The Development of an Educational Cloud for IS Curriculum through a Student-Run Data Center

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Abstract

The industry-wide emphasis on cloud computing has created a new focus in Information Systems (IS) education. As the demand for graduates with adequate knowledge and skills in cloud computing is on the rise, IS educators are facing a challenge to integrate cloud technology into their curricula. Although public cloud tools and services are available for many students today, education institutes can build a private, educational cloud to facilitate more practical, interactive and hands-on learning. This paper presents a proposal of building a student-run data center through an industry partnership between Cal Poly Pomona and leading cloud technology firms such as Microsoft, Avanade, Chef, and Juniper. The data center will create a private cloud to engage faculty and students in a highly accessible, experimental cloud environment, where through real-world experience faculty can teach and students can learn the design, configuration, deployment, management, and use of cloud solutions. This polytechnic approach in cloud curriculum integration will also allow the IS department to be simulated as a modern enterprise with a goal to virtualize its IT provisioning, where students can gain a broader, more enterprise-centric view of modern computing.

Keywords: IS Curriculum, Data Center, Cloud Computing

1. BACKGROUND

Cal Poly Pomona is one of two polytechnic universities in the public California State University system, the largest university system in the United States. The university motto is "Learn by Doing," and experiential and project-based learning is an important characteristic of a Cal Poly education. The CIS Department is part of the College of Business, and its undergraduates earn a Bachelor of Science degree in Business with an emphasis in Computer Information Systems.

A leading-edge curriculum that makes CIS graduates attractive to the IT industry is part of the culture and tradition of CIS at Cal Poly Pomona. During the late 1970s and early 1980s, CIS faculty members advocated the separation of business programming from computer science (Athey, 1979; Athey and Wagner, 1979, 1980) and were early leaders in the development of a model curriculum that emphasized business applications, known as the Cal Poly/DPMA Model Curriculum (Mitchell and Westfall, 1981). Other major achievements in IS curriculum development include: early adopter of object-oriented technology in mid 1990s, full curriculum development in Web technology, e-commerce, and Service-Oriented Architecture in late 1990s, and again early adopter of mobile applications development in 2013.

The CIS undergraduate curriculum is highly structured, with a strong common core and advanced career tracks. The CIS faculty first developed career tracks in 1980. They revise tracks regularly, based on changes in the IT industry and the availability of new faculty to teach courses in different areas. Currently, the department offers two career tracks: *Application Development* and *Information Assurance*. Security is a growing area, in which CIS is a leader, evidenced by its designation in 2006 and 2014 as a Center of Academic Excellence from both the National Security Agency and the Department of Homeland Security. Thanks to the continuous curriculum development, the faculty and student body of the CIS department today possess strong expertise in the areas of networking, security, and application development.

In 2014, the College of Business Administration received a $500,000 endowment gift from Avanade, a joint venture between Accenture and Microsoft, to support the legacy of Mitch C. Hill who was Avanade's former CEO and a distinguished Cal Poly Pomona graduate. The gift provided seed money to establish the Mitchell C. Hill Center for Applied Business Information Technology in Winter 2015, with a mission to provide a focal point and leadership role in applied business information technology through polytechnic education, applied research, and industry partnership. As its first initiative, the Center entrusts the CIS department to construct a student-run data center to engage students with modern cloud computing through creating, managing, and providing cloud services to enhance learning and research.

This paper is organized as follows. Section 2 discusses the definition, solutions and deployment models of cloud computing as well as information on the current demand for cloud data centers. Section 3 reports a summary of related literature in the area of cloud computing for higher education and IS curriculum. Section 4 describes the proposed data center, and Section 5 illustrates how cloud solutions can be integrated into the IS curriculum. Finally, Section 6 presents the conclusions.

2. CLOUD COMPUTING

The concept of cloud computing was first introduced in the 1960s (Marston, 2011) and has resurfaced in such forms as Application Management Services (AMS) and Application Service Providers (ASP) in the dot-com era. The basic idea of cloud computing is that the computing is "in the cloud," where the "cloud" is taken from the symbol in network diagrams that represents the Internet.

There seems to be little agreement in the definition of cloud computing between scholars, analysts, and IT experts, because they either approach it from different angles (Kovacevic et al., 2012) or the standards for connecting the computer systems and the software are not fully defined at the present time (Beal, 2015). Nonetheless, this paper uses the definition provided by the National Institute of Standards and Technology (NIST) as it has been cited often in the literature:

> "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."

The NIST's definition identifies five essential characteristics for the model of cloud computing: on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service. The manifestation of these characteristics in practice has also coined terms like "computing as a utility" and "computing as a service". Because of its significant impact on IT, cloud computing has been credited as a "genuine information technology revolution" (Morrison, 2011), a "potentially game-changing technology" (Kontzer, 2009), a "new computing paradigm" (Jararweh et. al, 2012), and the "fifth major paradigm shift in computing" following mainframe computing, personal computing, client-server computing, and web computing (Conn & Reichgelt, 2013). IT experts expect cloud computing to become the "dominant IT service delivery model" by the end of the decade (Jararweh et. al, 2012).
According to NIST's definition (NIST, 2011), cloud computing mainly offers three cloud solutions: *Software as a Service* (*SaaS*),

Platform as a Service (*PaaS*), and *Infrastructure as a Service* (*IaaS*). *SaaS* provides users with access to applications in the cloud such as email (e.g., GMail), text editors (e.g., Google Docs), or online storage (e.g., Dropbox). In a *PaaS* model, a cloud provider delivers a container environment with hardware and software tools to run the user's application components. For instance, application developers can deploy their own .NET Web applications onto Windows Azure cloud instances. With *IaaS*, cloud solution providers such as Amazon's Elastic Compute Cloud supplies infrastructure resources, usually in terms of virtual machines, upon which consumers can deploy and run arbitrary software including operating systems and applications. In broader terms, cloud solutions can be further categorized to include *Application as a Service*, *Database as a Service*, *Information as a Service*, *Infrastructure as a Service*, *Integration as a Service*, *Management as a Service*, *Process as a Service*, *Security as a Service*, *Storage as a Service* and *Testing as a Service* (Linthicum, 2010).

NIST lists four cloud deployment models. The *Private cloud* is built to be exclusively used by a single organization or a business unit. The *Community cloud* is provisioned for the exclusive use by a specific community of consumers from organizations that have shared needs or concerns. The use of the *Public cloud* is open to the general public. Finally, the *Hybrid cloud* is a composition of two or more distinct cloud infrastructures (private, community, or public). Each model yields distinct characteristics including varying pros and cons. Deployment decisions are determined by considering various influencing factors such as the requirements of an organization, type of organization and the scale of the organization (Kalpana & Laharika, 2013).

The essence of the cloud is that it makes computing resources always available from anywhere through a data center. A data center is the cloud hub where all the cloud services are designed, configured, deployed, secured, and provided. A data center is generally organized in rows of ‵‵racks" where each rack contains modular assets such as servers, switches, storage ‵‵bricks", or specialized appliances. Hardware or platform virtualization, the creation of a virtual machine to act like a real computer with an operating system, is the most common technology being employed by today's data centers to reduce costs, increase agility and enhance security.

Managing a large number of cloud services is an enormous task. The most recent technology in data center operations is the implementation of Software Defined Networking (SDN) (Sher-DeCusatis & DeCusatis, 2014). SDN commonly refers to a set of technologies that separate the network control and management functions from the data transmission functions. Rather than pre-configuring network devices to make hop-by-hop decisions on traffic routing, SDN provides Application Programming Interfaces (APIs) to automate network management currently performed by low level, manual commands. The ability to program network infrastructure APIs is rapidly emerging as a key differentiating skill for network architects and administrators, and will soon become a requirement for most employers (Sher-DeCusatis & DeCusatis, 2014).

Driven by the recent proliferation of cloud computing, data centers are experiencing rapid growth in both scale and complexity (Zhang et. al, 2011). According to a prominent market survey, (Research & Market, 2015) the global market for datacenter construction is expected to register an annual compound growth rate of 21 percent through 2018.

3. CLOUD COMPUTING FOR HIGHER EDUCATION AND IS CURRICULUM

The rapid migration toward cloud computing has also prompted higher education to consider adopting cloud technology to lower the cost of technology implementation and increase access to technology infrastructure. The potential academic benefits and efficiencies of cloud computing in higher education has been recognized by many universities (Marinela & Andreescu, 2011). In Gartner's 2012 CIO survey (Lowendahl, 2012), the 143 higher education respondents ranked cloud second after mobile among their technology priorities. The survey also indicates that the opportunities and challenges in leveraging cloud technology cannot be ignored by higher education. In fact, a recent national survey of computing and IT in US higher education (Green, 2014) has shown that the proportion of campuses reporting a strategic plan for cloud computing rose to 29 percent in fall 2014, up from 27 percent last year, 24 percent in 2012, 21 percent in 2011, and 9 percent in 2009.

While university administrations have interests in cloud computing in terms of efficiency, effectiveness and cost savings, higher education institutes also have an academic side goal of learning and knowledge production. As the demand for graduates with knowledge and skills in cloud computing is on the rise, IS educators have an urgent duty to help students respond to this rapidly evolving trend.

For IS programs, the challenge is to decide on how to design curriculum that teaches cloud technology and incorporates appropriate cloud-based technologies into their pedagogy. The literature shows that various approaches have been taken to integrate cloud computing into IS curricula.

Cloud computing can be integrated into a whole IS program or curriculum. For instance, Lawler and Joseph (2012) discuss how cloud technology can be integrated into a Technology Entrepreneurship program. In the program, students can learn skills for leveraging cloud computing practices in the context of an enterprise strategy. Chen et. al (2012) integrate cloud computing components into seven third/fourth-year undergraduate level information systems, computer science, and general science courses that are related to large-scale data processing and analysis. In an attempt to improve the existing IS Model Curriculum (e.g., IS Model Curriculum 2009), Lawler (2010) defines a more comprehensive and structured program by which computer science and information systems students can learn needed skills in cloud computing strategy and technology in four years.

Cloud computing as a core subject can also be created as a single course. There are a number of this type of courses being offered to teach the fundamentals and principles of cloud computing (e.g., Border, 2013; Chen et. al, 2012; Maraschini et. al, 2013; Lawler, 2011). Common knowledge units such as cloud technologies (e.g., firewalls, addressing and sub-netting, storage architectures, virtualization, service-oriented architectures, autonomic and utility computing, etc.), cloud services and provisioning, cloud design and deployment, and cloud management and governance are being taught in these courses.

With cloud technology, students' learning is no longer confined within the classroom. Learning environments could be improved by allowing students to access learning resources anywhere and anytime from clouds infrastructures. Therefore, cloud technology can be used as a tool to improve pedagogy and enhance student learning in individual IS courses. For instance, several IS courses (Chen et. al, 2012) use open-source computing tools such as Hadoop, Mahout, and Hive to enhance student learning environments. Realizing the fact that the advent of cloud computing has made modern data management technologies differ from the traditional ones, Grossniklaus and Maier (2012) taught cloud-based, scalable data stores such as NoSQL and VoltDB in their data management course. Instead of investing in more expensive computer labs and classrooms, Mrdalj (2011) proposes an attractive alternative for Business Intelligence courses that uses cloud technology to implement a rather cost-effective, rapid and dynamic environment. Finally, rather than having students use customary methodologies, such as the Unified Process, Agile, or others, Roggio (2011) proposes a new approach to teaching a two-course sequence capstone course in software development. The approach divides student teams into those who help in setting up the cloud infrastructure, platform, and applications support and those who use the cloud to develop applications.

There are two distinct perspectives on the cloud, either you are a user of a cloud or you are the developer or provider of cloud services to others. Thus, IS educators must not only educate students to be competent users of clouds but also train them to be capable cloud builders or service developers. There has been confusion among IS educators that cloud services available for education refer to only those provided by the public clouds (ISaila, 2014). In fact, educational, private clouds can be built to interconnect faculty and students with applications, platforms, content, and data in support of curriculum need (Conn & Reichgelt, 2013; Mathew, 2012).

For small and medium-sized organizations such as common education institutes, private clouds are prohibitively expensive (Harms & Yamartino, 2010). Until recently, it was not cost effective to provide students with access to real world examples of IT infrastructure (Sher-DeCusatis & DeCusatis, 2014). Fortunately, this problem can be addressed through industry and academic partnerships. This paper presents a proposal for building a student-run data center through an industry partnership between Cal Poly Pomona and leading cloud technology firms such as Microsoft, Avanade, Chef, and Juniper. The data center will create a private cloud to engage faculty and students in a highly accessible and experimental cloud environment where they can practically teach and learn the design, configuration, deployment, management, and use of cloud solutions.

4. THE DATA CENTER

The data center includes computing, networking and storage systems that are typical for use in cloud data centers. The design of the data center included participation from students, faculty and industry partners to ensure the facility was designed with student and curricular needs in mind while also representing industry best practice.

The room that houses the data center is approximately 15′ x 20′ and has a data-center grade air conditioning unit mounted in the ceiling. There is no backup air conditioning aside from the building-wide unit that only runs when the building is open and the ceiling-mounted room unit so a failure of the in-room air conditioning system will require the shutdown of computers within the facility. There is also no generator backup for the facility so a loss of power will mean that UPSs in the room will simply offer computers ample time to shut down gracefully. As a result of the size, air conditioning, and power constraints of the facility, the data center will run only curricular and research workloads. Projects in the data center that grow to needing large-scale deployment or robust uptime and availability will need to migrate to public cloud infrastructures.

The data center is being built in phases and when complete will include 128 RUs of space for servers in addition to 112 RUs of space allocated to storage, power backup, cable management etc. While Cal Poly Pomona is currently on the quarter system it is in the midst of a transition to semesters. As a result, the data center is divided into four quadrants with three quadrants being in use at any given time and the fourth quadrant being under construction.

In the first two years one quadrant will be built each semester and added to the production pool. By year three, servers in the first quadrant will be removed and reconditioned or replaced. The following semester the second quadrant would be rebuilt and so on. This process will ensure that a section of the data center is being built every semester which means that every student will participate in the construction of the data center. The continual reconstruction process will also provide ongoing upgrades and improvements that will keep the center aligned with industry best practices and with the evolving curricular and research needs of the university.

Data center hardware will be homogenous within each quadrant but heterogeneous across quadrants. The blend of architectures allows efficiencies of homogenous systems while also allowing the flexibility and scalability of heterogeneous systems. This will also offer the ability to pursue new design methods each semester while maintaining operational integrity for existing systems.

Students will study operating systems and networking in the second year of the program and will participate in data center construction during that year. In years three and four students operating the infrastructure will compete for data center administration positions including data center management, change management, systems and network administration, software development etc.

In addition to operating and maintaining systems within the data center, students will also research and implement best practices such as the optimization of energy consumption, flexible and scalable operations, virtualization, security and more. Through consultation with faculty and campus IT administration, students will continually refine the data center to meet goals pertaining to efficiency and effectiveness of operations

The design and operations of the data center will also be adaptable to research and curricular demands. The ability to modify the data center to facilitate curriculum and research will offer Cal Poly Pomona a unique ability to pursue projects and opportunities that would not otherwise be possible.

The goal of the data center is to allow users to acquire and provision resources with no direct interaction between student administrators and the computing systems within the facility. Instead, Chef Cloud management software will be used to fulfill user demands in real time. Student administrators will then tend to the care and feeding of the cloud platform while automated provisioning processes will tend to the fulfillment of user demands. Juniper Networks provided SDN-capable network hardware allowing both systems and networks to be automatically provisioned on demand.

Cybersecurity will be a key focus of the data center from operational, curricular and research perspectives. Faculty will use and teach best practices of organizations such as the Cloud Security Alliance (CSA). Access to the data center will initially be limited to the campus community. Operations staff will have access to the data center itself and direct fiber connects the data center to a student development lab offering unabated 10 Gbps IPv4 and IPv6 network access for developers. Additional access will make use of VPN tools to ensure that authentication, authorization and accounting controls are in place. As security controls are enhanced and matured, data center administrators will work with faculty and IT staff to open access to the entire campus community and eventually the Internet.

5. THE CLOUD SOLUTIONS AND THE CURRICULUM

The mission of the data center is to educate students not only to be competent users of clouds but also capable cloud builders and service developers. This can be achieved by simulating the CIS department as a modern enterprise with a goal to virtualize its IT environment. In this environment the student-run data center, with faculty supervision, can operate as the IT division of the enterprise through which a private cloud and its cloud solutions can be created and provided for curriculum needs. Through this cloud-enabled curriculum, faculty and students can be cloud users, cloud solution developers and cloud infrastructure developers. Through this highly accessible and experimental cloud environment, faculty and students can practically teach and learn the design, configuration, deployment, management, and use of cloud solutions. Table 1 shows that three "workforces" from the two career tracks of faculty and student body can be formed to create, provide, and manage the three major cloud solutions:

The *IaaS* is an on-demand cloud solution that provides an elastic approach to allocating compute and storage resources, generally in support of virtual appliances or machines. With this approach, CIS students can be allocated general purpose and specialized virtual machines for use in their coursework. IaaS provides the greatest strength to the Security and Networking Workforces who require reliable virtual machines to carry out simulations and projects related to their focus. In Azure, the IaaS role is implemented via the Virtual Machine Cloud resource provider that runs on top of a physical Hyper-V cluster managed by System Center 2012 Virtual Machine Manager. Due to the modularity of Azure, this cluster of physical Hyper-V servers can be horizontally expanded based on current resource needs and future growth.

Table 1. Workforces for Cloud Solutions

Solution	Application Workforce	Security Workforce	Networking Workforce
IaaS		x	x
Paas	x	x	x
Saas	x	x	

The *PaaS* is the cloud solution that provides the application development support. Isolated IIS, .NET Framework, Microsoft SQL and MySQL resources can be exposed to users of the cloud to develop web application projects requiring web and database services. Administrators are able to allocate these resources on-demand and can specifically define what is available given a particular project's requirements. This provides great assistance to the data center by offering a development environment more akin to that found in an enterprise rather than on personal hardware.

The *SaaS* cloud solution allows student access to web-based services that supply uniform functionality which caters more towards the managerial aspects of the CIS major. For example, Microsoft CRM is a web application designed to assist business interaction with customers by building quotes and managing relationships. This application does not require development skills on behalf of the user so is unlikely to be a part of the Azure Pack offering.

The next step is to identify the best possible cloud solutions for the curriculum. Table 2 illustrates the mapping between popular Microsoft Azure solutions and the existing CIS core and elective courses. The table suggests which Azure cloud solutions can be implemented for which course. For example, Microsoft's RemoteApp is a solution in Azure that allows users to use applications on any Android, iOS, Mac OS X, and Windows device. These applications are run on a Windows server through the Azure cloud via Microsoft's Remote Desktop Services. RemoteApp is an important and powerful tool that students can use in their CIS classes. By deploying any software needed onto RemoteApp, students can access and use required software on nearly any device, without needing to install anything other than the RemoteApp client. Since students do not have to install the applications themselves on their local device, there should be no instances of hardware and software compatibility issues.

Table 2. Cloud Solutions for CIS Courses

CIS Course	Cloud Solution
CIS 231 - Fundamentals of CIS	5, 10
CIS 234 - Object-Oriented Java	5
CIS 304 - Intermediate Java Programming	5
CIS 305 - Database Design Development	5, 6
CIS 307 - Business Telecommunications	5, 9, 8
CIS 310 - Management Information Systems	7
CIS 311 - Interactive Web Dev.	5, 10
CIS 315 - Intro to Sys. Analysis and Design	5, 6, 10
CIS 388 - Client/Server App. Dev.	5, 6, 10
CIS 345 - Data Modeling	1, 2, 5, 6, 7
CIS 347 - Telecommunication Networks	5, 9
CIS 415 - Adv. Object Oriented Systems	1, 5
CIS 417 - Broadband & Multimedia Networks	5, 9
CIS 421 - Multimedia Application Dev.	1, 2, 3, 7,10
CIS 424 - Advanced Java Programming	5, 6
CIS 427 - Mobile Comm. and Networks	4, 5, 9
CIS 433 - IS Auditing	1, 7, 10
CIS 451 - E-commerce App. Dev.	5, 6, 7, 10
CIS 466 - Systems Development Project	5, 6, 7, 10
CIS 467 - Network Security	5, 8, 9
CIS 471 - Internet Security	5, 7, 9
CIS 481 - Computer Forensics	5, 10
CIS 491 - Secure Web Dev.	5, 10
CIS 499 – Mobile App Dev.	5, 4, 10

* Analytics(1), CDN(2), Cloud API(3), Mobile Services (4), RemoteApp (5), SQL Database (6), Storage (7), VM (8), Virtual Networking (9), Websites (10)

The following three use cases further explain how an individual course can request and use Azure cloud solutions:

Use Case 1: CIS 305 Database Design and Development

CIS 305, Database Design and Development, is one of the core courses where students learn data modeling and normalization, relational database design and development, CASE tools, and SQL. Since this course is taught by multiple instructors, the course coordinator will request a SaaS cloud solution to let students model data and conduct database projects. The data center will setup a virtual machine as a PaaS for the SQL Database cloud solution to be integrated into the course.

Upon logging into a Windows 7 Professional virtual machine the student would notice Erwin Data Modeler pre-installed. The Erwin Data Modeler is used on Azure to provide a powerful way for students to visualize and manage data from multiple sources on-premise or in the cloud. Historically, students have had to install a version of Microsoft SQL Server on their own machine. With Azure, each student is then able to carry out their projects from an accessible location with adequate hardware resources. Because configuration of the database is addressed by the provisioning process and hardware resources are allocated based on best practices for database services, many technical problems experienced by students today become a non-issue. Students would be able to provide their instructors with connection information that would give the instructor access to grade their live database, thus eliminating the need to export and submit database files.

Use Case 2: CIS 451 E-commerce Application Development

CIS 451, E-commerce Application Development, is one of the elective courses in the Application Development career track. This course is designed to provide students with an overview of e-commerce computing and an analysis of the architectures, technologies, practices, and trends of e-commerce systems from both technical and managerial perspectives. In this class, each student is required to create three e-commerce applications: an online store, an API-based payment processing module, and an XML Web service application.

Since this course covers application development, the instructor will request a SaaS cloud solution to let students develop and store e-commerce applications and data in the Azure cloud. The data center will then configure and create a virtual machine as a PaaS and then complete the installation of a Visual Studio 2015 instance as a SaaS. With the use of Visual Studio in the cloud, students are no longer tied to using only their personal computer but are able to program their assignments from any computer at any location. Another way for students to access Visual Studio in the cloud is to use RemoteApp, which allows any Windows application to be run on any Android, iOS, Mac OS X, or Windows device remotely through the RemoteApp client. In addition, projects and other relevant data and files can be shared, accessed, and modified through Microsoft OneDrive.

Through Azure's web-based cloud solution, students will be able to work on a "live" website hosted on the cloud. Students and professors can view updated changes in real time. The Storage cloud solution will also allow the students to store their website templates and professors to store relevant teaching materials and sample code. For applications that require database management, a cloud-based SQL database can be provided by the SQL Database cloud solution.

Use Case 3: CIS 466 Systems Development Project
CIS 466, Systems Development Project, is the capstone course, where student teams are formed to take on real-world IS projects. There are various types of projects that cover areas such as business plans, website development, e-commerce applications development, mobile applications development, network configuration and management, information assurance and audit, computer forensics, and so on.

Depending on the project types, the course instructors can request Saas, Paas, and/or IaaS cloud solutions from the data center. For example, a mobile application project can use the Mobile Service to allow a student team to rapidly build cross-platform and native apps for iOS, Android, Windows or Mac, store app data in the cloud or on-premises, authenticate users, send push notifications, as well as add the custom backend logic in C# or Node.js. For a networking project, the Virtual Machines or Virtual Networks can be provisioned using PaaS and then provided to deploy and manage Windows and Linux Virtual Machines including VM Templates, scaling and Virtual Networking options.

6. CONCLUSIONS

Cloud computing is a rapidly growing area and training students to be well-versed with this technology when they graduate is urgent. There are many approaches to integrating cloud computing into IS curriculum. This paper describes an innovative way for the curriculum integration to be implemented with minimum budget overhead through partnering with industry donors. The data center, with the highly accessible and experimental cloud, will allow faculty and students to learn cloud technology in a simulated enterprise environment where IT provisioning is virtualized.

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