IOWA STATE UNIVERSITY
Department of Electrical and Computer Engineering

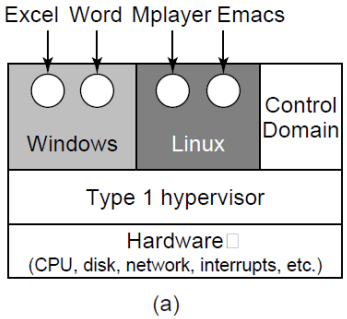
Lecture 39: Virtualization & Cloud II

Agenda

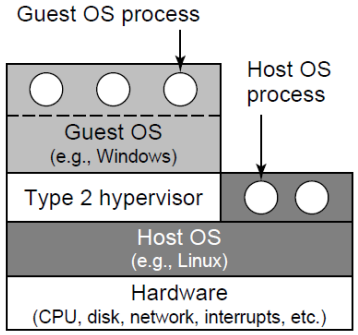
- Recap
- Cloud Computing

Recap

- Virtual Machine Monitor (VMM)
  - "Hypervisor"
    - Type 1: run on bare metal
    - Type 2: run on a host OS
  - Key responsibilities
    - Time-share CPU among guests
    - Space-share memory among guests
    - Simulate disk, network, and other devices



(a)



(b)

Recap

- Virtualization Techniques
  - Naive Approach: Simulation
    - Interpret every guest instruction and emulate in software
  - 2nd Approach: Trap-and-Emulate
    - Execute guest instructions on real CPU when possible
    - Privileged instructions trap, and VMM emulates
  - 3rd Approach: Binary Translation
    - translate non-trapping instructions that read/write sensitive state to trap instruction and emulate the effects
  - 4th Approach: Hardware Support
    - E.g., Intel VT, AMD SVM

Recap

- Paravirtualization
  - Do not aim to present a VM that looks just like the actual underlying hardware
    - Present a machine-like software interface that explicitly exposes the fact that it is a virtualized environment
      - e.g., a set of *hypercalls*, which allow the guest to send explicit requests to the hypervisor for executing privileged sensitive operations
    - Guest has to be aware of the hypervisor API
      - explicitly modified for the hypervisor
      - in cooperation with the hypervisor
  - "Xen and the Art of Virtualization" [SOSP'03]

Agenda

- ~~Recap~~
- Cloud Computing

What's Cloud Computing

- Informal:
  - computing with large datacenters
  - users generally do not even know the exact location of "their" resources or even which country they are located in

What's Cloud Computing

- NIST (National Institute of Standards and Technology)
  - Five Essential Characteristics
    - 1. On-demand self-service
      - Users should be able to provision resources automatically
    - 2. Broad network access
      - All resources should be available over the network
    - 3. Resource pooling
      - resources should be pooled to serve multiple users dynamically
    - 4. Rapid elasticity
      - acquire/release resources elastically to scale with the demands
    - 5. Measured service
      - The cloud provider meters the resources used in a way that matches the type of service agreed upon

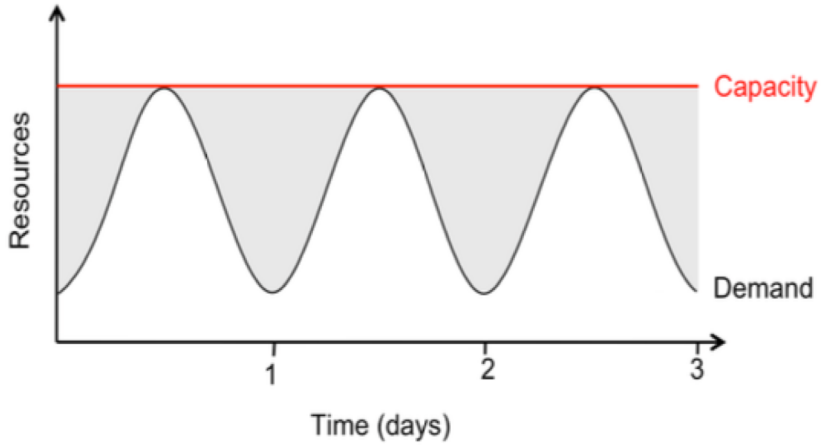
Types of Cloud

- Infrastructure as a Service (IaaS)
  - e.g., Amazon EC2, VMs, disks
- Platform as a Service (PaaS)
  - e.g., OS, Database, Web server, MapReduce
- Software as a Service (SaaS)
  - e.g., Email, GitHub

- Public vs. private clouds:
  - Shared across arbitrary organizations/customers vs. Internal to one organization

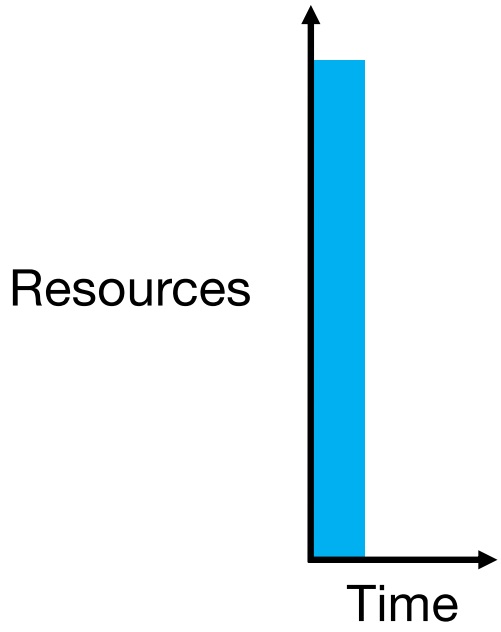
Cloud Economics: For Users

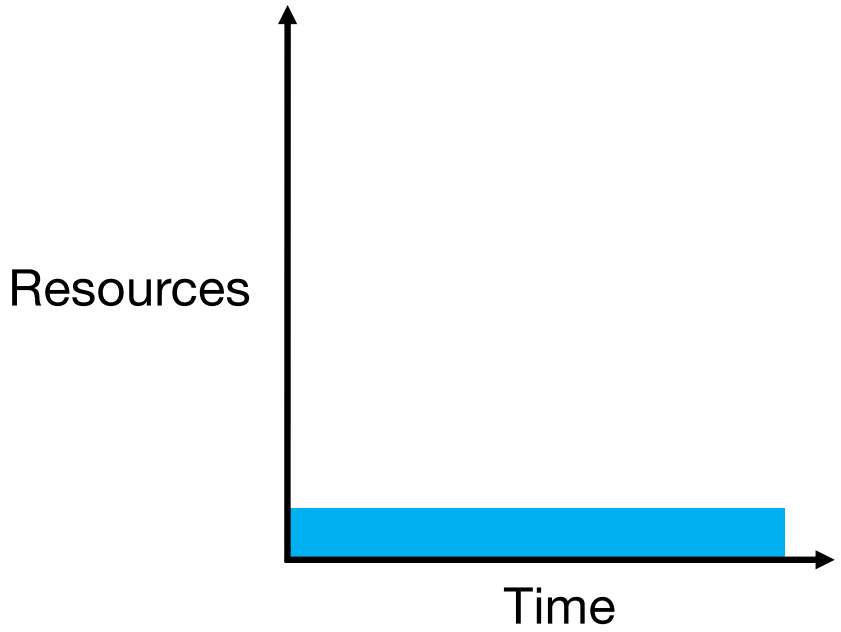
- Pay-as-you-go (usage-based) pricing:
  - "Computing as a utility"
  - Most services charge per minute, per byte, etc
  - No minimum or up-front fee
  - Helpful when apps have variable utilization



Cloud Economics: For Users

- Elasticity
  - Using 1000 servers for 1 hour costs the same as 1 server for 1000 hours
  - Same price to get a result faster!



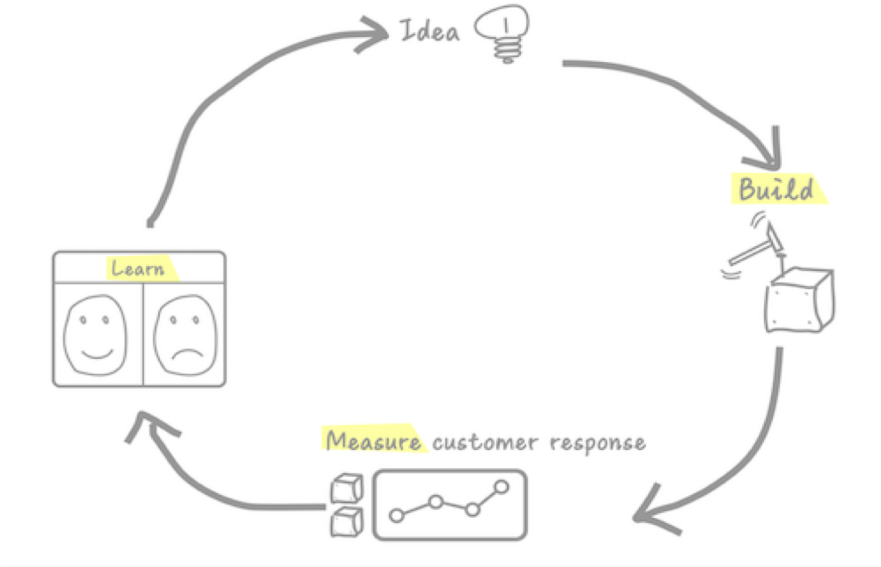


Cloud Economics: For Providers

- Economies of scale:
  - Purchasing, powering & managing machines at scale gives lower per-unit costs than regular customers'

Cloud Economics: For Providers

- Speed of iteration:
  - Software as a service means fast time-to-market, updates, and detailed monitoring/feedback
  - Compare to speed of iteration with ordinary software distribution



Other Features Enabled

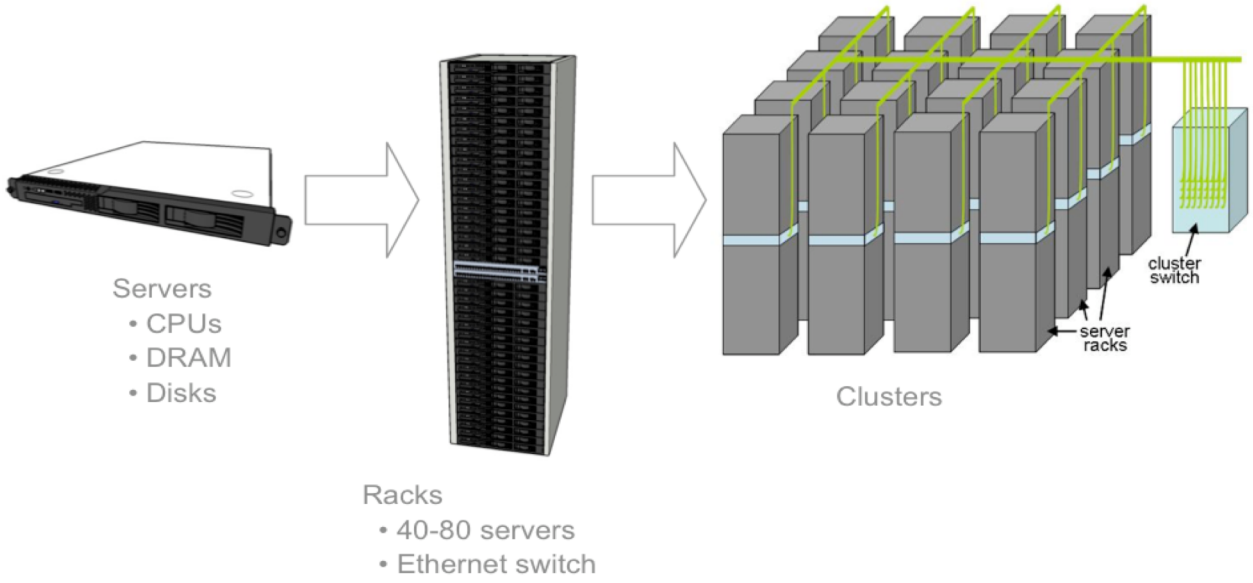
- Disaster recovery
  - replication across regions/countries/continents
- Ability to quickly try exotic hardware
  - e.g., Google TPU
- Ability to A/B test anything
  - compare two versions of any software comonents
- ...

Common Cloud Applications

- Web and mobile applications
- Data analytics
  - MapReduce, SQL, ML, etc.
- Stream processing
  - sensor data, twitter trending, etc.
- Batch computation
  - HPC, video, etc

Cloud Hardware

- "Warehouse-Scale Computer"
  - Datacenter as a computer
    - Rows of rack-mounted servers
    - Often organized as a few mostly independent clusters



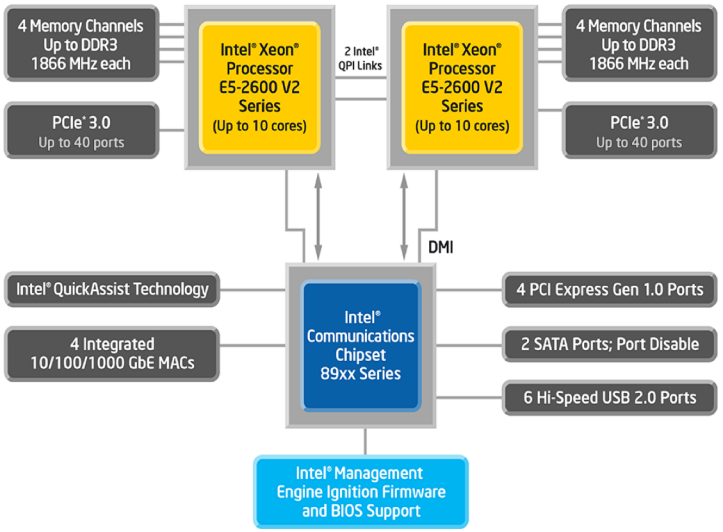
Cloud Hardware

- "Warehouse-Scale Computer"
  - Datacenter as a computer
    - E.g.,

Cloud Hardware

- Compute
  - The Basics
    - Multi-core CPU servers
    - Multiple sockets
  - What's New
    - GPUs
    - FPGAs
    - Custom accelerators (AI)

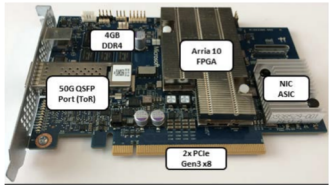
2-socket server



Nvidia Tesla

Google TPU

Microsoft Catapult



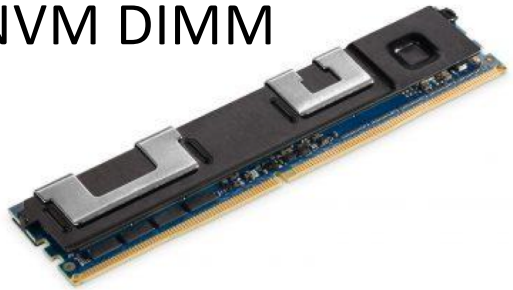
Cloud Hardware

- Storage
  - The Basics
    - HDDs
    - RAID
  - What's New
    - Flash-based SSDs
    - Non-volatile memories (NVM)

JBOD disk array

NVMe Flash

NVM DIMM

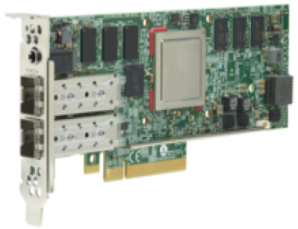


Cloud Hardware

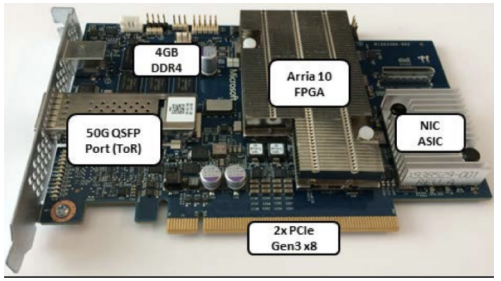
- Network
  - The Basics
    - 10, 25, and 40GbE NICs
    - 40 to 100GbE switches
  - What's New
    - Software defined networking (SDN)
    - Smart NICs
    - FPGAs

40GbE Switch

Smart NIC

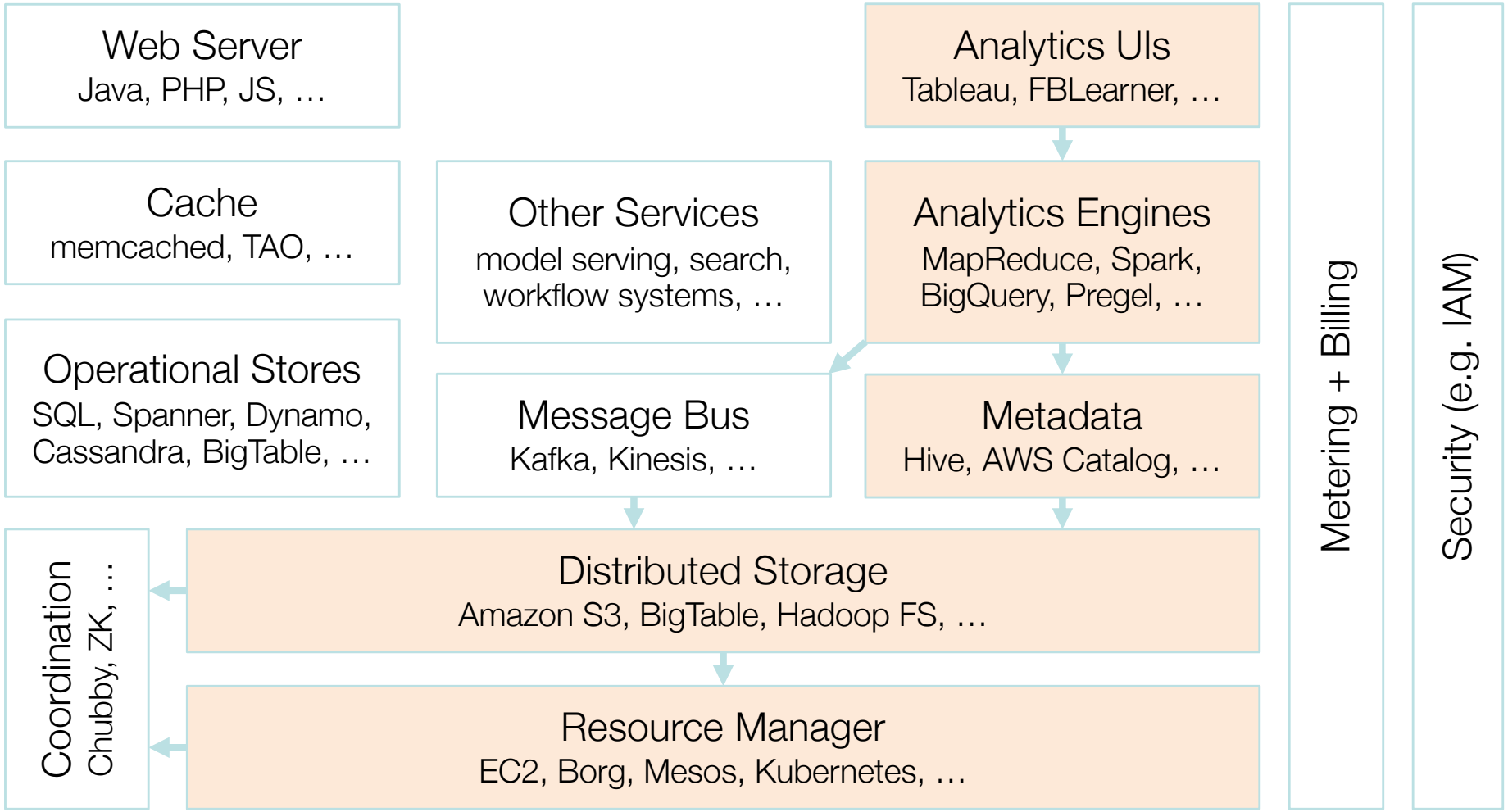


Microsoft Catapult



Cloud Software Stack

- E.g., Big Data Analytics (colored)



Agenda

- ~~Recap~~
- ~~Cloud Computing~~

Questions?

*acknowledgement: slides include content from “Modern Operating Systems” by A. Tanenbaum, “Operating Systems Concepts” by A. Silberschatz etc., “Operating Systems: Three Easy Pieces” by R. Arpaci-Dusseau etc., lectures from Stanford and UC Berkeley, and anonymous pictures from internet

Midterm 2 Feedback

- Raw score 80, scale to 100
  - e.g., 80/80 = 100/100, 72/80 = 90/100, 56/80 = 70/100
- Most students achieve a higher score in midterm 2 compared to midterm 1
- Most Valuable Player (MVP) Award
  - metric: midterm1score + midterm2score
- Most Improved Player (MIP) Award
  - metric: midterm2score – midterm1score

Midterm 2 Feedback

- Raw score 80, scale to 100
  - e.g., 80/80 = 100/100, 72/80 = 90/100, 56/80 = 70/100
- Most students achieve a higher score in midterm 2 compared to midterm 1
- Most Valuable Player (MVP) Award
  - metric: midterm1score + midterm2score
  - Ross Thedens
- Most Improved Player (MIP) Award
  - metric: midterm2score – midterm1score
  - Daniel Laracuenta & Nikhilesh Thota