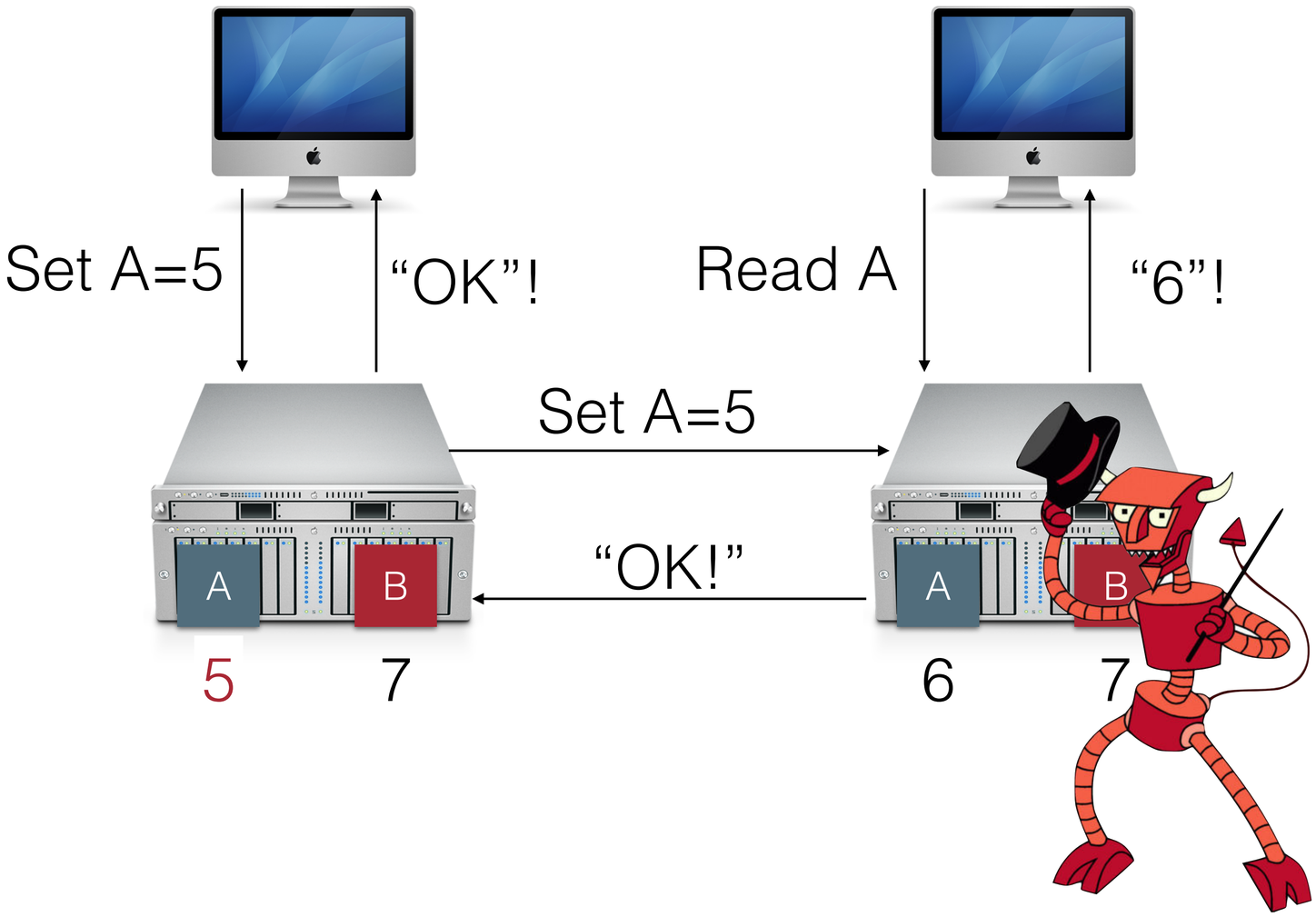
Security in Distributed Systems

CS 475, Spring 2019
Concurrent & Distributed Systems

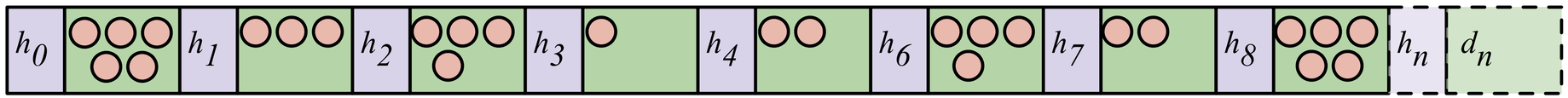
GEORGE MASON UNIVERSITY

Byzantine Faults



Blockchains

- Solution: make it hard for participants to take over the network; provide rewards for participants so they will still participate
- Each participant stores the entire record of transactions as blocks
- Each block contains some number of transactions and the *hash* of the previous block
- All participants follow a set of rules to determine if a new block is valid



Today

- Today:
  - Security in Distributed Systems
  - Discussion of course structure
- Final Exam info:
  - Primary focus is second half of semester (starting from Networks), still responsible for concepts from first half (notably mutual exclusion, locking granularity)
- Reminder - Project is out!
  - Fault-tolerant, sequentially consistent replicated key value store
  - Can do in a group (1 to 3 students per group)

Security isn't (always) free

- You just moved to a new house, someone just moved out of it. What do you do to protect your belongings/property?
- Do you change the locks?
- Do you buy security cameras?
- Do you hire a security guard?
- Do you even bother locking the door?

Security: Managing Risk

- Security architecture is a set of mechanisms and policies that we build into our system to mitigate risks from threats
- Threat: potential event that could compromise a security requirement
- Attack: realization of a threat
- Vulnerability: a characteristic or flaw in system design or implementation, or in the security procedures, that, if exploited, could result in a security compromise

What does it mean for a distributed system to be secure?

- Maintain a secure channel between nodes:
  - Authenticity (Who am I talking to?)
  - Confidentiality (Is my data hidden?)
  - Integrity (Has my data been modified?)
  - Availability (Can I reach the destination?)
- Maintain some security about who participates in the system?
- What cryptographic tools are available to us?

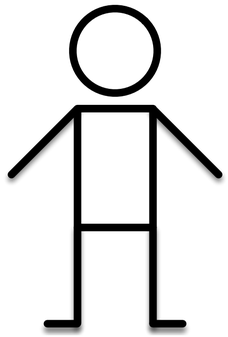
Costs & Benefits

- Increasing security might:
  - Increase development & maintenance cost
  - Increase infrastructure requirements
  - Degrade performance
- But, if we are attacked, increasing security might also:
  - Decrease financial and intangible losses
- So: How likely do we think we are to be attacked in way **X**?

Threat Models

- What is being defended?
  - What resources are important to defend?
  - What malicious actors exist and what attacks might they employ?
- Who do we trust?
  - What entities or parts of system can be considered secure and trusted
  - Have to trust **something**!

Example Threat: Web Server



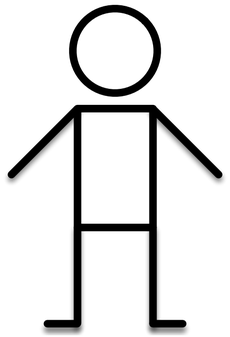
HTTP Request

HTTP Response

client page
(the “user”)

server

Example Threat: Web Server



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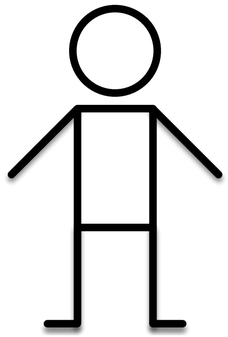
server

Do I trust that this request *really* came from the user?

Example Threat: Web Server



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Do I trust that this response *really* came from the server?

Do I trust that this request *really* came from the user?

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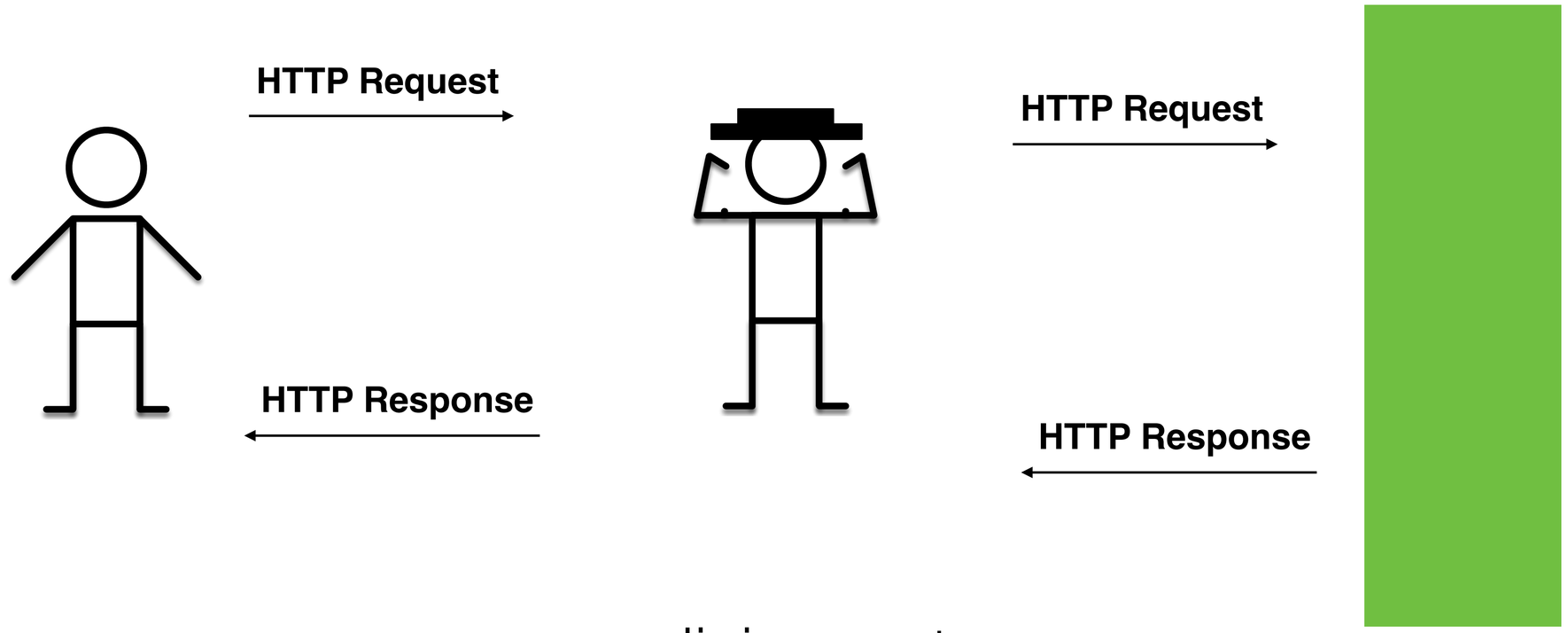


client page
(the "user")

malicious actor
"black hat"

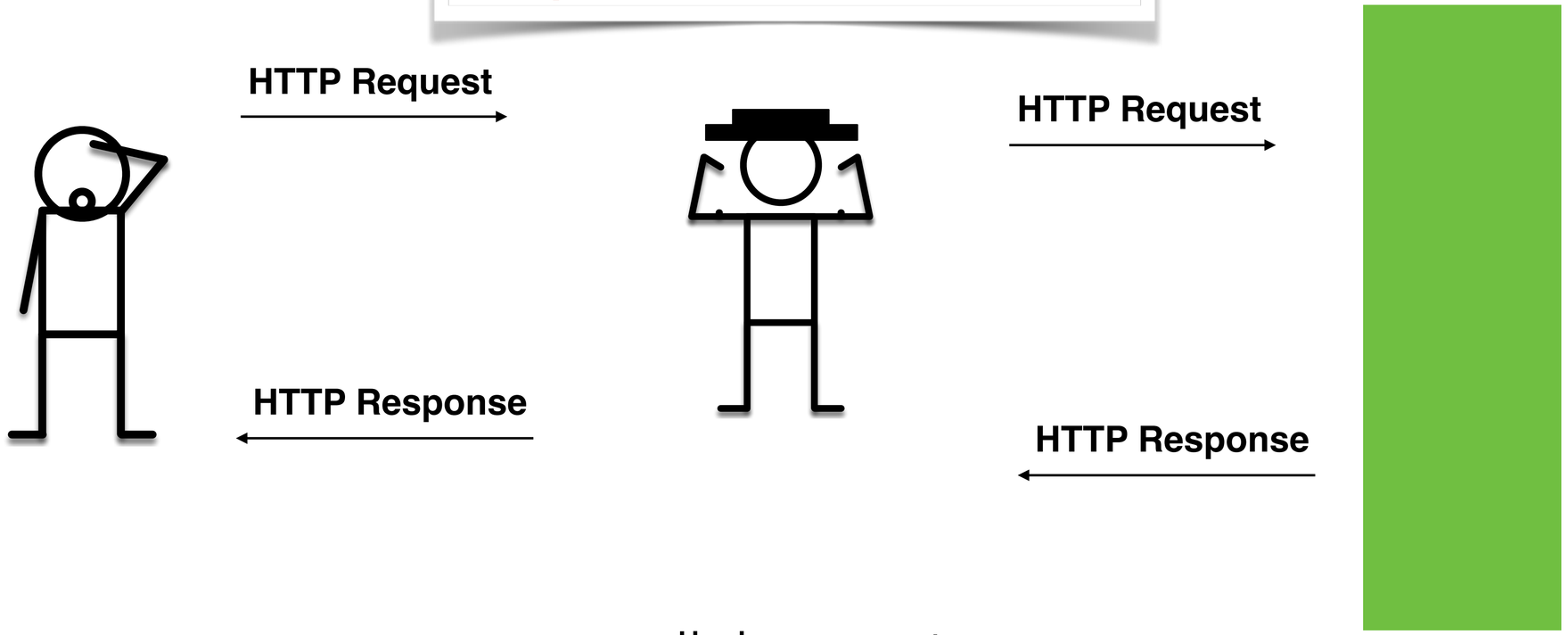
server

Do I trust that this response *really* came from the server?

Do I trust that this request *really* came from the user?

Example Threat: Web Server

Might be "man in the middle" that intercepts requests and impersonates user or server.



client page
(the "user")

malicious actor
"black hat"

server

Do I trust that this response *really* came from the server?

Do I trust that this request *really* came from the user?

Other Risks

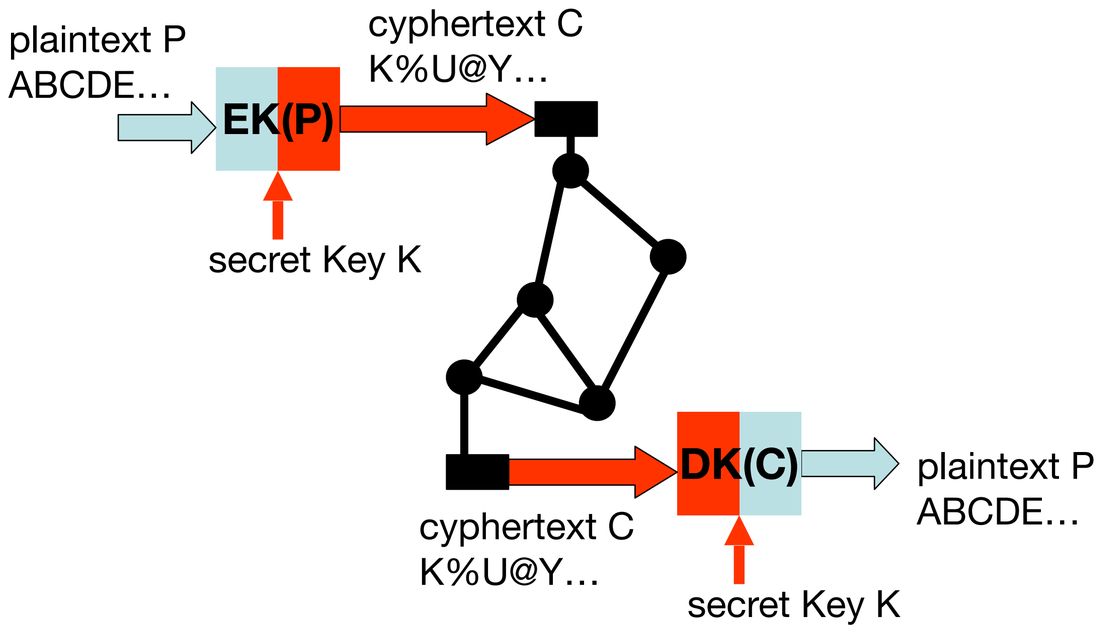
- Is our network well behaved?
- Is our network malicious?
- Who can access our system?
- Are our users well-behaved?
- Are our users malicious?
- Is our system well behaved?

Protection Concerns

- Secure channels of communication
  - Authentication: is everyone who they say they are?
  - Confidentiality & integrity: is a third party interfering in our communication?
- Access Controls
  - Authorization: Who has access to an operation/resource?
  - Accountability: Maintaining an audit trail
  - Non-repudiation: A participant can not deny some action that they took with the system

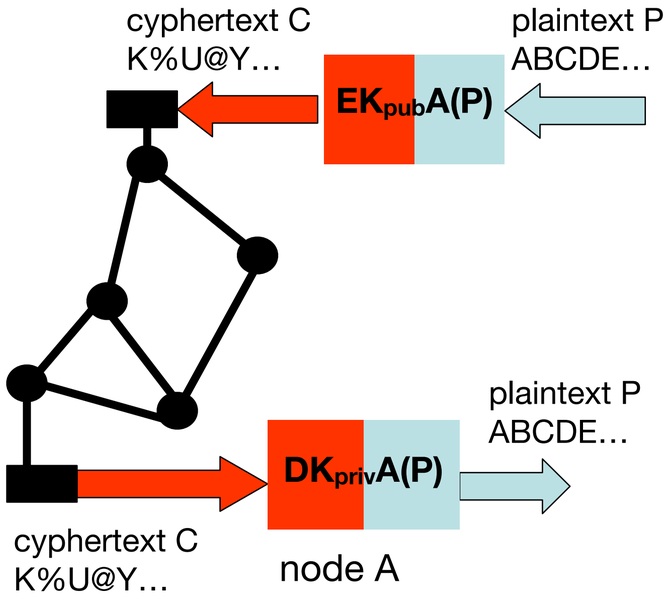
Symmetric encryption, aka shared secret key

- $M = D_K(E_K(M))$
- M is the data, D is decrypt, E is encrypt, and k is the key
- Computationally efficient (relatively)
- Can have hardware support too (e.g. iPhone)



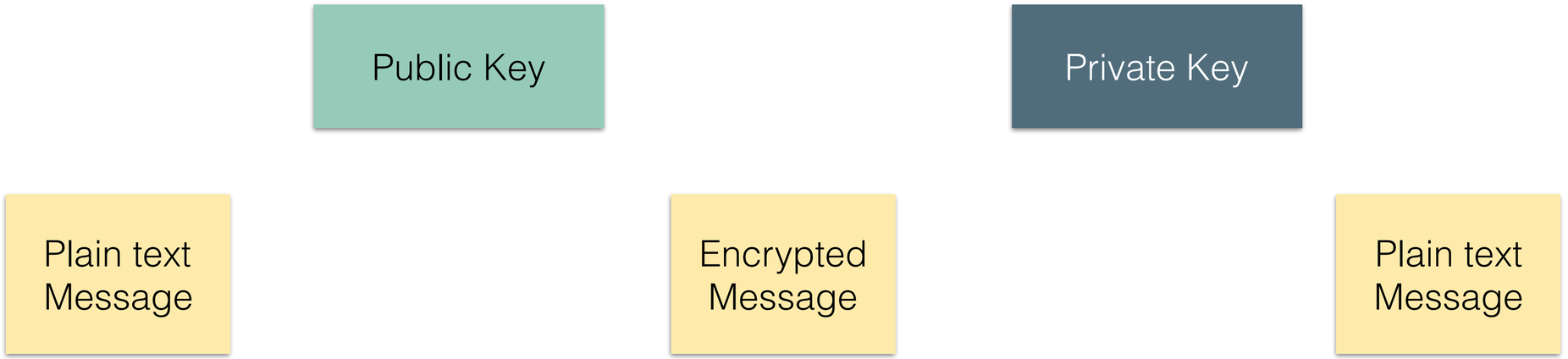
Asymmetric encryption, aka public key/private key

- $M=DK_{priv}(EK_{pub}(M))=DK_{pub}(EK_{priv}(M))$
- When a node B wants to send a message to node A, it obtains A's public key and uses $K_{APublic}$ to encrypt the message
- Only A can decrypt the message using its private key
- Computationally expensive



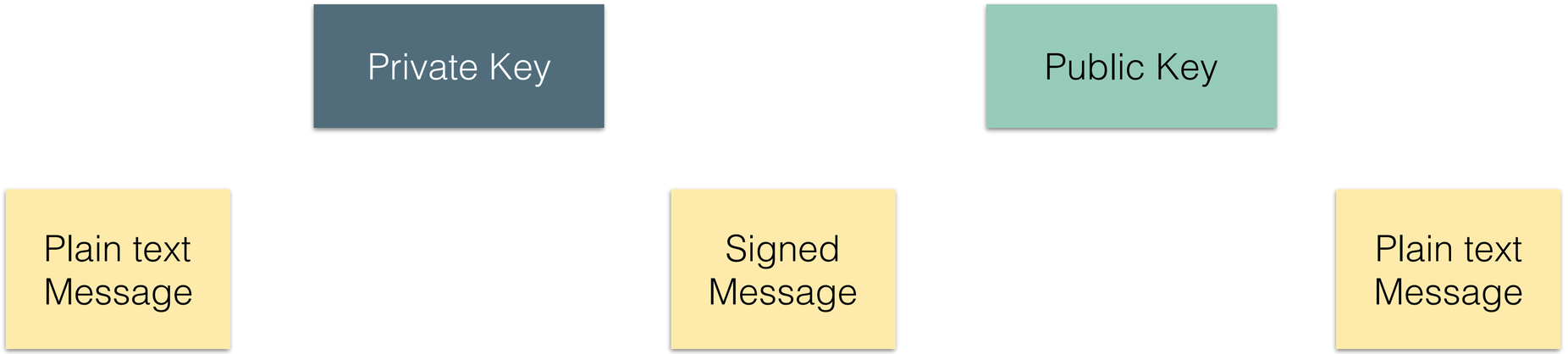
Public/Private Key Encryption

- Encrypt with public key: only private key holder can decrypt



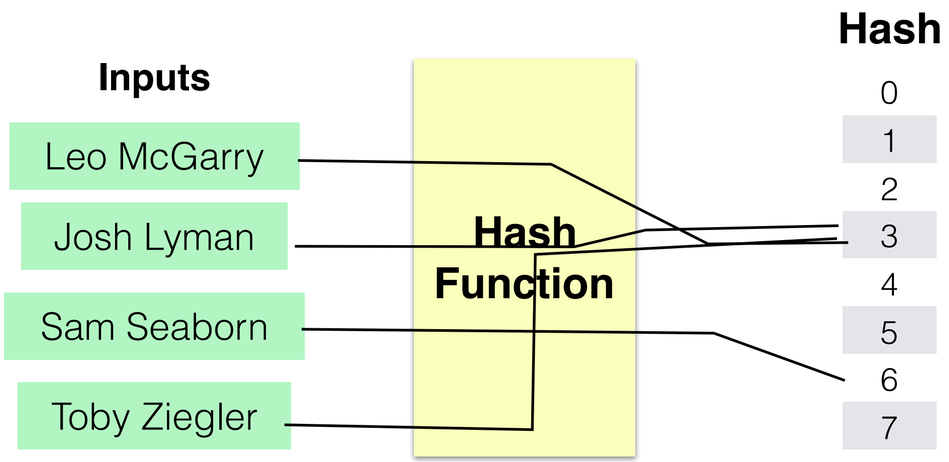
Public/Private Key Encryption

- Encrypt with private key: anyone with public key can decrypt



Hashing

- S = H(M)
- S, aka digest, is a unique representation of data such that an accidental or intentional change to the data will change the representation
- Fixed size and independent of size of M
- Computationally efficient



Hashing to verify messages

- Just sending a hash of the message isn't enough!
- How do we know that a third party didn't tamper with the message *and* the hash?
- Solution: encrypt the hash using your private key. Anyone can verify that the hash was "signed" by you

Symmetric vs Asymmetric Crypto

	Symmetric Crypto	Asymmetric Crypto
Requires a pre-shared secret	Yes	No
Relative speed	Very fast	Very slow

Asymmetric Cryptography

- So, great: no need to pre-share anything, right!
- Widely used for instance... HTTPS! SSL!
- But: there's a bootstrapping problem
- When you visit amazon.com, the site will sign its content using its private key
- You can use amazon.com's public key to verify it's really from amazon.com
- How do you know what amazon.com's public key is though?
- “PKI” - Public Key Infrastructure

Certificate Authorities

- A certificate authority (or CA) binds some public key to a real-world entity that we might be familiar with
- The CA is the clearinghouse that verifies that amazon.com is truly amazon.com
- CA creates a certificate that binds amazon.com's public key to the CA's public key (signing it using the CA's private key)

Certificate Authorities

Amazon

amazon.com
private key

amazon.com
public key

Some [illegible] world proof th[illegible]ve are r[illegible] amazon.com

amazon.com certificate
(AZ's public key + CA's sig)

amazon.com certificate
(AZ's public key + CA's sig)

Certificate Authority

CA private key

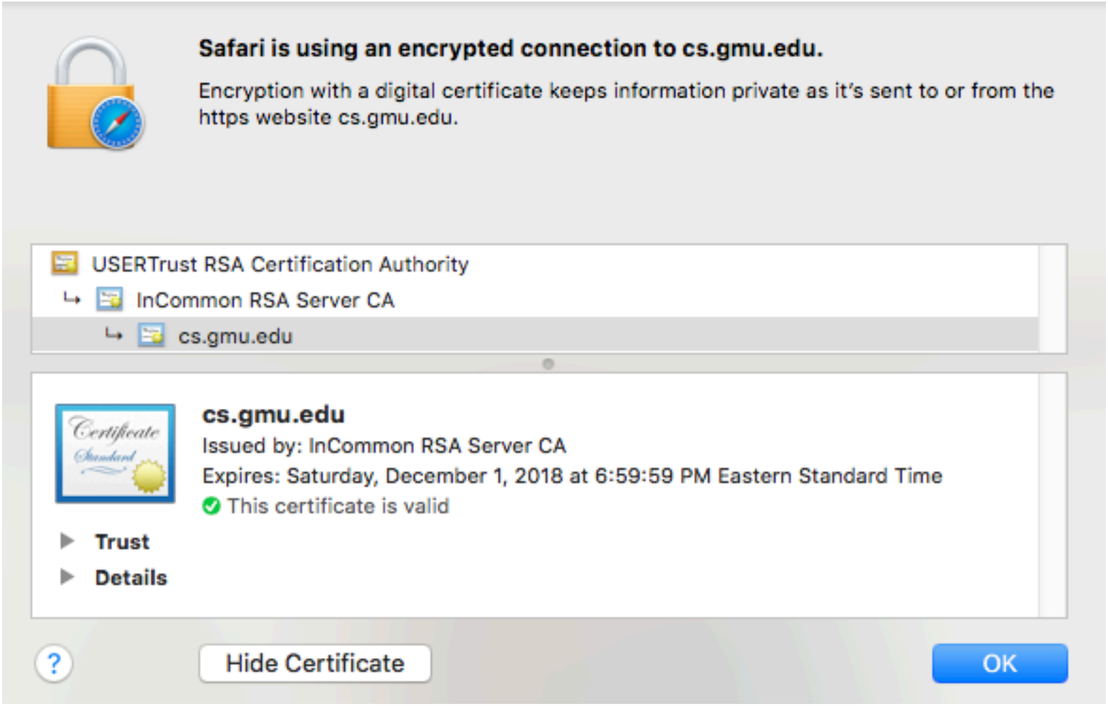
CA public key

My Laptop

CA public key

Certificate Authorities

- Note: We had to already know the CA's public key
- There are a small set of “root” CA’s (think: root DNS servers)
- Every computer/browser is shipped with these root CA public keys



Certificate Authorities

- What happens if a CA is compromised, and issues invalid certificates?
- Not good times.

Security

Fuming Google tears Symantec a new one over rogue SSL certs

We've got just the thing for you, Symantec ...

By Iain Thomson in San Francisco 29 Oct 2015 at 21:32 36 SHARE ▼

Google has read the riot act to Symantec, scolding the security biz for its

Security

Comodo-gate hacker brags about forged certificate exploit

Tiger-blooded Persian cracker boasts of mighty exploits

Denial of Service Attacks

- A significant concern for distributed systems
- An attack on **availability** - attackers prevent legitimate users from accessing system
- Can attack:
  - Bandwidth
  - CPU
  - Memory
- Core problem:
  - Costs more to process a message than to send it

Distributed Denial of Service Attacks (DDoS)

- Model: Attacker has (hundreds of?) thousands of machines at disposal to attack
- Most common form of DoS today
- Exhausts network bandwidth
- Typically rooted in a botnet - some command and control infrastructure setup by an attacker, who then controls all of these machines

Strawman Defenses

- Make a filter list of bad addresses?
- Trace down the person responsible?

Heuristic Defenses

- Overprovision
- Black-hole routing
- Filter anomalies
- Replication

Overprovisioning

- Make a DDoS-proof site by making it far bigger than it needs to be
- Provision 100x bandwidth, 100x server capacity etc. compared to what you expect
- A losing battle: an attacker can always get more bots!

Black-Hole Routing

- Limits the impact of an attack
- ISP re-routes traffic to the target site to a black hole
- Site still goes offline
- But not crashed, other sites on servers sharing network links are OK
- Most DDoS attacks are short-lived, so clears up later

Anomaly Filtering

- DDoS traffic usually has something peculiar about it…
  - Automatically generated requests following a pattern?
- Route all traffic through black-box filters that try to learn this stuff and identify anomalies
- Imperfect, but often works

Other DoS attacks

- Reflector
- Complexity

Reflector Attacks

- Exploits a publicly available service to amplify an attack
- Example: DNS
- Attacker makes a (relatively small) DNS request
- Attacker forges their own IP address with the victim's
- DNS server responds to the victim's IP address

Complexity Attacks

- Increasingly common as we find defenses for other attacks
- Idea: Can I make one request that is 100 times as hard to process as other requests?
  - Then I only need to make 1% of the requests I would have had to otherwise, in order to get the same attack!

Billion lolz

```
<?xml version="1.0"?>
<!DOCTYPE lolz [
 <!ENTITY lol "lol">
 <!ELEMENT lolz (#PCDATA)>
 <!ENTITY lol1 "&lol;&lol;&lol;&lol;&lol;&lol;&lol;&lol;&lol;&lol;">
 <!ENTITY lol2 "&lol1;&lol1;&lol1;&lol1;&lol1;&lol1;&lol1;&lol1;&lol1;&lol1;">
 <!ENTITY lol3 "&lol2;&lol2;&lol2;&lol2;&lol2;&lol2;&lol2;&lol2;&lol2;&lol2;">
 <!ENTITY lol4 "&lol3;&lol3;&lol3;&lol3;&lol3;&lol3;&lol3;&lol3;&lol3;&lol3;">
 <!ENTITY lol5 "&lol4;&lol4;&lol4;&lol4;&lol4;&lol4;&lol4;&lol4;&lol4;&lol4;">
 <!ENTITY lol6 "&lol5;&lol5;&lol5;&lol5;&lol5;&lol5;&lol5;&lol5;&lol5;&lol5;">
 <!ENTITY lol7 "&lol6;&lol6;&lol6;&lol6;&lol6;&lol6;&lol6;&lol6;&lol6;&lol6;">
 <!ENTITY lol8 "&lol7;&lol7;&lol7;&lol7;&lol7;&lol7;&lol7;&lol7;&lol7;&lol7;">
 <!ENTITY lol9 "&lol8;&lol8;&lol8;&lol8;&lol8;&lol8;&lol8;&lol8;&lol8;&lol8;">
]>
<lolz>&lol9;</lolz>
```

After parsing: this document contains “lol” repeated literally a billion times… ~3GB of RAM

Discussion of course structure

- First assignment without concurrency?
- More/less concurrency discussion at start?
- More/less programming?
- More/less detail on some topics?

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