CPSC 422/522 Design & Implementation of Operating Systems

Lecture 22: Distributed Systems

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Acknowledgement: some slides are taken from previous lectures by Dr. Ennan Zhai

Have you used distributed system?

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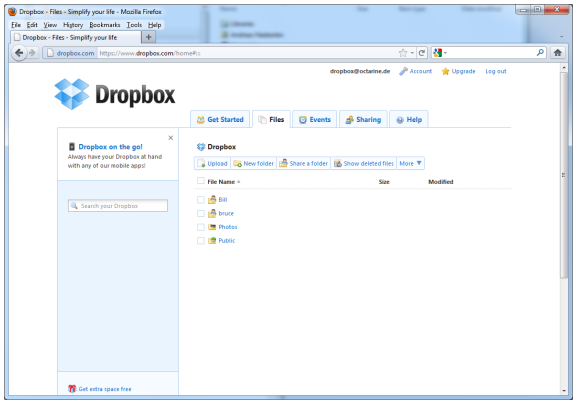

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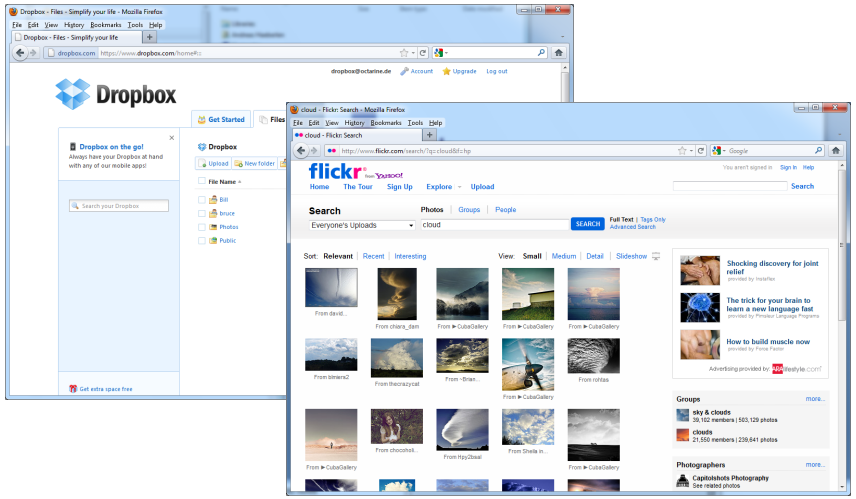

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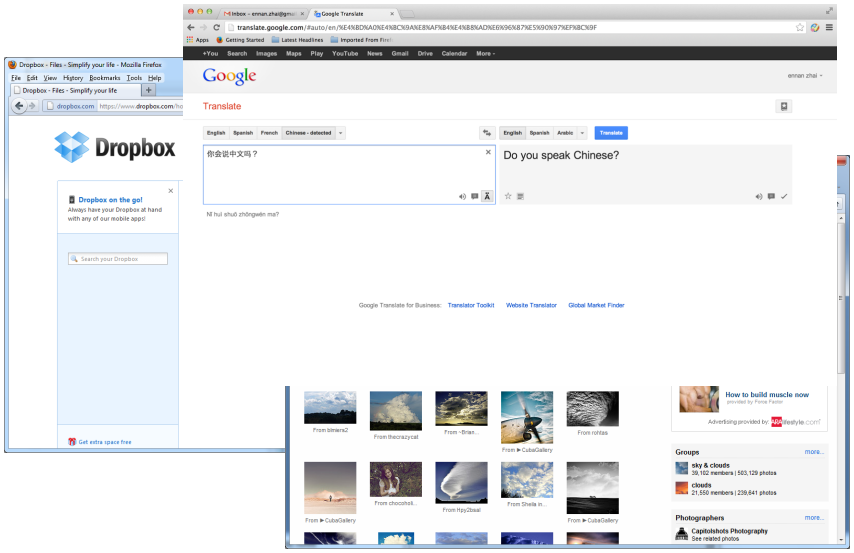

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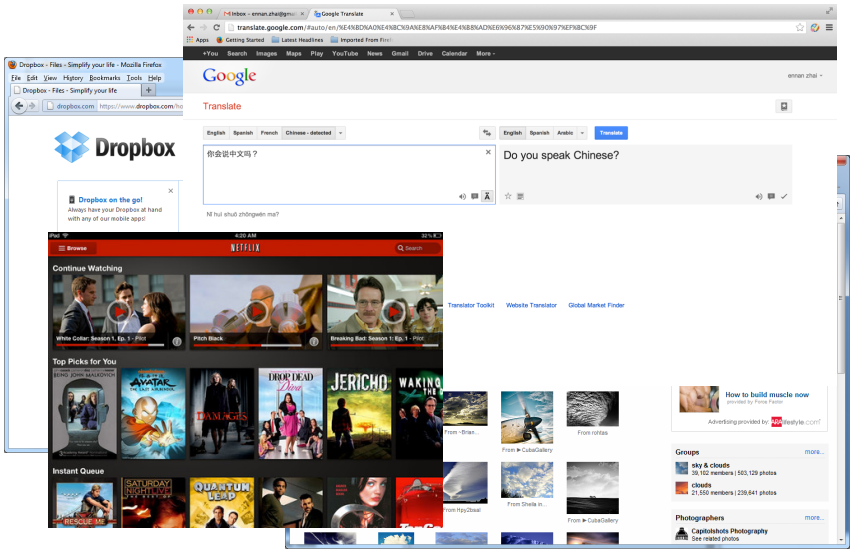

What is a distributed system?

- A system of multiple computers (nodes) communicating over a network

What is a distributed system?

- A system of multiple computers (nodes) communicating over a network
- Some following questions:
  - What is a decentralized system?
  - What is a cloud system?
  - What is a centralized distributed system?

Network Basics

- We connect computers via point-to-point links:
  - Local area network, DNS and ISP routers
  - Communications are unreliable
  - No global control of the network

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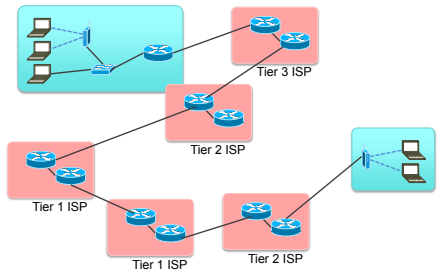
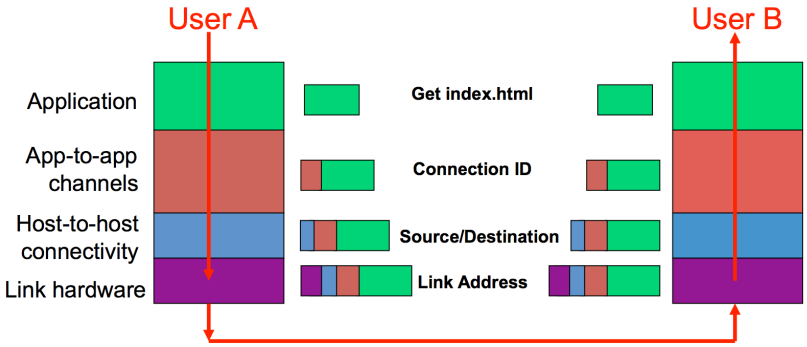
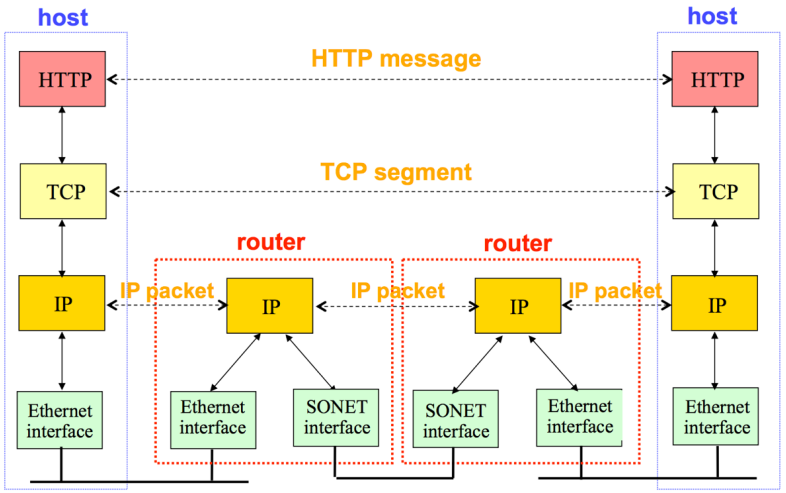


Example: HTTP Layer Encapsulation



End Hosts vs. Routers



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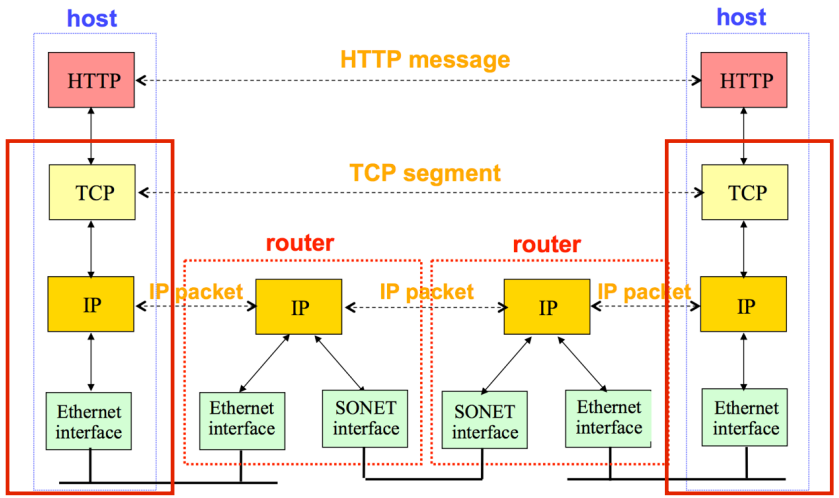

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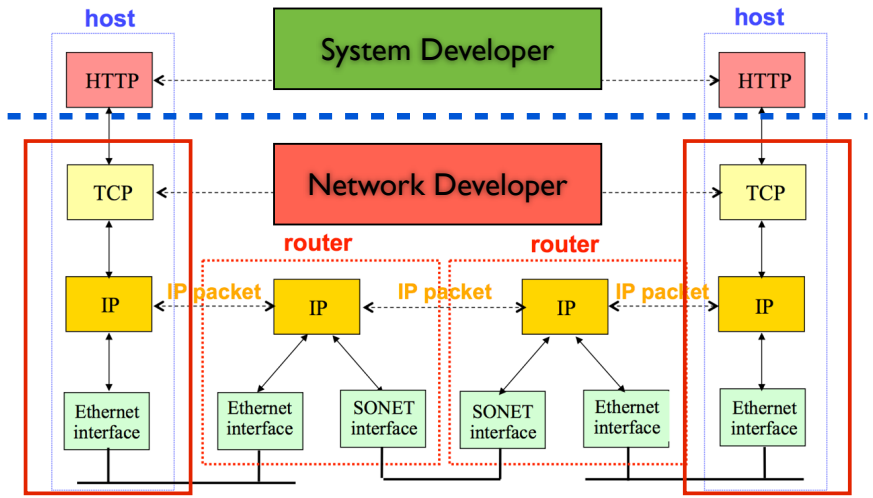

Finding Nodes

Network Basics

- Each interface on a host has a unique MAC address:
  - My machine 48-bit ethernet address = 32:00:19:ac:b1:40

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Why we need a physical address?

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Why we need a physical address?

Which layer in OSI model it belongs to?

Network Basics

- Each interface on a host has a unique MAC address:
  - My machine 48-bit ethernet address = 32:00:19:ac:b1:40

- This is *not* too interesting to us as programmers
  - We usually do not communicate at the data link layer

Network Basics

- Addressing applications:
  - IP address (32-bit for IPv4) and port number (16-bit)
  - Well-known port numbers (0-1023), e.g., ftp, ssh and http

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- We have two transport-layer protocols
  - TCP (SSH and FTP) and UDP (Streaming and local broadcast)
  - What is the difference?

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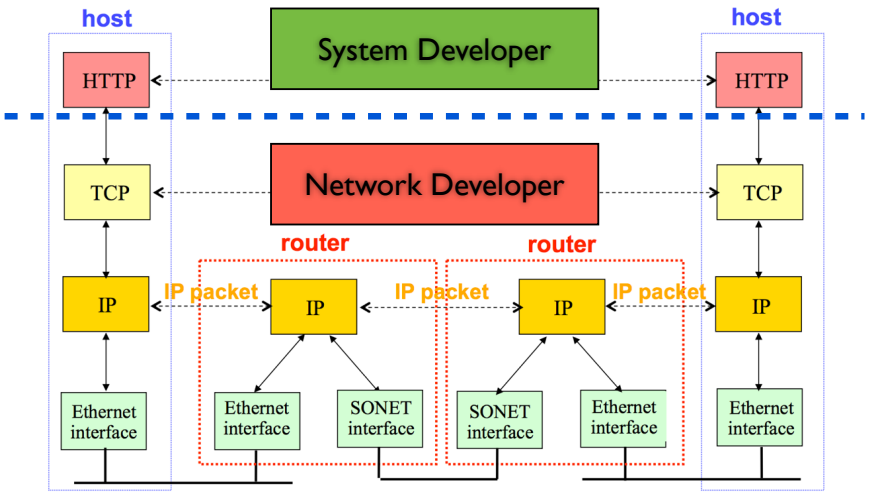

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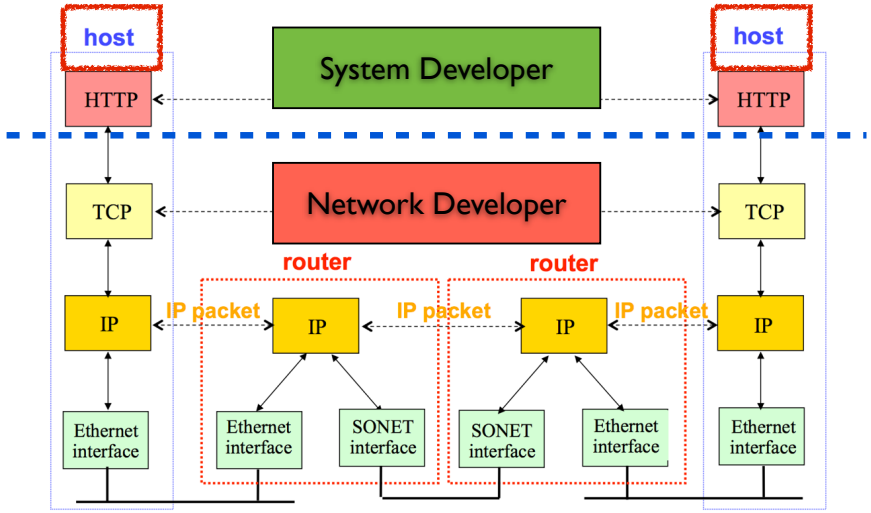

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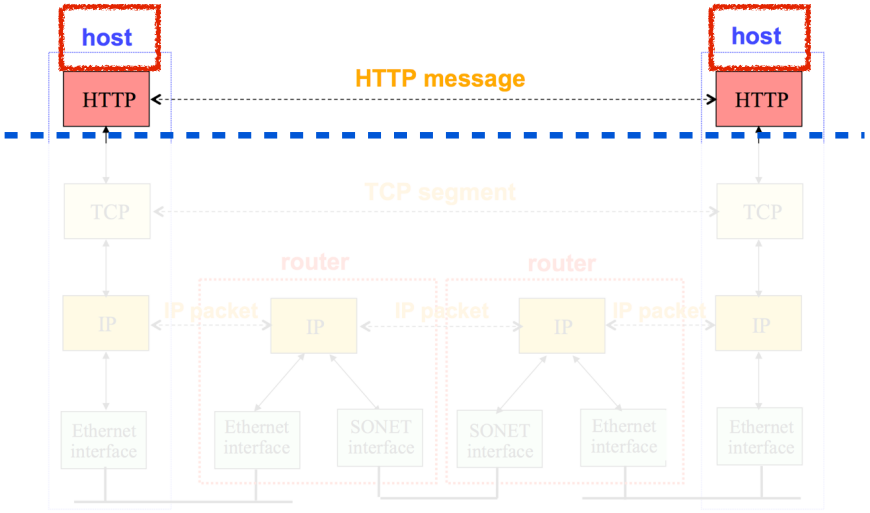

Today's Cluster

PC

Today's Cluster

PC

Server

Today's Cluster

PC

Server

Cluster

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Rack

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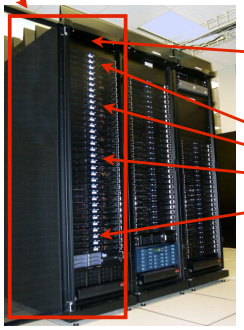
Network switches (connects nodes with each other and with other racks)

Today's Cluster

Rack



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

Many nodes/blades (often identical)

Today's Cluster

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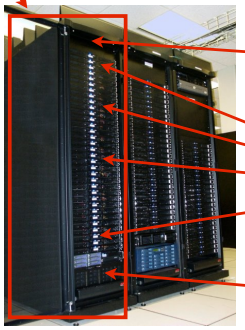


Network switches (connects nodes with each other and with other racks)

Many nodes/blades (often identical)

Storage device(s)

Today's Cluster


PC


Server


Cluster

- What if cluster is too big to fit into machine room?

Datacenter


PC


Server


Cluster

- What if cluster is too big to fit into machine room?
  - Build a separate building for the cluster
  - Building can have lots of cooling and power

Datacenter


PC


Server


Cluster


Data center

- What if cluster is too big to fit into machine room?
  - Build a separate building for the cluster
  - Building can have lots of cooling and power
  - Result: Data center

Google Datacenter in Oregon

Google Datacenter in Oregon

Data centers (size of a football field)

Google Datacenter in Oregon

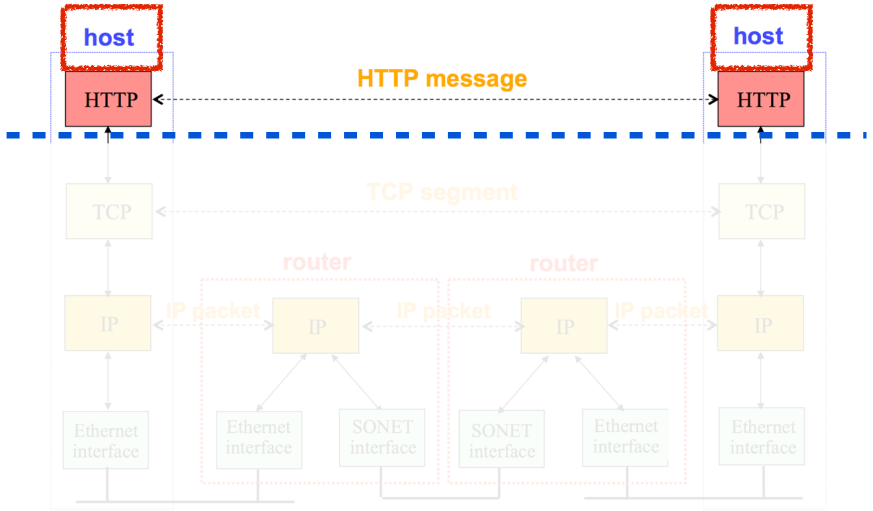
Data centers (size of a football field)

- 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)

Google Datacenters in the US

Google Datacenters in this World

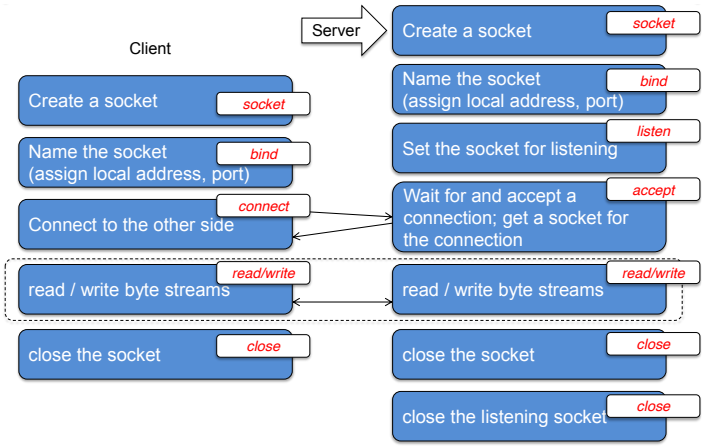
End Hosts vs. Routers



Network APIs

- Programmers need to access the network
- A network application programming interface (API)
  - Socket programming
  - Remote procedure calls

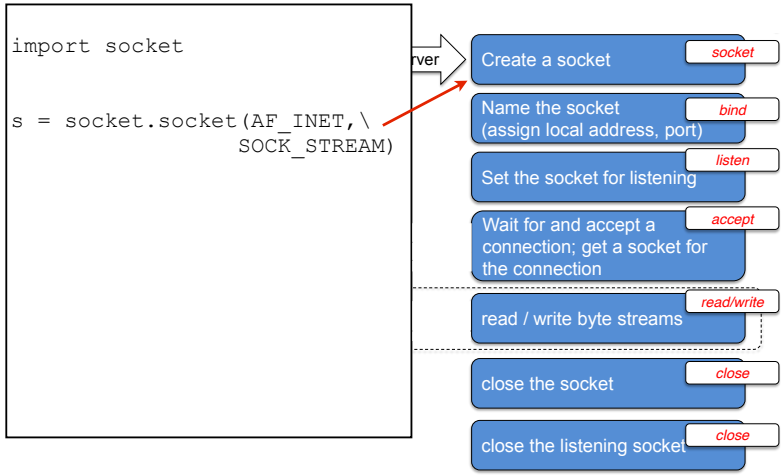
Socket (TCP)



Socket (TCP)

```
import socket
```

Socket (TCP)



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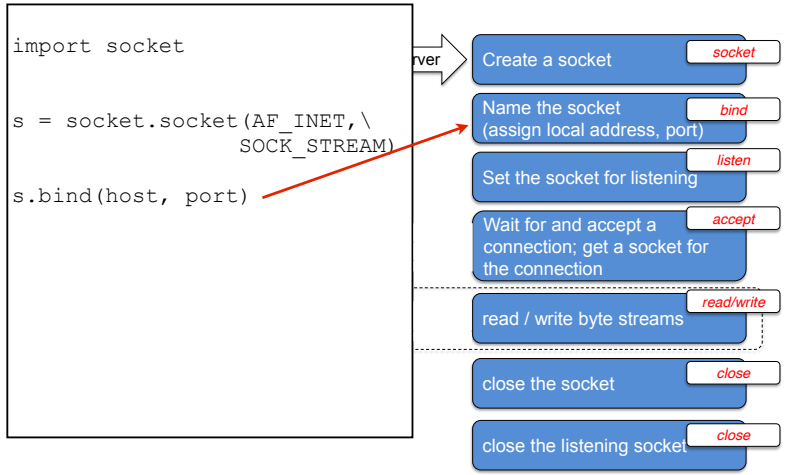

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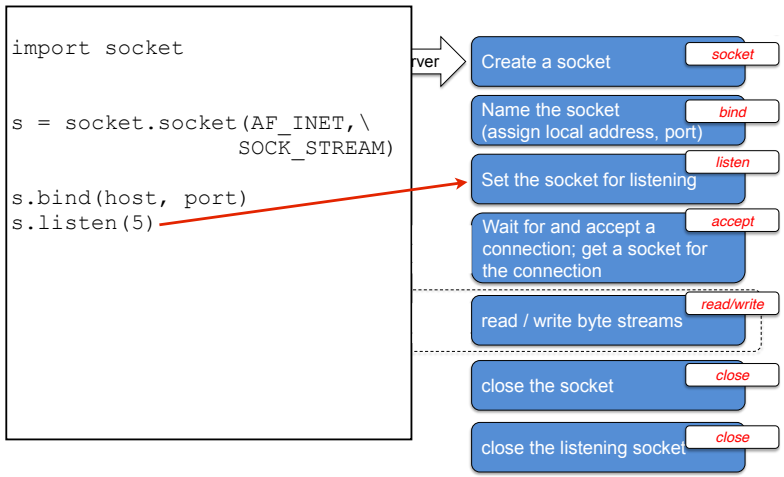

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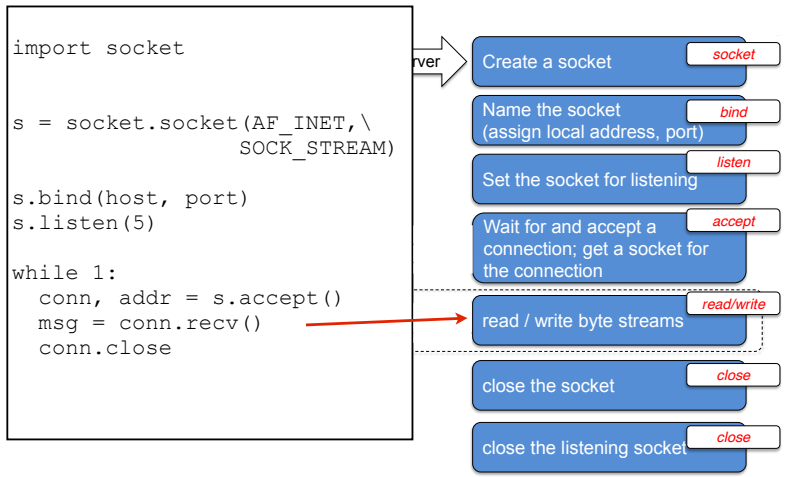


Socket (TCP)

```
import socket


s = socket.socket(AF_INET,\
                  SOCK_STREAM)

s.bind(host, port)
s.listen(5)

while 1:
  conn, addr = s.accept()
  msg = conn.recv()
  conn.close

s.close
```

rver

- Create a socket — *socket*
- Name the socket (assign local address, port) — *bind*
- Set the socket for listening — *listen*
- Wait for and accept a connection; get a socket for the connection — *accept*
- read / write byte streams — *read/write*
- close the socket — *close*
- close the listening socket — *close*

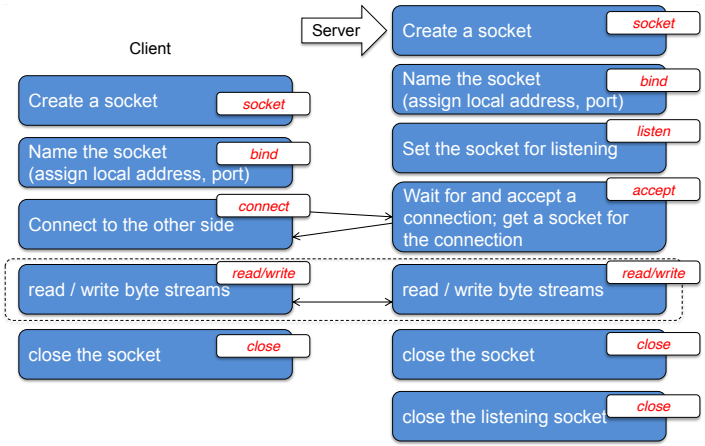
Socket (TCP)

Client

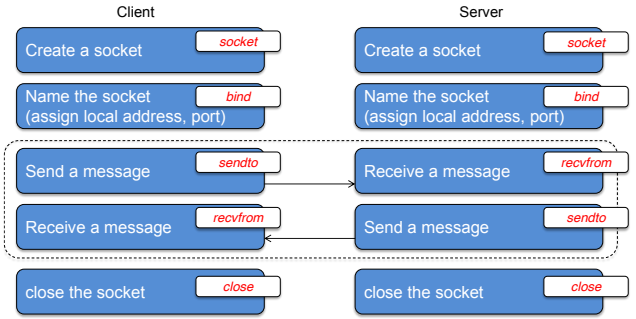
- Create a socket — *socket*
- Name the socket (assign local address, port) — *bind*
- Connect to the other side — *connect*
- read / write byte streams — *read/write*
- close the socket — *close*

```
import socket


s = socket.socket(AF_INET,\
                  SOCK_STREAM)

a = socket.gethostbyname(host)
s.connect(a, port)
s.sendall(msg)
```

Socket (TCP)



Socket (UDP)



What's the Cloud Computing

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Cloud computing is a business model for enabling convenient network access to a shared pool of configurable resources which can be rapidly provisioned and released with minimal management effort or service provider interaction.

--- according to NIST(National Institute of Standards and Technology)

Have You Used the Cloud?

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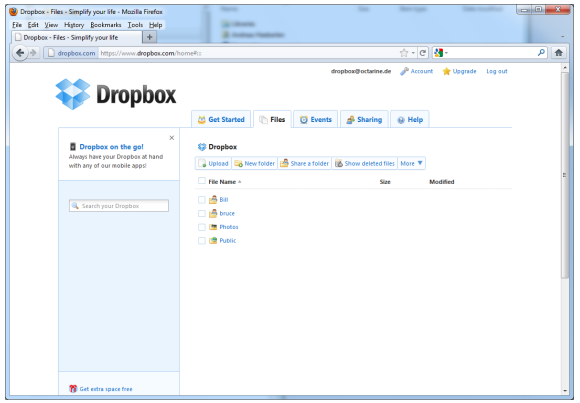

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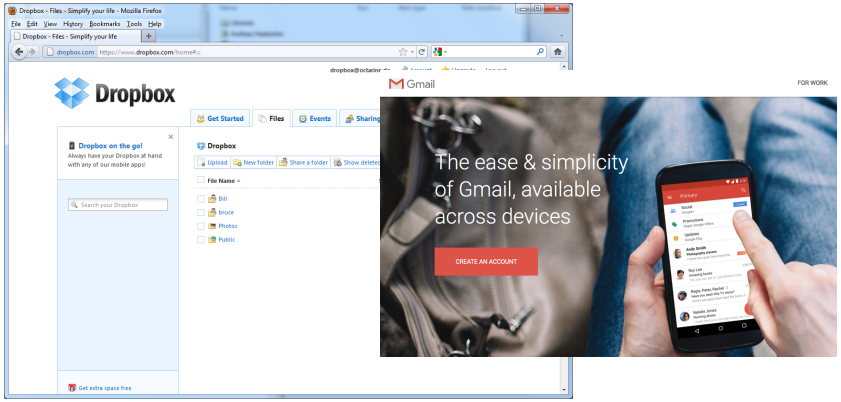

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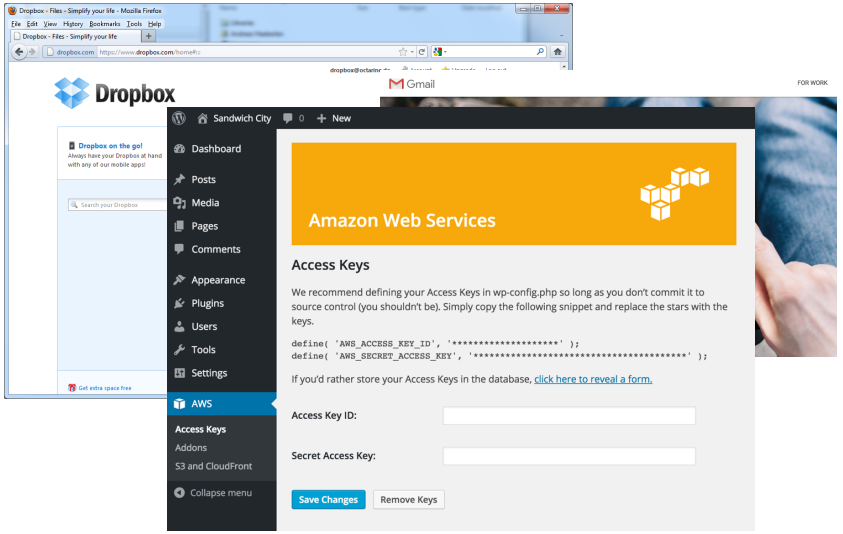

Why We Like It?

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- Why users like it?
  - Do not care where it is, it is "just there"
  - Access from "any" platform

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Cloud Services v.s. Traditional Distributed Systems

Why We Like It?

- Why users like it?
  - Do not care where it is, it is "just there"
  - Access from "any" platform
- Why CS researchers like it?
  - High-performance computation with less money
  - Lots of *hard* and *interesting* new challenges

Building Blocks

- What techniques are used to support cloud?
  - Internet
  - Smart and cheap personal devices
  - Robust and scalable software systems
  - Virtualization
  - ... ...

Types of Cloud Services

- Three types of services:

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  it.

  - Infrastructure as a Service (IaaS)
    - Analogy: Grocery store. Provides raw ingredients.

Types of Cloud Services

- Three types of services:

  - 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.

Types of Cloud Services

- Three types of services:
  - Software as a Service (SaaS)
    - Analogy: Restaurant. Prepares&serves entire meal, does the dishes, etc
  - Platform as a Service (PaaS)
    - Analogy: Take-out food. Prepares meal but does not serve it.
  - Infrastructure as a Service (IaaS)
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Software as a Service (SaaS)

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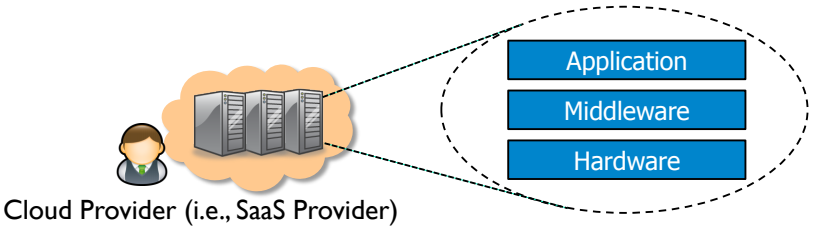

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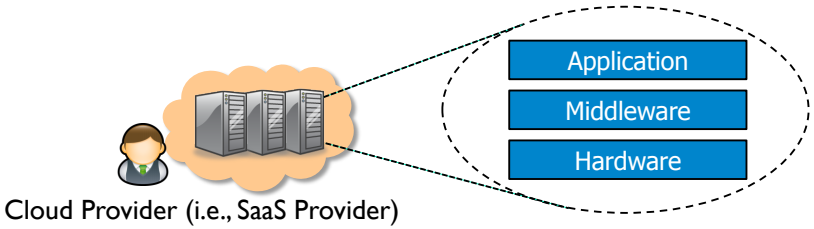
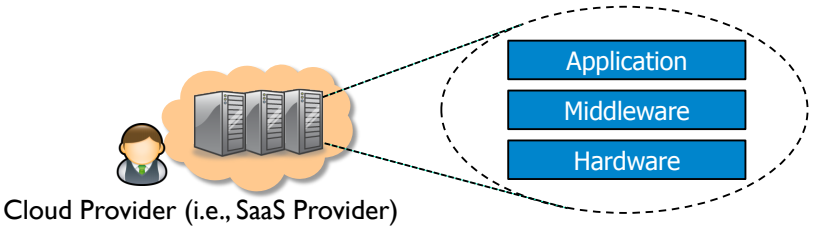


- SaaS provider offers an entire application

Software as a Service (SaaS)



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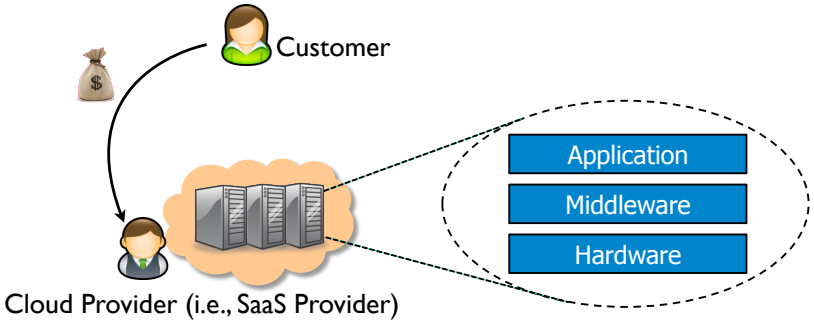

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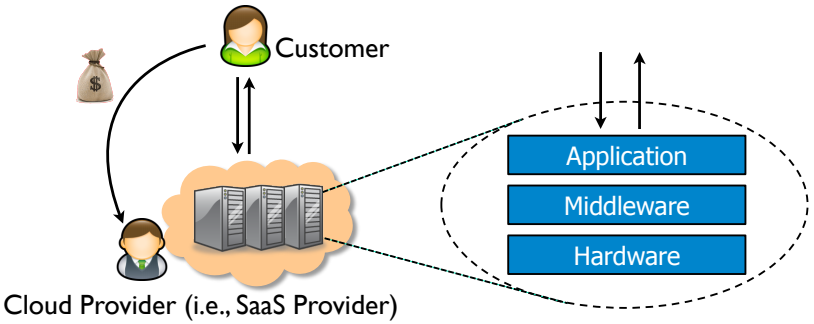

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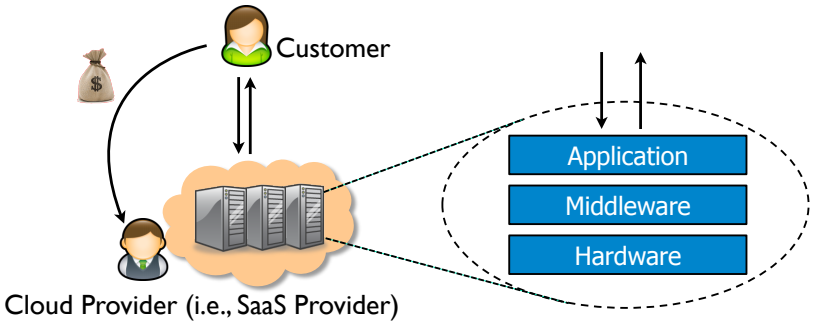

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  - Example: Google Apps, Salesforce.com, etc.

SaaS Example: Gmail

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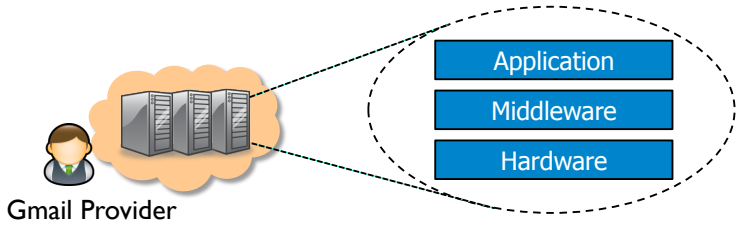

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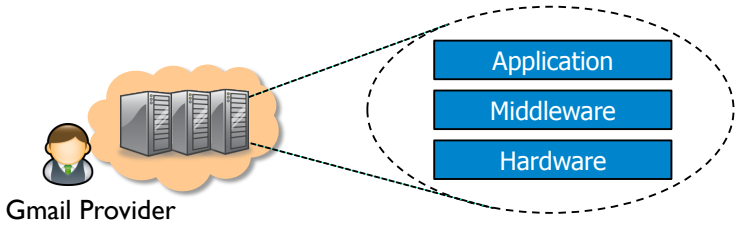

- Outsourcing your e-mail software:
  - Distributed, replicated message store in BigTable

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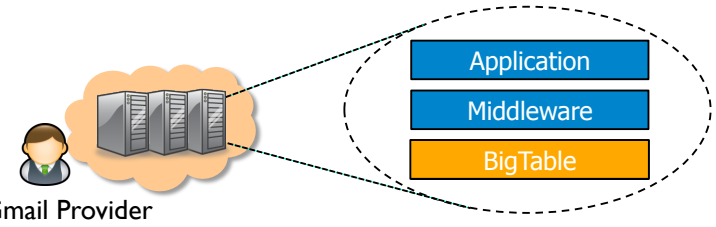

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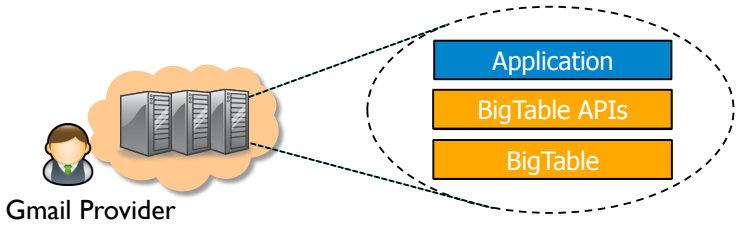

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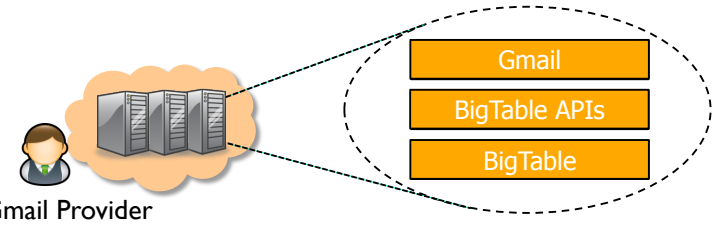

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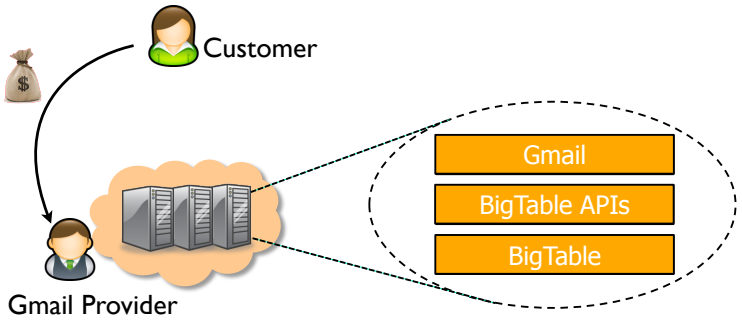

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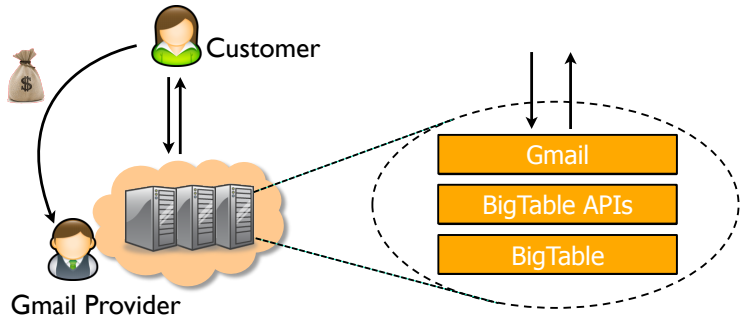

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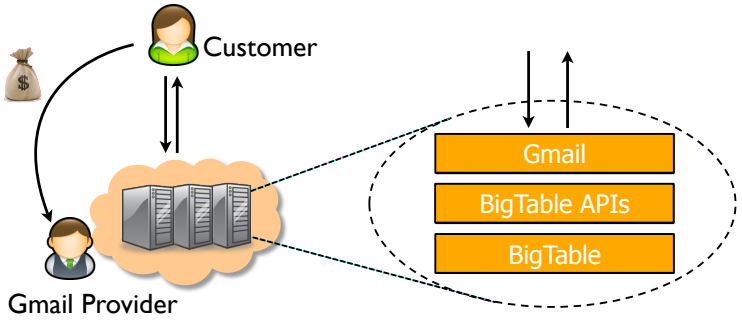

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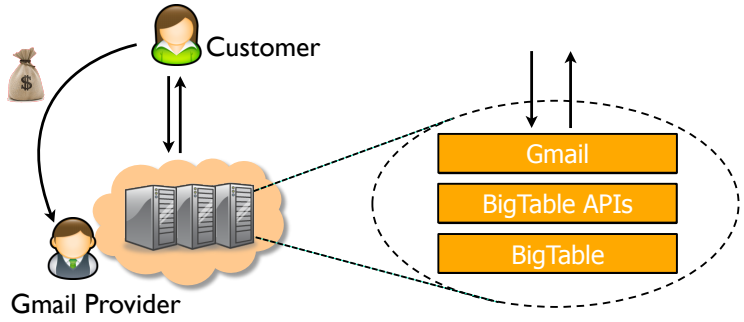

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  - Distributed, replicated message store in BigTable
  - Weak consistency model for some operations (e.g., msg read)
  - Stronger consistency for others (e.g., send msg)

Platform as a Service (PaaS)

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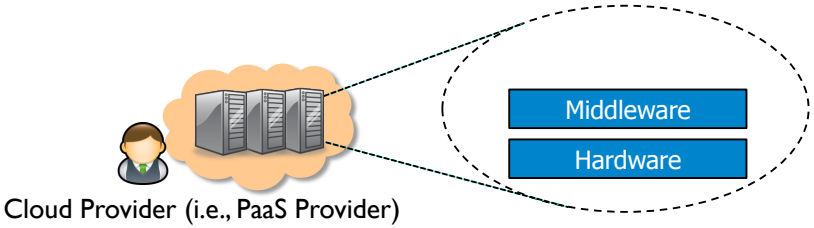
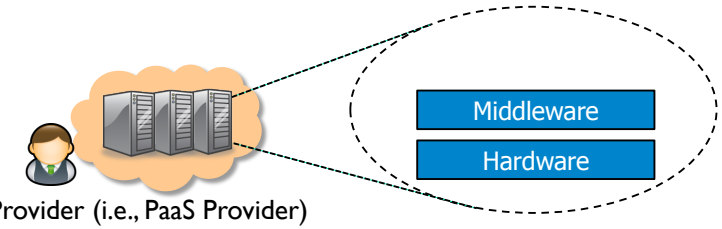


- Cloud provides middleware/infrastructure

Platform as a Service (PaaS)



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  - For example, Microsoft Common Language Runtime (CLR)

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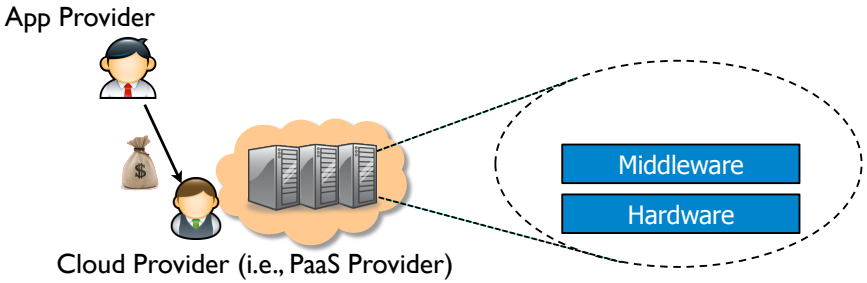

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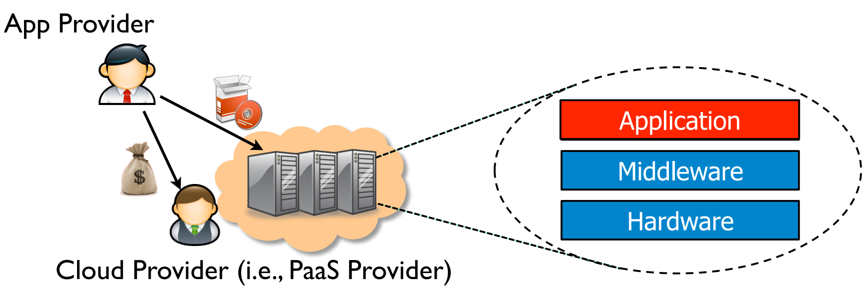

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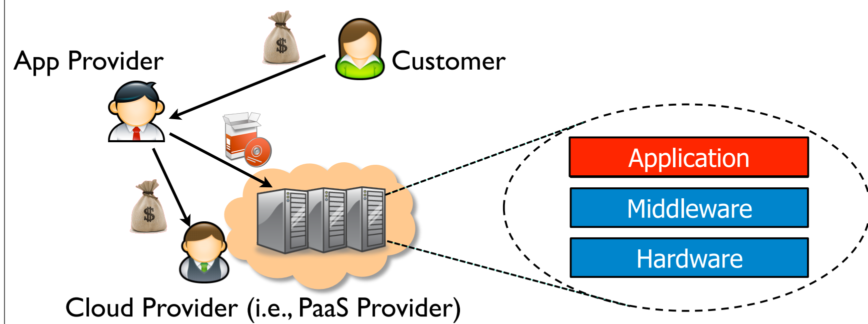

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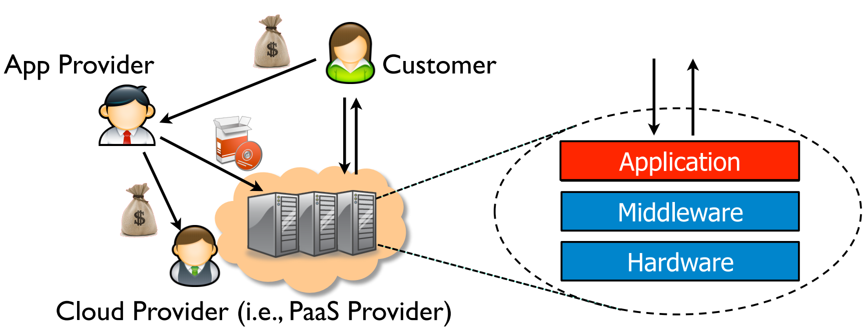

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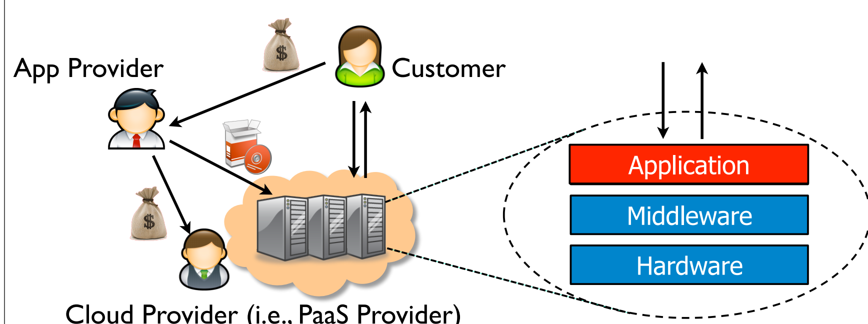

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  - Example: Windows Azure, Google App Engine, etc.

PaaS Example: Facebook

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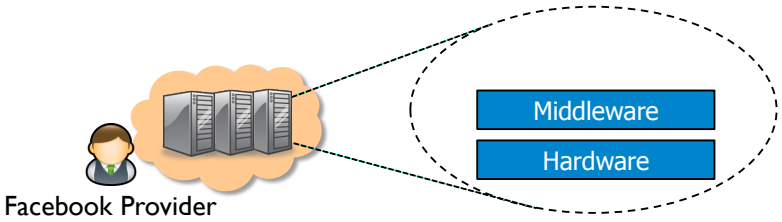

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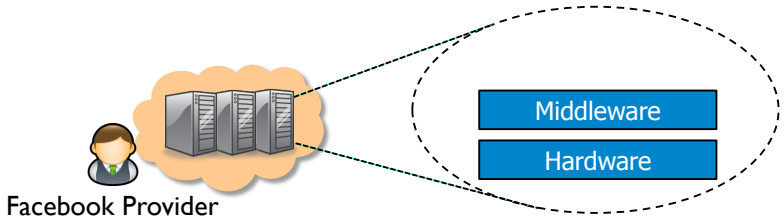
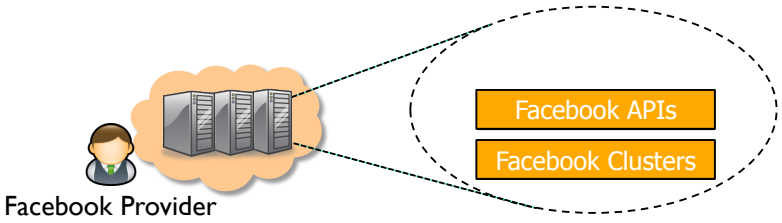


- Facebook offers PaaS capabilities to App provider

PaaS Example: Facebook



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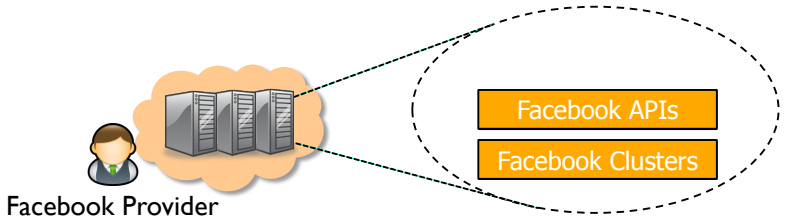

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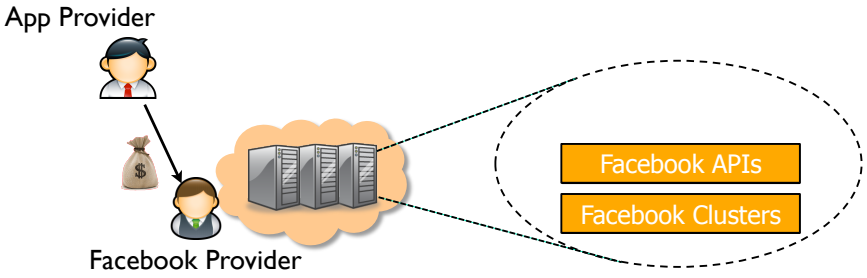

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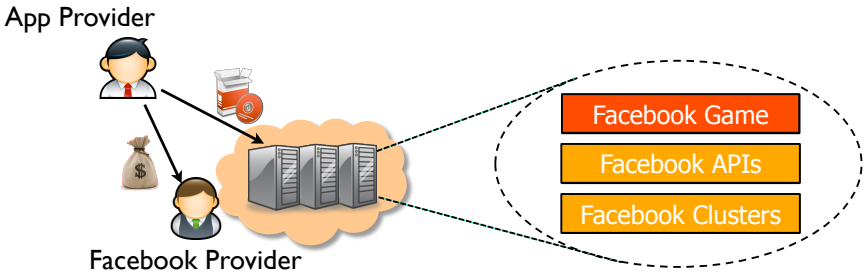

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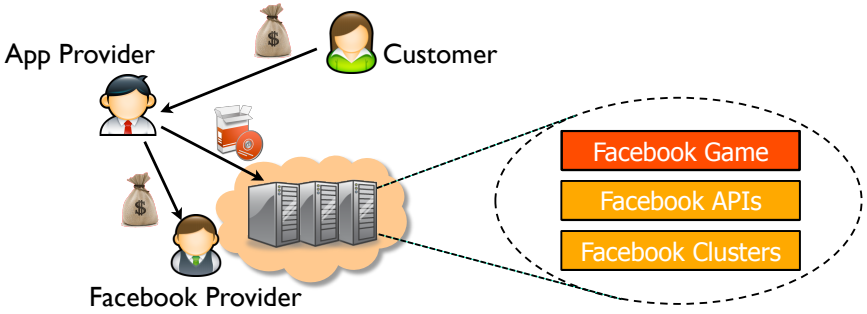

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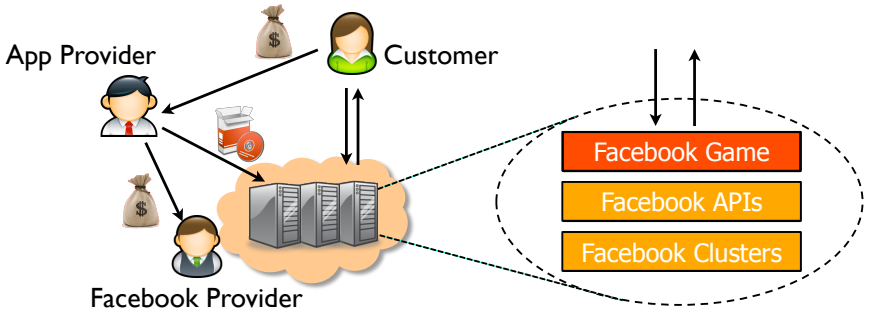

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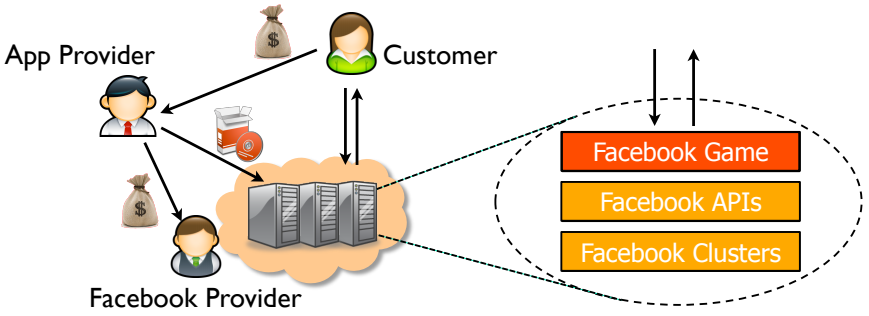

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  - Facebook itself also uses PaaS provided by its company, e.g., log analysis for recommendations

Infrastructure as a Service (IaaS)

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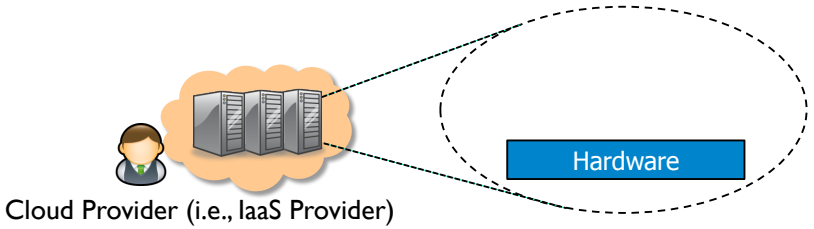

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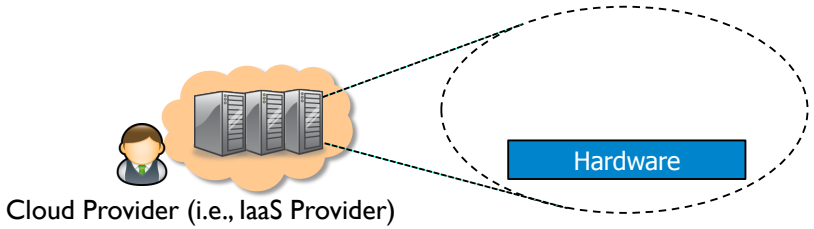

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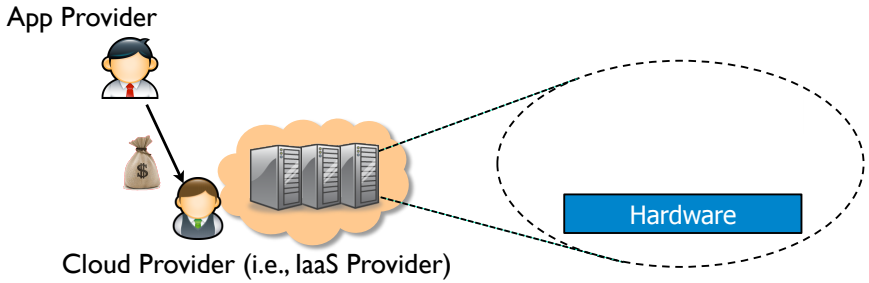

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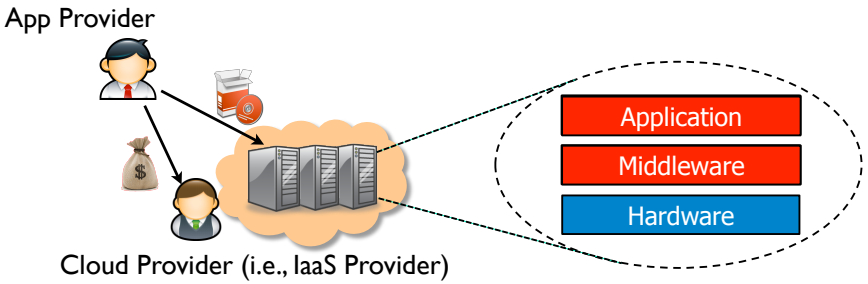

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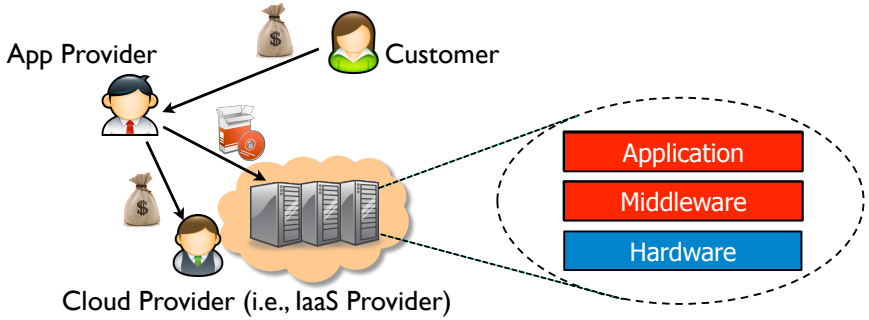

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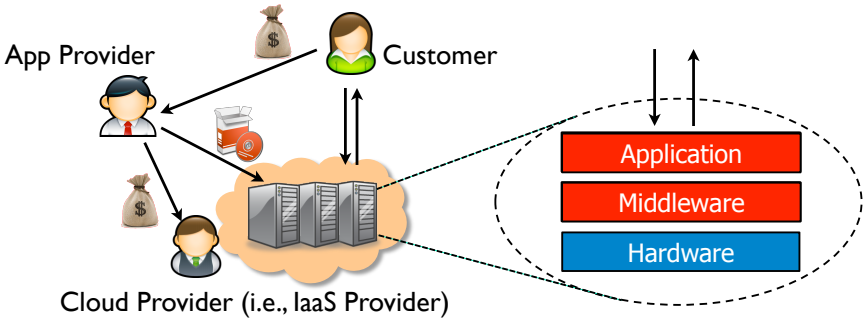

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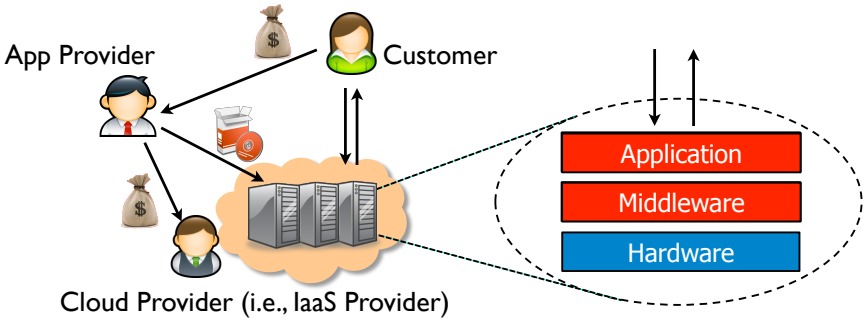

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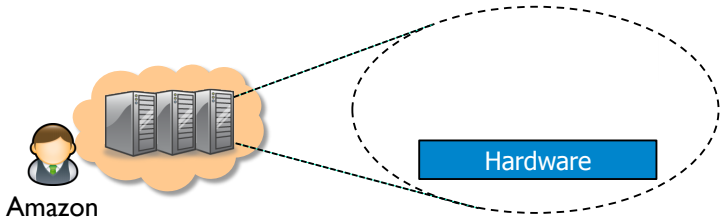
  - Example: Amazon Web Services, Rackspace Cloud, etc.

IaaS Example: EC2 and S3

(Elastic Compute Cloud & Simple Storage Service)



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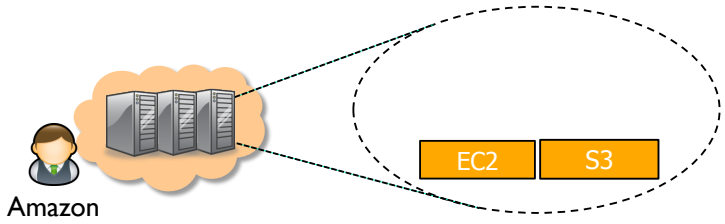

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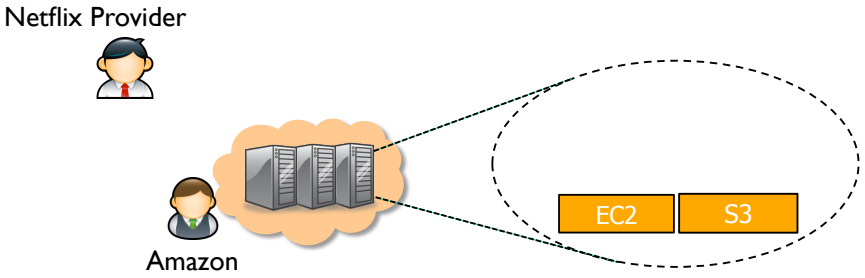
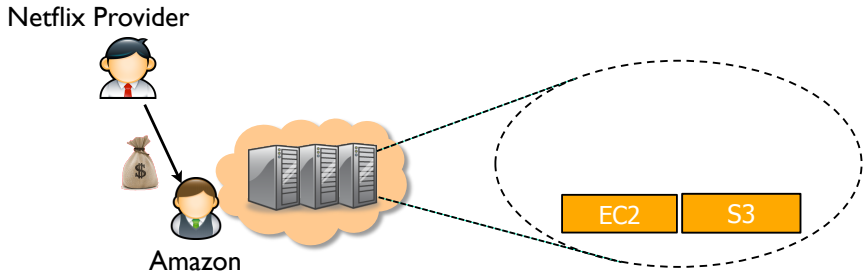


- Netflix (app) heavily depends on Amazon AWS:

IaaS Example: EC2 and S3



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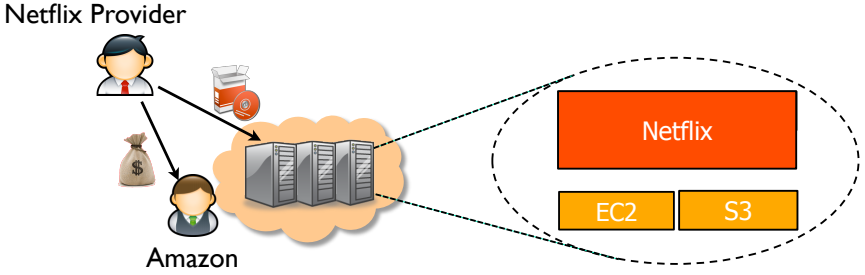

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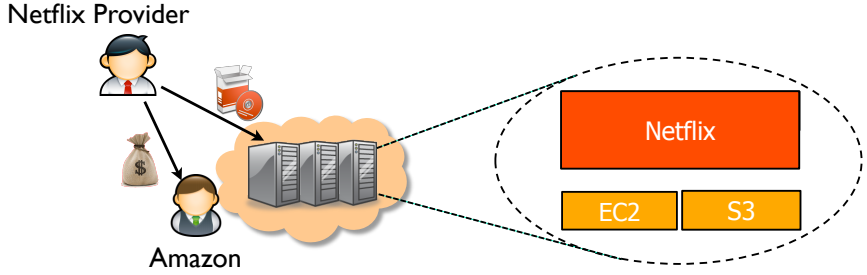

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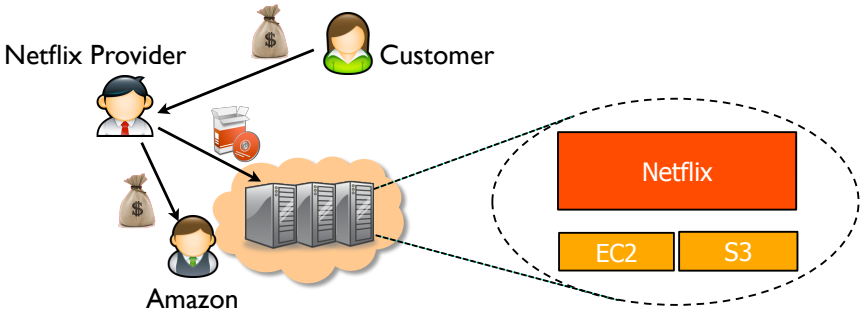
  - Transcoding to target devices (e.g., iPad) using EC2

IaaS Example: EC2 and S3



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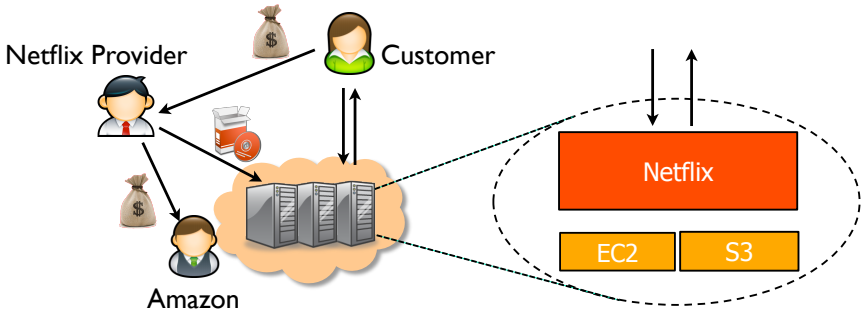

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Types of Cloud Services

- Three types of services:
  - Software as a Service (SaaS)
    - Analogy: Restaurant. Prepares&serves entire meal, does the dishes, etc
  - 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.

The Major Cloud Providers

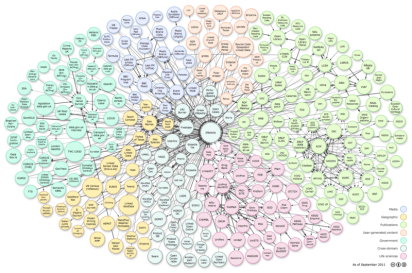
- Amazon is the big player:
  - Infrastructure as a service (e.g., EC2)
  - Storage as a service (e.g., S3)

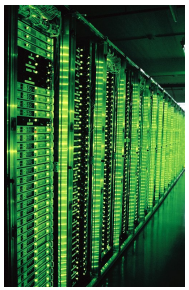
The Major Cloud Providers

- Amazon is the big player:
  - Infrastructure as a service (e.g., EC2)
  - Storage as a service (e.g., S3)
- But there are many others:
  - Microsoft Azure: It has similar services to Amazon, with an emphasis on .Net programming model
  - Google App Engine: It offers programming interface, Hadoop, also software as a service, e.g., Gmail and Google Docs
  - IBM, HP, Yahoo!: They seem to focus on enterprise scale cloud apps

Challenges?

In the cloud, we have much more data and users than before





Data! Users! Traffic!

PC

Server

Cluster

Data center

- What if cluster is too big to fit into machine room?
  - Build a separate building for the cluster
  - Building can have lots of cooling and power
  - Result: Data center

Google's Datacenter in Oregon

Data centers (size of a football field)

- 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)

Google's Datacenter Locations

Challenges?

- How to manage a huge group of data?
  - How to store the data?
  - How to process and extract something from the data?
  - How to handle multiple availability and consistency?
  - How to preserve the data privacy?

Example: Google

- How to manage a huge group of data?
  - How to store the data? Google File System & BigTable
  - How to process and extract something fro MapReduce
  - How to handle multiple ava Paxos onsistency?
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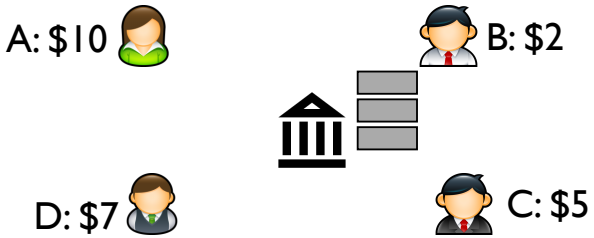
BitCoin ≠ Blockchain

The Blockchain



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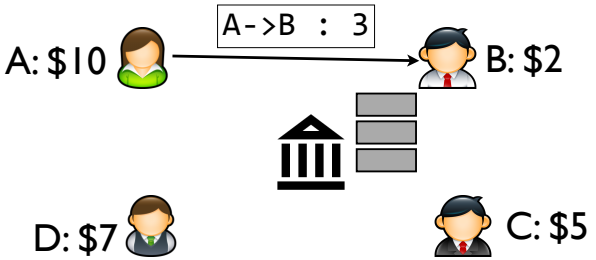

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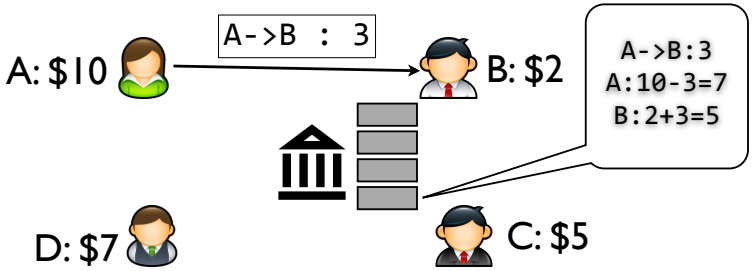

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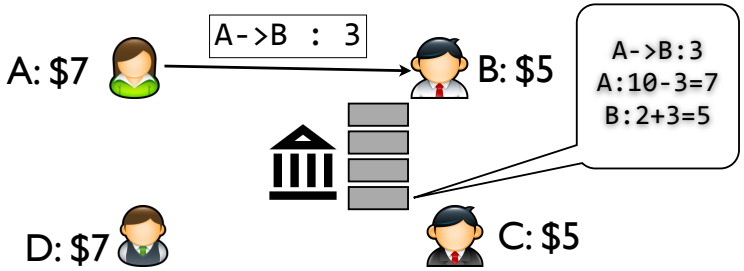

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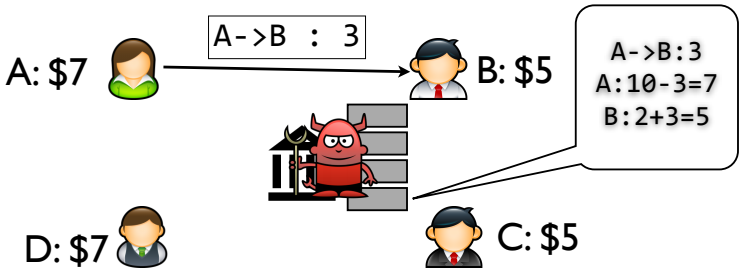
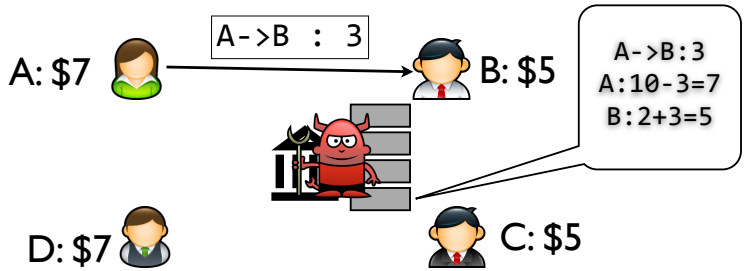


The Blockchain

- Blockchain is used to decentralize the log:



The Blockchain

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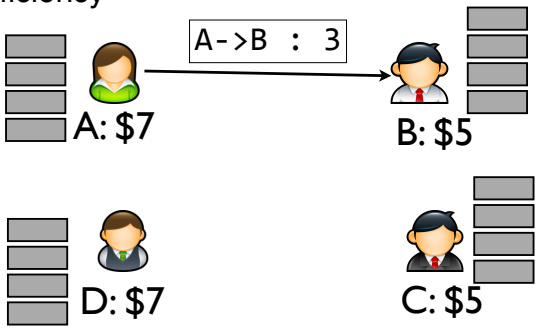
  - Decentralization
  - Public accountability
  - Efficiency



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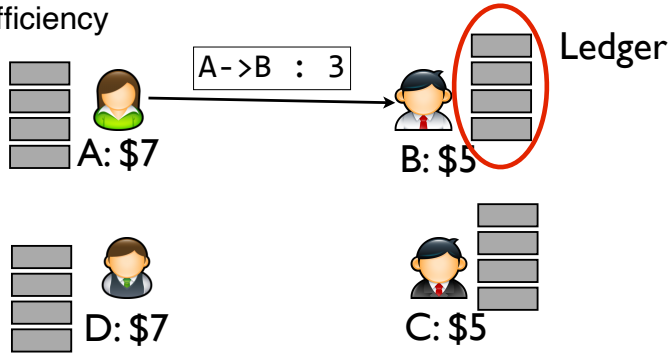
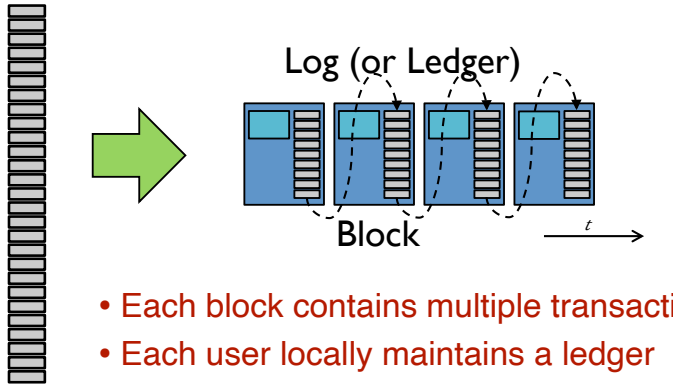


The Blockchain

Log (or Ledger)



- Each block contains multiple transactions
- Each user locally maintains a ledger
- All ledgers should have the same data

The Blockchain

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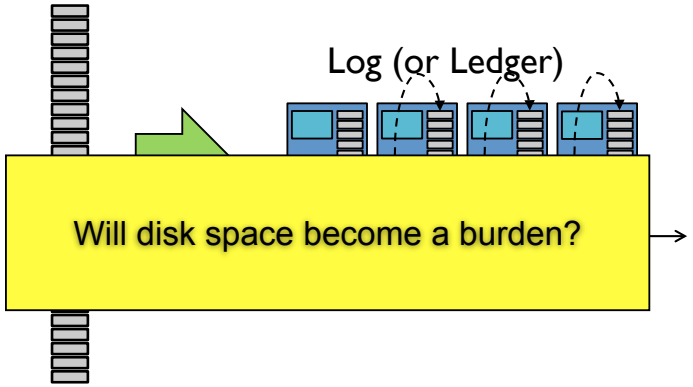

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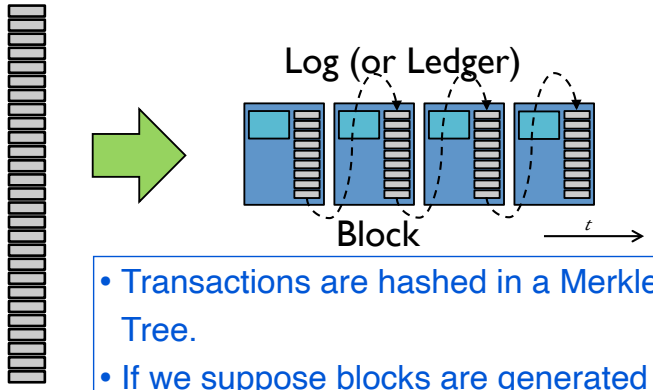

- Transactions are hashed in a Merkle Tree.
- If we suppose blocks are generated every 10 minutes, then 4.2MB per year.

The Blockchain

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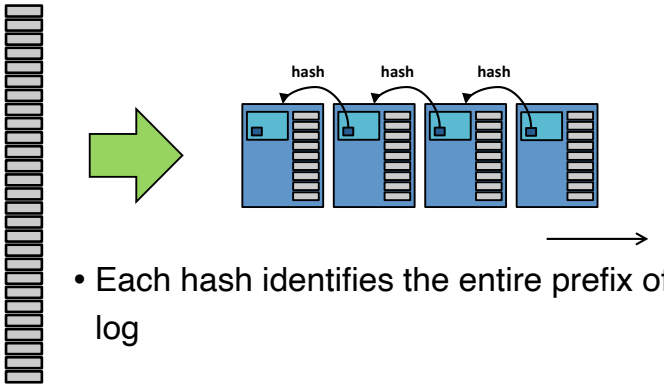
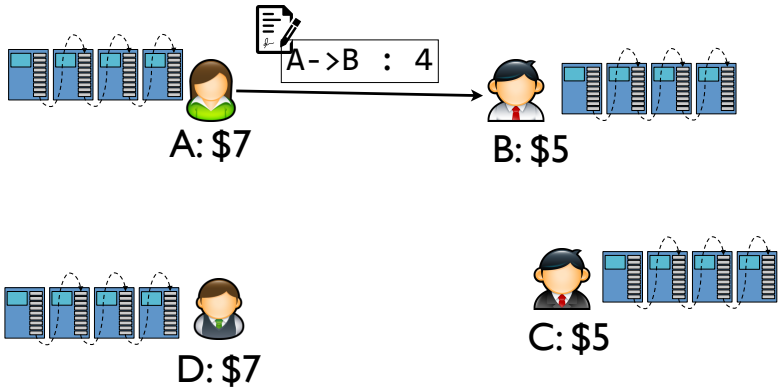


- Each hash identifies the entire prefix of the log

Transactions in the Blockchain



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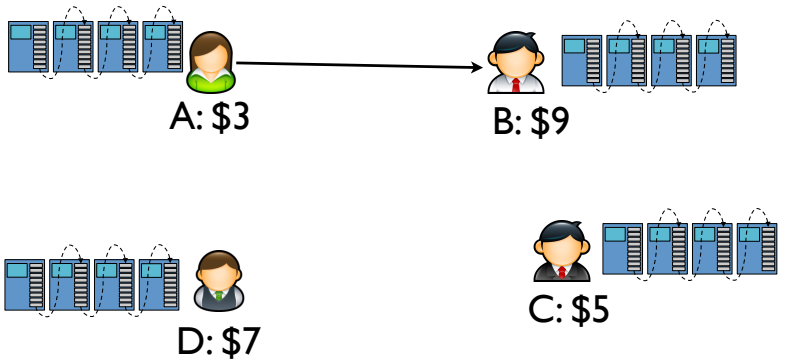

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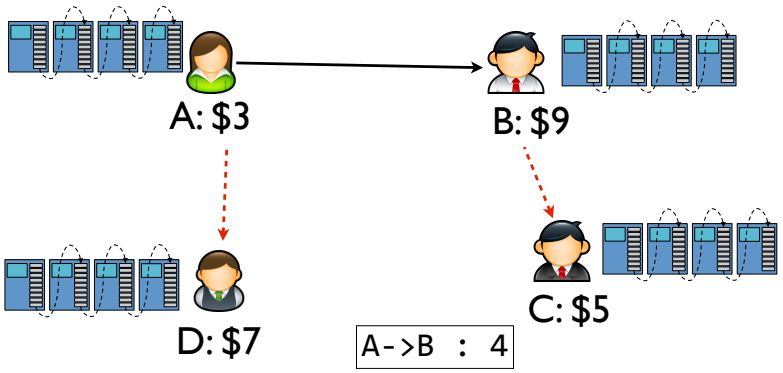

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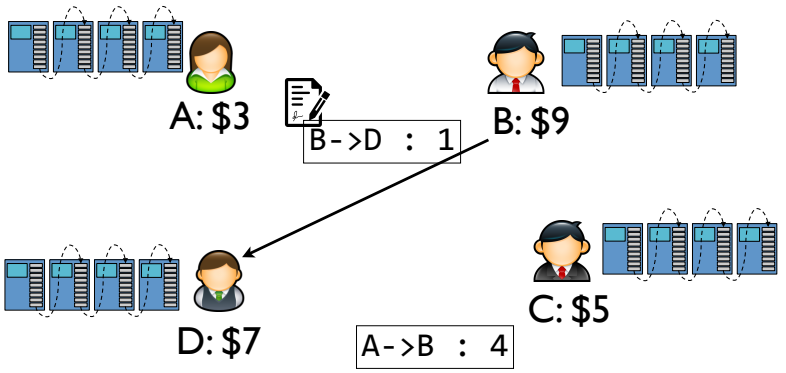

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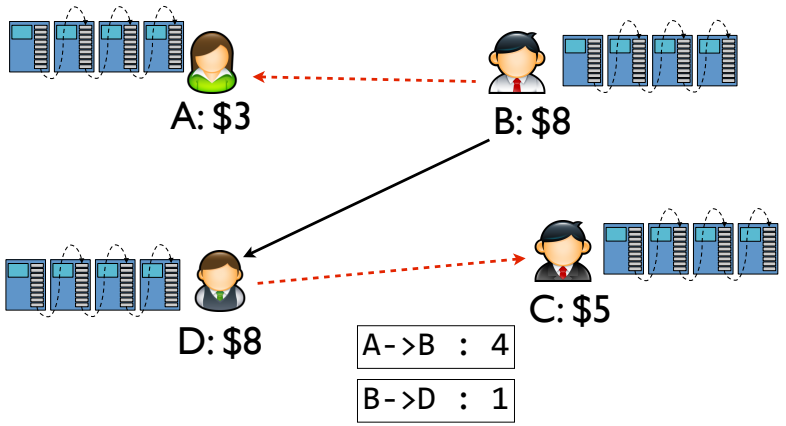
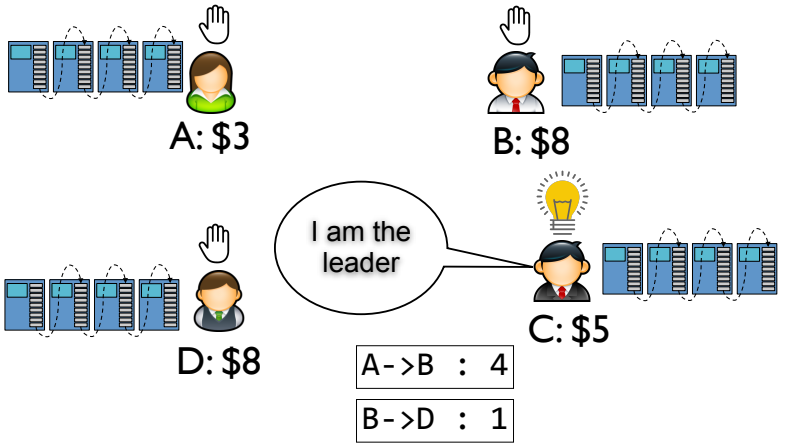
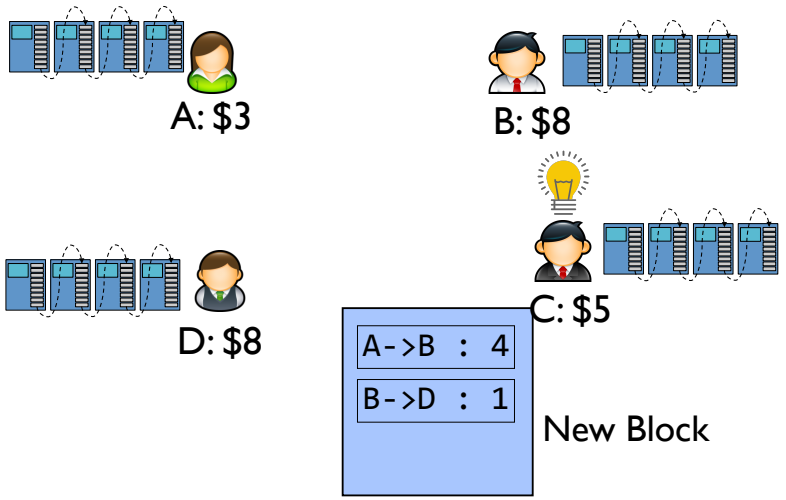


Consensus



New Block Generation



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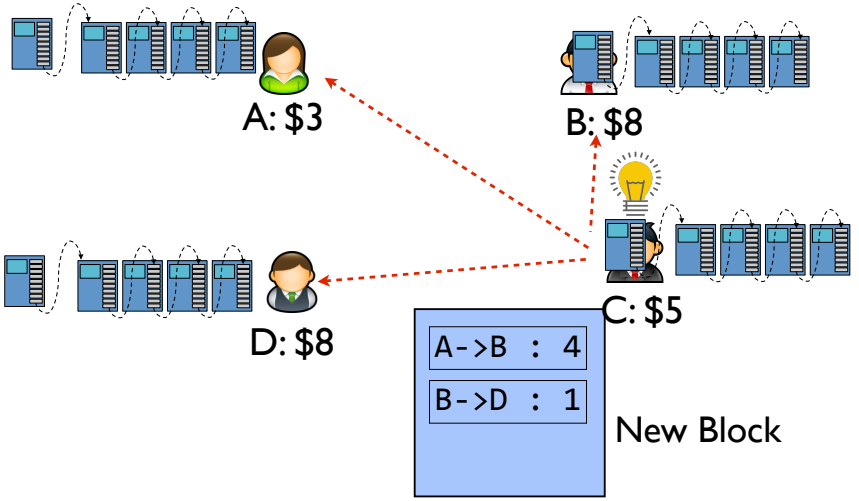

The Blockchain

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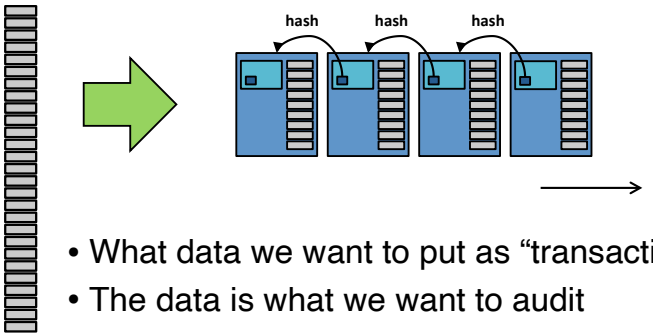
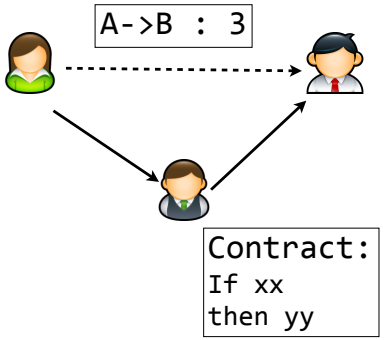
How to decentralize app via blockchain?

Log (or Ledger)



- What data we want to put as “transaction”
- The data is what we want to audit

Smart Contract



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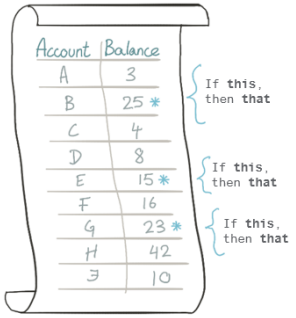

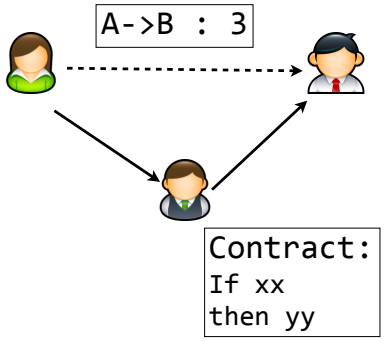

Example

- You are planning to ship a laptop to your friend Bob
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You and Tom have to sign a contract.

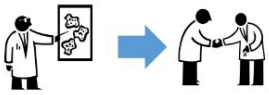
Example

- We can use smart contract:
  - You and Tom define all the rules in code
  - You make a payment for shipment to smart contract on a day of loading.
  - It holds payment till shipment delivery is confirmed by Bob.
  - Smart contract releases the payment and money is transferred to Tom automatically.

Another Example

Doctor informs patient that they need to exercise

Another Example



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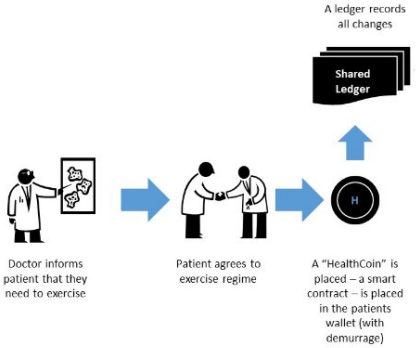

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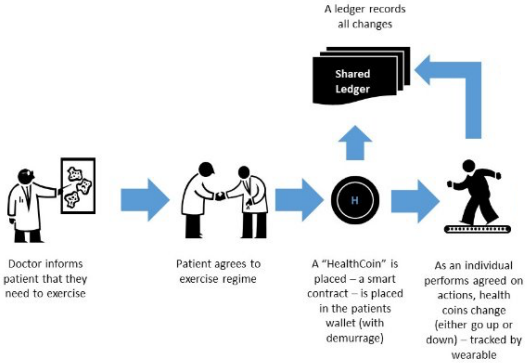

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As an individual performs agreed on actions, health coins change (either go up or down) – tracked by wearable

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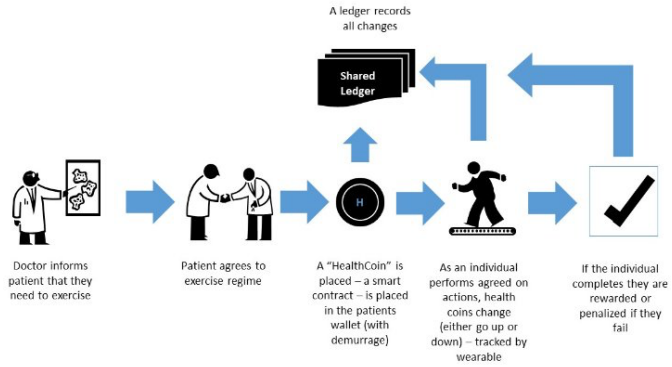

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- We still have two problems:
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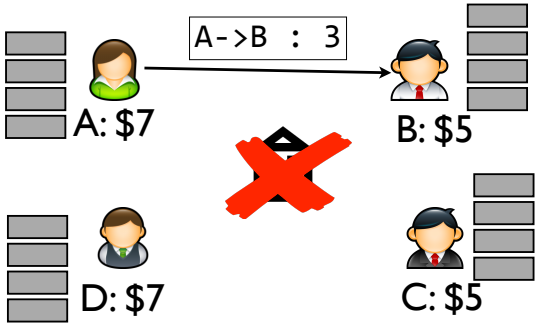
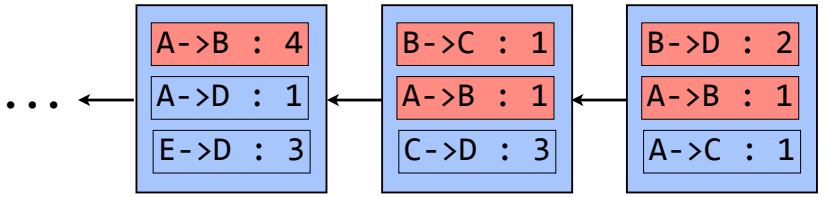
Deployment of BitCoin Nodes

- Blockchain is used for a decentralized bank:
  - Each user has several wallets (public keys)
  - They sign the money transaction using the private key



How to compute BitCoin?



If B's initial value is 0, then B is 4-1+1-2+1=3

How to compute BitCoin?

Inputs

Previous output (index)	Amount	From address	Type	ScriptSig
eb38f77560ca…:1	8	1P9SgqzjFWgWVAuZBFwimNPV7LauaJpgTj	Address	30450220078df7c48ed152bd40eaee4a73afefc3 044760639da2c0d6158484e1a4dab332fefc4bb
b912994fca58…:1	0.03	18Mk65wV1E5kCVHFShvUTU6zt4yVFKM5Ft	Address	304502204e877fc5ca3783e165052e64c4788dd 04769bbfc55cbd412784e024c8624f8c4f42d7cb
58379d94fe85…:15	1	1G4hfnM2nfAPEECdawg5grvUTBB2PxvLr2	Address	3044022075d23fd4a80048667772 10f51f46c96 046dd45b37fe3ff33f1563458cfbdfb7f922d1b4a
fc9d1cd1c2ac…:1	130	1LpQVnJSMgqqhQBGZwboobdX2Glm9YWyC7	Address	3046022100a65a188b89a4e5ae2eaa5ba387503 04ba81a1a538c5ddf7e0c76884497ab522456b9
7b6f7d4a521c…:1	0.55357267	16Kb6XppHUbjgmYQDpRyxz9JNE9Az5Xvcb	Address	3045022100eeb76e61abe62d38fd462eafd1d11f 04f4fa1d3e26f3e7058038871a31b8bf636fd127f6
544097a30e09…:0	0.03270607	1JnsDx1g6c757z8AnJUemj46YQgCTw54QN	Address	3045022100859df2ced47493e86a849cce10615 04de257fe6490bd16188be6d06ca7b34816fa4b

139.6

Outputs

Index	Redeemed at input	Amount	To address	Type	ScriptPubKey
0	8baaca27d158…	0.01071174	1E7BgzQbyWTWzEMUKNrzLdjkbjaQT9K96m	Address	OP_DUP OP_HASH160 9abd2e0c0a63dea36b75c3128fe15d82f274e394 OP_EQUALVERIFY OP_CHECKSIG
1	1bb973b4cce8…	139.605567	1NT2rFMa11NiCZydt4kqgXRZPf3iS6ZPGZ	Address	OP_DUP OP_HASH160 eb471d7a903e538cb94c1f2faf20eaadad8479af OP_EQUALVERIFY OP_CHECKSIG

139.6

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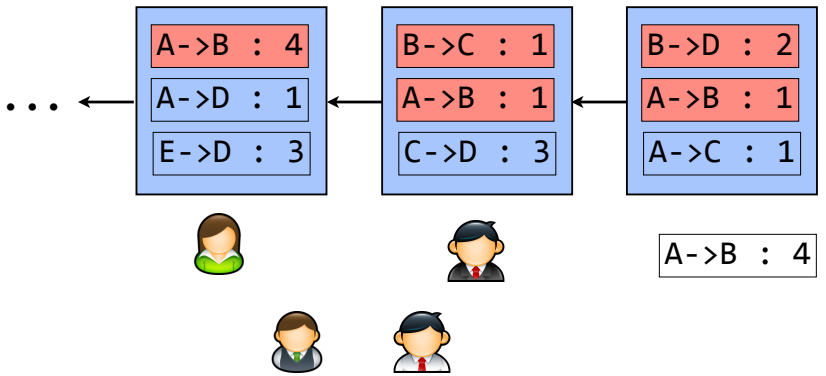

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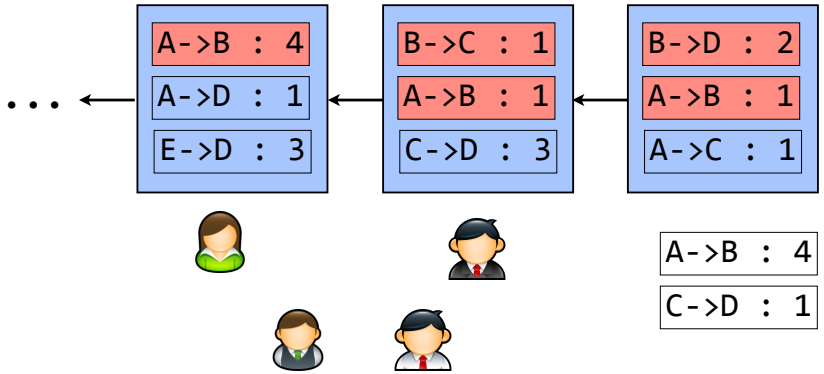
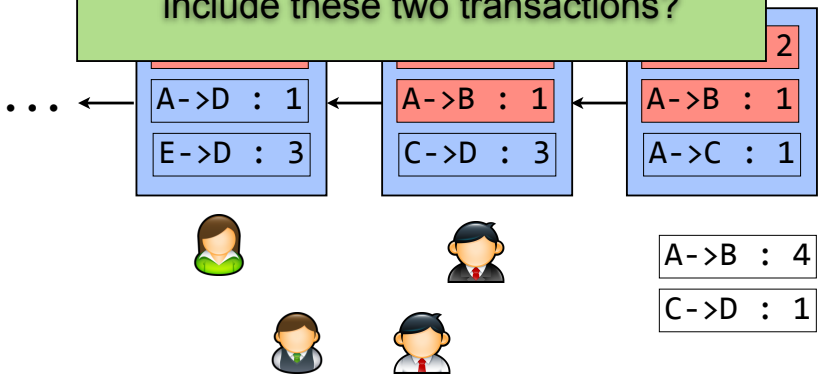
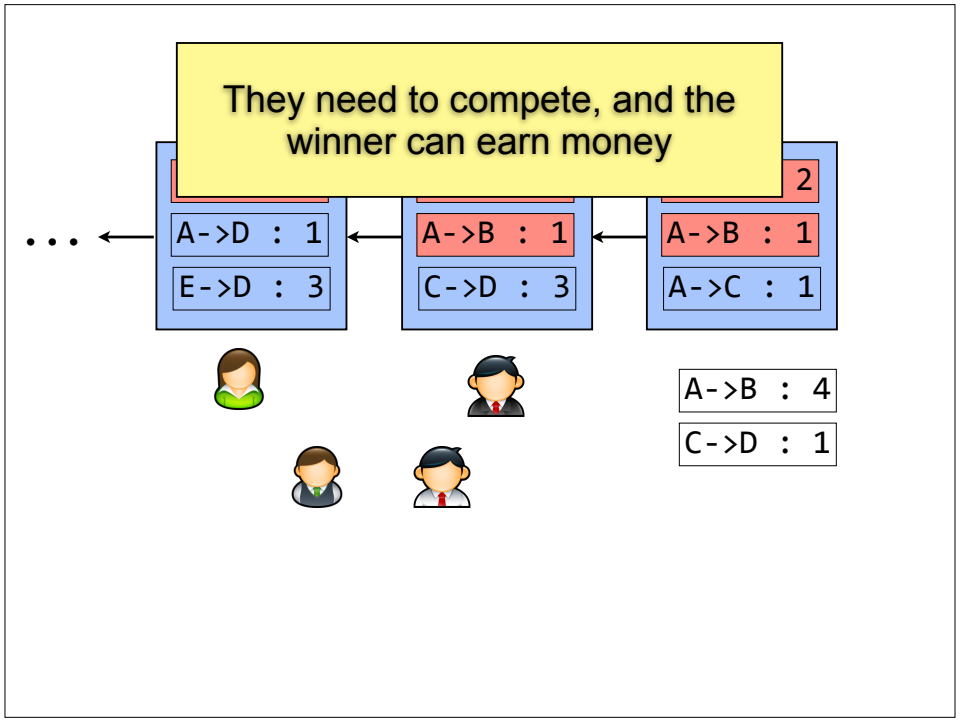
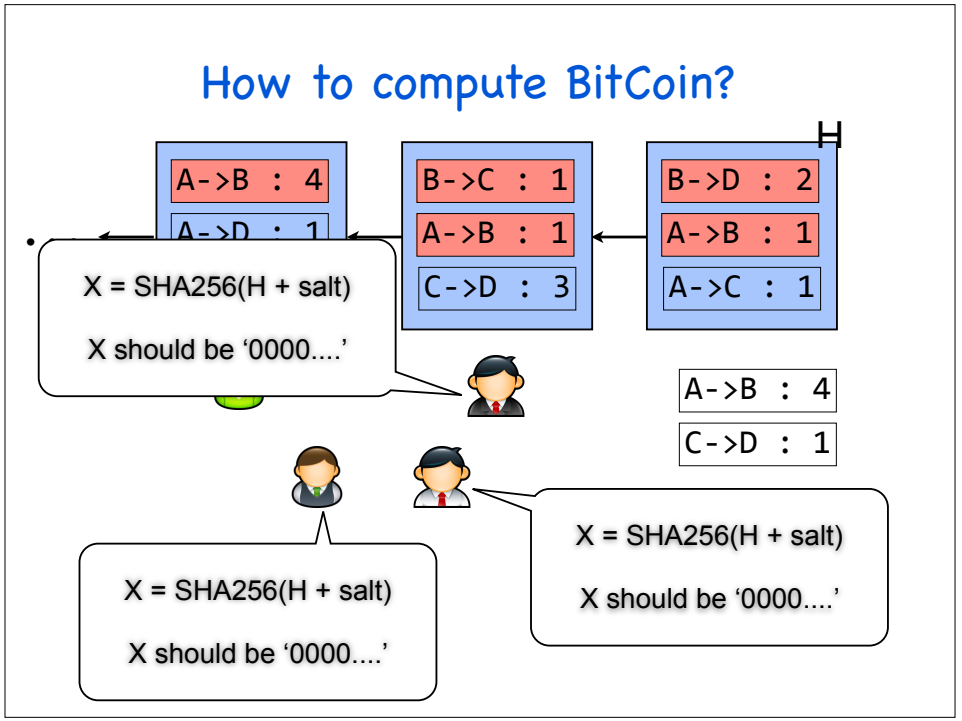


Who should generate a new block to include these two transactions?




They need to compete, and the winner can earn money
A->D : 1
E->D : 3
A->B : 1
C->D : 3
A->B : 1
A->C : 1
A->B : 4
C->D : 1


How to compute BitCoin?
H
A->B : 4
B->C : 1
A->B : 1
C->D : 3
B->D : 2
A->B : 1
A->C : 1
X = SHA256(H + salt)
X should be '0000....'
A->B : 4
C->D : 1
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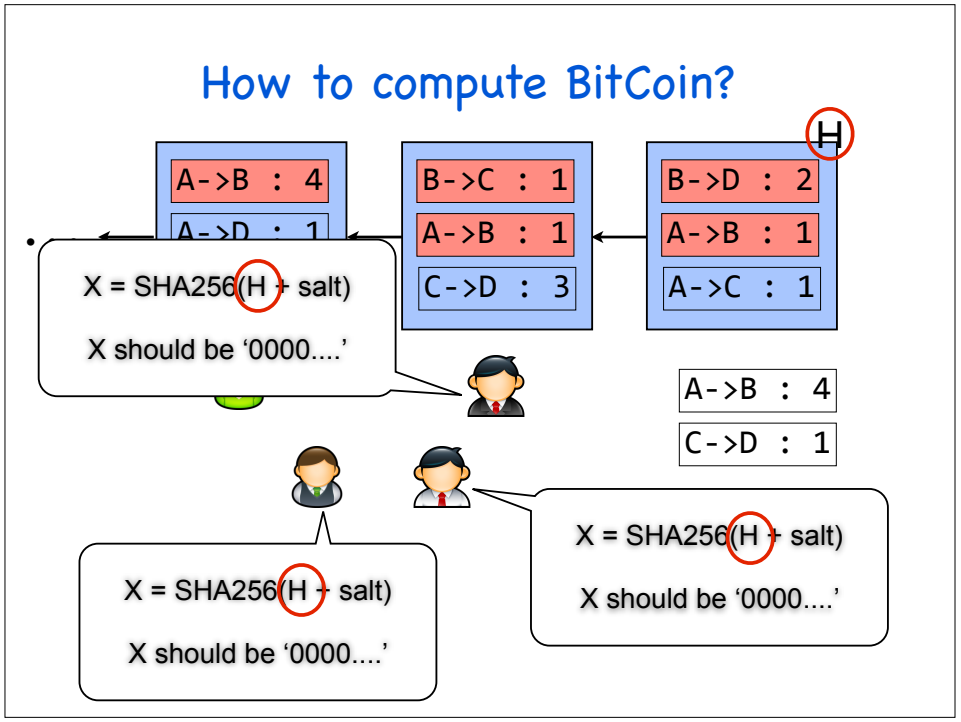
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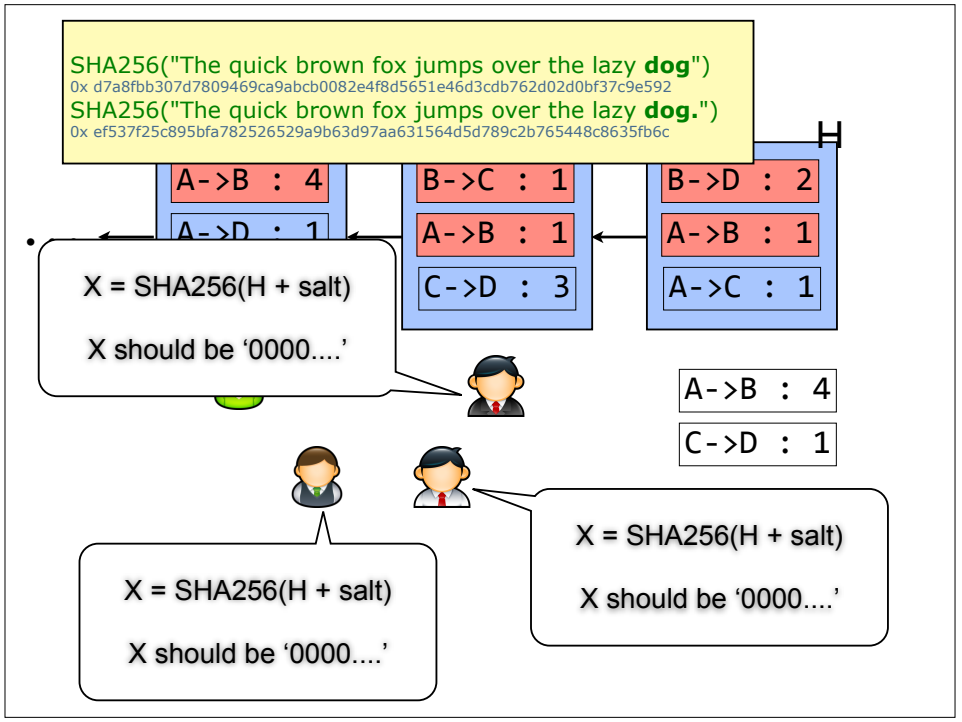
SHA256("The quick brown fox jumps over the lazy dog")
0x d7a8fbb307d7809469ca9abcb0082e4f8d5651e46d3cdb762d02d0bf37c9e592
SHA256("The quick brown fox jumps over the lazy dog.")
0x ef537f25c895bfa782526529a9b63d97aa631564d5d789c2b765448c8635fb6c
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B->C : 1
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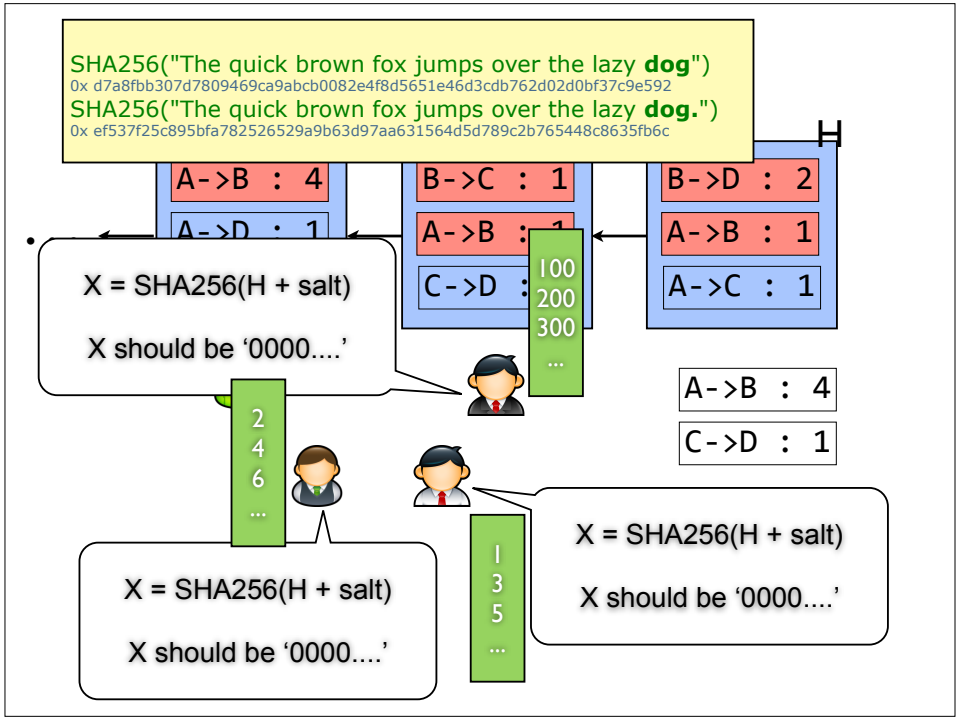

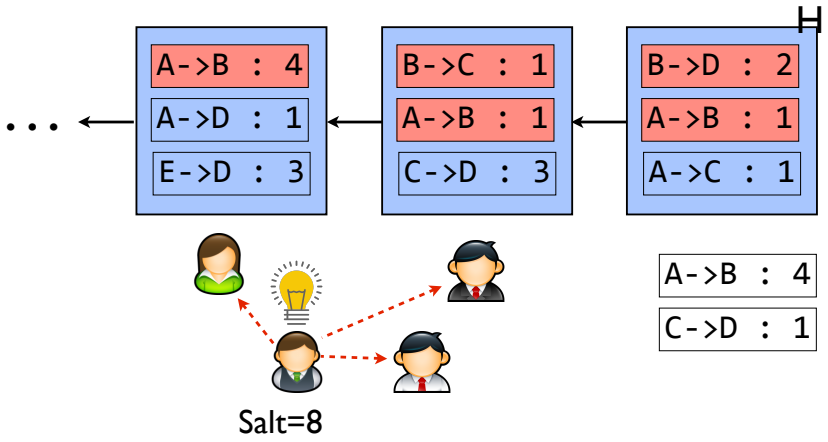

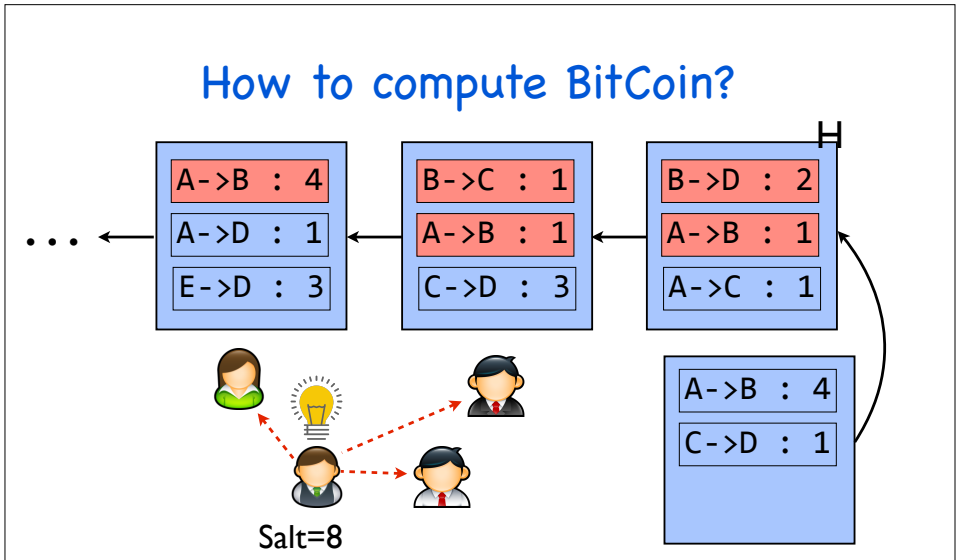

Proof of Work

- BitCoin uses the proof of work to achieve many goals:
  - Generating additional money
  - Achieving consensus while tolerating malicious users
  - A great incentive mechanism

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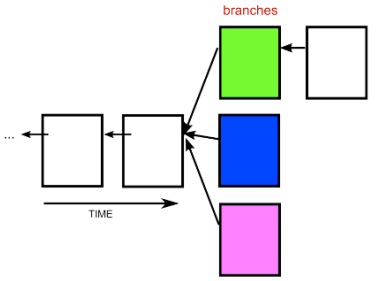
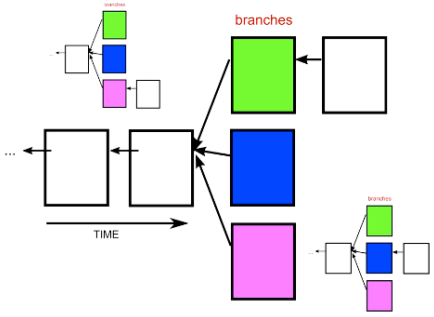
Proof of Work

- Occasionally, more than one block will be solved at the same time, leading to several possible branches



Proof of Work

- We should build on top of the first one you received.
- Others may have received the blocks in a different order, and will be building on the first block they received



Example

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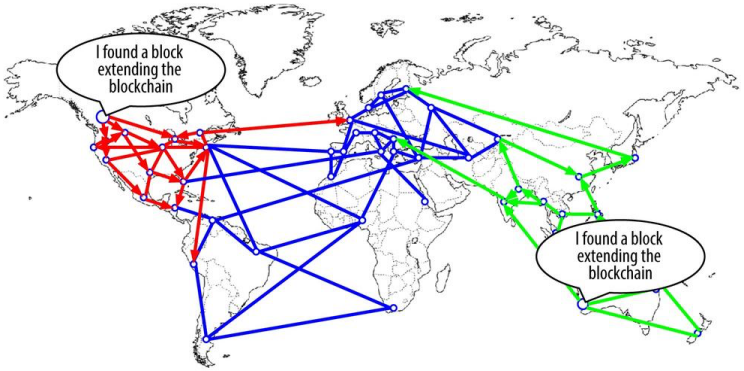

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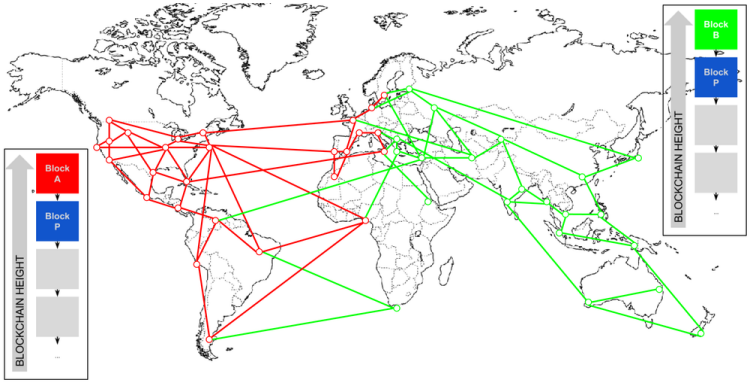

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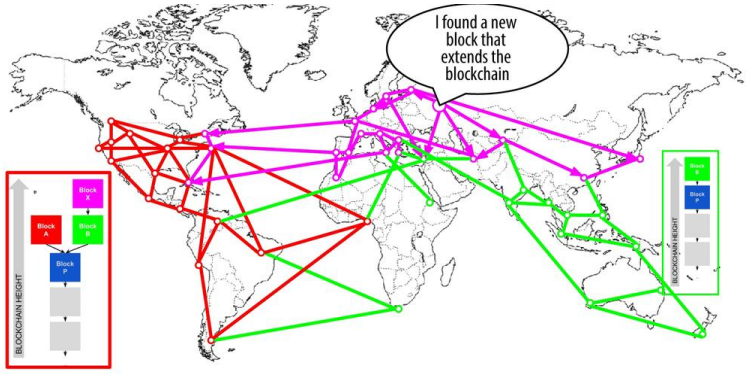

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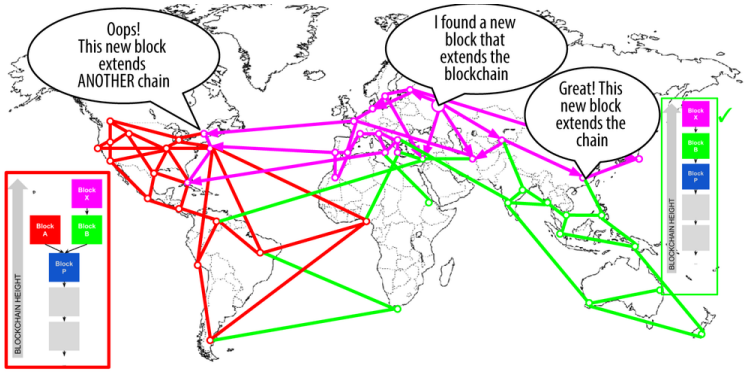

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- We do not need to worry about the branch problem:
  - You always immediately switch to the longest branch
  - The math makes it rare for blocks to be solved at the same time, and even more rare for this to happen multiple times
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Miners in BitCoin can earn a lot of money!

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- Your transactions are confirmed after 6 blocks

Miner's life