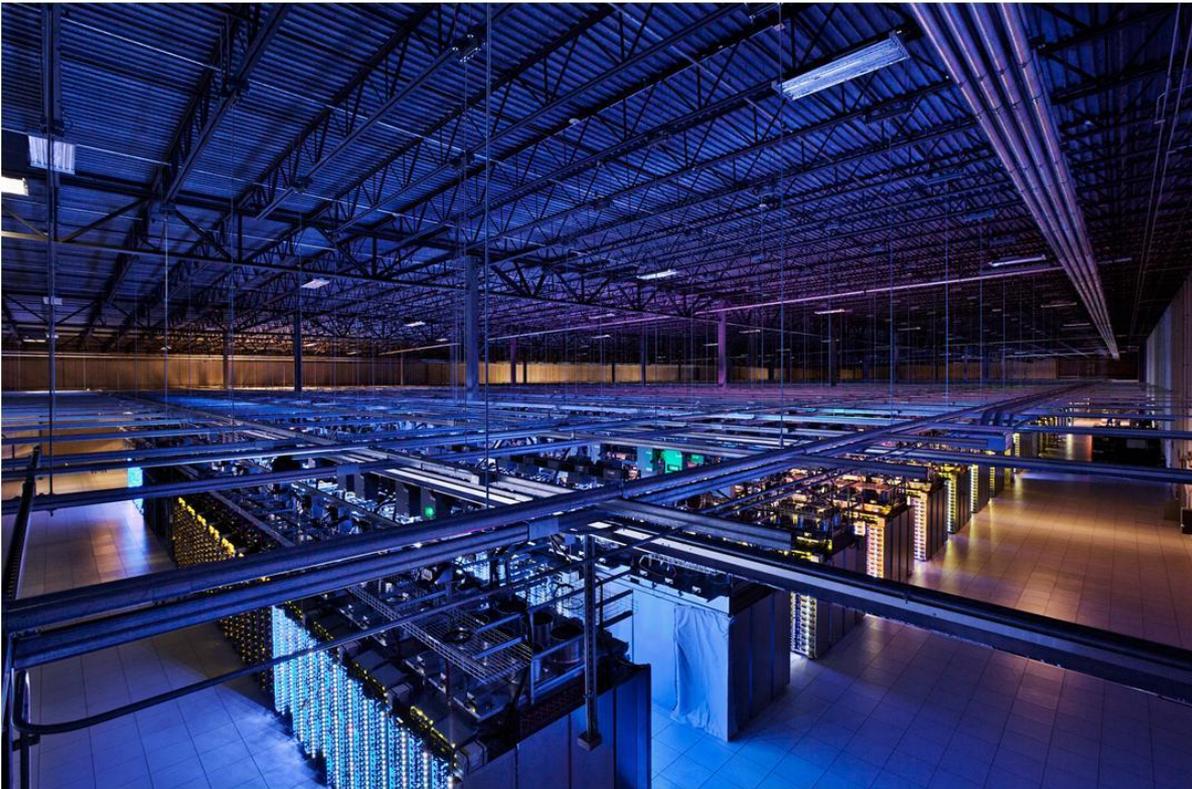# Large-Scale Data Engineering
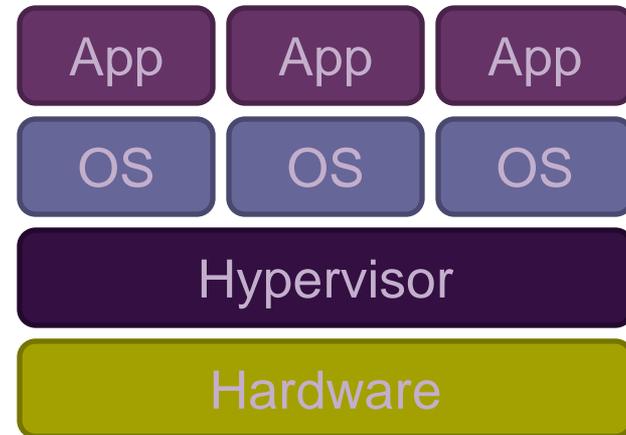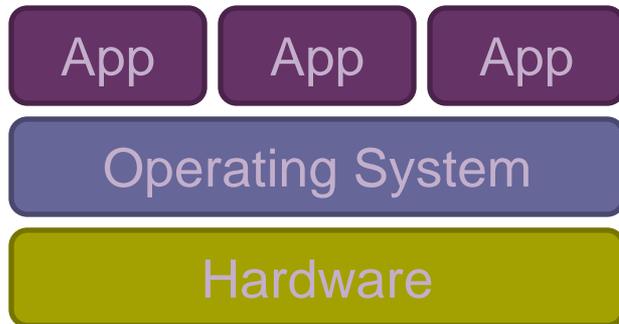
Cloud Computing - Computing as a Service

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Utility computing

- What?
  - Computing resources as a metered service ("pay as you go")
  - Ability to dynamically provision virtual machines
- Why?
  - Cost: capital vs. operating expenses
  - Scalability: "infinite" capacity
  - Elasticity: scale up or down on demand
- Does it make sense?
  - Benefits to cloud users
  - Business case for cloud providers

Enabling technology: virtualisation

App	App	App

Operating System

Hardware

App	App	App

OS	OS	OS

Hypervisor

| Hardware |
|----------|

Everything as a service

- Utility computing = Infrastructure as a Service (IaaS)
    - Why buy machines when you can rent cycles?
    - Examples: Amazon's EC2, Rackspace
- Platform as a Service (PaaS)
    - Give me nice API and take care of the maintenance, upgrades
    - Example: Google App Engine
- Software as a Service (SaaS)
    - Just run it for me!
    - Example: Gmail, Salesforce

Several Historical Trends (3/3)

- Minicomputers (1960-1990)
  - IBM AS/400, DEC VAX
- The age of the x86 PC (1990-2010)
  - IBM PC, Windows (1-7)
  - Linux takes the server market (2000-)
  - Hardware innovation focused on Gaming/Video (GPU), Laptop
- Mobile and Server separate (2010-)
  - Ultramobile (tablet,phone) .➔ ARM
  - Server ➔ x86 still but much more influence on hardware design
    - Parallel processing galore (software challenge!)
    - Large utility computing provides build their own hardware
      - Amazon SSD cards (FusionIO)
      - Google network Routers

Big picture overview

- Client requests are handled in the first tier by
  - PHP or ASP pages
  - Associated logic
- These lightweight services are fast and very nimble
- Much use of caching: the second tier

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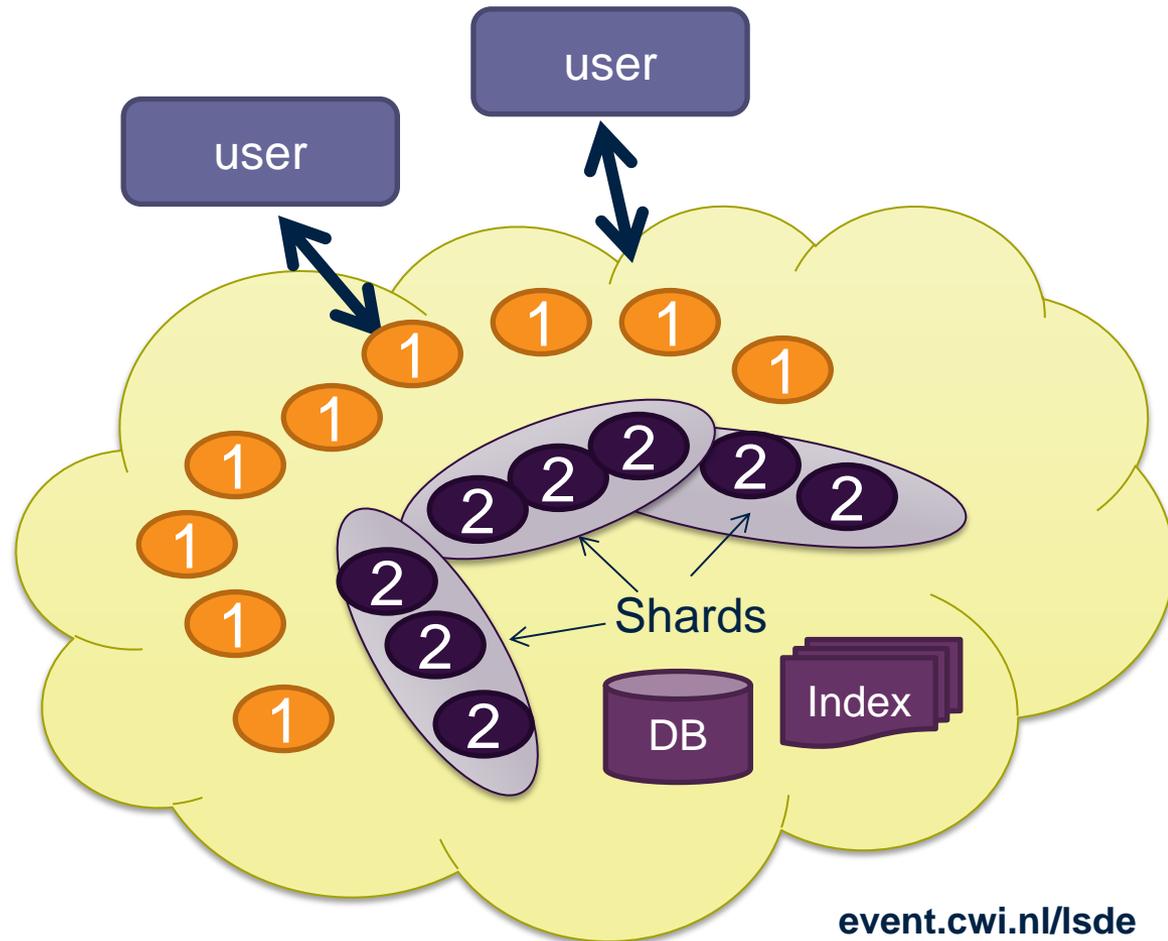
In the outer tiers replication is key

- We need to replicate
  - Processing
    - Each client has what seems to be a private, dedicated server (for a little while)
  - Data
    - As much as possible!
    - Server has copies of the data it needs to respond to client requests without any delay at all
  - Control information
    - The entire system is managed in an agreed-upon way by a decentralised cloud management infrastructure

Read vs. write

- Parallelisation works fine, so long as we are reading

- If we break a large read request into multiple read requests for sub-components to be run in parallel, how long do we need to wait?

  – Answer: as long as the slowest read

- How about breaking a large write request?

  – Duh… we still wait till the slowest write finishes

- But what if these are not sub-components, but alternative copies of the same resource?

  – Also known as replicas

  – We wait the same time, but when do we make the individual writes visible?

Replication solves one problem but introduces another

More on updating replicas in parallel

- Several issues now arise
  - Are all the replicas applying updates in the same order?
    - Might not matter unless the same data item is being changed
    - But then clearly we do need some agreement on order
  - What if the leader replies to the end user but then crashes and it turns out that the updates were lost in the network?
    - Data center networks are surprisingly lossy at times
    - Also, bursts of updates can queue up
- Such issues result in inconsistency

Eric Brewer's CAP theorem

- In a famous 2000 keynote talk at ACM PODC, Eric Brewer proposed that
    - "*You can have just two from Consistency, Availability and Partition Tolerance*"

- He argues that data centres need very fast response, hence availability is paramount

- And they should be responsive even if a transient fault makes it hard to reach some service

- So they should use cached data to respond faster even if the cached entry cannot be validated and might be stale!

- Conclusion: weaken consistency for faster response

- We will revisit this as we go along

Is inconsistency a bad thing?

- How much consistency is really needed in the first tier of the cloud?

  – Think about YouTube videos. Would consistency be an issue here?

  – What about the Amazon "number of units available" counters. Will people notice if those are a bit off?

    - Probably not unless you are buying the last unit

    - End even then, you might be inclined to say "oh, bad luck"

CASE STUDY:
AMAZON WEB SERVICES

Amazon AWS

- Grew out of Amazon's need to rapidly provision and configure machines of standard configurations for its own business.

- Early 2000s – Both private and shared data centers began using virtualization to perform "server consolidation"

- 2003 – Internal memo by Chris Pinkham describing an "infrastructure service for the world."

- 2006 – S3 first deployed in the spring, EC2 in the fall

- 2008 – Elastic Block Store available.

- 2009 – Relational Database Service

- 2012 – DynamoDB

Terminology

- Instance = One running virtual machine.

- Instance Type = hardware configuration: cores, memory, disk.

- Instance Store Volume = Temporary disk associated with instance.

- Image (AMI) = Stored bits which can be turned into instances.

- Key Pair = Credentials used to access VM from command line.

- Region = Geographic location, price, laws, network locality.

- Availability Zone = Subdivision of region the is fault-independent.

Amazon AWS
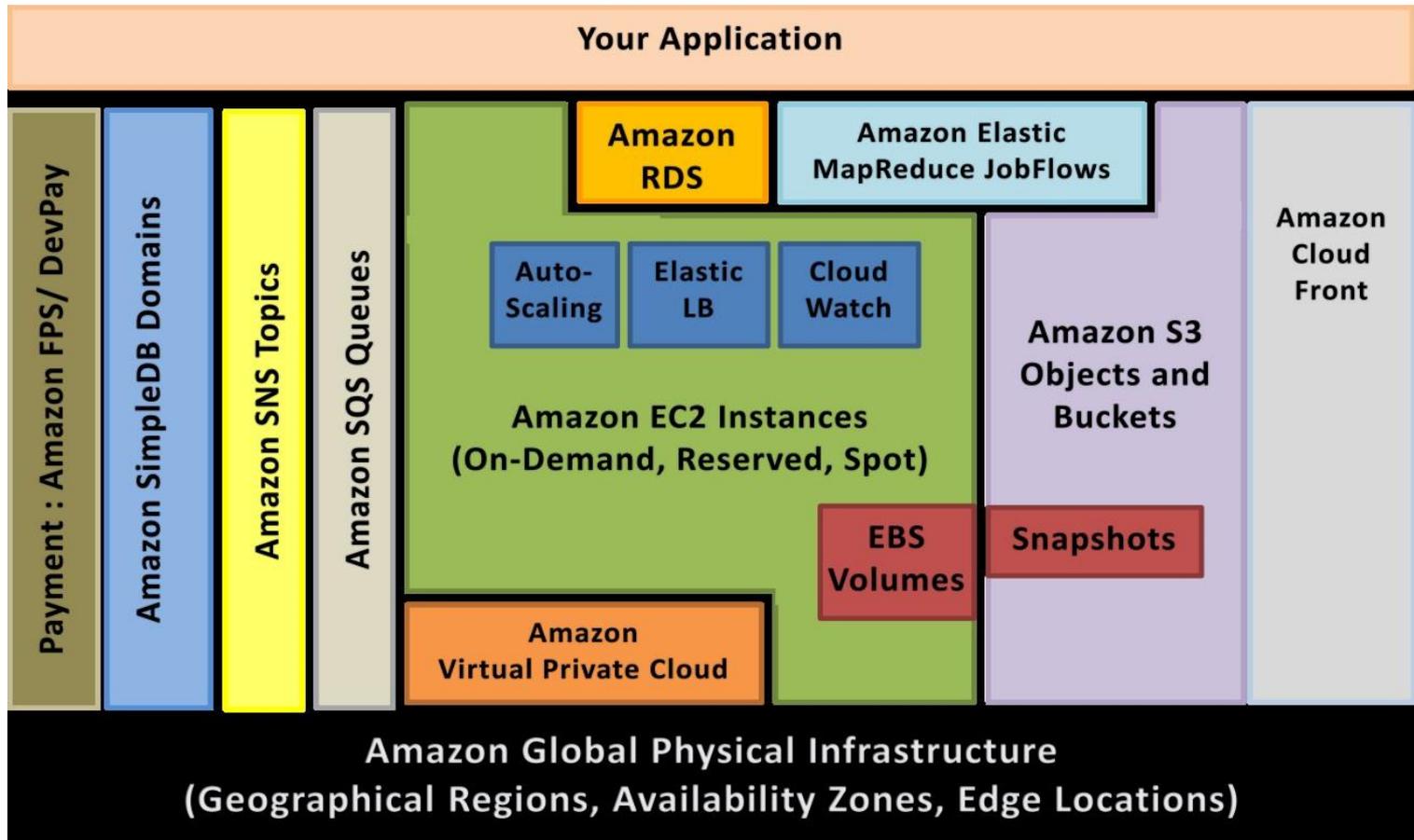
EC2 Architecture
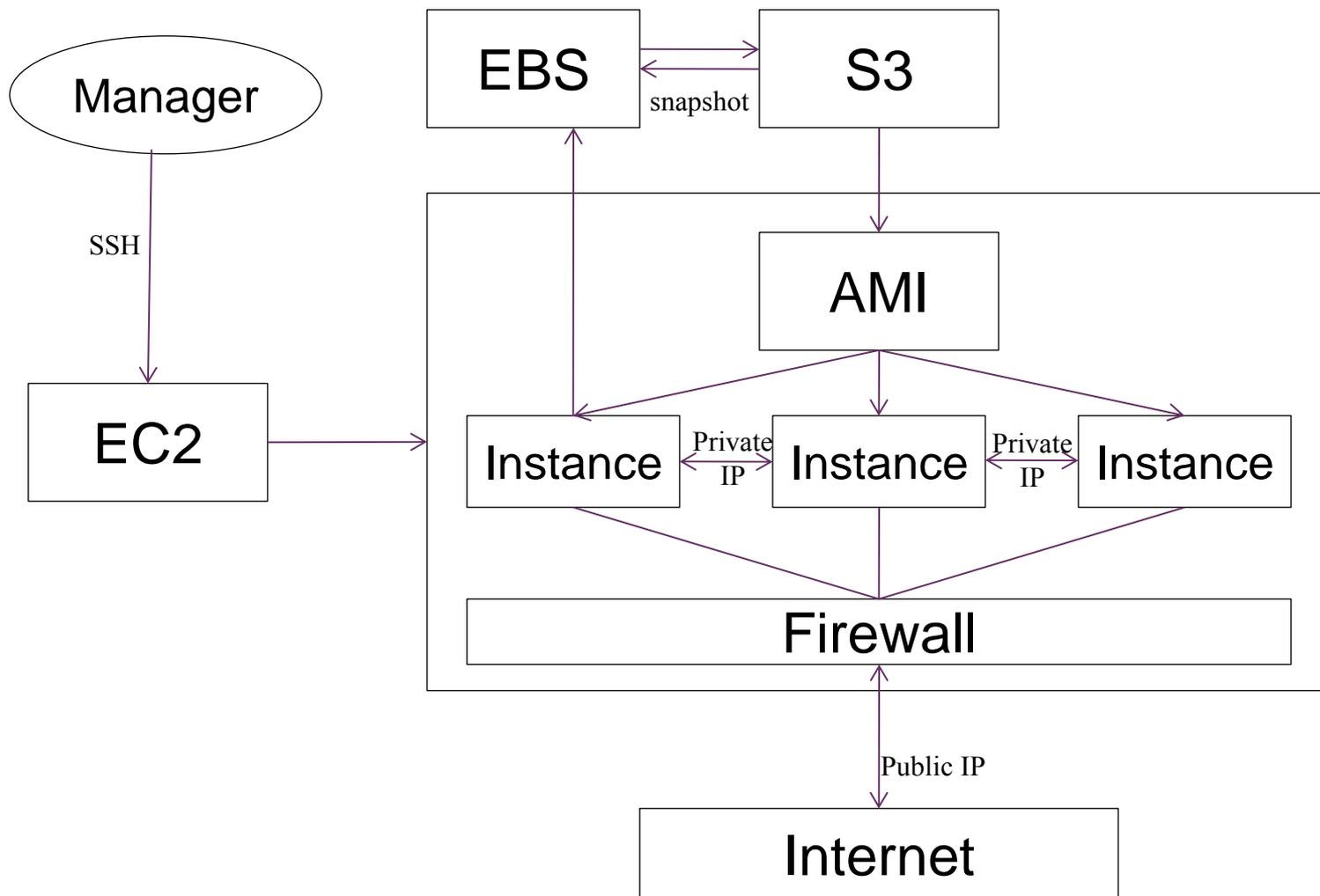
Model	vCPU	CPU Credits / hour	Mem (GiB)	Storage (GB)
t2.micro	1	6	1	EBS Only
t2.small	1	12	2	EBS Only
t2.medium	2	24	4	EBS Only

Model	vCPU	Mem (GiB)	SSD Storage (GB)
m3.medium	1	3.75	1 x 4
m3.large	2	7.5	1 x 32
m3.xlarge	4	15	2 x 40
m3.2xlarge	8	30	2 x 80

Model	vCPU	Mem (GiB)	SSD Storage (GB)
c3.large	2	3.75	2 x 16
c3.xlarge	4	7.5	2 x 40
c3.2xlarge	8	15	2 x 80
c3.4xlarge	16	30	2 x 160
c3.8xlarge	32	60	2 x 320

Model	vCPU	Mem (GiB)	SSD Storage (GB)
r3.large	2	15.25	1 x 32
r3.xlarge	4	30.5	1 x 80
r3.2xlarge	8	61	1 x 160
r3.4xlarge	16	122	1 x 320
r3.8xlarge	32	244	2 x 320

Use Cases

High performance front-end fleets, web-servers, on-demand batch processing, distributed analytics, high performance science and engineering applications, ad serving, batch processing, MMO gaming, video encoding, and distributed analytics.

Use Cases

We recommend memory-optimized instances for high performance databases, distributed memory caches, in-memory analytics, genome assembly and analysis, larger deployments of SAP, Microsoft SharePoint, and other enterprise applications.

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EC2 Pricing Model

- Free Usage Tier
- On-Demand Instances
  - Start and stop instances whenever you like, costs are rounded up to the nearest hour. (Worst price)
- Reserved Instances
  - Pay up front for one/three years in advance. (Best price)
  - Unused instances can be sold on a secondary market.
- Spot Instances
  - Specify the price you are willing to pay, and instances get started and stopped without any warning as the marked changes. (Kind of like Condor!)
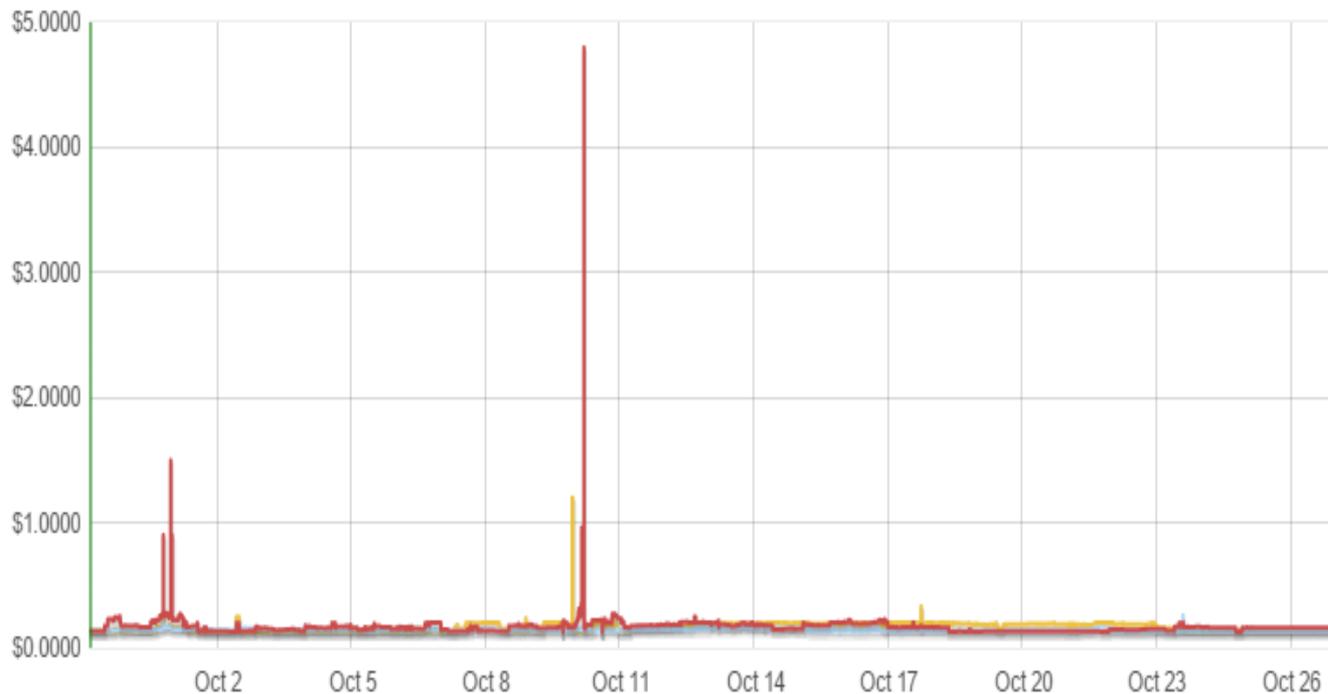
Free Usage Tier

- 750 hours of EC2 running Linux, RHEL, or SLES t2.micro instance usage

- 750 hours of EC2 running Microsoft Windows Server t2.micro instance usage

- 750 hours of Elastic Load Balancing plus 15 GB data processing

- 30 GB of Amazon Elastic Block Storage in any combination of General Purpose (SSD) or Magnetic, plus 2 million I/Os (with Magnetic) and 1 GB of snapshot storage

- 15 GB of bandwidth out aggregated across all AWS services

- 1 GB of Regional Data Transfer

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Simple Storage Service (S3)

- A **bucket** is a container for objects and describes location, logging, accounting, and access control. A bucket can hold any number of **objects**, which are files of up to 5TB. A bucket has a name that must be **globally unique**.

- Fundamental operations corresponding to HTTP actions:

  - http://**bucket**.s3.amazonaws.com/**object**

  - POST a new object or update an existing object.

  - GET an existing object from a bucket.

  - DELETE an object from the bucket

  - LIST keys present in a bucket, with a filter.

- A bucket has a **flat directory structure** (despite the appearance given by the interactive web interface.)

S3 Weak Consistency Model

Direct quote from the Amazon developer API:

"Updates to a single key are **atomic**...."

"Amazon S3 achieves high availability by replicating data across multiple servers within Amazon's data centers. If a PUT request is successful, your data is safely stored. However, information about the changes must replicate across Amazon S3, which can take some time, and so you might observe the following behaviors:

- A process writes a new object to Amazon S3 and immediately attempts to read it. Until the change is fully propagated, Amazon S3 might report "key does not exist."

- A process writes a new object to Amazon S3 and immediately lists keys within its bucket. Until the change is fully propagated, the object might not appear in the list.

- A process replaces an existing object and immediately attempts to read it. Until the change is fully propagated, Amazon S3 might return the prior data.

- A process deletes an existing object and immediately attempts to read it. Until the deletion is fully propagated, Amazon S3 might return the deleted data."

Storage Pricing

Region: [US Standard ▲▼]

	Standard Storage	Reduced Redundancy Storage	Glacier Storage
First 1 TB / month	$0.0300 per GB	$0.0240 per GB	$0.0100 per GB
Next 49 TB / month	$0.0295 per GB	$0.0236 per GB	$0.0100 per GB
Next 450 TB / month	$0.0290 per GB	$0.0232 per GB	$0.0100 per GB
Next 500 TB / month	$0.0285 per GB	$0.0228 per GB	$0.0100 per GB
Next 4000 TB / month	$0.0280 per GB	$0.0224 per GB	$0.0100 per GB
Over 5000 TB / month	$0.0275 per GB	$0.0220 per GB	$0.0100 per GB

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Request Pricing

Region: [US Standard ▼]

	Pricing
PUT, COPY, POST, or LIST Requests	$0.005 per 1,000 requests
Glacier Archive and Restore Requests	$0.05 per 1,000 requests
Delete Requests	Free †
GET and all other Requests	$0.004 per 10,000 requests
Glacier Data Restores	Free ‡

† No charge for delete requests of Standard or RRS objects. For objects that are archived to Glacier, there is a pro-rated charge of $0.03 per gigabyte for objects deleted prior to 90 days. Learn more.

‡ Glacier is designed with the expectation that restores are infrequent and unusual, and data will be stored for extended periods of time. You can restore up to 5% of your average monthly Glacier storage (pro-rated daily) for free each month. If you choose to restore more than this amount of data in a month, you are charged a restore fee starting at $0.01 per gigabyte. Learn more.

Data Transfer Pricing

The pricing below is based on data transferred "in" to and "out" of Amazon S3.

Region: US Standard ▼

	Pricing
Data Transfer IN To Amazon S3	
All data transfer in	$0.000 per GB
Data Transfer OUT From Amazon S3 To	
Amazon EC2 in the Northern Virginia Region	$0.000 per GB
Another AWS Region or Amazon CloudFront	$0.020 per GB
Data Transfer OUT From Amazon S3 To Internet	
First 1 GB / month	$0.000 per GB
Up to 10 TB / month	$0.120 per GB
Next 40 TB / month	$0.090 per GB
Next 100 TB / month	$0.070 per GB

Elastic Block Store

- An EBS volume is a **virtual disk** of a fixed size with a block read/write interface. It can be **mounted** as a filesystem on a running EC2 instance where it can be **updated incrementally.** Unlike an instance store, an EBS volume is **persistent.**

- (Compare to an S3 object, which is essentially a file that must be accessed in its entirety.)

- Fundamental operations:
  - CREATE a new volume (1GB-1TB)
  - COPY a volume from an existing EBS volume or S3 object.
  - MOUNT on one instance at a time.
  - SNAPSHOT current state to an S3 object.

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EBS is approx. 3x more expensive by volume and 10x more expensive by IOPS than S3.

How does storage work on AWS?
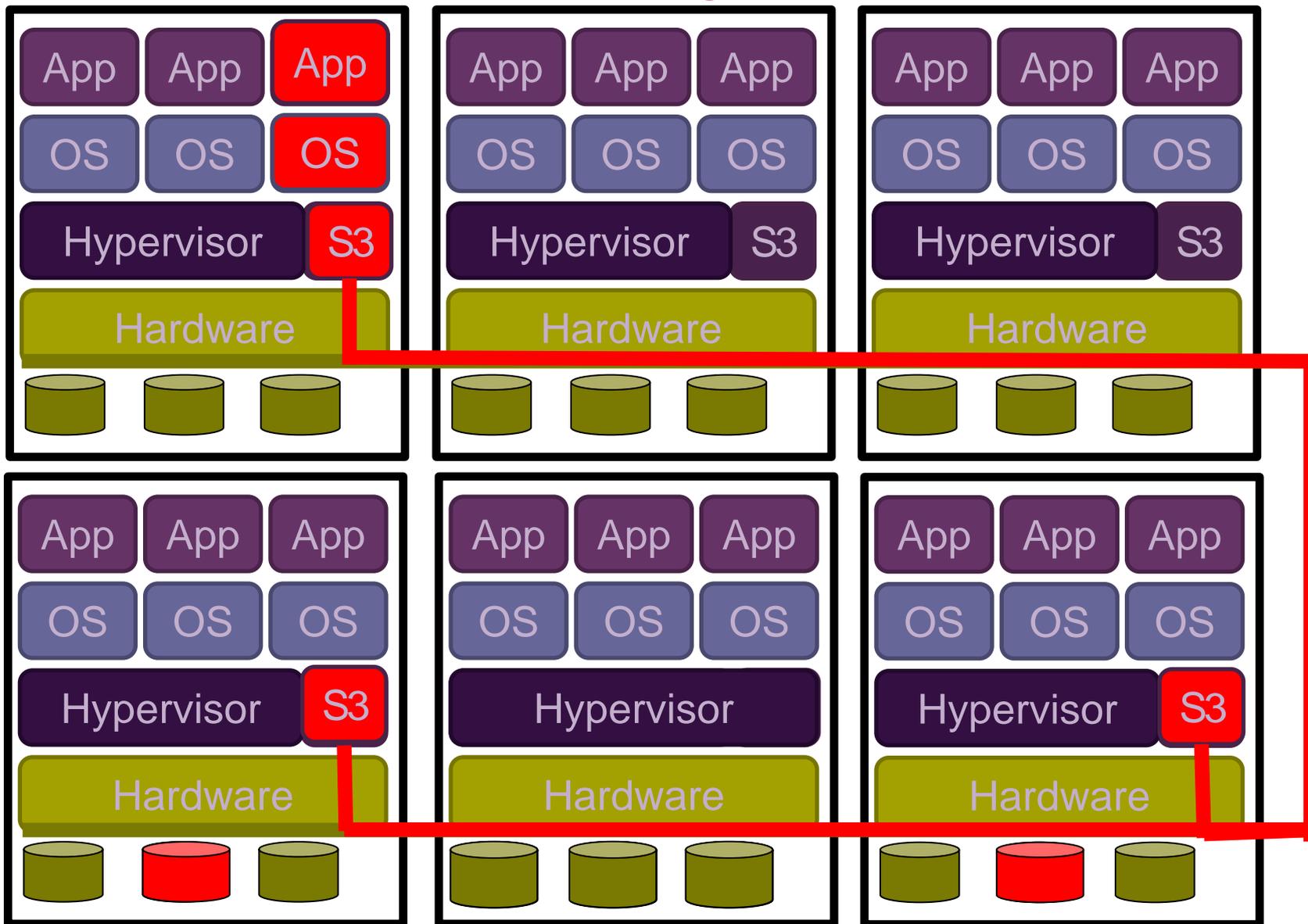
How does AWS work

- S3 the cornerstone for reliable storage
  - Data blocks are replicated over the cluster
  - All (many) nodes in the Amazon clusters contribute their disk to S3
    - S3 is not the only Amazon service on the machines
    - Instead of 'hypervisor' likely a barebones Linux-a-like OS
- File-system (EBS and also HDFS) is an abstraction on top S3
  - if nodes go down or instances hang, the data is safe in S3
  - disk access speed depends on network and caching (!)
- Private disk storage is an expensive extra
  - One can get access to dedicated (flash) disk, for controllable I/O
  - Amazon makes no persistence or reliability guarantees (when you boot, it is empty). Makes it hard to use.

Summary

- Utility Computing – Cloud Computing for rent

- Cloud Computing infrastructures

  – Virtualization

  – Caching, Replication, Sharding

  – Eric Brewer' CAP theorem: can't have:

    • Consistency & Availability & Partition-tolerance

- Amazon Web Services tour

  – EC2: Instance types, pricing models, & other terminology

  – Storage: EBS/S3/Glacier