.com/2013/10/the-roots-of-cloud-computing/ (11 January 2017); last accessed on 01/11/2017.

56 John McCarthy was an American computer scientist and cognitive scientist. McCarthy was one of the founders of the discipline of artificial intelligence. He coined the term "artificial intelligence" (AI), developed the Lisp programming language family, significantly influenced the design of the ALGOL programming language, popularized timesharing, and was very influential in the early development of AI. (https://en.wikipedia.org/wiki/John_McCarthy_(computer_scientist); last accessed on 01/11/2017.)

57 M. Arif (note 46).

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Salesforce.com[58] in 1999, which pioneered the concept of delivering enterprise applications via a simple website. The services firm paved the way for both specialist and mainstream software firms to deliver applications over the internet.

The next important step was Amazon Web Services[59] in 2002, which provided a suite of cloud based services including storage, computation and even human intelligence.

Another big milestone came in 2009, with the advent of Web 2.0[60], when Google and others started to offer browser-based enterprise applications through services such as Google Apps[61].

c. The NIST definition of cloud computing; a starting point

It has been so far impossible among stakeholders, namely, regulators, the IT industry etc., to agree on a universally acceptable definition of cloud computing. However, for the purposes of this study when reference is made to 'cloud computing' this is to be understood under the definition published in 2011 by the US National Institute of Standards and Technology (NIST); so far, this definition is generally heralded as the most preva-

58 Salesforce.com is a cloud computing company headquartered in San Francisco, California. Though its profits come basically from a customer relationship management (CRM) product, Salesforce also tries capitalizing on commercial applications of social networking through acquisition. (https://en.wikipedia.org/wiki/Salesforce.com; last accessed on 01/11/2017.)

59 Amazon Web Services (AWS) is a collection of remote computing services, also called web services, that make up a cloud computing platform offered by Amazon.com. These services are based in 11 geographical regions across the world. The most central and well-known of these services are Amazon Elastic Compute Cloud and Amazon S3. These products are marketed as a service to provide large computing capacity more quickly and cheaper than a client company building an actual physical server farm. (https://en.wikipedia.org/wiki/Amazon_Web_Services; last accessed on 01/11/2017.)

60 Web 2.0 describes World Wide Web sites that emphasize user-generated content, usability, and interoperability. Although Web 2.0 suggests a new version of the World Wide Web, it does not refer to an update to any technical specification, but rather to cumulative changes in the way Web pages are made and used. (https://en.wikipedia.org/wiki/Web_2.0; last accessed on 01/11/2017.)

61 Google Apps is a suite of cloud computing productivity and collaboration software tools and software offered by Google. (https://en.wikipedia.org/wiki/Google_Apps_for_Work; last accessed on 01/11/2017.)

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lent[62] in explaining the 'cloud' and it reads as follows: "Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model is composed of five essential characteristics, three service models, and four deployment models"[63].

The most essential characteristics of cloud computing technologies and of the services developed based on them are[64]:

– **On-demand self-service**: A consumer can unilaterally calculate and preorder or buy in real time computing capabilities, such as server time and network storage, as needed, automatically without requiring human interaction with a salesperson or service provider;
– **Broad network access**: Services are available over the network and accessed through standard mechanisms that promote use by heterogeneous client platforms (e.g., mobile phones, tablets, laptops, and workstations);
– **Resource pooling**: The provider's computing resources are pooled to serve multiple consumers using a multi-tenant model, with different physical and virtual resources dynamically assigned and reassigned according to consumer demand. There is an impression of location independence owing to the fact that the customer generally has no control or knowledge over the exact location of the provided resources but may be able to specify location at a higher level of abstraction (e.g., country, state, or datacenter). Examples of resources include storage, processing, memory and network bandwidth;
– **Rapid elasticity**: Resources can be elastically provisioned and released, in some cases automatically, to scale rapidly outward and inward in accordance with demand. To the consumer, the resources available for provisioning often appear to be unlimited and can be appropriated in any quantity at any time;

62 Bill Williams, The economics of cloud computing (2012.)

63 Peter Mell & Timothy Grance, The NIST Definition of Cloud Computing. Recommendations of the National Institute of Standards and Technology, available at: http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf (4 November 2015.)

64 Thomas Erl, Richardo Puttini & Zaigham Mahmood (note 46).; Peter Mell & Timothy Grance (note 63); Bill Williams (note 62).

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- **Measured service**: Cloud systems automatically control and optimize use of resources by leveraging a metering capability at some level of abstraction appropriate to the type of service (e.g., storage, processing, bandwidth and active user accounts). Resource usage can be monitored, controlled and reported, providing transparency for both providers and consumers of the utilized service.

Cloud computing services come in several different genres. These broad categories under which cloud-based applications fall are typically called 'service models' and they are the following[65]:

- **Software as a Service (SaaS):** The consumer can use the provider's applications running on a cloud infrastructure. The applications are accessible from various client devices through either a thin client interface, such as a web browser (e.g. web-based email), or a program interface (e.g. a Dropbox installation on the user's laptop). The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited user-specific application configuration settings;
- **Platform as a Service (PaaS):** The capability provided to the consumer is to deploy onto the cloud infrastructure consumer-created or acquired applications built using programming languages, libraries, services, and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, or storage, but has control over the deployed applications and possibly configuration settings for the application-hosting environment;
- **Infrastructure as a Service (IaaS):** The capability provided to the consumer is to provision processing, storage, networks and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage and

65 Christof Weinhardt, Arun Anandasivam, Benjamin Blau, Nikolay Borissov, Thomas Meinl, Wibke Michalk & Jochen Stößer, *Cloud Computing – A Classification, Business Models, and Research Directions*, 1 Bus. Inf. Syst. Eng. 391–399 (2009); Bill Williams (note 62); Norman Pelzl, Methodische Entwicklung von zukunftsorientierten Geschäftsmodellen im Cloud-Computing, Band 88 (2016.)

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deployed applications; and possibly limited control of select networking components (e.g., host firewalls).

According to the different types of users that use a given cloud infrastructure, these are the major cloud deployment models[66]:

- **Private cloud:** The cloud infrastructure is provisioned for exclusive use by a single organization comprising multiple consumers (e.g., business units). It may be owned, managed and operated by the organization, a third party or some combination of them, and it may be situated on or off premises;
- **Community cloud:** The cloud infrastructure is provisioned for exclusive use by a specific community of consumers from organizations that have shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be owned, managed and operated by one or more of the organizations in the community, a third party or some combination of them, and it may be located on or off premises;
- **Public cloud:** The cloud infrastructure is provisioned for open use by the general public. It may be owned, managed and operated by a business, academic or government organization or some combination of them. It is located on the premises of the cloud provider;
- **Hybrid cloud:** The cloud infrastructure is a composition of two or more distinct cloud infrastructures (private, community or public) that remain unique entities, but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load balancing between clouds).

d. The technologies that preceded cloud computing; a brief overview and comparison

i. Cloud computing compared to traditional IT – Their main differences and why the cloud matters

In attempting to answer whether cloud computing is fundamentally different from IT technologies that had existed before, the prime question to answer is what it means for an organization to "do" cloud computing. The response to this question will give us in the end an estimate as to whether

66 Christof Weinhardt, Arun Anandasivam, Benjamin Blau, Nikolay Borissov, Thomas Meinl, Wibke Michalk & Jochen Stößer (note 65).

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the cloud is a revolution or simply a 'version 2.0' of a continuous series of innovations.

In this debate, Oracle's CEO Larry Ellison[67] has a history of discounting cloud computing as no more than a new name for what has already been in place since long ago. Actually, in a 2009 interview that has become somewhat of a web cult classic, he declared: "All the cloud is, is computers in a network… Our industry is so bizarre. I mean, they just change a term and they think they've invented technology."[68].

From certain aspects, this statement is correct. Many of cloud computing's most common features – namely, virtualization, pay-as-you-go, reduced cost and moving IT responsibility to third parties – have been around much longer than "the cloud". Yet there are also those who argue that despite the similarities to what had already existed before, cloud computing is fundamentally different.

One of the most outright supporters of this opinion has been Salesforce.com's CEO Marc Benioff[69]. In a keynote speech at the Oracle OpenWorld 2010 conference, Benioff outlined his own definition of cloud computing: "Our definition of cloud computing is multi-tenant, it's faster, half the cost, pay as you go, it grows as you grow or shrinks as you shrink. It is extremely efficient. We're not going to show you computers taller than you. We're not going to show you a cloud in a box because clouds don't come in a box. They never have. That's the whole idea"[70].

67 Lawrence Joseph "Larry" Ellison (born August 17, 1944) is an American programmer, internet entrepreneur, businessman and philanthropist. He has been the chief executive officer of the software company Oracle Corporation from its foundation in 1977. (https://en.wikipedia.org/wiki/Larry_Ellison; last accessed on 01/11/2017.)

68 Larry Ellison, Larry Ellison on cloud computing (2009.)

69 Marc Russell Benioff (born September 25, 1964) is an American internet entrepreneur, author and philanthropist. He is the founder, chairman and CEO of salesforce.com, a cloud computing company. (https://en.wikipedia.org/wiki/Marc_Benioff; last accessed on 01/11/2017.)

70 C. Tuna, *Ellison and Benioff Spar Over Cloud Credentials* Wall Street Journal (2010.)

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In the end, cloud computing offers a breakthrough in at least four main areas in comparison to the past[71]:

– Virtualization, i.e. the ability to increase computing efficiency
– Democratization of computing, by bringing enterprise scale infrastructure to small and medium businesses
– Scalability and fast provisioning, by bringing web scale IT at a rapid pace
– Commoditization of infrastructure, by enabling IT to focus on the strategic aspects of its role.

Although any of these areas may not qualify as a computing revolution by itself, one could persuasively argue all of them, put together, have fundamentally changed computing.

ii. Cloud computing environments compared to client-server systems

Client-server is a method where information processing is split between a client and a server[72]. Back in the days, time share computers[73] were used that were accessed by terminals that only handled the display of information without doing any processing.

An easy-to-grasp example of a client/server service is the email. The email client[74] processes incoming email and then presents it to the user. The mail server[75] processes email messages and figures out where they go next.

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71 2009 ICSE Workshop on Software Engineering Challenges of Cloud Computing.

72 M. Arif (note 46).

73 Time share computing: A technique permitting many users simultaneous access to a central computer through remote terminals. (https://www.britannica.com/technology/time-sharing; last accessed on 01/11/2017.)

74 An email client, email reader or more formally mail user agent (MUA) is a computer program used to access and manage a user's email. (https://en.wikipedia.org/wiki/Email_client; last accessed on 01/11/2017.)

75 A mail server, or e-mail server is a computer within a network that works as a virtual post office. A mail server usually consists of a storage area where e-mail is stored for local users, a set of user definable rules which determine how the mail server should react to the destination of a specific message, a database of user accounts that the mail server recognizes and will deal with locally, and communications modules which are the components that actually handle the transfer of messages to and from other mail servers and email clients. (http://www.webopedia.com/TERM/E/e_mail_server.html; last accessed on 01/11/2017.)

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Cloud computing is a different story altogether. Cloud computing embodies the ideas that you can abstract the software from the hardware, have applications that can scale up and down based on factors such as demand, time, etc. The act of services provisioning in the cloud is automated and requires no user intervention. Cloud services are also on-demand and can be metered meaning that you are only charged for the resources that you eventually use. Ultimately, cloud computing can be more precisely described as a consumption model[76].

As it has been already demonstrated, a cloud can be a public one, where someone else manages the hardware and infrastructure and the user just puts his operating systems and apps into. There can also be a private cloud, where the same entity owns the hardware and infrastructure and out of them derives a scalable, automated, metered service. And, lastly, there is hybrid cloud which is when one has apps that reside in both.

In other words, the ‘client server’ concept describes how applications are modeled. Cloud computing, on the other hand, describes and focuses on the environment that applications reside in.

iii. Cloud computing compared to outsourcing – The key differences

Before the emergence of cloud computing, computational and data processing needs of organizations and individual users were largely covered through outsourcing[77]. As a result, initial IT laws envisaged traditional outsourcing and the stand-alone databases that had been in use when they were drafted. In addition, it needs to be pointed out that this inspiration coming mainly from the outsourcing model still prevails across a wide range of IT legislation given the difference in pace in which technical standards have evolved compared to the respective evolutionary cycles of IT legislation.

Traditional outsourcing of data processing involved commissioning agents, who were provided with data and tasked with processing that data actively for the user according to the user's mandate. The agent had the possibility to engage sub-processors to assist with this processing[78]. With

76 Bill Williams (note 62).
77 W. Kuan Hon & C. Millard, *Cloud Computing vs. Traditional Outsourcing – Key Differences*, 23 Computers & Law (2012.)
78 *Id.*

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today's public cloud services[79], users 'rent' pre-packaged IT resources from providers and then process data themselves in a self-service manner, using infrastructure and/or resources supplied by the provider.

With traditional outsourcing, a user would hire a processor to meet its specific processing needs. The processor might then engage sub-processors to help fulfil this contract with the user. Successive contracts down the chain of processors could therefore be easily tailored, from both timing and control perspectives. With cloud computing, however, the sequence of events and direction of travel of data are quite the opposite. Many cloud services are pre-packaged standardized commoditized services, which may be built on existing sub-provider services on the sub-provider's standard terms. The sub-service in turn may be based on other existing services. Users choose the provider and pre-built package that they think that best meets their specific processing and other needs. Public cloud computing providers use standardized, shared infrastructure/environments, often using relatively cheap commodity hardware, rather than tailoring to each customer. Similarly, some traditional outsourced processing might have used standardized infrastructure, sometimes at large scale, but it is unlikely that it was shared to such a degree as in cloud computing[80].

With traditional outsourcing, the user had control over its processor through the contract and its instructions to the processor. With cloud computing, while it is commonly thought cloud users lose control, much depends on the type of service and exact nature and design of individual services. A 'one size fits all' approach to cloud is common, but would not be wise, because there are significant differences between services and, respectively, many different cloud arrangement versions through which to provide those services.

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79 The same largely applies also for community and hybrid cloud arrangements. Private clouds also share these characteristics but, due to their 'secluded' nature, they also differentiate on certain aspects from what applies to public, community or hybrid cloud installations.

80 For more extensive analysis and comparison between cloud computing and traditional outsourcing of computational tasks, refer also to: Bill Williams (note 62)., as well as to a comparative presentation of the two alternatives from a prominent tailored cloud services provider, GetCloud Services, under http://www.getcloudservices.com/blog/cloud-computing-vs-traditional-outsourcing/ (last accessed on 01/12/2017.)

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e. Data handling needs and the parallel technological evolution – How developing computational requirements led to technological progress

At this point, it is worth briefly summarizing the sequence of innovations related to computing technologies parallel to the evolution of the volume of computational needs. When widespread corporate computing initially occurred, it was based on a shared resources model where massive computer facilities took up acres of space within dingy warehouses and users would book time for both the machines themselves and the skilled technicians who knew how to operate them. Their standard use was narrow business analysis and hence computing had a very limited sphere of influence[81].

Later, the introduction of mini computers[82] and the personal computer[83] in the 1970s meant the ability to utilize the benefits of technology extended to a much broader audience. While still relatively expensive and functionally basic machines, personal computers put computing onto (almost) any desktop in a reasonably well resourced organization.

The arrival of the Internet, however, changed things for good, both from the perspective of the network and that of individual computers. The increased reliability and reduced cost of the internet (in comparison to older proprietary networks) along with the decreasing cost of computers, led to increased use of web based applications. This, along with the demand for application access via multiple devices, led to a rapid growth for cloud computing[84] – at an infrastructure, a platform and an application level.

81 M. Arif (note 46).

82 A minicomputer, or colloquially mini, is a class of smaller computers that were developed in the mid-1960s and sold for much less than mainframe and mid-size computers from IBM and its direct competitors. In a 1970 survey, the New York Times suggested a consensus definition of a minicomputer as a machine costing less than 25,000 USD, with an input-output device such as a teleprinter and at least four thousand words of memory, that is capable of running programs in a higher-level language, such as Fortran or BASIC. The class formed a distinct group with its own software architectures and operating systems. (https://en.wikipedia.org/wiki/Minicomputer; last accessed on 01/12/2017.)

83 A personal computer is a general-purpose computer whose size, capabilities and original sale price make it useful for individuals, and is intended to be operated directly by an end-user with no intervening computer operator. (https://en.wikipedia.org/wiki/Personal_computer; last accessed on 01/12/2017.)

84 Bill Williams (note 62).

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f. Explaining cloud computing and its predecessors – what did the cloud replace and what is now done different than before?

Having gone through the history and evolution of the cloud, through the most predominant theory and policy approaches currently on the table about it and the fields where it is mostly used, it is now time to examine what cloud computing did actually replace. Further to that, it is also in order now to explain what the technological and business differences between cloud computing and the precedent technological status quo actually are.

In a nutshell, one could say that the cloud itself is not an out-of-nowhere invention nor did it come to replace anything in particular. As it has already been demonstrated[85] cloud computing was not invented or discovered; it simply evolved out of pre-existing technologies that matured over time as the possibilities they offered were better understood and been taken advantage of. Naturally, cloud did not take over from one day to the other but it gained ground, and at a faster and faster pace, because it was becoming clearer that it offered competitive advantages over its predecessors, mainly in the field of economies of scale and ease of use[86]. However, as the economic aspects of the cloud phenomenon are beyond the scope of this study, the overview that follows will focus on how the cloud evolved from a technological point of view and what it does differently when applied and not so much on what differences it brings about in the economic factors of the sectors where it is applied.

The technologies that cloud computing replaced could be generically described as based on a Service Oriented Architecture (SOA)[87]. In other words, they were technological arrangements which had been primarily developed not so much with efficiency or economies of scale in mind but mostly with fulfilling particular service needs as primary goal. In layman's terms, what defined SOA-focused arrangements was not how to do the job in the most economically and resources-efficient manner but, merely, how to get the job done. Therefore, from the simplest SOA system [i.e. the Local Area Network (LAN)] to the most complex data handling systems

85 Chapter 2.a.

86 *Id.*

87 D. Linthicum, MSDN Documentation. Service Oriented Architecture (SOA), available at: https://msdn.microsoft.com/en-us/library/bb833022.aspx (4 November 2015.)

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based on the SOA perspective, one can always recognize the predominantly linear connections between different building parts of the network, be them servers, computers, printers etc.

A generic definition of service oriented architecture (SOA) would be: "Loosely coupled services with well-defined interfaces that provide business functionality and can be shared or reused across and beyond the network's constituting parts. These services can be discovered through a registry/repository or other directory, and can be assembled and disassembled to meet current business process demands"[88].

Generally observing the SOA logic, hereunder are the main technologies that pre-existed the cloud and whose revisited use led to what we know nowadays as cloud computing technologies:

i. File hosting

"File hosting services provide a broad range of services to businesses, including building an intranet and managing an overall internal network"[89]. File hosting and the enabling technologies have existed for decades, ever since businesses turned to the Internet for storage solutions and project management. Yet, while file hosting is more localized and focused on an internal aspect of getting everyone in an office or organizational complex on the same page, cloud computing goes far beyond this.

ii. Clustering

"A cluster is a group of independent IT resources that are interconnected and work as a single system."[90] Clusters were developed in an effort to re-

88 *Id.*

89 R. Peeva, File Hosting vs. Cloud Computing, available at: http://www.websitepulse.com/blog/file-hosting-vs-cloud-computing (4 November 2015.)

90 A cluster server is a group of independent servers working together as a single system to provide high availability of services for clients. When a failure occurs on one computer in a cluster, resources are redirected and the workload is redistributed to another computer in the cluster. You can use server clusters to ensure that users have constant access to important server-based resources. Server clusters are designed for applications that have long-running in-memory state or frequently updated data. Typical uses for server clusters include file servers, print servers, data-

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duce system failure rates and, at the same time, increase availability and reliability; these were made possible thanks to redundancy and failover features inherent to clusters. In terms of hardware used to build cluster installations, a general prerequisite was that its component systems had reasonably identical hardware and operating systems so that similar performance levels could be achieved when one failed component was to be replaced by another. Component devices forming a cluster were kept continuously synced through dedicated, high speed communication links.

Stemming from clusters, this basic concept of built-in redundancy and failover was carried out today to be in the core of cloud platforms.

iii. Grid Computing

"A computing grid (or 'computational grid') provides a platform in which computing resources are organized into one or more logical pools. These pools are collectively coordinated to provide a high performance distributed grid, sometimes referred to as a 'super virtual computer'."[91] Grid computing was different from clustering in that grid systems were much more loosely coupled and distributed, already allowing for greater flexibility and reallocation of resources of the network to ensure the best possible efficiency at all times. As a result, grid computing systems were the first to involve computing resources of heterogeneous nature and geographically dispersed, which was generally not possible with the preceding cluster computing-based systems.

Grid computing was firstly conceptualized in the early 1990s and has been constantly under review and further research ever since[92]. The technological advancements achieved through that research into grid computing projects have influenced various aspects of cloud computing platforms and mechanisms, particularly in relation to feature sets such as networked access, resource pooling, scalability and resiliency. These features were

base servers, and messaging servers. A more detailed description of the cluster server is available at https://technet.microsoft.com/en-us/library/cc785197(v=ws.10).aspx; last accessed on 01/12/2017.

91 Thomas Erl, Richardo Puttini & Zaigham Mahmood (note 46).

92 Ian Foster, Yong Zhao, Ioan Raicu & Shiyong Lu, *Cloud Computing and Grid Computing 360-Degree Compared," IEEE Grid Computing Environments (GCE08) 2008, co-located with IEEE/ACM Supercomputing 2008* 2012 ACM/IEEE 13TH INTERNATIONAL CONFERENCE ON GRID COMPUTING 1–10.

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initially introduced via grid computing systems. Today, they have been incorporated in cloud computing arrangements with updated distinctive approaches.

iv. Virtualization

"Virtualization represents a technology platform used for the creation of virtual instances of IT resources. A layer of virtualization software allows physical IT resources to provide multiple virtual images of themselves so that their underlying processing capabilities can be shared by multiple users. Prior to the advent of virtualization technologies, software was limited to residing on and being coupled with static hardware environments. The virtualization process made redundant this software-hardware dependency, as hardware requirements can be simulated by emulation software running in virtualized environments."[93]

Elements of virtualization technologies can be traced in several cloud computing mechanisms and they have also inspired many of the core features of modern cloud systems. As cloud computing evolved, it brought along a new generation of modern virtualization technologies, which, based on the know-how from the past, have now managed to overcome the performance, reliability and scalability limitations of traditional virtualization platforms. In other words, lying at the foundations of contemporary cloud technology, modern virtualization concepts provide a variety of virtualization types and technology layers that have facilitated optimization of cloud platforms to the flexible, adaptable systems we know today.

g. Cloud computing: its core philosophy and structural features

Bringing together features and functionalities of all main IT concepts that preceded it, cloud computing rose to be today's standard technology for data handling. But before pointing out what it does differently from past solutions and IT systems, it is essential to describe the founding features upon which it has been built to become what we know and extensively use today as possibly the most popular way of handling and processing data.

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93 Thomas Erl, Richardo Puttini & Zaigham Mahmood (note 46).

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i. The cloud's business model

The prevalent cloud-based business model[94] has the customer paying the provider on a consumption basis. In effect, use of cloud solutions is charged under the same principle applied by utility companies when they charge for basic utilities such as electricity, gas, and water. This arrangement relies on economies of scale in an effort to drive prices down for users and maximize profits for providers[95].

ii. The architecture of cloud computing systems

Cloud-based technologies have been developed to be able to address Internet-scale computing problems; this actually means that some of the key assumptions of the data handling tasks clouds are expected to carry out are essentially different from those of the technologies that the cloud succeeded[96]. The term 'clouds' is usually understood to refer to "a large pool of computing and/or storage resources, which can be accessed via standard protocols via an abstract interface"[97]. Cloud systems have actually been built on top of many pre-existing protocols such as Web Services[98] or other advanced Web 2.0 technologies[99].

In line with the observation that cloud computing is actually not an out-of-nowhere technology but the result of continuous evolution of pre-existing IT tools, its architecture is not a linear one but, rather, includes elements of all technologies upon which the cloud is based. As a rule, the cloud's architecture is divided in four layers, in particular, the fabric, unified resource, platform, and application layers[100].

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94 Christof Weinhardt, Arun Anandasivam, Benjamin Blau, Nikolay Borissov, Thomas Meinl, Wibke Michalk & Jochen Stößer (note 65).
95 Bill Williams (note 62); Norman Pelzl (note 65).
96 Liang-Jie Zhang & Qun Zhou, CCOA: Cloud Computing Open Architecture (2009.)
97 Ian Foster, Yong Zhao, Ioan Raicu & Shiyong Lu (note 92).
98 Thomas Erl, Richardo Puttini & Zaigham Mahmood (note 46).
99 *Id.*
100 In addition to this structural analysis of cloud's architecture, in Chapter 8 there is an analytical presentation of the internal organization of cloud networks, which, combined, serve as the basis for the regulatory proposals contained in this study.

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The fabric layer contains all raw hardware level elements, such as compute, storage and network resources. The unified resource layer contains resources that have been abstracted/encapsulated (usually by virtualization) so that they can be exposed to upper layer and end users as integrated resources, for instance, a virtual computer/cluster, a logical file system, a database system, etc[101]. The platform layer is where a collection of specialized tools, middleware and services on top of the unified resources are categorized; for example, a Web hosting environment or a scheduling service. These elements are necessary in order to facilitate the development and/or deployment of the cloud platform. Finally, the application layer contains the applications that would run on this cloud-based system[102].

h. The resource management aspects of the cloud

i. The cloud's compute model

The cloud's compute model is fundamentally different from that of its preceding technologies, with resources in the cloud being dynamically shared by all users at all times; in contrast to that, technologies previous to cloud systems were governing resources in a queuing manner, assigning to them the execution of computational tasks in the order that these tasks were given to the system[103].

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101 *Id.*
102 One could easily recognize these layers if the architecture of a widely known service such as Dropbox is brought to mind; a. fabric layer is Dropbox's server farms and infrastructure (either privately owned or sublet); b. the unified resource layer corresponds to Dropbox's way of organizing the content of its users' folders content, the way it arranges their files into parent folders, sub-folders etc.; c. the platform layer is Dropbox's backend, the environment from which Dropbox stuff can control and make sure that their service runs smoothly towards the users; finally, d. the application layer, which contains all the editing tools and applications that Dropbox makes available to users to work with the files they host on the service.
103 *Id.*

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ii. Virtualization[104]

Virtualization has preceded the cloud and was deeply incorporated in cloud systems to become a quasi-indispensable ingredient for most of them in order to enhance their abstraction and encapsulation. Virtualization is the tool thanks to which clouds, which need to run vast numbers of user applications, make it appear as if all these applications were running simultaneously and had ready for use all the available resources in the cloud facility[105]. Virtualization offers to the cloud all necessary abstraction so that the underlying elements of a cloud system (storage, network resources etc.) can be unified to resemble a pool of resources so that then resource overlays (e.g. web hosting environments) can be built on top of them. Virtualization also permits each cloud application to be encapsulated so that it can be configured, deployed, migrated, suspended, stopped, etc., and thus provides better security, manageability, and isolation.

One can reasonably argue that virtualization is the technology from which the cloud borrowed more features than any other from those that it succeeded. There are indeed many valid reasons that support such a claim[106]:

- virtualization offers to cloud systems the server and application consolidation they need in order to be able to run as many applications as needed on the same server by making use of available resources in the most efficient manner possible;
- high degree configurability is also possible thanks to virtualization: as resource requirements for the various applications running on a cloud facility differ significantly, virtualization is necessary in order to dynamically configure and aggregate resources for these varying needs, given that this is not achievable at the hardware level;
- optimized application availability; virtualization permits quick recovery from unplanned outages, as virtual environments can be backed up and migrated without interruption in service;
- last but not least, virtualization has offered to the cloud improved responsiveness, as resource provisioning, monitoring and maintenance

104 *Id.*

105 Christof Weinhardt, Arun Anandasivam, Benjamin Blau, Nikolay Borissov, Thomas Meinl, Wibke Michalk & Jochen Stößer (note 65).

106 Liang-Jie Zhang & Qun Zhou (note 96).

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can be automated, while common or residual resources can be cached and reused.

Virtualization with all these features has actually been the basis for cloud systems to meet the stringent requirements of the tasks they are carried out through them.

iii. Monitoring[107]

The extensive use of virtualization technology in cloud environments caused as a side-effect the difficulty in maintaining control over the monitoring of resources of the system. When utilizing applications hosted on the cloud, different levels of services can be offered to each end user; nevertheless, every user is only exposed to a predefined API[108] while lower level resources are invisible to them. Apart from interacting with the standard API users do not have the liberty to deploy their own monitoring mechanisms over the cloud resources of the platform, while the limited information returned to them most commonly does not provide adequate level of details that would permit them to figure out what the resource status is at any given moment[109]. Essentially, monitoring a cloud facility is a quite complicated process requiring a fine balance of business application monitoring, enterprise server management, virtual machine monitoring, and hardware maintenance[110]. It is worth mentioning, however, that, as technology evolves, it is already possible that, in the near future, user-end monitoring might become less important as cloud systems become more sophisticated, more self-maintained and self-healing[111].

107 *Id.*

108 In computer programming, an application programming interface (API) is a set of routines, protocols, and tools for building software applications. (https://en.wikipedia.org/wiki/Application_programming_interface; last accessed on 01/12/2017.)

109 Larry Ellison (note 68).

110 Liang-Jie Zhang & Qun Zhou (note 96).

111 Benoit Dupont, *Cybersecurity Futures: How Can We Regulate Emergent Risks?* Technology Innovation Management Review 6–11 (2013); Willcocks, Leslie P., Venters, Will and Whitley, Edgar A., Cloud and the future of business: from costs to innovation: part two: challenges (2012.)

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iv. Provenance

"Provenance refers to the derivation history of a data product, including all the data sources, intermediate data products, and the procedures that were applied to produce the data product. Provenance information is vital in understanding, discovering, validating, and sharing a certain data product as well as the applications and programs used to derive it"[112]. In some disciplines, such as finance and medicine, this provenance path is also mandatory to provide and it is called an 'audit trail' at all times so that a thorough audition over the course the data has followed is at all times possible. Cloud platforms are becoming the new standard playground for modern scientific research and, consequently, provenance management is extremely important in order to track the processes and support the reproducibility of scientific results. What is more, this provenance feature can also serve as the key to overall efficient regulation of cloud computing: when coupled with the teleological principle, provenance mechanisms can very effectively serve the crucial issue of regulating cloud computing no matter for what purpose it is utilized[113].

i. The application model of the cloud

Cloud computing could in principle cater to the whole set of applications most commonly needed by the average user who needs to perform data computational processing. This is not of course to be understood as implying that all other technologies are bound to cease to exist. Most probably, there will always be tasks and specific data processing queries that, for reasons of security (or other similar grounds) will preferably continue to run in non-cloud environments and on platforms based on the technologies that pre-existed the cloud. However, given that already these exceptions are an ever-dwindling minority and, also, due to the undeniable power of the comparative advantages of the cloud, it should not come as a surprise if, eventually, the cloud unquestionably prevails over all other options[114]. Therefore, a timely regulation of the cloud is necessary as soon as possible

112 Ian Foster, Yong Zhao, Ioan Raicu & Shiyong Lu (note 92).
113 See also Chapter 10.
114 Liang-Jie Zhang & Qun Zhou (note 96).

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if we are to be able to handle all issues that may arise out of it and call for settlement.

j. The security model of the cloud

Cloud systems today usually comprise dedicated data centers belonging to the same organization. In each of these data centers, hardware and software configurations along with supporting platforms are in general more homogeneous as compared with those in data environments built on technologies prior to cloud computing[115]. Interoperability is clearly one of the most serious issues for cross-data center, cross-administration domain interactions[116]. Currently, the security model for clouds typically relies on Web forms (over SSL[117]) that allow creation and easy management of account information for end-users, whom they also permit to reset their old and receive new elements of these accounts (such as passwords) even in unsafe and unencrypted communication channels (for example, via emails). As a rule, new users can use cloud-based services more easily and almost instantly (most of the times, it is possible to create a profile just with a credit card and/or an email address). On the contrary, data environments based on technologies prior to cloud computing were usually stricter about security but, of course, at the same time, were readily addressed only to a limited and very specific pool of users (for example, the members of the organization which a grid-based data center belonged to)[118].

Security has been and still is one of the greatest concerns regarding the adoption of cloud computing[119]. To give a thorough catalogue of all secu-

115 Ian Foster, Yong Zhao, Ioan Raicu & Shiyong Lu (note 92).

116 Sean Marston, Zhi Li, Subhajyoti Bandyopadhyay, Juheng Zhang & Anand Ghalsasi, *Cloud computing — The business perspective*, 51 Decision Support Systems 176–189 (2011.)

117 Transport Layer Security (TLS) and its predecessor, Secure Sockets Layer (SSL), both of which are frequently referred to as 'SSL', are cryptographic protocols designed to provide communications security over a computer network. (https://en.wikipedia.org/wiki/Transport_Layer_Security; last accessed on 01/12/2017.)

118 Ian Foster, Yong Zhao, Ioan Raicu & Shiyong Lu (note 92).

119 For an analytical overview of the security parameter as one of the main determinant factors for growth and further adoption of cloud computing, refer to: W. K. Hon, C. Millard & I. Walden, *The problem of 'personal data' in cloud computing:*

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rity questions surrounding the cloud, it would be extensively technical and beyond the scope of this paper. However, here is a list of the seven most common (and potentially affecting most users) security threats coming with the adoption of cloud computing:

– **Privileged user access**[120]: whenever cloud-based services users need to perform computational tasks involving sensitive data on a cloud system from which they lease resources, it is very common that they ask for assurances that any processing done to those data will only be accessible by those privileged users;
– **Regulatory compliance**[121]: customers who decide to turn to cloud services commonly ask to verify if their cloud provider has external audits and security certifications and if they truly comply to the awarded security certificates they demonstrate;
– **Data location**[122]: this is one the most fervently debated and contested issues regarding cloud technology. Extensive discourse will be made over data location and cloud computing in the course of this study. However, at this point one could briefly mention that currently, since a

what information is regulated?--the cloud of unknowing, 1 International Data Privacy Law 211–228 (2011); Dara Hallinan, Michael Friedewald, Paul McCarthy, *Citizens' Perceptions of Data Protection and Privacy in Europe*, 28 Computer Law and Security Review 263–272 (2012); M. Friedewald & R. J. Pohoryles, Privacy and Security in the Digital Age: Privacy in the Age of Super-Technologies (2016); Neil Robinson, Lorenzo Valeri, Jonathan Cave, Tony Starkey, Hans Graux, Sadie Creese & Paul P. Hopkins, The Cloud: Understanding the Security, Privacy and Trust Challenges. Prepared for Unit F.5, Directorate-General Information Society and Media, European Commission (2012); S. Subashini & V. Kavitha, *A survey on security issues in service delivery models of cloud computing*, 34 Journal of Network and Computer Applications 1–11 (2011); Hassan Takabi, James B. D. Joshi & Gail-Joon Ahn, *Security and Privacy Challenges in Cloud Computing Environments* IEEE Security & Privacy 24–31 (2010); A. van Cleeff, W. Pieters & R. J. Wieringa, Security Implications of Virtualization: A Literature Study, vol. 3; A. E. Whitley, P. L. Willcocks & W. Venters, *Privacy and Security in the Cloud: A Review of Guidance and Responses*, 22 Journal of International Technology and Information Management 75–92 (2013); M. Zhou, R. Zhang, W. Xie, W. Qian & A. Zhou, Security and Privacy in Cloud Computing: A Survey; Kirstin Brennscheidt, Cloud Computing und Datenschutz.

120 Christof Weinhardt, Arun Anandasivam, Benjamin Blau, Nikolay Borissov, Thomas Meinl, Wibke Michalk & Jochen Stößer (note 65).

121 Liang-Jie Zhang & Qun Zhou (note 96).

122 Sean Marston, Zhi Li, Subhajyoti Bandyopadhyay, Juheng Zhang & Anand Ghalsasi (note 116).

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customer does not immediately know where data are stored, it is not uncommon for mid- and big-scale users of cloud services to ask their providers for reassurances regarding storing and processing data in specific jurisdictions and under pre-defined privacy requirements on behalf of the customer;
- **Data segregation**[123]: mid- to big-scale users often ask for reassurances that their data is fully segregated from data belonging to other users of the same cloud facility;
- **Recovery**[124]: it is a pressing request from the market that cloud providers have an efficient replication and recovery mechanism to restore data if a disaster occurs;
- **Investigative support**[125]: Cloud services are especially difficult to investigate but not at all impossible. Right now, if this is important for a customer, it is usually concretized in the contractual agreement between the customer and the cloud service provider. However, in the future and as investigative mechanisms for the cloud will become more and more efficient, they can actually be among the cornerstone of an efficient regulatory mechanism for cloud computing;
- **Long-term viability**[126]: obviously, it is already a pressing demand from users that data remain viable even when the cloud provider is acquired by another company.

k. What is cloud computing after all and why does it merit a new regulatory approach?

In conclusion, it can now be said without hesitation that cloud computing is an operations model, not a technology[127]. What makes cloud computing stand out from other data handling technologies is the fact that the physical resources of a cloud facility are operated to deliver abstract IT resources on-demand, at scale, and (almost always) in a multi-tenant envi-

123 Christof Weinhardt, Arun Anandasivam, Benjamin Blau, Nikolay Borissov, Thomas Meinl, Wibke Michalk & Jochen Stößer (note 65).
124 W. K. Hon, C. Millard & I. Walden (note 119).
125 *Id.*
126 Liang-Jie Zhang & Qun Zhou (note 96).
127 See also Chapter 9.

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ronment[128]. In a nutshell, cloud computing as a term should be understood to signify the way in which available technologies for data handling are involved to maximize efficiency, economies of scale and ease of use.

Cloud borrows much from long established technologies and from various long standing operation models. However, the combination of all these technologies and models in an on-demand, at scale and multi-tenant infrastructure is relatively unique for the post client-server era, and is the main reason why cloud computing has had such an impact on the standards of data handling industry, rather than being another passing fad.

Consequently, cloud computing is the evolutionary climax of several decades of technological progress in the field of computational data processing. It is a 'revolution', since it fundamentally simplified and optimized the processes involving digital data but, at the same time, it is not a 'revolution' in the sense of a phenomenon coming out of nowhere. The cloud has firm roots to almost all technological steps that preceded it, it borrows features from most of them yet it rearranges them in an entirely new spectrum. This new arrangement results in different processes, problems and challenges that will ensure that the processes carried out through it are flawless and respectful of the rights and duties of all the actors involved (from data subjects to data owners to data controllers and regulators). Nevertheless, the fact that it happened so gradually and in a rather 'natural evolution' pattern has resulted in ignoring, to some extent, its gravity and differentiation from the previous status quo. As it will be demonstrated immediately after, this has resulted in a current situation where the cloud is attempted to be regulated with pre-existing norms and rules, which were produced in the era of its preceding technologies[129]. However, things in the cloud era are essentially different and they merit a new regulatory approach which will be explored over the course of this study.

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128 Software Multitenancy refers to a software architecture in which a single instance of a software runs on a server and serves multiple tenants. A tenant is a group of users who share a common access with specific privileges to the software instance. With a multitenant architecture, a software application is designed to provide every tenant a dedicated share of the instance including its data, configuration, user management, tenant individual functionality and non-functional properties. Multitenancy contrasts with multi-instance architectures, where separate software instances operate on behalf of different tenants. (https://en.wikipedia.org/wiki/Multitenancy; last accessed on 11/4/2015.)

129 See Chapter 2.e.

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