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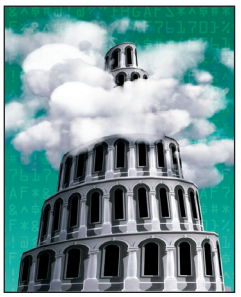

Cloud Computing

The New Frontier of Internet Computing

George Pallis • *University of Cyprus*

Cloud computing is a new field in Internet computing that provides novel perspectives in internetworking technologies and raises issues in the architecture, design, and implementation of existing networks and data centers. The relevant research has just recently gained momentum, and the space of potential ideas and solutions is still far from being widely explored.

After *IEEE Internet Computing*'s recent editorial board meeting in March 2010, editor in chief Fred Douglis invited me to be department editor for this new cloud computing department. This is a topic that's gaining considerable research interest and momentum, and it's expected to be the next generation of Internet computing. Through this department, I hope to use this momentum to gather articles from diverse sources, ranging from researchers in academia to industry leaders who implement innovative cloud services.

Cloud Computing: Current Status and Trends

As more aspects of our work and life move online and the Web expands beyond a communication medium to become a platform for business and society, a new paradigm of large-scale distributed computing has emerged in our lives. Cloud computing has very quickly become one of the hottest topics — if not the hottest one — for practicing engineers and academics in domains related to engineering, science, and art for building large-scale networks and Internet applications. Nowadays, everyone's talking about clouds. In academia, numerous research papers, tutorials, workshops, and panels on this emerging topic have been presented at major conferences and published in the top-level computer science journals and magazines. Also, several universities have added courses that are dedicated to cloud computing principles. A plethora of blogs, forums, and discussion groups on the subject are available on the Web. In industry, companies are devoting great resources to investing in cloud computing, either by building their own infrastructures or developing innovative cloud services.

Cloud computing is a new multidisciplinary research field, considered to be the evolution and convergence of several independent computing trends such as Internet delivery, "pay-as-you-go" utility computing, elasticity, virtualization, grid computing, distributed computing, storage, content outsourcing, security, and Web 2.0. However, cloud computing's multidisciplinarity has raised questions in the research community about how novel this new paradigm is because it includes almost everything that existing technologies already do. Michael Armbrust and his colleagues try to clarify cloud computing's innovative aspects, identifying its major technical and nontechnical challenges.[1]

Even if we can't precisely define the cloud because it's an evolving paradigm, the US National Institute of Standards and Technology's definition covers the most important aspects of the cloud vision (see http://csrc.nist.gov/groups/SNS/cloud-computing):

> Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (for example, networks, servers, storage, applications, and services) that can be rapidly provisioned and released

 1089-7801/10/$26.00 © 2010 IEEE

with minimal management effort or service provider interaction. This cloud model promotes availability and is composed of five essential characteristics [on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service], three service models [cloud software as a service, cloud platform as a service, and cloud infrastructure as a service], and four deployment models [private cloud, community cloud, public cloud, and hybrid cloud].

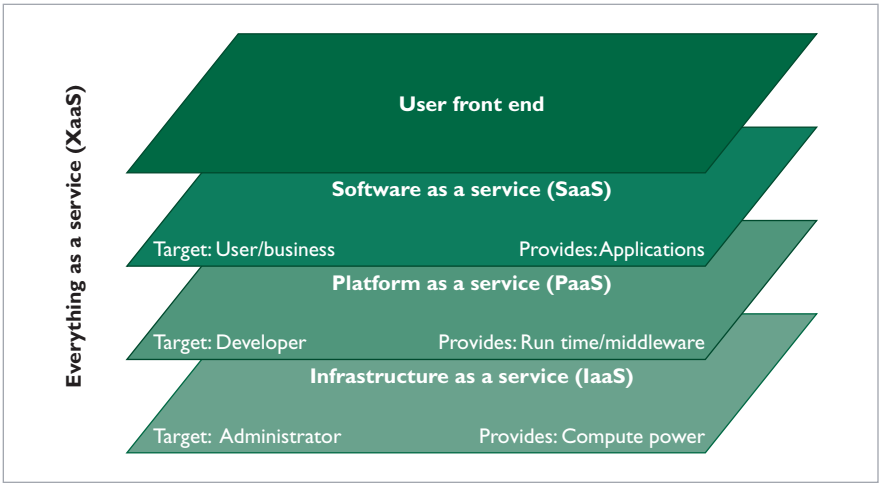

Figure 1. A general layered architecture of cloud infrastructures. Cloud computing uses IT infrastructure as a service. Its architecture defines three distinct layers from computing resources to end-user applications.

Cloud computing grew out of our never-ending hunger for ever-faster and ever-cheaper computation. The key driving forces behind it are the promise of broadband and wireless networking ubiquity, lower storage and mobile device costs, and progressive improvements in Internet computing software and mobile computing. The perceived advantages for cloud-service clients include the ability to improve use by adding more capacity at peak demand, reducing costs, experimenting with new services, and removing unneeded capacity.

From a technical viewpoint, a cloud's system elements include processing, network, and storage elements. The cloud architecture consists of three abstract layers: infrastructure, platform, and application. Infrastructure is the lowest layer and is a means of providing processing, storage, networks, and other fundamental computing resources as standardized services over the network. Servers, storage systems, switches, routers, and other systems handle specific types of workloads from batch processing to server-storage augmentation during peak loads. Cloud providers' clients can deploy and run operating systems and software for their underlying infrastructures. The middle layer provides higher abstractions and services to develop, test, deploy, host, and maintain applications in the same integrated development environment. This layer provides a runtime environment and middleware to deploy applications using programming languages and tools the cloud provider supports. The application layer is the highest layer and features a complete application offered as a service. Figure 1 shows a cloud infrastructure's general layered architecture, with the additional user interface layer, which enables seamless interaction with all the underlying everything-as-a-service layers.

The European Commission recently published a technical report that aims to outline future directions for cloud computing research (see http://cordis.europa.eu/fp7/ict/ssai/docs/cloud-report-final.pdf). The report's authors concluded that

> Cloud technologies and models have not yet received their full potential, and many of the capabilities associated with clouds are not yet developed and researched to a degree that allows their exploitation to the full degree, respectively meeting all potential circumstances of usage.

Cloud computing's emergence has added new issues and perspectives to current Internet technologies because many system facets will need to be revised in a new context.[2] For instance, we should invest in new service-level agreements between cloud service consumers and providers. In terms of content delivery, integrating cloud computing in this process has changed the architecture, design, and implementation of existing content-delivery networks. Using a network of edge locations around the world, cloud providers provide mechanisms that distribute not only content but also services to end users with low latency and high data-transfer speeds. Also, we should introduce new standards to improve cloud interoperability. The problem is that, although a wide range of vendors provide cloud services, clients remain stuck. Considering that a plethora of cloud providers are flooding the market, this is a real obstacle on the road to the future Internet of services' cloud marketplace due to vendor lock-in. Currently, a trend in improving cloud interoperability exists. The recently formed Cloud Computing Interoperability Forum moves in this direction, enabling cloud infrastructures to evolve into a transparent platform. Regarding security and privacy issues, the move to cloud services results in developing new data-protection mechanisms to

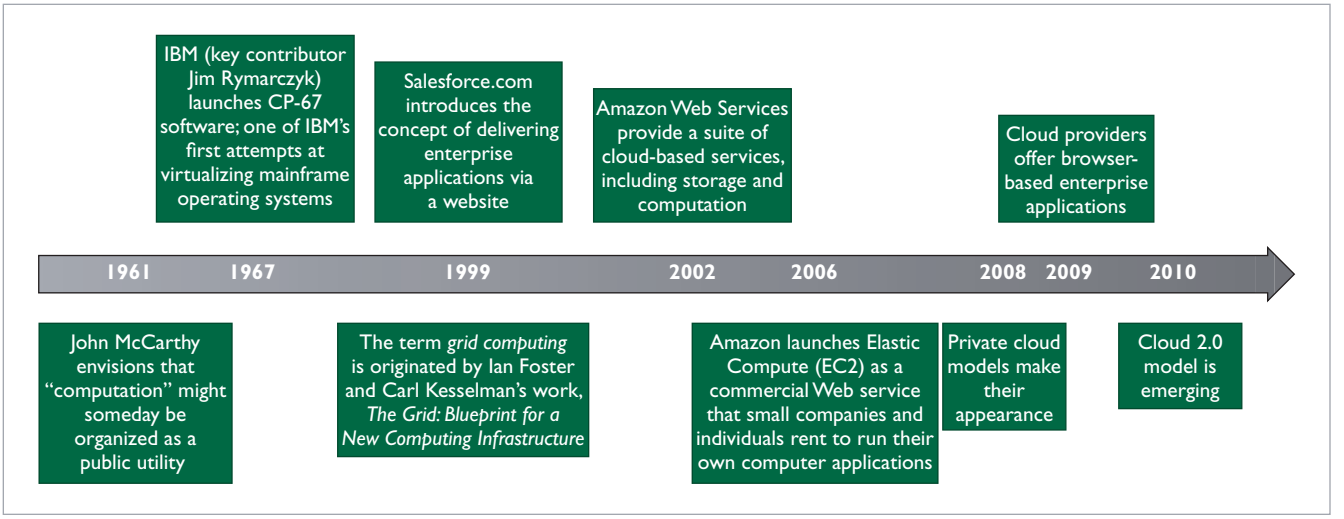

Figure 2. Cloud computing timeline. Cloud computing has evolved from previous computing paradigms going back to the days of mainframes.

secure data privacy, resource security, and content copyrights.

Recently, many people argue that we're moving from cloud 1.0 to cloud 2.0. Although it's too early to speak for the next cloud generation, its evolution will integrate Web 2.0 social networking features and functionality into cloud-based applications. In this context, social cloud is another emerging trend in which users can discover and trade storage and computing services contributed by their friends in an online social network (for example, Facebook), taking advantage of pre-existing trust relationships.[3] According to Dave Durkee, the bottom line is that the cloud 2.0 model belongs to both small and medium enterprise and large enterprise markets.[4] Specifically, Durkee believes that the "cloud 2.0 model will be focused on delivering a high-performance, highly available, and secure computing infrastructure for business-critical production applications." Figure 2 shows a cloud computing timeline, highlighting key dates.

Embracing cloud computing's growth and challenges, several companies have built high-performance systems (for example, Google's Bigtable) and Internet applications such as search, social networks, content delivery, collaborative software development, and online games and e-commerce applications. Using a cloud provider, companies can start small and increase hardware resources only when necessary. This eliminates the need to plan far ahead for provisioning computing resources. In the market, companies have built cloud services to predict market trends, tailor pricing, and optimize procurement and manufacturing. In academia, college students use the cloud infrastructure to develop their skills and build next-generation computing infrastructures and applications.

All this advocates that this discipline has a prosperous future and will become one of the most significant industries. The Pew Research Center's Internet and American Life Project and Elon University recently conducted a survey of 900 Internet practitioners, social analysts, and researchers; their survey results confirm this viewpoint. Specifically, most of the survey respondents believe that Internet users will "live mostly in the cloud" by 2020. Also, a recent Market Research Media study forecasts that "US government spending on cloud computing [will] enter an explosive growth phase — at about 40 percent compound annual growth rate — over the next six years and [that] expenditure will pass $7 billion by 2015" (see www.marketresearchmedia.com/2009/05/20/us-federal-cloud-computing-market-forecast-2010-2015).

Initiatives and Objectives

In this department, I hope to establish a respected information source on foundational research and trends in cloud computing. Specifically, my vision is to have articles, position statements, and viewpoints written by academics in this area and researchers affiliated with companies that provide cloud services. The department will aim at delivering the state-of-the-art research on current cloud computing topics, and at promoting the internetworking discipline by discussing novel problems that must be investigated and will enhance the evolution of next-generation cloud-based networks. Possible topics include

- platform, software, and infrastructure as a service;
- cloud elasticity and availability;
- power-efficient computing;
- security and privacy;
- migration;
- management and configuration;

- interoperability;
- economics;
- new applications; and
- use scenarios.

Another objective is to cover major innovations and events (such as conferences, symposiums, and so on) that have taken place around the world.

Regarding this department's long-term objectives, I envision it as a focal point for practicing engineers and academics who work in the Internet computing area. This department will provide a platform to exchange and collaborate on research in a comprehensive, coordinated, and integrated manner. I anticipate this department will establish a pathway for the development of future-generation clouds.

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revised 17 Jun. 2010

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