Cloud Computing Education Strategies

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Abstract

Cloud Computing is changing the services consumption and delivery platform as well as the way businesses and users interact with IT resources. It represents a major conceptual shift that introduces new elements in programming models and development environments that are not present in traditional technologies. The evolution of Cloud Computing motivates teaching Cloud Computing to computer science senior students and graduate students so that they can gain broad exposure to the main body of knowledge of Cloud Computing and get prepared for occupations in industry. There is thus a strong need for having a Cloud Computing education course that (i) has a broad coverage of different roles interacting with a cloud; and (ii) leverages Cloud Computing concepts, technology and architecture topics at both introductory and advanced level. In this paper, we describe the demand for understanding the impact of Cloud Computing in computer science higher education. We propose education strategies for teaching Cloud Computing, including key knowledge areas for an enduring Cloud Computing course.

1. Introduction

In recent years, Cloud Computing has emerged as a new paradigm in the field of network-based services within many industrial and application domains. It offers a pool of virtualized computing resources at various levels, covering infrastructure, platforms or software delivered to users as on-demand services from the cloud, or Business Processes as Service (http://www.gartner.com/it-glossary/business-process-as-a-service-bpaas), i.e. from a network that ensures resources and services. In this way, Cloud Computing is changing the services consumption and delivery platform as well as the way businesses and users interact with IT resources [1].

In early 2008, the IEEE Transaction on Services Computing (TSC) adopted Cloud Computing to be included in the taxonomy as a body of knowledge area of Services Computing [2]. Since then, a series of events, conferences and workshops have been launched and dedicated to Cloud Computing and related technologies. Within EU, Cloud Computing is listed as one hot topic. The European Commission, which represents the interests of the EU as a whole, outlined a European Cloud Computing Strategy [3], and urged for the need to ensure Europe being at the forefront of the development of Cloud Computing and to benefit on both demand and supply side through wide-spread cloud use and cloud provision. In line with this, there has been a number of EU-funded research activities in Cloud Computing, covering various aspects such as virtualization, data storage, security, business models, migrating to the cloud, and more.

In addition to academia, there is a growing interest of Cloud Computing topic within industry as well. Today's industrial systems are characterized by a strong dependency on comprehensive IT infrastructure at the customer's site. In the whole lifecycle of such systems, the costs for the IT hardware, infrastructure, and maintenance are high. Cloud Computing provides a new way of delivering industrial software and providing services to customers on demand. There are major opportunities for industry in terms of providing cloud services, which in turn increase the competitiveness by providing cutting edge cloud solutions for interacting with and controlling complex industrial systems. Two major trends are happening in information technology [4]: (i) IT efficiency, i.e., the power of modern computers is utilized more efficiently through highly scalable hardware and software resources; and (ii) business agility, i.e., IT is used as a competitive tool that allows for real time response to user requirements in a variety of areas such as rapid deployment, parallel batch processing, use of compute-intensive business analytics, and mobile interactive applications. In this context, Cloud Computing has emerged as a commercial response to competitive needs [5]. Many organizations have begun either shifting to the Cloud Computing model or evaluating such a transition [6].

As Cloud Computing gains more and more influence in information industry, it becomes part of the mandatory skill sets for professionals. The higher education needs thus to be in a constant state of evolution to reflect these advances in technology [7], and to bring comprehensive knowledge of relevant topics of Cloud Computing in curriculum so as to prepare students for occupations in IT. Cloud Computing introduces new elements in computation and programming models as well as development environments that are not present in traditional curricular. The main objectives of this paper is thus to discuss education strategies for teaching Cloud Computing for higher education, and to reason about the essential aspects of Cloud Computing body of knowledge that constitutes an enduring course.

The remainder of this paper is structured as follows: Section 2 analyzes the demand for Cloud Computing education. Section 3 presents the key concepts and technologies of Cloud Computing. Section 4 discusses strategies for teaching Cloud Computing, and Section 5 concludes the paper.

2. Demand for Cloud Computing Education

Cloud Computing builds upon a number of concepts and technologies that have existed in computer technology such as broadband networks, internet, and utility computing [8]. In the curricula today, there are many elements that are used by Cloud Computing, including databases, communication, distributed systems, parallel computing, etc. Nevertheless, Cloud Computing represents a major paradigm shift in computing in terms of how computing services are produced and consumed. Along with this change, Cloud Computing introduces new development environments and new concerns in development process [5] that are not present in traditional local or on-premise software solutions and technologies. Some examples are data center technology, multitenant technology, new computation and programming models that enable distributed computing on clouds and distributed processing of large datasets such as MapReduce [9] and Apache Hadoop [10]. Apart from providing functionality as required, an example of additional new concerns in the development process for designing cloud-based solutions is how to design resilient cloud-based applications and systems with high availability and reliability to avoid cloud-related failures. Cloud Computing introduces new infrastructural aspects as well, such as cloud management mechanisms of the infrastructure, platform and software deployed on datacenters, and the life cycle management of cloud services.

The evolution of Cloud Computing along with the new topologies and infrastructural aspects motivates teaching Cloud Computing to computer science seniors and graduate students so that they gain broad exposure to the main body of knowledge of Cloud Computing and get prepared for occupations in industry. A number of Cloud Computing courses have been developed in the recent two years, and mostly leverage Cloud Computing concepts and technologies at introductory level:

- Lee Gillam's course at Surrey University [11] is an introductory course that teaches the notions of software-as-a-service (SaaS), platform-as-a-service (PaaS), and infrastructure-as-a-service (IaaS). The course covers cloud protocols such as SOAP and REST, the principles of map-reduce computational model through hands-on using Hadoop, related paradigms such as grids and peer-to-peer (P2P) computing, and some discussions on service level agreements, cloud economics, green clouds, cloud security, and cloud use cases. This course offers practical exercises in lab-based sessions, and lacks any utilization of real-world systems.
- The undergraduate-level course at the Carnegie Mellon University in Qatar [5] focuses on the technological and programming aspects. The course starts with the general introductory materials of Cloud Computing, and covers specific Cloud Computing topics such as virtualization, MapReduce basics and Hadoop, distributed storage, Hadoop Distributed File System (HDFS) and algorithms in Hadoop. Guest lecture sessions cover functional programming, cloud diagnostics, cloud business model, and cloud economics. This course focused on developing code in their own private IaaS cloud and the Hadoop/MapReduce program model. It did not feature other PaaS cloud technologies and platforms or any public cloud infrastructure.
- The course at Universidad Rey Juan Carlos [12] proposes a curricular module that has been designed to be included in a graduate course. It emphasizes computer architecture, operating system and middleware concepts. The course covers introductory information of Cloud Computing, data center elements, virtualization technology, resource utilization, cloud management products, cloud service lifecycle management. Although this course aims to focus its contents on the advanced topics specially related to the architecture/system level of cloud systems, it does not address systematically the underlying mechanisms and architectures that make up Cloud Computing environments. The course offers lab-based sessions using CloudSim simulator for emulating data centers. Similar to the other Cloud Computing courses, there is a lack of real-world systems utilization.

The above courses cover the topics from principles and key characteristics of Cloud Computing to specific programming model and cloud infrastructures. However, they do not address the details and cloud-related topics that are required in terms of e.g., (i) developing applications in the cloud; (ii) building cloud-based architectures; (iii) evaluating when and how to start a transition to Cloud Computing in an organization; (iv) real-world systems utilization; and (v) security and compliance, etc.

Therefore, there is a strong need for having a Cloud Computing education course that complements with these details and fulfill the following requirements:

- *Clarify Cloud Computing concepts*. Leverage Cloud Computing concepts, technology and architecture topics at both fundamental and advanced level.
- *Include underlying technologies targeting different roles in a cloud*. Teach underlying technologies with a broad coverage of different roles interacting with a cloud, i.e., not only from cloud consumer perspective as in most of the courses offered, but also from the perspectives of other types of roles involved when interacting with the cloud, such as cloud provider, cloud service owner, and cloud resource administrator. This is an essential part of the course considering the transition of traditional industrial applications to the cloud computing model [6] and the corresponding roles involved in this process.
- *Integrate both educator's goals and a practitioner's objectives*. Focus on principle knowledge of Cloud Computing with lasting value, and develop students' skills for job

markets by capturing the range of problem complexities and the current technologies within industry settings for optimal education outcomes.

3. Cloud Computing Concepts and Technologies

The National Institute of Standards and Technology [13] defines Cloud Computing as a model for enabling 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. Some key attributes that Cloud Computing offer include:

- Resource utilization – A cloud service provider creates resources that are pooled together and offered to multiple cloud consumers through an abstracted infrastructure, which means that the details of system implementation is abstracted from users by presenting pooled physical resources as a virtual resource .
- Multi-tenancy – Resources are shared among multiple clients using mechanisms that protect and isolate tenants from each other.
- Elasticity – It refers to the dynamic scalability of resources, i.e., resources are rapidly scaled both up and down based on user demand.
- On-demand self-provisioning of resources – A client can provision computer resources without the need for interaction with cloud service provider personnel.
- Ubiquitous access – This is reflected in two aspects, including (i) device independence, i.e., resources in the cloud is provided to clients of all types such as laptops, mobile phones, and PDA; and (ii) location independence, i.e., users can share the actual physical resources underneath the cloud infrastructure from different locations.
- Operational expense model – The use of cloud system resources is measured and reported to the customer based on a metered system, which facilitates usage reporting and a pay-as-you-go model for charging customers to pay for the resources they need. Cloud consumers' realize their potential in business agility through combining and sharing computing resources instead of spending investment on building, maintaining and upgrading infrastructure.

A number of underlying technologies enable the above key attributes and features of Cloud Computing, such as (i) broadband networks and internet that allow for remote provisioning of IT resources; (ii) data centers that host centralized physical IT resources; (iii) abstraction and virtualization [14] that abstract physical resources into virtual resources, and offer loose coupling with minimized dependencies between cloud service providers and service requesters; and (iv) service technologies [15] that leverage the distributed nature of cloud, as the logic and structure of service-oriented architecture (SOA) [16] offers a design methodology that underpins a large majority of cloud-enabled applications [17].

4. Strategies for Teaching Cloud Computing

The existing Cloud Computing courses reported in literatures do not address enough details and cloud-related topics that are required in terms of building cloud-based architectures, developing and migrating applications in the cloud. They also fail to provide examples of real-world systems utilization. To address these weaknesses, we present below a number of education strategies when implementing a Cloud Computing course that complements the existing ones.

4.1. Define Motivation and Context for Cloud Computing

Teaching Cloud Computing is challenging since many of its principles are connected to the infrastructural support and the real benefits are usually viable for large complex systems. In the meantime, research [18] has shown that students are more motivated and will obtain a greater understanding when they see how a concept applies in a context. It is therefore important to introduce students to concrete problem domains as examples, which illustrate for students how Cloud Computing is changing the way businesses and users interact with IT resources.

Many people use some kind of applications powered from the infrastructure running on the cloud without realizing it, e.g., social networking, web based conferencing, office document creation, etc. These examples provide an easy entry point for students to understand how individuals and businesses use the cloud. In addition to these examples, students need to be familiar with concrete domains and business types for Cloud Computing at the enterprise level [19] as well, for instance:

- Data analytics and computation – High-performance parallel batch processing requires complex data analysis using processor-intensive applications such as mathematical simulations in Matlab. Cloud Computing can provide elastic computation and storage to perform analytics on large datasets.
- Development and test bed – In the early stages of new product development, the actual hardware is usually not available at all. The access to hardware for each software developer is typically limited. The same holds for system testing, where accessibility to the few test rigs becomes a bottleneck. Cloud Computing can quickly provision an infrastructure and environment for development and testing.
- Global team collaboration – Cloud Computing allows people to work simultaneously not only on common data and information, but also development processes and tools [20]. When organizations with different sets of tools collaborate with each other, Cloud Computing can leverage tools as a service to global software development teams through a cloud-based collaboration infrastructure.

Introducing these concrete examples to students helps them to understand the abstract nature of Cloud Computing. In this way, they can correlate the obtained knowledge of the advantages and disadvantages of Cloud Computing to the concrete problem domains, and understand the main drivers for the adoption of Cloud Computing and barriers to its adoption [17].

4.2. Leverage Cloud Computing Architectural Concepts

We advocate the necessity of leveraging Cloud Computing concepts not only at introductory level, but also at advanced level, covering Cloud technology architectural concepts to better explain the underlying mechanisms for Cloud Computing environment and the implementations of Cloud solutions. For instance, the key attributes of Cloud Computing are built upon the Cloud infrastructure mechanisms and Cloud architectures [21] such as workload distribution architecture, resource pooling architecture, dynamic scalability architecture, elastic resource provisioning architecture, and service load balancing architecture [22]. It is therefore important to learn the various architectures, design patterns (http://www.cloudpatterns.org) and architectural styles for the cloud [23] as well as design tactics for building new applications or migrating existing applications.

4.3. Broad Coverage of Different Roles Interacting with a Cloud

The course contents are not designed with only Cloud consumers in focus, as in most the Cloud Computing courses offered. It is designed to cover cloud aspects that concern different roles interacting with the cloud [24], i.e., (i) consumers who purchase the use of system from the providers on an operational expense basis; (ii) providers who own and operate Cloud Computing systems to deliver service to third parties; (iii) enablers who sell products and services that facilitate the delivery and adoption of Cloud Computing; and (iv) regulators who deal with regulatory issues in cloud. The course contents cover relevant aspects that concern these different roles, including: (i) for cloud consumers: evaluating cloud services, using cloud-based software and services, addressing security, cost, privacy issues, and performance of applications; (ii) for cloud providers: IaaS, PaaS, SaaS, elements of a data center, virtualization technologies, load balancing, scaling and provisioning, and cloud management; (iii) for cloud enablers: developing cloud applications for customers, providing migration strategies for existing applications, and migrating legacy system application to cloud; and (iv) for regulators: security standards and issues, service level agreement (SLA), regulation policy and compliances.

4.4. Academia-Industry Partnerships

The evolution of Cloud Computing has been mainly industry-driven [23]. This is also reflected in the design of course contents of the existing courses [5, 11, 12]. As pointed in [12], there is a lack of real-world systems utilization in the Cloud Computing course. It is therefore of great benefit to have academia-industry collaboration in order to (i) co-develop Cloud Computing course and study program; and (ii) strengthen Cloud Computing course with knowledge and expertise from industrial systems perspective. By completion of such educational course that is strengthened with influence from industry, the students not only gain a comprehensive view of the Cloud Computing field from literature reading and lab exercises, but also from real-world case studies in industry. This academia-industry partnership supplements course content, directs curricula to reflect industry needs, and get students better prepared for job markets. The academic-industry partnerships are reflected in a number of ways:

- The development of the course material comes not only from the existing literature but also from practice through close connection to the concrete projects running at industry. This leads to benefits for academia to be improved with “up-to-date” curriculum that both satisfies the industrial needs and follows the trends in research in software engineering. For instance, the adoption of Cloud Computing in an organization enriches the curriculum with real-world considerations when working with cloud-based environment in terms of business cases justification, architectural decisions that support the quality requirements of a cloud application such as availability, scalability, and performance.
- Invited guest speeches from industry to academia, giving first-hand experiences in challenges and opportunities in industry, architectural decisions and evolution paths of legacy software migration to cloud environment, and major concerns such as privacy issues, federated cloud to avoid vendor lock-in, and security issues in deciding to migrate to Cloud Computing [25]. This can be further reinforced with students doing a case study of a particular aspect, e.g., managing load balance and performance. This form of cooperation provides concrete benefits to the student such as understanding how the principles are implemented through studying concrete industrial cases, and understanding what are the challenges for the company, and what the company puts the most efforts on.

4.5. Teaching Enduring Principles

Cloud Computing is a complex and rapidly evolving concept [26]. There are a variety of tools and cloud service providers involved, of which the technical details of hardware/software capabilities and environments change rapidly and differ among business vendors. Some of these vendors may only exist for a short period of time. According to the study in [27], "a subject is more comprehensive if students and teachers grasp its fundamental principles. Fundamental ideas, and condense information by organizing incoherent details into a linking structure will be kept in mind for a longer time." Therefore, it is important to teach platforms and technologies that are the most generalized so that students can learn the enduring fundamental principles that continue to have relevance and value in the long term, i.e., with lasting value and is not purely a reflection of currently available features from some cloud provider that may become quickly out of date [28]. The course does not provide huge coverage of specific Cloud Computing vendor products and technologies, though some specific technologies are used as a means to reinforce the understanding and learning results of the course contents.

4.6. Different Ways of Learning

Besides lectures, the enduring principles of Cloud Computing are taught through different additional ways as well, offering both theoretical and practical trainings to students:

- Readings – Reading assignments are focused on a specific topic and connected with subjects that are planned to discuss in class. This creates a clear connection between the reading and the expectations of the students. Publications in form of literature surveys, systematic reviews in particular, are good sources for reading to get an overview picture of a specific topic. For instance, students get reading assignments to read papers [29, 30] to understand the fundamentals and security issues in Cloud Computing, and they can discuss their reflections during class discussion sessions.
- Class discussions - The primary method to bring about active learning is discussion [31]. Topics for discussions are usually from reading assignments. Particular topics of interest to many students provide also input to the topic selection for guest lectures.
- Guest lectures – Invited speech from both industry and academia to give informative update of first-hand experiences in challenges and opportunities in industry as well as research progress in the research community of Cloud Computing. For instance, invite people from academic and industrial partners involved in e.g., EU-funded research activities in Cloud Computing, covering various aspects such as virtualization, data security and storage, business models, and migrating to the cloud.
- Projects – Hands-on working in projects makes sure that students not only understand the major concepts and principles, but also know how to apply them in operational software as well as understanding new systems and services. This is done in both (i) lab environment where students test out a specific cloud platform technology, using for instance, Windows Azure Training Kit [32], Google AppEngine [33], or Amazon Web Services [34]; and (ii) as thesis work at industry, doing for instance, IaaS/PaaS evaluation and benchmarking.

4.7. Key Knowledge Areas

The Cloud Computing course covers the following key knowledge areas, covering both fundamental and advanced topics with architectural aspects in focus:

- Cloud fundamentals – This includes understanding the key attributes of Cloud Computing, the underlying mechanisms and architectures that enable these characteristics, as well as the cloud architecture on infrastructure and platform levels.
- Architecting for the cloud – This is a topic that includes design considerations when designing cloud-based solutions and building cloud-based architectures that meet system requirements in terms of e.g., availability, interoperability, maintainability, performance, reliability, scalability, testability, etc.
- Design for resilience – This includes how to design cloud-based systems with redundancy within and across cloud providers to tolerate and quickly recover from provider failures [28], failover mechanisms provided in Cloud Computing, dynamic backup and recovery.
- Cloud security and compliance – This includes understanding the advantages and disadvantages of using a cloud-based provider, common security threats to cloud-based environments both to cloud-based and on-site solutions.
- Migrating to the cloud – Cloud Computing poses new challenges to evolving software intensive systems [35]. This topic includes therefore evaluating when and how to start a transition to Cloud Computing in an organization, examining requirements for migrating an application to the cloud, business model and cost calculations, defining counter measures to vendor lock-in, and defining design decisions, evolution path and concepts for software migration to cloud environment.

5. Conclusions

Cloud Computing represents a major conceptual shift, introducing new elements in programming models and development environments that are not covered in traditional technologies. This motivates teaching Cloud Computing to computer science seniors and graduate students so that they can gain broad exposure to the main body of knowledge of Cloud Computing and get prepared for occupations in industry. However, the existing Cloud Computing courses reported in literatures do not address enough details and cloud-related topics that are required in terms of building cloud-based architectures, developing and migrating applications in the cloud. They are also lacks utilization of real-world systems.

In this paper, we have identified a number of education strategies including key knowledge areas when implementing such a Cloud Computing course that complements the existing ones. We advocate for introducing students to the abstract nature of Cloud Computing through concrete examples of problem domains. The course is designed to have a significant coverage of architectural aspects to explain the underlying mechanisms for Cloud Computing environment and the implementations of cloud solutions from the perspectives of different stakeholders involved when interacting with the cloud. The course is also designed to introduce students to the real-world systems utilization and provide access to industry projects related to developing cloud-based solutions through close academia-industry partnership. The learning outcomes of the course are enduring concepts and principles that continue to have relevance and value in the long term.

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