Cyber Education Motivated the Creation of the Virtual Instruction Cloud CLaaS, a New Distance Learning Modality

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Abstract

Cyber security training and skills can best be learned by hands-on, experiential learning. Virtualization facilitated the delivery of the computing resources needed to complete hands-on lab exercises. The accelerated need for cyber warriors in the workforce led to the design of an online MS in Cyber Security (MSCS) program in an internet-paced delivery modality of one-course-per-month format. Usage of a virtual computer lab for hands-on learning in both the online and onsite curriculum became the signature differentiator for this MSCS program. Out of necessity, the delivery infrastructure evolved from a LAN to a private cloud as virtualization facilitated cloud deployment. The progression has been "hands-on", "virtualization", "need for accelerated teaching", "online", "one-course-per-month" to "cloud".

The constant challenges of managing a sophisticated private cloud for National University led the authors to identify the requirements embodied in the class/lab module of the Virtual Instruction Cloud (VIC), a new model for distance education. CLaaS, or Computer Lab-as-a-Service is a trademark of iNetwork and embodies features of the class/lab module. Additionally, recent advances in technology including new mobile devices, the ability of MOOCs to reach thousands of students (distance learners) and the wide spread use of social media as a ubiquitous communication method have reshaped the educational environment, reinforcing the need for CLaaS.

A Computer Lab as a Service (CLaaS) in the cloud enhances the educational content delivered by MOOCs; and specifically, cyber MOOCs. Together, VIC and its computer class/lab module, herein referred to as CLaaS, deliver new technology, provide provenance for new forms of educational content, protect developer IP and also protect academic revenue streams. This paper describes CLaaS. CLaaS allows the instructor to return her focus to teaching. Today, CLaaS is particularly useful in meeting the special needs of the cyber education community in its drive to better prepare cyber warriors to secure the future of our global infrastructure and economy.

Introduction

There are ongoing debates regarding the relative value of theoretical versus practical knowledge. Computer Science and computer-intensive disciplines require students to utilize both theoretical and practical methods of learning. Successful entrepreneurs do not succeed in the modern world if they cannot combine theory with practical application of algorithms that perform useful functions. Ever since the advent of computer technology education in the 1960s, academic institutions have invested large sums of capital to equip their programs with the computing equipment necessary to support the learning outcomes defined in their computer related curricula[1]. Innovative programs provide students with an educational experience that conforms to this axiom. Distance learning methods have now evolved to the point that academic institutions have the ability to offer students vetted course credit via instruction methods that invoke both methods of computer science learning (theory and practical application of knowledge).

Siemens pioneered open Connectivist courses for over 15,000 students and educators in thirty countries and his colleagues, in 2008, named these the first Massively Open Online Courses (MOOC)[2]. Siemens, Groom and Couros base their online teaching on a pedagogical participatory model (Siemens, 2012; Groom, 2012; Couros, 2012) that differs from the elite and well-funded university model (Coursera/EDx) that was initiated in 2012-13 and is more publicized. Siemens distinguishes between the two as being Connectivist (Siemens, Couros) versus Constructivist (Coursera, EDx). The Connectivist model is an online teaching method based on a participatory pedagogical model. Constructivism is a learning model which is now vying for a place in the mainstream educational process as a new educative practice. As Egan stated in 2004: ".. the Constructivists adopt a traditional view of knowledge and learning. Instead of distributed knowledge networks, the Constructivist courses (now, generally referred to as MOOCs) are based on a hub and spoke model with the faculty (knowledge) at the center and the learners replicators of knowledge) as spokes.[3] " However, these diverse Connectivist and Constructivist perspectives can be combined in a hybrid model, CLaaS, which is the premise of this paper. The Computer Lab as a Service platform developed by the authors is a tool that Computer Science instructors, being the focus of this paper, will find useful in their delivery of both educational theory and hands-on instruction.

CLaaS Definition

Computer Lab as a Service (CLaaS) is a cloud based system that provides educators with a platform to create and deliver computer based laboratory (lab) exercises to students. CLaaS is ideally suited to provide unique capabilities for distance education, and it also functions in a traditional brick and mortar environment. CLaaS combines virtual machines and network resources in a lab configuration that emulates real world computing technology supported by a pedagogical learning infrastructure that makes the lab useable by instructors with minimal personal administration, configuration and maintenance.

The lab environments created in CLaaS are tied directly to specific learning outcomes and more granular learning objectives defined in the academic progress tracking system. CLaaS is one instance of the Class/Lab module identified in the Virtual Instruction Cloud (VIC) patent developed by the authors. The CLaaS product features are a product of industry observation (iNetwork, Inc.) and analysis which occurred during the agile development of an MS in Cyber Security and Information Assurance (MS-CSIA) program created and deployed at National University (NU).

The Virtual Instruction Cloud (VIC), of which CLaaS is just one component, represents a new pedagogical model for higher education which synergistically incorporates current social behavior in an academic system. VIC combines both Connectivist and Constructivist theories in a way that provides structured accreditation for MOOCs and preserves the revenue stream for traditional academic institutions. Increasingly, virtualization (and changing trends in on-line education such as MOOCs) provides a greatly enhanced service capability at a significantly reduced cost per student. The Constructivists disagree, pointing out that their MOOCs are based on a hub and spoke model which maintains the faculty and the knowledge at the center and the students external to that nexus. VIC falls somewhere along the continuum, depending upon administrator preference, between the Connectivist and Constructivist models and, consequently, the traditional fee structure and higher education revenue model will still apply.

The premise of this paper is that CLaaS provides university administrators, department chairs and faculty with a tool that reduces capital expenditures by changing the financial model for hands-on-computer technology labs from a capital outlay to an operating expense. At the same time, CLaaS represents a transformative educational technology which shifts the computer education landscape and refocuses it on emerging Web 2.0 and 3.0 trends in student directed learning represented by MOOCs, YouTube videos, Coursera and other new on-line learning methodologies.

Computer Lab Libraries

Based on the observations of current industry trends, as well as additional work done by the authors researching CompTia, SANs Institute and ECC certificate programs, the following labs have been defined and pre-configured in the CLaaS Lab library.

Individual Labs (one student, one virtual machine)

Kali Linux	Ruby on Rails
Backtrack 5	MySQL Database Server
Metasploit	Apache Web Server
Security Onion	OWASP
Win2k10, IIS	Burp Suite
Win2k10, Domain Controller	Vyatta Router
Wireless Access Points (virtual)	PSI firewall

Teaming Labs (multiple students, multiple virtual machines)

Red vs. Blue Team
Penetration Testing
Small Business, Single Domain, Multiple Departments
Enterprise Business, Multiple domains, virtual WAN

In addition to these pre-defined labs, the authors have dialoged with professors at the University of Southern California (USC) Viterbi School of Engineering, Information Sciences Institute (ISI) about the possibility of integrating some of the DeterLab[4] functions currently used in the USC Cyber Security Master's program with a remotely accessible CLaaS portal. The pre-defined lab environments listed above are specific to the Cyber Education space. Although the Cyber Education space represents the initial target market for CLaaS, the implementation of specific laboratory environments for a large variety of computer science educational topics is consistent with the ease of use concepts embodied by the CLaaS eGUI and database structures.

There have been a number of papers published on the implementation of educational computer science laboratory environments using virtualization (VLabs). During the requirements definition phase of the CLaaS product development process the authors referenced their own experience dating back to 2001, as well as that of their academic peers which was discovered during abstract and journal research on VLabs and distance education. As result they would like to acknowledge and thank their peers in both the Department of Defense[5] as well as the commercial space[6,7,8] for their efforts to publish innovative ideas on VLabs. For researchers in any field, it is most helpful to observe experiences by others that corroborate one's own assumptions, theories and models. The CLaaS product features presented in the following sections build on the general capabilities represented by virtualized and cloud-based computing resources to create a unified virtual computer laboratory system which higher level (Department Chairs and Professors) educators can use to create and maintain a variety of computer laboratory environments.

CLaaS Educator Graphical User Interface (eGUI)

Instructors interface with CLaaS via a user-friendly educator graphical user interface (eGUI) that provides setup and configuration functions for virtual machines as well as virtual appliances such as routers, switches and firewalls. A variety of network infrastructure models are supported including single and multiple virtual local area networks (vLANs), multi-level tree structures and virtual wide area networks (vWANs). Students interface with CLaaS via their own computer and a VPN connection into an "Arena" (think sandbox) environment, preconfigured with the virtual machines, appliances and the network structures necessary for course specific learning outcomes. Outside observers have the opportunity to monitor both instructor and student actions. The following screen shot depicts the CLaaS Main Menu:

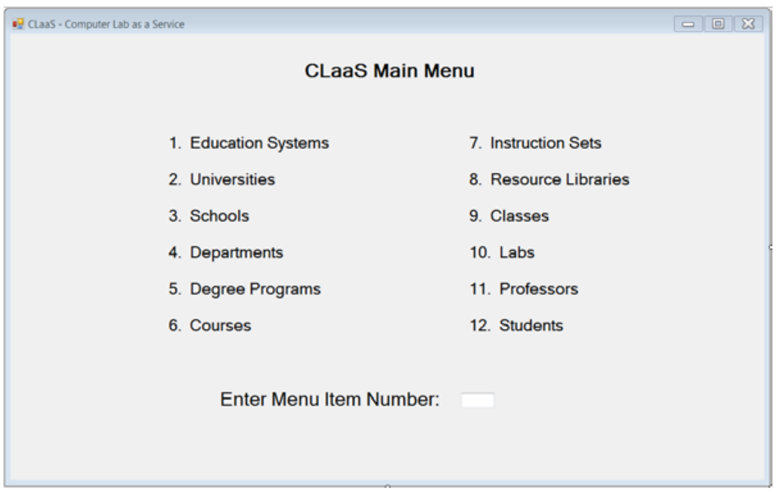

Figure 1. CLaaS main menu.

Academic Variables

As indicated in the preceding section, many individual professors and the schools they are associated with have experimented with and implemented a variety of virtual lab (vLab) environments. CLaaS is unique because it builds on these experiences to define an approach to vLabs that incorporates both academic-administrative and technological parameters. Academic-administration is addressed as opposed to technological administration (for example system administration of a network infrastructure) that would be covered in the technological area.

Many universities have attempted to setup and administer vLab environments thinking that it is simply a matter of outsourcing technology, when, in reality, there is an academic-administration requirement that must be filled because faculty want to teach and not administer. This is where CLaaS becomes unique and stands out as it provides both a technological as well as an academic-administration solution. Courseware must be developed and maintained as the labs just do not magically come together for a given class without structure and organization simply by assigning a group of virtual machines to a specific semester class. This section will describe some of the database table structures which CLaaS implements to track student progress against specific course objectives and learning outcomes. The CLaaS Academic Progress Tracking System uses the following database tables structures as part of the laboratory setup and configuration process:

Table Name	*Sample (examples) Table Entries*
Education System	University of California or California State and their various campus locations Bridgepoint Ashford and other institutions
University	UCSD, UCLA, SDSU, Cal State San Marcos Ashford is a University, but also part of Bridgepoint National University (NU) is a single entity with 28 schools Coleman is a single college
Schools	Viterbi School of Engineering (USC) Forbes School of Business (Ashford) School of Engineering Technology and Media (NU)
Course	A defined set of material with specific learning objectives
Instruction Sets	A set of content objects sequenced in a manner that facilitates learning. Specifically, the knowledge acquisition and retention of the information defined by learning objectives associated with the successful matriculation of the course.
Resource Library	A collection of content objects which includes educational material in many forms including word documents, power point presentations, video clips, pictures, animations, audio tracks and virtual environments.
Class	One instance of a course A defined group of students are enrolled in a course A class has a professor A class may be taught on-site and have a classroom number A class may be taught on-line and thus not have a physical room A class may have one or more laboratory environments (arenas) An arena may have one or more lab assignments The Class table is a container which in conjunction with other database tables will track student academic progress
Lab	A laboratory assignment may have one or more learning objectives Labs, via their association with a class will have specific students

A lab assignment will have a student performance rubric
Labs may be persistent (re-entrant) or non-persistent
Final lab configurations will be maintained beyond the last day of class to accommodate both grading and protest periods

These database structures are presented to the user (typically lead professor) in a menu driven graphical user interface that facilitates the definition of specific course learning objectives, which then serve as the driving factors for class specific assignments. In addition, the database tables listed below support a variety of other administrative functions such as:

- *Table Name* *Sample Table Entries*
- Tracking Student ID:course:date:cohort:grade
- Demographic Info Student ID:Name:Specializtion:Status (active/drop out)
- Student Enrollment Status History Contact info, User/Password, Qualifications, Pre-Requisite

Virtual Machine and Network Structures

The CLaaS laboratory arena setup and configuration function provides the user (typically lead professor) with a menu driven system that makes it easy to choose and define specific technical elements. Some of these functions include:

- Virtual Machine (vm) Templates: currently the library contains more than 100 vm ISOs including a variety of Windows and Linux operating systems
- vLan Types: Null, Flat, 2 vLans, 1 level Tree (3 vLans),
- Virtual Switches
- Virtual Routers
- Virtual Firewalls
- Virtual Wide Area Networks (vWan), Simulated ISPs, vWAN with multiple domains

The following screen shot depicts the CLaas Network Selection GUI:

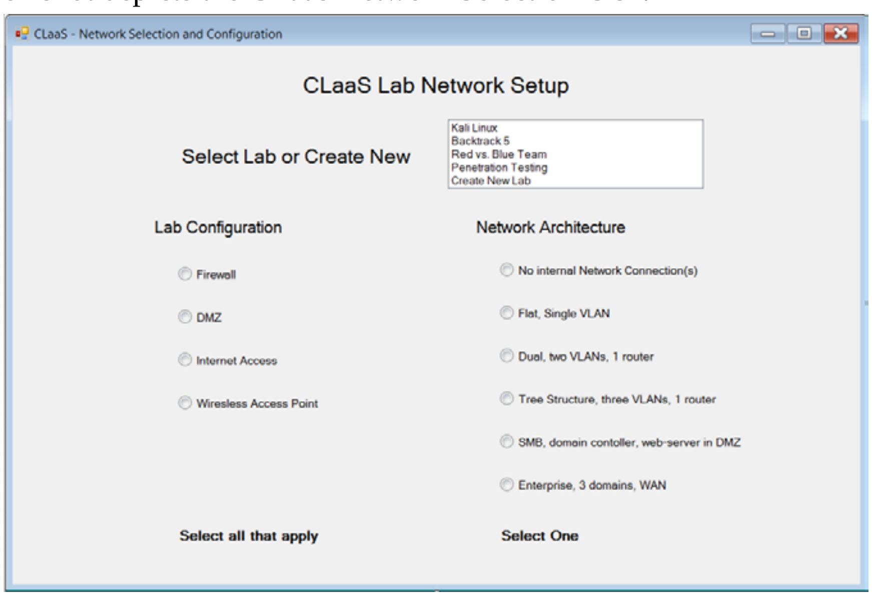

Figure 2. Laboratory network setup.

The following screen shot depicts the virtual machine selection process:

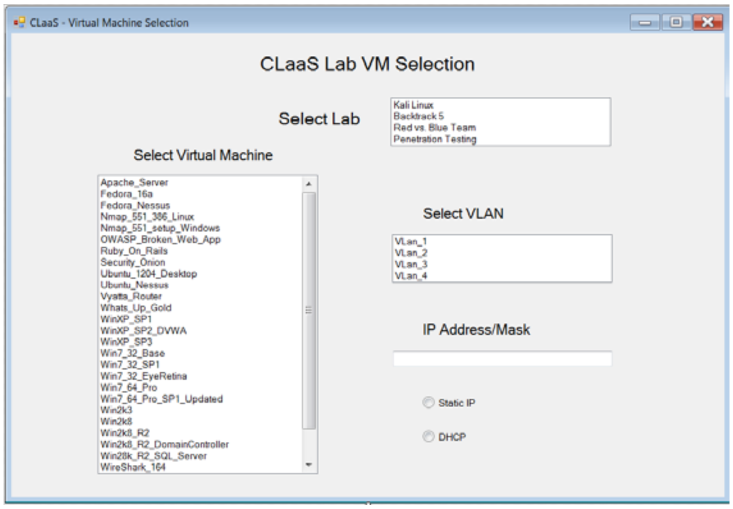

Figure 3. Laboratory virtual machine selection.

One of the unique features of CLaaS is the ability to support teaming environments. CLaaS goes beyond the simplistic one student, one virtual machine concept. CLaaS is capable of using multi-factor authentication combined with Active Directory credentials and two factor authentication[9] to provide role based access to specific sets of computing resources. Figure 4 depicts a multi-student, teaming environment.

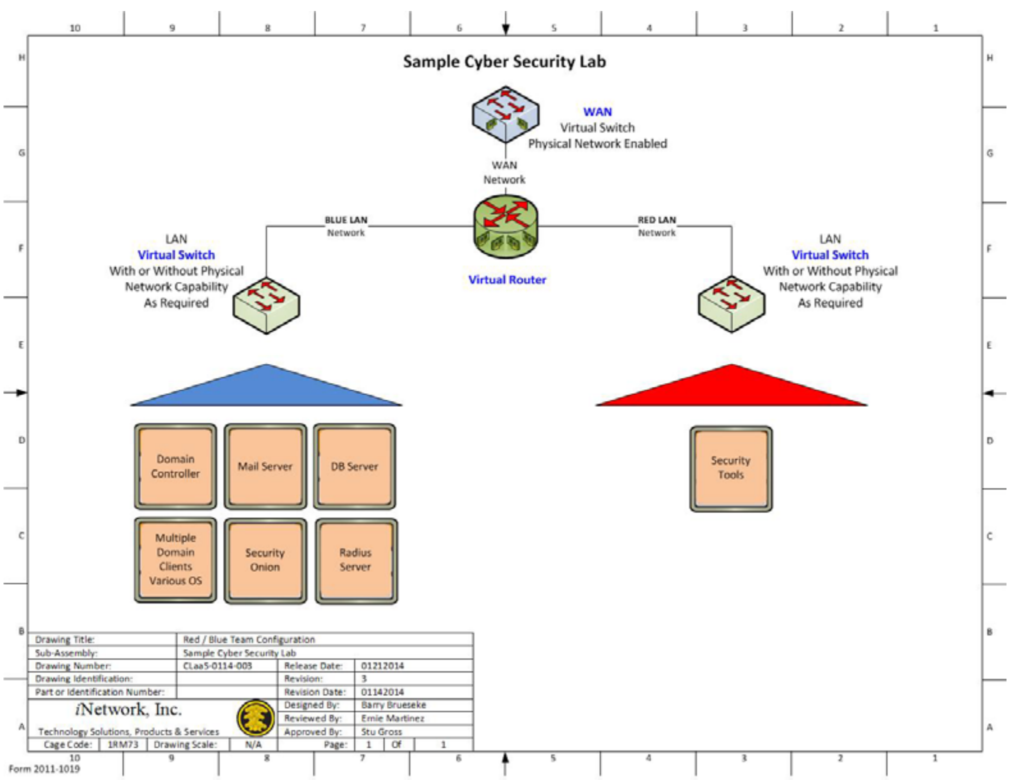

Figure 4. Example, multi-student/multi-team lab configuration.

This multi-student, teaming capability expands the teaching horizon from individual exercises to include team based assignments such as Capture the Flag and Red/Blue team warfare simulations. Access to multiple resources provides curriculum designers with the ability to simulate both small/medium sized businesses (SMB) and larger, enterprise class environments.

"Hands-on lab exercises play an important role in teaching a computer and network security course because they can help students apply basic security principles and techniques to the protection of real world computer and network systems.[6]" The ability to incorporate real world scenarios in a hands-on environment provides the academic institution with the ability to promote the unique and superior nature of its computer science education program. The CLaaS Academic Progress Tracking System records student participation in laboratory exercises and facilitates the class grading process used by the instructor to ensure students have completed the associated rubrics to necessary for academic credit.

CLaaS Deployment

Content specific vLabs, setup using the CLaaS modules shown in Figures 2 and 3 are available (7x24) at a website portal accessible by anyone with a broad band internet connection and valid login credentials. The vLab setup and configuration process can be performed by faculty. An alternative is available in the form of a professional services team, trained to ensure that specific learning objectives are implemented, tested and ready for use prior to the 1st day of student activity. The product is currently in beta testing, with full deployment scheduled to support the 2014 fall semester. There are multiple pricing tiers dependent upon the complexity of the desired vLab configuration. For example, vLabs with multiple vLans and multiple virtual machines (VMs) per student will cost more than simple vLabs consisting of a flat network and a 1:1 student/VM ratio. The target price for basic CLaaS vLab configurations is the cost of an expensive text book. The business model assumes that academic institutions will develop (setup/configure) vLabs with specific learning objectives prior to the start of a semester and then reserve vLab space in the CLaaS portal based on expected enrollment for the course(s) to be taught during a semester. It is anticipated that institutions will have the ability to pass the cost of vLabs on the students in the form of a lab fee.

Conclusion

Advances in virtualization technology have provided academic institutions with opportunities to deliver computer science education using innovative techniques. These opportunities have brought with them both change and conflict. Many instructors have embraced the chance to provide their students with hands on experiential learning opportunities using cutting edge technology. Conflicts arise when academic institutions are unable to approve curriculum changes in a timely manner. Additionally, the responsibility for system maintenance and repeatable delivery of consistent laboratory experiences from class to class is a challenge that grows larger as the use of virtualization methods increases.

The system administration role in computer science laboratories has traditionally been performed by graduate students and/or representatives from the academic institutions Information Technology department. The increasing adoption of virtualization technology has made it possible for instructors to define and create lab environments tailored to their teaching methods.

Now that this practice is become widespread, institutions need new methods to define and deploy easily laboratory configurations in a repeatable manner which is consistent with course learning objectives. This need applies to courses taught in both brick and mortar classrooms as well as the virtual classrooms populated by distance learners.

The nation faces an ever growing number of cyber security threats from causal hackers, cyber criminals, adversarial nation states and other bad actors. These threats are evolving at an exponential pace. There is presently a significant shortage of qualified cyber security engineers in the workplace. The academic community has the opportunity to address this shortage with new computer science programs focused on computer network defense and other areas of cyber security study. New tools are required to develop and implement the new curriculum in a time cycle required to keep pace with the rapidly evolving field of cyber security.

The Computer Lab as a Service platform CLaaS developed by the authors meets these needs. CLaaS provides Department Chairs and Lead Professors with a tool which maps computer science labs to learning objectives and learning objectives back to specific courses. In addition, CLaaS provides an Academic Progress Tracking System which records Professor and Student activities and accomplishments. CLaaS is unique in that it combines these important academic functions with an innovative graphical user interface that allows users to easily establish libraries of various computer science laboratory configurations. A CLaaS lab configuration can range from a simple collection of virtual machines in a non-networked environment all the way up to a complex simulation of an enterprise network environment consisting of multiple domains connected across a virtual wide area network. The library function addresses the important issue of repeatability. Once defined, the particular lab associated with a course's learning objectives can be easily redeployed for each new class of students, ensuring hands-on learning experiences consistent with the standards of education excellence demanded by institutions with rigorous accreditation standards. Most important, CLaaS standardizes the use of virtualization technology and allows the instruction to return their focus to teaching.

In the last few years, virtualization has facilitated the delivery of the computing resources needed to complete hands-on lab exercises. The use of virtualization has brought with it increasingly more time consuming setup and administrative tasks which have grown beyond the normal duties performed by faculty and staff. CLaaS allows the instructor to return her focus to teaching. Today, CLaaS is particularly useful in meeting the special needs of the cyber education community. In the future, CLaaS will be used to deliver a broad range of experiential learning activities to the growing population of distance learners.

Glossary of Information Technology Terminology

Agile: Ability to move quickly as applied to pedagogy, delivery, development and management.
Authentication: Validating identity of a person or object.
CLaaS: Computer Lab as a Service. Specific computer services delivered via cloud resources.
Cloud: The internet or network of computing resources; may be either public or private.
Cloud computing: The delivery of computing resources or services via the internet.
Cyber security: The discipline of securing computer resources and information.
Firewall: A hardware or software system designed to prevent unauthorized access to an infrastructure.
Golden image: A deployed 'iso' image of a virtual machine ready for use and lab exercise.
Hypervisor: Computer software or hardware that manages and executes virtual machines.

Infrastructure: Physical computing hardware and resources that are part of a network, a cloud or the internet.
Private cloud: A cloud that is private to an enterprise and may be physically local to the user.
Public cloud: A cloud available to the public at large and normally physically remote from the user.
Virtual laboratory: Facilitates the use of virtualization in laboratory exercises.
Virtual machine: An instance or emulation of a real, physical computer with its own segmented, private, unshared operating system and memory space.
Virtualization: The act of using a hypervisor and virtual machines to provide a virtual, non-physical computing resource environment.
VM: A virtual machine.
Web 2.0: The second stage of implementation of the World Wide Web or internet characterized by social networking and general collaboration.
Web 3.0: The next, future and anticipated evolution of the World Wide Web that has been under definition for at least five years.
Wi-Fi: Wireless technology that uses high frequency radio waves to send and receive data and normally connects with the internet.
Wireless network: A computing infrastructure that supports cable-less connectivity of computing and mobile devices frequently through Wi-Fi technology.

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