Resource Virtualization and the Enterprise

Syllabus

Web Page

http://www.cs.northwestern.edu/~pdinda/virt-mitp

Instructor

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Prerequisites

I recommend that students be familiar with the general principles of operating systems. Students should also have had some practical experience in installing operating systems and managing infrastructure. Students should have been exposed to the concepts of an instruction set architecture and a machine architecture.

Materials

Students will be provided with the following materials:

- Wolf and Halter, *Virtualization: From the Desktop to the Enterprise*, Apress, 2005. This is the main text for the class. It is targeted at a working IT professional and it contains both low-level detail on how to use virtualization tools such as VMware and Virtual PC/Server, and high-level material on designing and managing virtualized infrastructure.
- The May, 2005 issue of *IEEE Computer*, a special issue on resource virtualization that was guest edited by me. The papers in this issue describe several important concepts beyond the book that we will cover, including a taxonomy of virtual machines, Intel's VT hardware extensions, para-virtualization, and an example of virtualization based adaptation / autonomic computing.
- Infoworld's *Virtualization Report*, a freely available blog providing up to the minute commercial news and podcasts on virtualization for IT professionals. http://weblog.infoworld.com/virtualization/
- A Xen Live CD. This CD will boot a computer with the Xen open source virtual machine monitor and allow multiple Linux virtual machines to be

instantiated. This makes it possible for the student to play with concepts described in the class without having to install any software.

- VMware Server, as available from http://vmware.com. VMware has made two of their products, VMware Server (formerly VMware GSX Server) and VMware Player available for free. These are high quality virtual machine monitors that can boot any operating system. Both Windows and Linux versions are available. The user interface and concepts behind these tools are very similar to the slightly older VMware versions that the Wolf and Halter book describes.

Students who are interested in understanding virtual machines at a deeper level and in research related to virtual machines will find the second book and the materials listed in a related course (see below) to be helpful.

- Smith and Nair, *Virtual Machines: Versatile Platforms for Systems and Processes*, Morgan Kaufman, 2005.

Related non-MITP Course

Contemporaneous with this course, I am teaching quarter-long graduate research seminar on resource virtualization, EECS 441. Students are welcome to attend meetings of that seminar. If the interest is too great, however, I reserve the right to limit the number allowed in. For more information on the graduate seminar, see http://www.cs.northwestern.edu/~pdinda/virt.

Objectives, framework, philosophy, and caveats

Indirection is concept that's used throughout computer science to simplify problems and systems, and to add functionality. Currently, there is considerable excitement among IT practitioners, IT managers, and the systems research community over a form of indirection that we shall call *resource virtualization*. The basic idea is to add a software layer that provides virtual machines, virtual networks, virtual services, and even virtual infrastructures that are implemented on top of the existing physical resources and services in the network. Because these resources are virtual, we can potentially create a great many of them, make them private to their users, customize them to particular purposes, simplify their administration by making them user- or group-specific, and even inspect them from the *outside* to monitor their performance or detect intrusions.

This course will examine resource virtualization from a practical point of view, focusing for the most part on the current state of the art in practice. We will also touch on the history of this technology and on current research results that may become practice in the short run.

As a result of this course, students will be able to:

- Differentiate among the various forms of CPU virtualization: language-level, OS-level, virtual servers, and emulators.
- Explain the differences between "pure" and paravirtualized virtual machine monitors (VMMs) and between type-I and type-II VMMs.
- Understand why VMMs interact with architecture and why the Intel VT and AMD Pacifica hardware extensions are changing the face of modern VMMs.
- Have hands-on experience with two modern VMMs, VMWare and Xen.
- Understand what is meant by network virtualuzation.
- Understand what is meant by storage virtualization and how it differs from network file systems.
- Explain some of the common scenarios in which virtualization is used today, including server consolidation, software development, debugging, fault tolerance, and security.
- Explain the concept of virtual infrastructure.
- Gain some insight into the futures that industry and researchers expect from virtualization, including specialized high-level service providers, low-level service marketplaces, and adaptive/autonomic computing.

This is my first time teaching an MITP course. I will attempt to modulate the difficulty and expectations to keep students challenged. Student feedback is encouraged!

Homework

Students are expected to make use of the virtualization software provided in the course to gain first hand experience with Xen and VMware.

Students can use their own computers to run both VMMs. If you do not have your own computer for this purpose, please see me for an account on a department computer.

Students will investigate some topics in depth and write short essays about them.

Exams

There will be no exams.

Grading

50 % Class participation
50% Homework

Schedule

Week 1 (3 hours) – Virtual Machines

- Introduction and history
- Industry background (VMware, Xen, Microsoft, Sun, IBM, etc)

- Forms of CPU virtualization
  - Language level (abstract virtual machines (JVM, .NET CLR))
  - OS level (Classic "pure" type-I and type-II VMMs (VM/VMware/VirtualPC), Paravirtualization (Xen), virtual servers (VServer, Zones), emulators (QEMU))
- Demonstrations
- **Readings**
  - Wolf&Halter, *Virtualization: From the Desktop to the Enterprise*
    - Chapters 1, 4, 6, focusing on VMware – these chapters give a high-level perspective of OS level VMM software and then describe how to create VMs in the desktop and server versions of common software.
      - Ideally, you will read these chapters while working on the assignment.
      - Optional: Chapters 3 and 6 describe how to install the VMM software itself. You will find that current VMware Server (what the book calls GSX server) is easy enough to install even without this information.
  - Special issue of *Computer*
    - *Resource Virtualization Renaissance* – High level perspective from me.
    - *The Architecture of Virtual Machines*
      - Optional: Chapter 1 from Smith and Nair, which is an extended version of this article
    - *Virtual Machine Monitors: Current Technology and Trends*
      - Optional: Chapter 8 from Smith and Nair, which deeply examines the design of OS level VMMs.
- **Assignment**
  - Install your copy of VMware Virtual Server on a machine of your choice, including all forms of networking support.
  - Create a virtual machine that boots the Knoppix Live Linux distribution, either from CD or from ISO image.
  - Install an operating system in your VM and configure it with bridged networking so that it is a first class machine on your network. (knoppix-install if you want to just install from the previous step.)
  - Send your instructor an IP address, username, and password to log into your virtual machine via ssh.

Week 2 (3 hours) – More Resource Virtualization

- Paravirtualualization and the Xen phenomenon
- Consequences of new architectural extensions (Intel VT, AMD Pacifica)
- Virtualizing storage
  - SANs versus file servers
  - P2P file systems
- Virtualizing the network (overlay networks)

  - TOR example
  - VPN example (perhaps SSH)
  - VNET example
- **Readings**
  - Wolf&Halter, *Virtualization: From the Desktop to the Enterprise*
    - Chapters 8, 12, 13 (network file systems and SANs)
  - Reading on P2P: TBD
  - VNET reading TBD, probably usenix 04 paper
  - Special issue of *Computer*
    - *Rethinking the Design of Virtual Machine Monitors*
    - *Intel Virtualization Technology*
- **Assignment**
  - Boot your copy of the Xen Live CD on a machine of your choice. Create a Linux VM, configure it with bridged networking, and email your instructor with a description of how to log into your VM via ssh. (This is the Xen version of last week's assignment. It'll go much faster this time!)
  - Modern Xen can make use of a processor with Intel VT extensions to run operating systems (like Windows) that have *not* been ported to Xen's hypercall interface. Investigate how this is done and write a short essay (2-3 pages) explaining how it's done.

Week 3 (3 hours) – Using Virtualization Now and In The Future

- The security argument (isolation argument, size argument)
- Development, debugging, and testing
- IT configuration testing and incremental rollout
- Server consolidation
- Live migration and replication of VMs and their consequences for reliability and scaling
- Desktop replacement via migration or consolidation
- Attestation and capsule computing
- Computing marketplaces (and their current limitations)
- Adaptive and/or autonomic systems
- The arguments *against* virtualization
- **Readings**
  - Wolf&Halter, *Virtualization: From the Desktop to the Enterprise*
    - Chapter 14
  - Special issue of *Computer*
    - *Virtual Distributed Environments in a Shared Infrastructure*
  - Smith&Nair, *Virtual Machines: Versatile Platforms for Systems and Processes*
    - Chapter 10
- **Assignment**
  - Select two of the following topics, investigate them, and write a 10 page essay examining their *juxtaposition*:
    - Live migration, as implemented in Xen and VMware

- Load balancing
- Attestation, as in the Terra system
- Autonomic computing
- Overlay multicast
- Co-designed virtual machines
- Web hosting
- Secure function evaluation
- Grid computing and utility computing
- Structured peer-to-peer systems (DHTs)
- Overlay networks