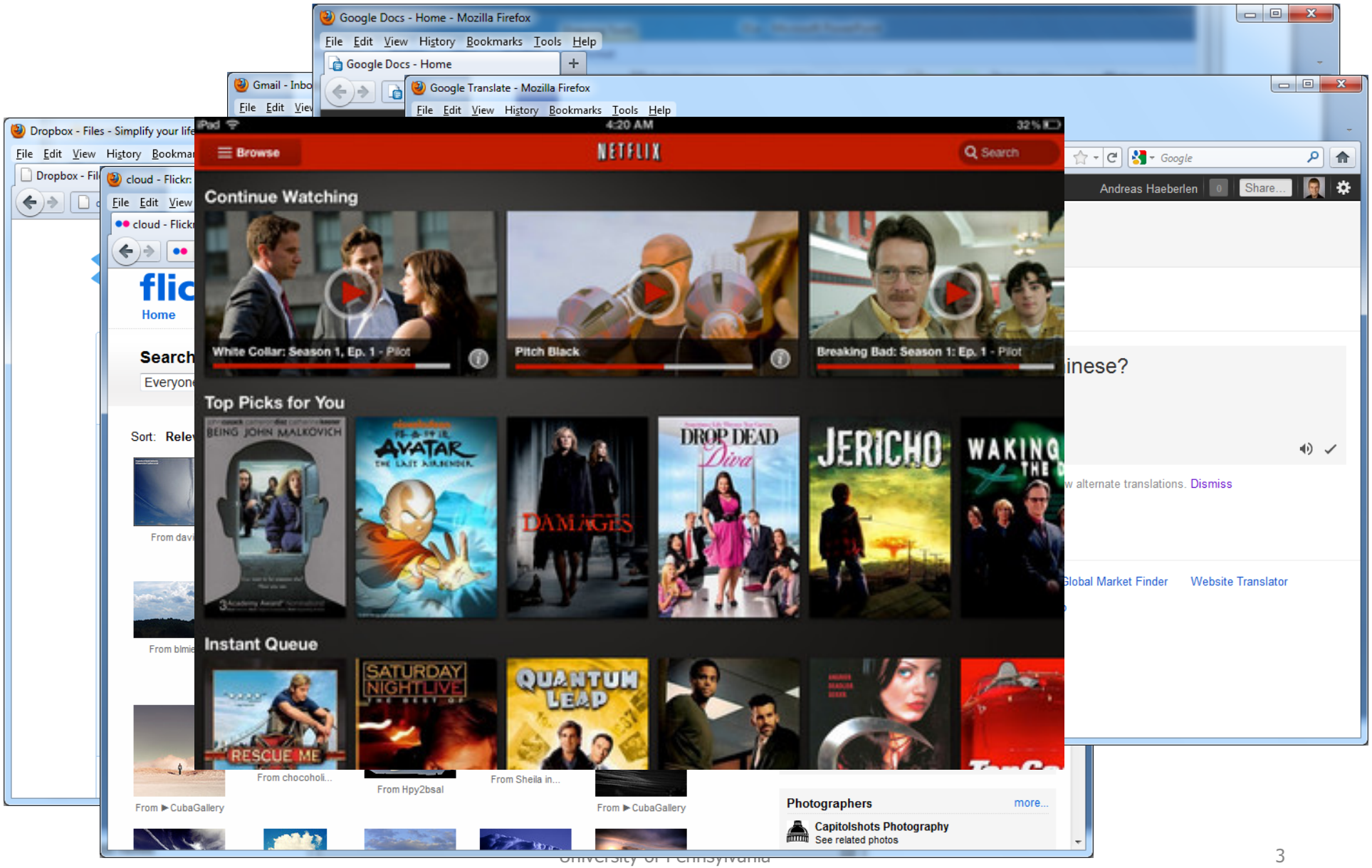
CSC 3322: Computer Architecture

Cloud Computing

Overview

- Computing at Scale
  - Need for scalability
  - From PCs to Data Centers
- Cloud Computing
  - What kinds of clouds exist today?
  - What kinds of applications run on the cloud?
  - Virtualization: How clouds work 'under the hood’

Have you used these before?



What is so special about them?

- The key challenge is scale!
  - Lots of data, lots of users everywhere on the planet
  - Hosted on massive shared infrastructure (data centers – think computers the size of a football field!)
- Scale brings new challenges
  - Many algorithms do not work at these scales
  - Need special solutions for security, performance, ...
  - "Big Data": Data analysis at scale

How many users and objects?

- Flickr has >6 billion photos
- Facebook has 1.7 billion active users
- Google is serving >1.2 billion queries/day on more than 27 billion items
- >2 billion videos/day watched on YouTube

How much data?

- Modern applications use massive data:
  - Rendering 'Avatar' movie required >1 petabyte of storage (1 million GB or a thousand TB)
  - eBay has >6.5 petabytes of user data
  - CERN's LHC will produce about 15 petabytes of data per year
  - In 2008, Google processed 20 petabytes per day
  - German Climate computing center dimensioned for 60 petabytes of climate data
  - Google now designing for 1 Exabyte (1B GB) of storage
  - NSA Utah Data Center is said to have 5 zettabyte (thousand Exabyte))
- How much is a zettabyte?
  - 1,000,000,000,000,000,000,000 bytes
  - A stack of 1TB hard disks that is 25,400 km high

How much computation?

- No single computer can process that much data
  - Need many computers!
  - Need parallel processing!
- How many computers do modern services need?
  - Facebook is thought to have more than 60,000 servers
  - 1&1 Internet has over 70,000 servers
  - Akamai has 95,000 servers in 71 countries
  - Intel has ~100,000 servers in 97 data centers
  - Microsoft reportedly had at least 200,000 servers in 2008
  - Google is thought to have more than 1 million servers, is planning for 10 million.

Scaling up

PC

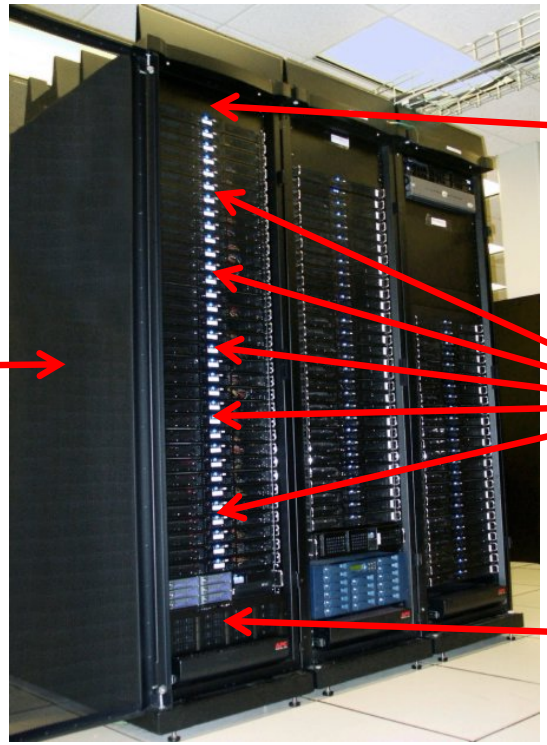
Server

Cluster

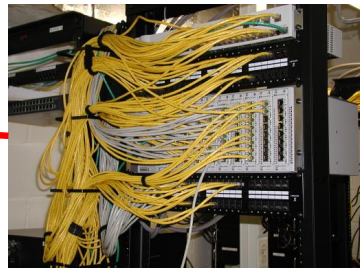
Data center

Network of data centers

Clusters



Rack



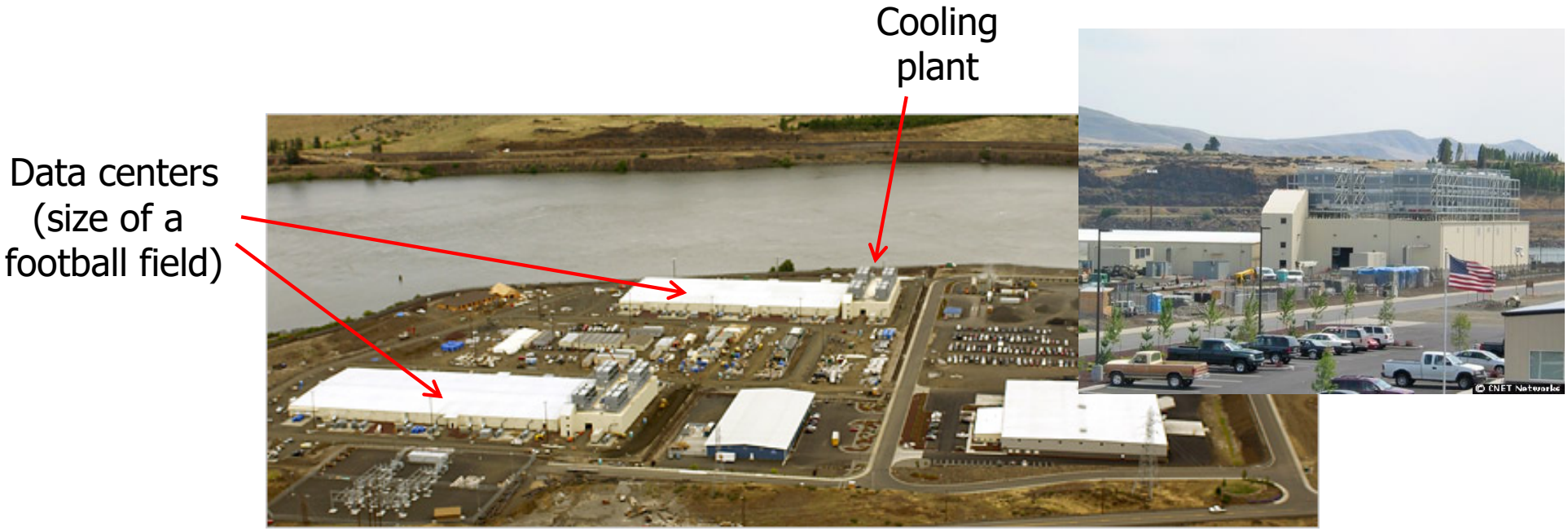
Network switch
(connects nodes with each other and with other racks)

Many nodes/blades
(often identical)

Storage device(s)

- Characteristics of a cluster:
  - Many similar machines, close interconnection (same room?)
  - Often special, standardized hardware (racks, blades)
  - Usually owned and used by a single organization
  - Needs lot of power and massive cooling.

What does a data center look like?



Google data center in The Dalles, Oregon

- A separate building that holds the clusters and have lots of cooling and power
- A warehouse-sized computer
  - A single data center can easily contain 10,000 racks with 100 cores in each rack (1,000,000 cores total)

Global distribution of Data Centers

http://www.google.com/about/datacenters/inside/locations/index.html

- Data centers are often globally distributed
  - Example above: Google data center locations
- Why?
  - Need to be close to users (physics!)
  - Cheaper resources
  - Data replication
  - Protection against failures

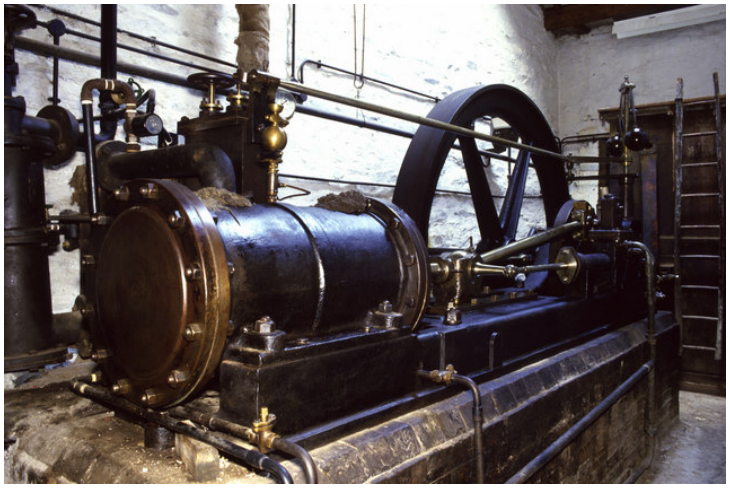
Cloud Computing

The vision...


I need to grow my infrastructure, but I do not know for how long...
I have a lot of infrastructure that I want to rent ...
I have a surplus of infrastructure that I want to make use of
I cannot invest in infrastructure, I just started my business....
I have infrastructure and middleware and I can host applications
Global Cloud Marketplace
I want to focus on application logic and not maintenance and scalability issues
I have infrastructure and provide application services
I want to access and edit my documents and photos from everywhere..

The power plant analogy

Waterwheel at the Neuhausen ob Eck Open-Air Museum



Steam engine at Stott Park Bobbin Mill

- It used to be that everyone had their own power source
  - Challenges are similar to the cluster: Needs large up-front investment, expertise to operate, difficult to scale up/down...

Scaling the power plant




- Then people started to build large, centralized power plants with very large capacity...

Metered usage model

- Power plants are connected to customers by a network
- Usage is metered, and everyone (basically) pays only for what they actually use

Why is this a good thing?

Electricity

- Economies of scale
  - Cheaper to run one big power plant than many small ones
- Statistical multiplexing
  - High utilization!
- No up-front commitment
  - No investment in generator; pay-as-you-go model
- Scalability
  - Thousands of kilowatts available on demand; add more within seconds

Computing

Cheaper to run one big data center than many small ones

High utilization!

No investment in data center; pay-as-you-go model

Thousands of computers available on demand; add more within seconds

So what is Cloud Computing?

According to *Buyya et al*

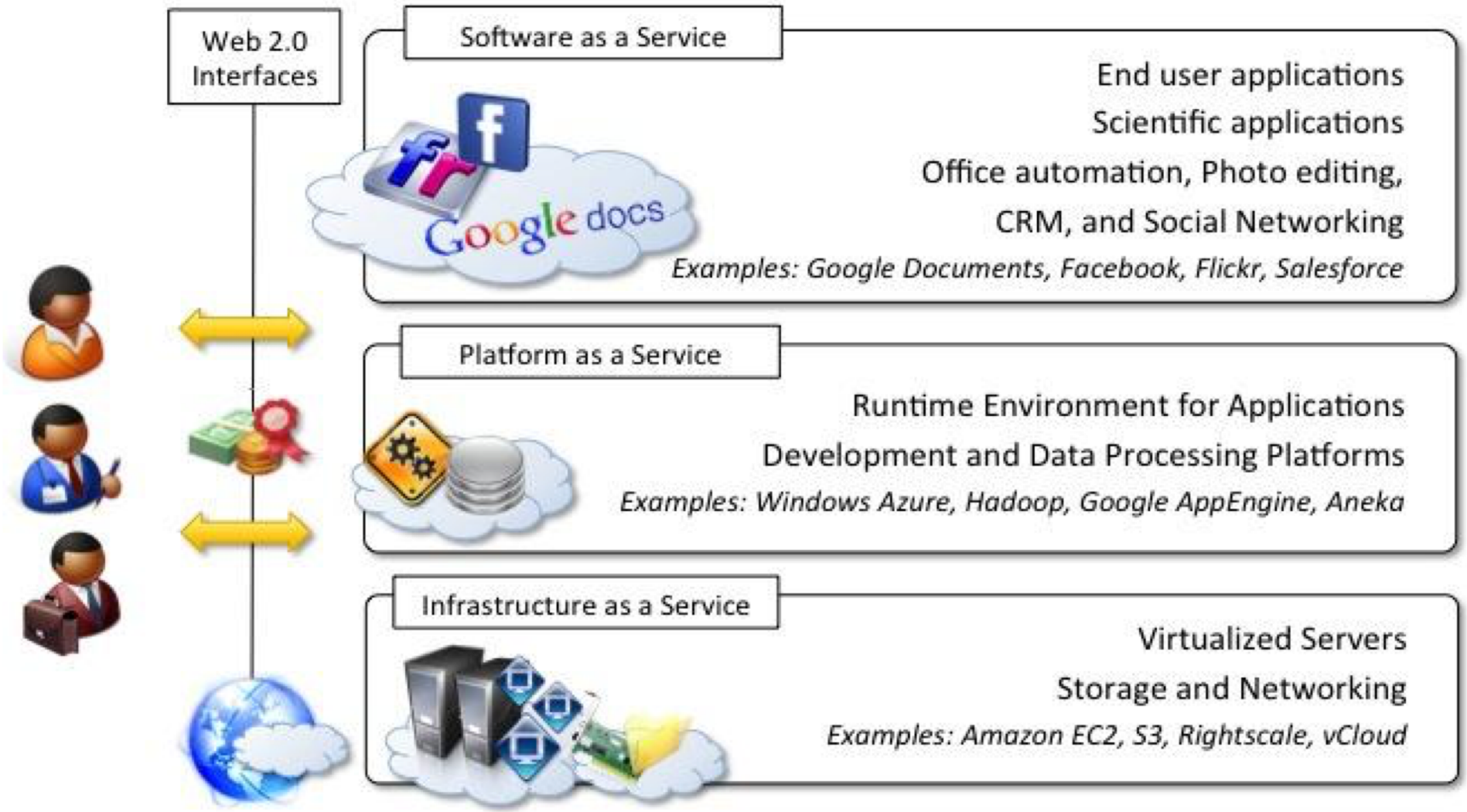
A cloud is a type of parallel and distributed system consisting of a collection of interconnected and virtualized computers that are dynamically provisioned and presented as one or more unified computing resources based on service-level agreements established through negotiation between the service provider and consumers.

- Essential characteristics:
  - On-demand self service
  - Broad network access
  - Resource pooling
  - Rapid elasticity
  - Measured service

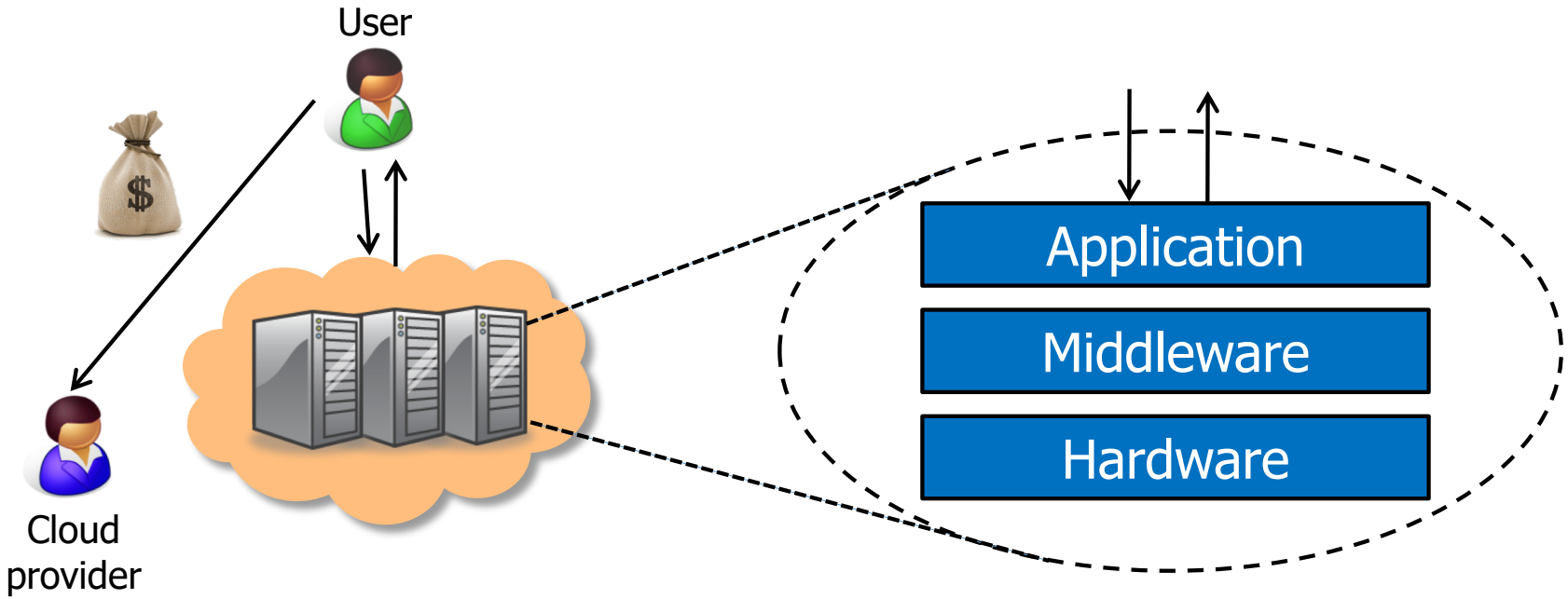
Everything as a Service

- What kind of service does the cloud provide?
  - Does it offer an entire application, or just resources?
  - If resources, what kind / level of abstraction?
- Three types commonly distinguished:
  - Software as a service (SaaS)
    - Analogy: Restaurant. Prepares & serves entire meal, does the dishes, ...
  - Platform as a service (PaaS)
    - Analogy: Take-out food. Prepares meal, but does not serve it.
  - Infrastructure as a service (IaaS)
    - Analogy: Grocery store. Provides raw ingredients.
  - Other xaaS types have been defined, but are less common

Reference Models

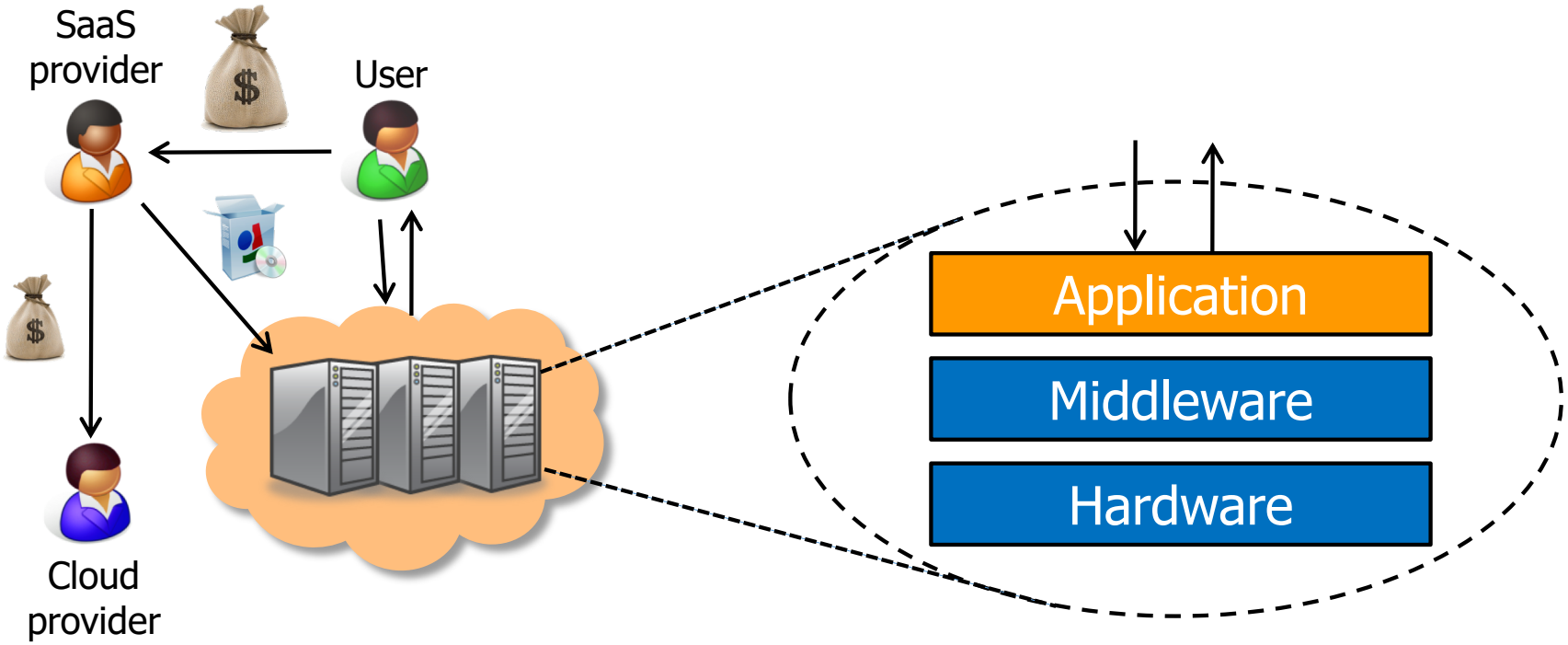


Software as a Service (SaaS)



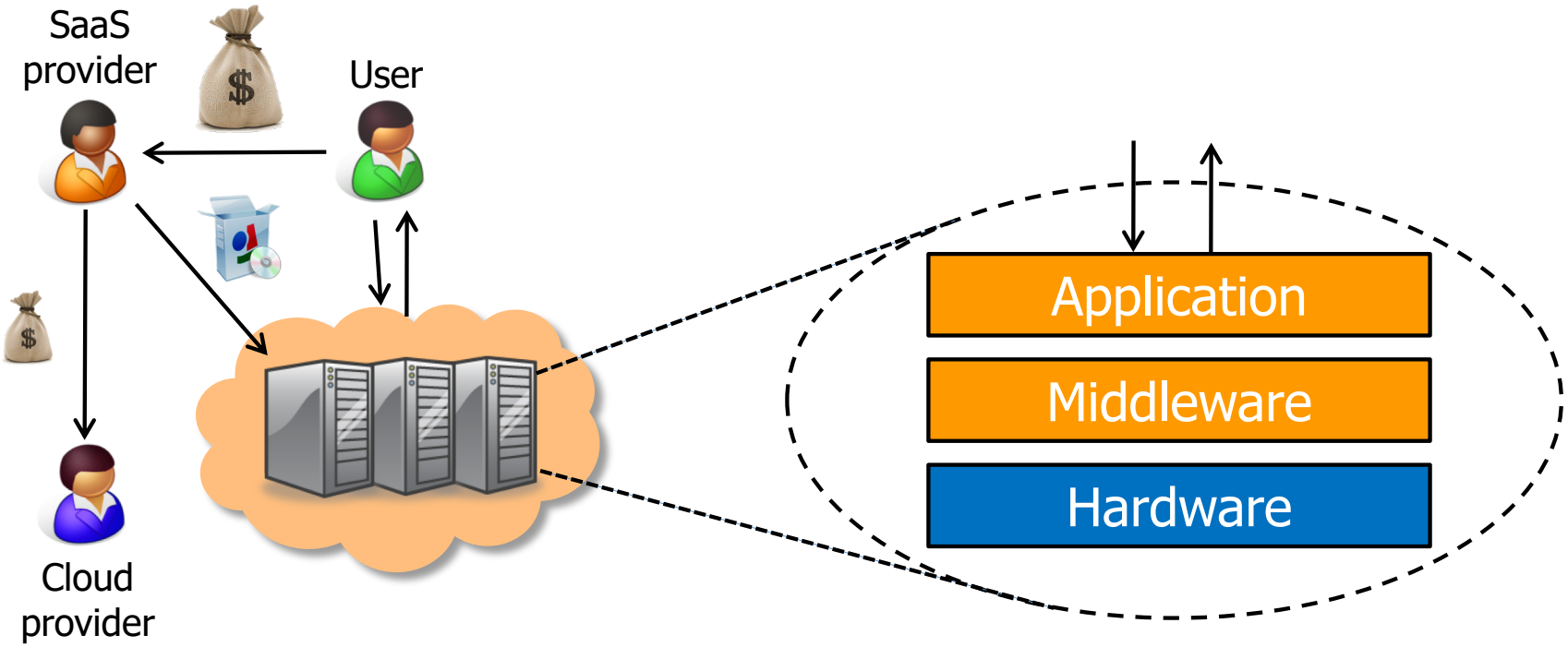
- Cloud provides an entire application
  - Word processor, spreadsheet, CRM software, calendar...
  - Customer pays cloud provider
  - Example: Google Apps, Salesforce.com

Platform as a Service (PaaS)



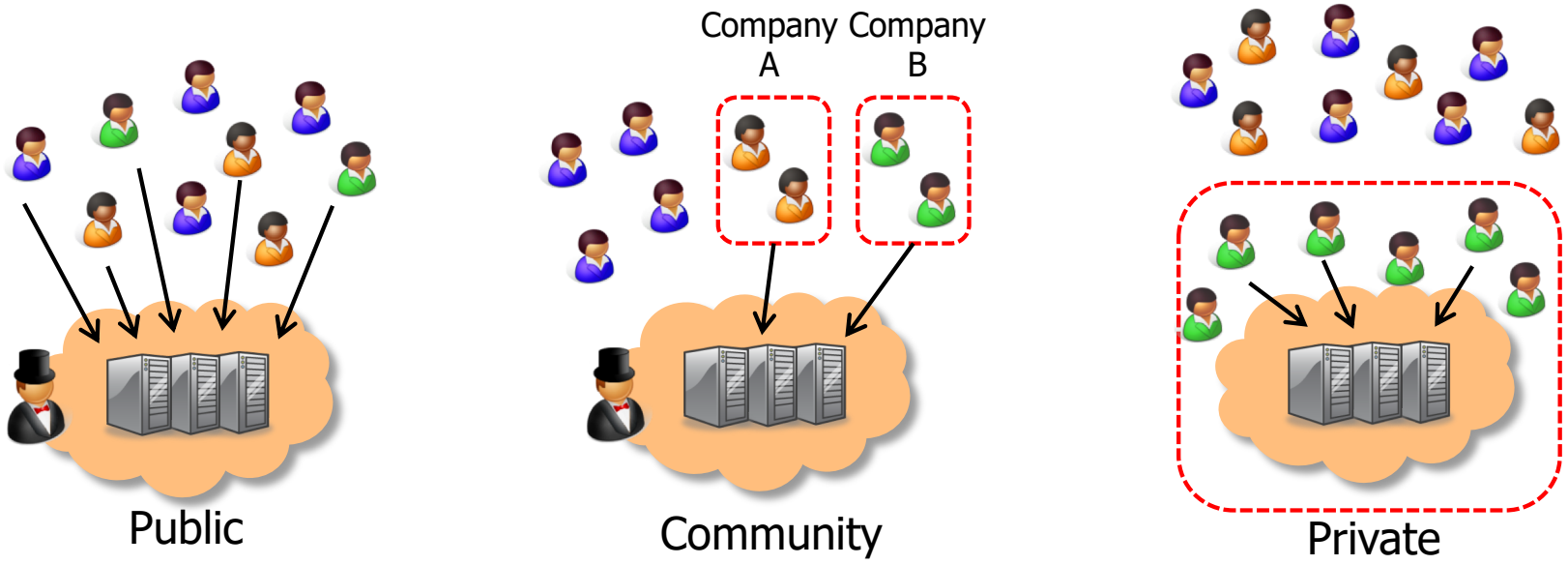
- Cloud provides middleware/infrastructure
  - For example, Microsoft Common Language Runtime (CLR) manages the execution of .NET programs.
  - Customer pays SaaS provider for the service; SaaS provider pays the cloud for the infrastructure
  - Example: Windows Azure, Google App Engine

Infrastructure as a Service (IaaS)



- Cloud provides raw computing resources
  - Virtual machine, blade server, hard disk, ...
  - Customer pays SaaS provider for the service; SaaS provider pays the cloud for the resources
  - Examples: Amazon Web Services, Rackspace Cloud, GoGrid

Private/hybrid/community clouds



- Who can become a customer of the cloud?
  - Public cloud: Commercial service; open to (almost) anyone. Example: Amazon AWS, Microsoft Azure, Google App Engine
  - Community cloud: Shared by several similar organizations. Example: Amazon's "GovCloud"
  - Private cloud: Shared within a single organization. Example: Internal datacenter of a large company.

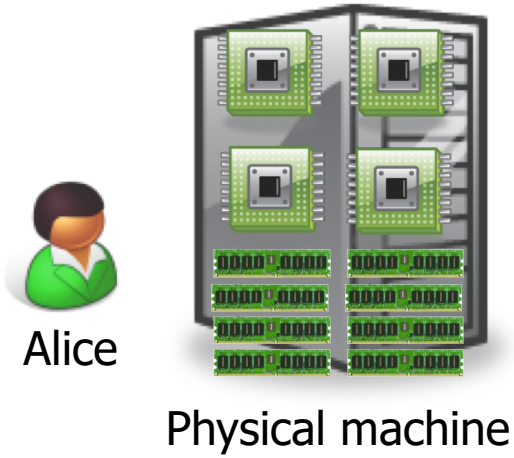
Examples of cloud applications

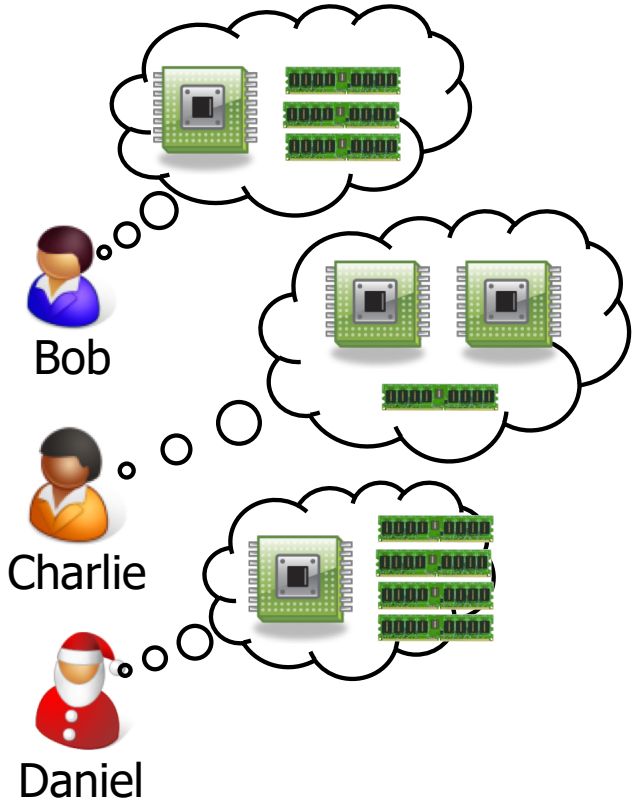
- Application hosting
- Backup and Storage
- Content delivery
- E-commerce
- High-performance computing
- Media hosting
- On-demand workforce
- Search engines
- Web hosting

Case study: The Washington Post

- March 19, 2008: Hillary Clinton's official White House schedule released to the public
  - 17,481 pages of non-searchable, low-quality PDF
  - Very interesting to journalists, but would have required hundreds of man-hours to evaluate
  - Peter Harkins, Senior Engineer at The Washington Post: Can we make that data available more quickly, ideally within the same news cycle?
  - Tested various Optical Character Recognition (OCR) programs; estimated required speed
  - Launched 200 Amazon EC2 instances; project was completed within nine hours (!) using 1,407 hours of virtual machine (VM) time ($144.62)
  - Results available on the web only 26 hours after the release

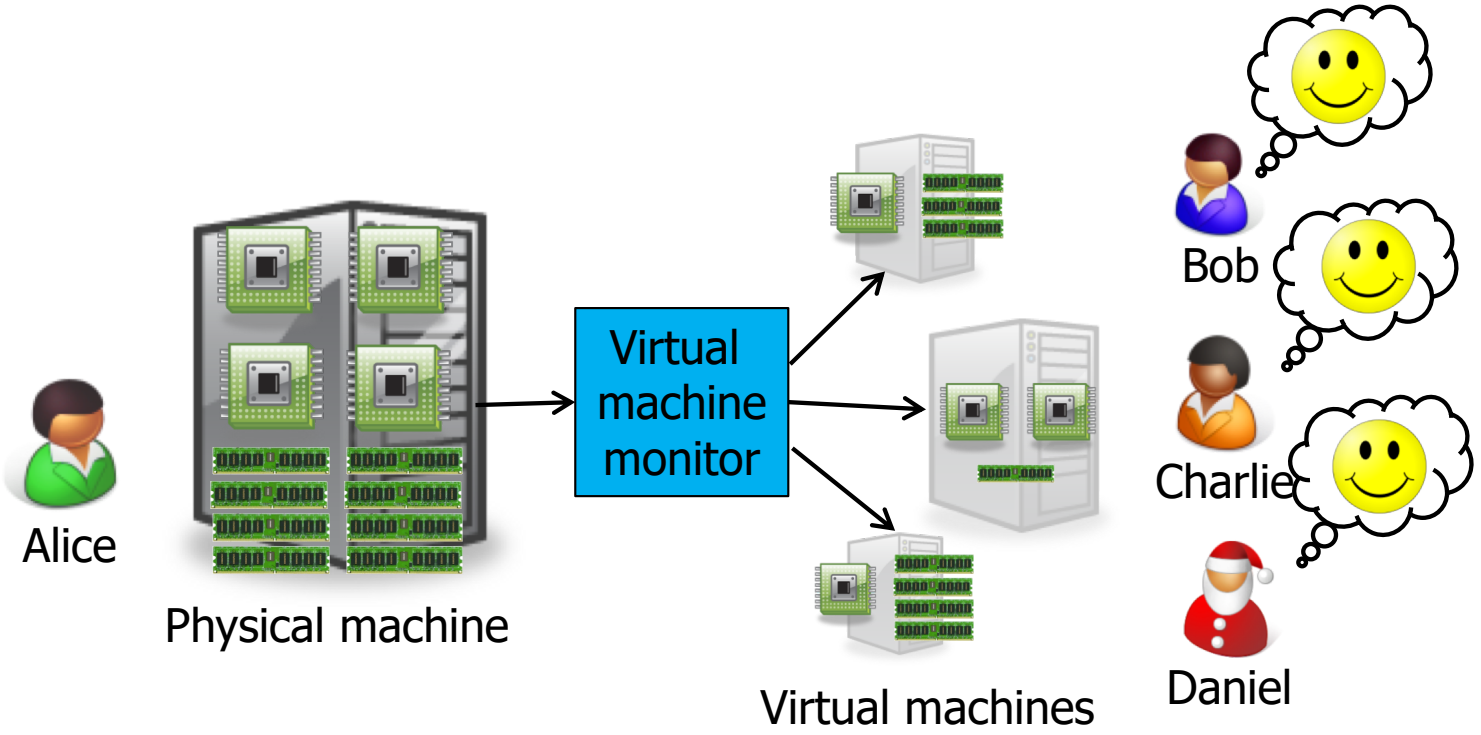
What is virtualization?





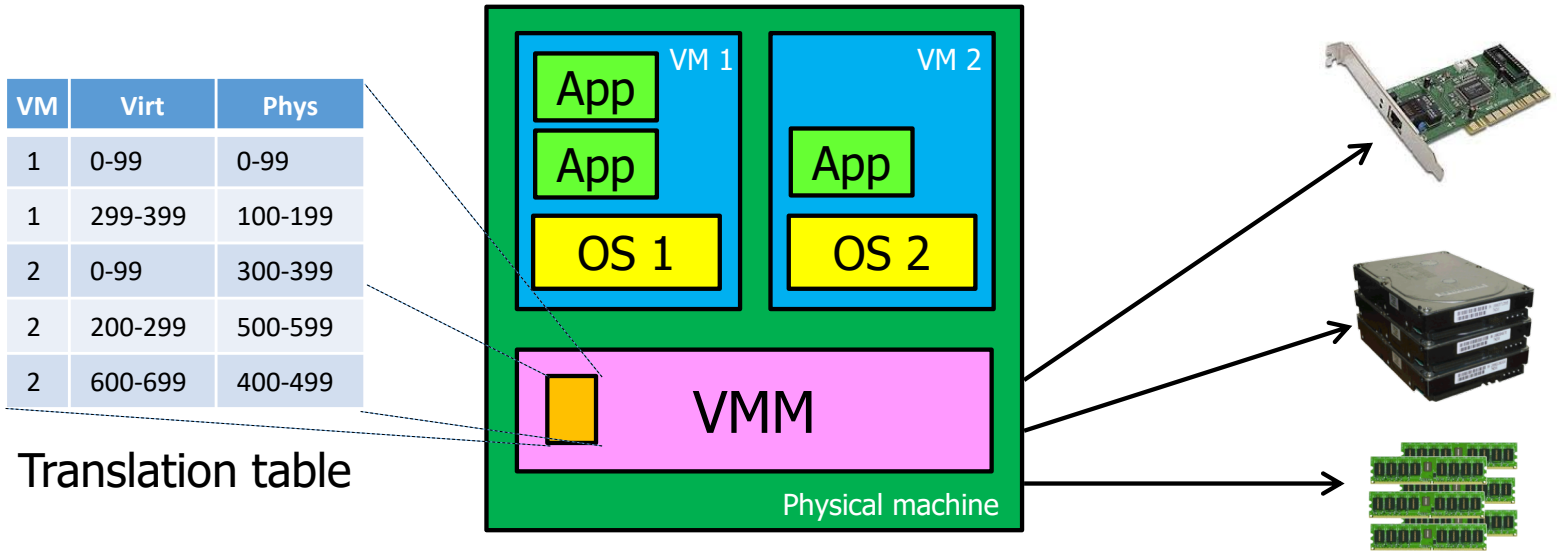
- Suppose Alice has a machine with 4 CPUs and 8 GB of memory, and three customers:
  - Bob wants a machine with 1 CPU and 3GB of memory
  - Charlie wants 2 CPUs and 1GB of memory
  - Daniel wants 1 CPU and 4GB of memory
- What should Alice do?

What is virtualization?



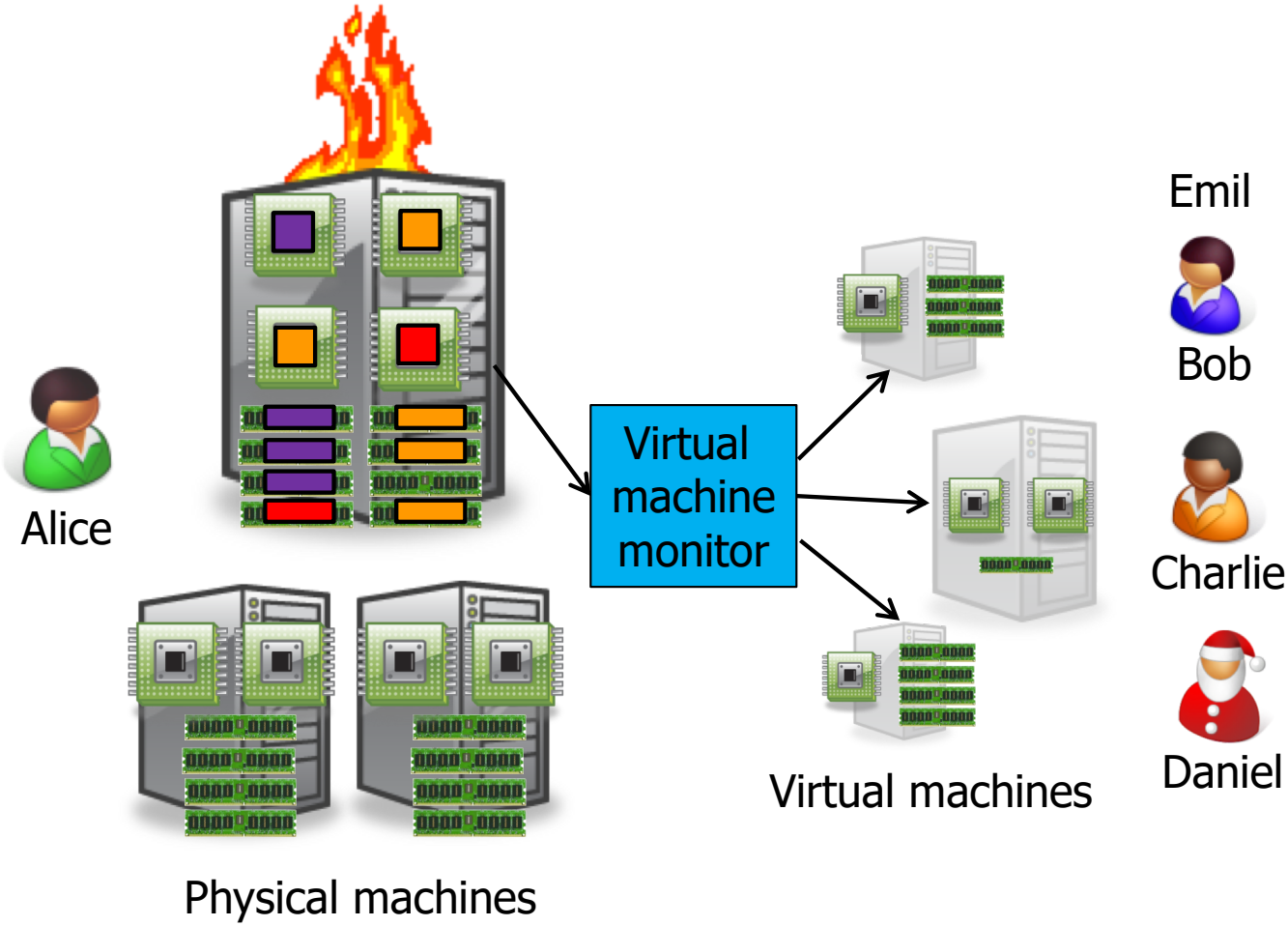
- Alice can sell each customer a virtual machine (VM) with the requested resources
  - From each customer's perspective, it appears as if they had a physical machine all by themselves (isolation)

How does it work?



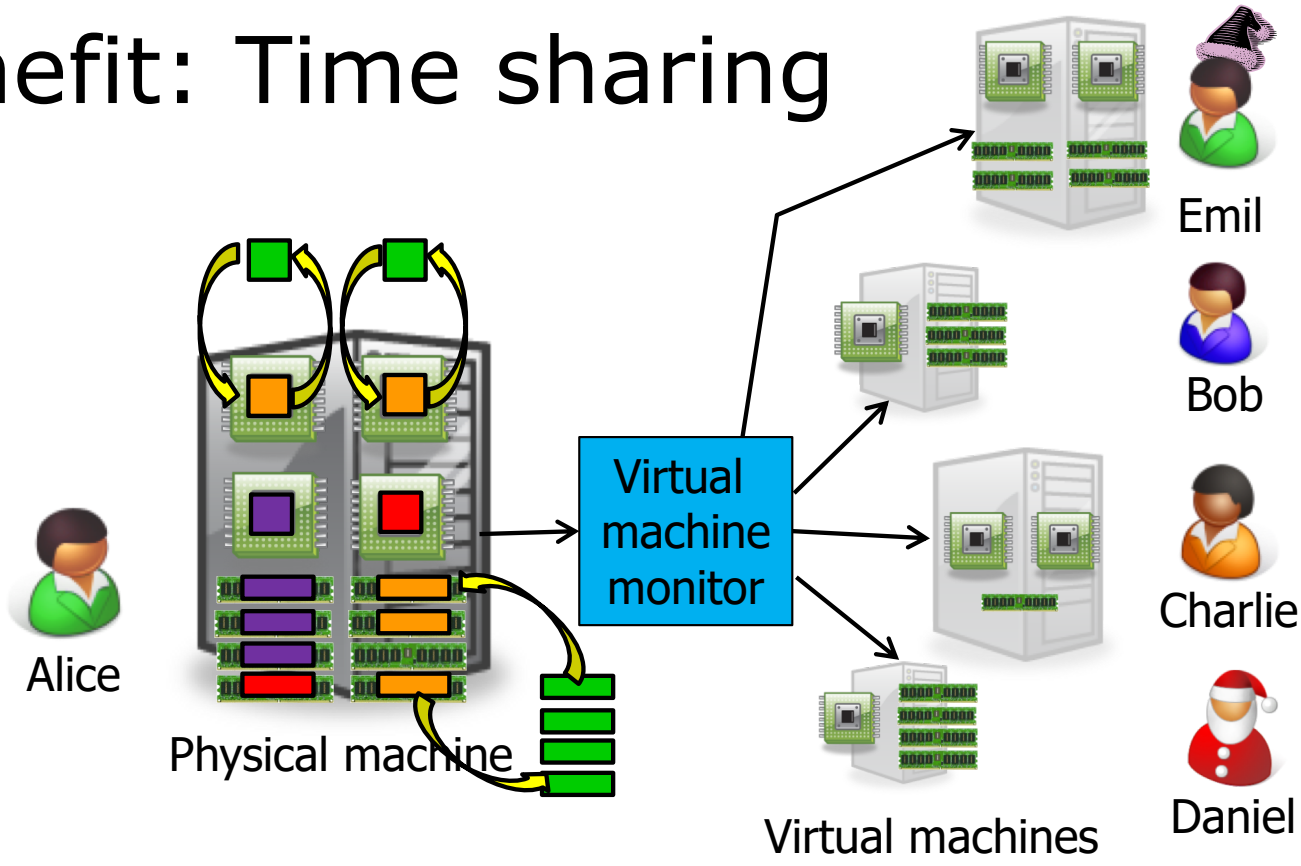
- Resources (CPU, memory, ...) are virtualized
  - VMM ("Hypervisor") has translation tables that map requests for virtual resources to physical resources
  - Example: VM 1 accesses memory cell #323; VMM maps this to memory cell 123.

Benefit: Migration



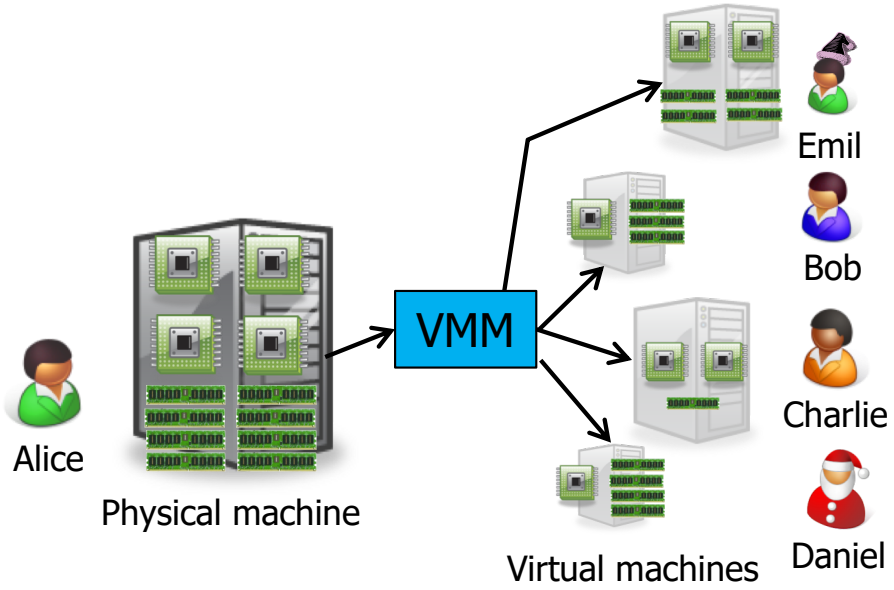
- What if the machine needs to be shut down?
  - e.g., for maintenance, consolidation, ...
  - Alice can migrate the VMs to different physical machines without any customers noticing

Benefit: Time sharing



- What if Alice gets another customer?
  - Multiple VMs can time-share the existing resources
  - Result: Alice has more virtual CPUs and virtual memory than physical resources (but not all can be active at the same time)

Benefit and challenge: Isolation



- Good: Emil can't access Charlie's data
- Bad: What if the machine load suddenly increases?
  - Example: Emil's VM shares CPUs with Charlie's VM, and Charlie suddenly starts a large compute job
  - Emil's performance may decrease as a result
  - VMM can move Emil's software to a different CPU, or migrate it to a different machine

Recap: Virtualization in the cloud

- Gives cloud provider a lot of flexibility
  - Can produce VMs with different capabilities
  - Can migrate VMs if necessary (e.g., for maintenance)
  - Can increase load by overcommitting resources
- Provides security and isolation
  - Programs in one VM cannot influence programs in another
- Convenient for users
  - Complete control over the virtual 'hardware' (can install own operating system own applications, ...)
- But: Performance may be hard to predict
  - Load changes in other VMs on the same physical machine may affect the performance seen by the customer

Cloud Computing Challenges

1. Availability
   - What happens to my business if there is an outage in the cloud?
2. Data lock-in
   - How do I move my data from one cloud to another?
3. Data confidentiality and auditability
   - How do I make sure that the cloud doesn't leak my confidential data?
   - Can I comply with regulations like HIPAA?

Service	Duration	Date
S3	6-8 hrs	7/20/08
AppEngine	5 hrs	6/17/08
Gmail	1.5 hrs	8/11/08
Azure	22 hrs	3/13/09
Intuit	36 hrs	6/16/10
EBS	>3 days	4/21/11
ECC	~2 hrs	6/30/12

Some prominent cloud outages

Cloud Computing Challenges

4. Data transfer bottlenecks
   - How do I copy large amounts of data from/to the cloud?
   - Example: 10 TB from UC Berkeley to Amazon in Seattle, WA
   - Motivated Import/Export feature on AWS

Method	Time
Internet (20Mbps)	45 days
FedEx	1 day

Time to transfer 10TB [AF10]

5. Performance unpredictability
   - Example: VMs sharing the same disk → I/O interference
   - Example: HPC tasks that require coordinated scheduling

Primitive	Mean perf.	Std dev
Memory bandwidth	1.3GB/s	0.05GB/s (4%)
Disk bandwidth	55MB/s	9MB/s (16%)

Performance of 75 EC2 instances in benchmarks

What are the benefits to a (regular) business?

- No up-front commitments
- On-demand access
- Nice pricing (capital costs -> utility costs, no depreciation)
- Simplified app acceleration and scalability
- Efficient resource allocation
- Energy efficiency??
- Seamless creation and use of third-party services

Benefits for a software company going to SaaS?

- NO deployment issues (CDs, downloads, etc)
- No need to support multiple OSs
- Faster to market
- A/B testing of features
- Efficiency and reliability now key
- More efficient developers, just try it!

Problems?

- Security
  - Confidentiality, Secrecy, Protection
- Legal
  - Google/Facebook privacy
  - Differing viewing laws
- Performance & Data Location