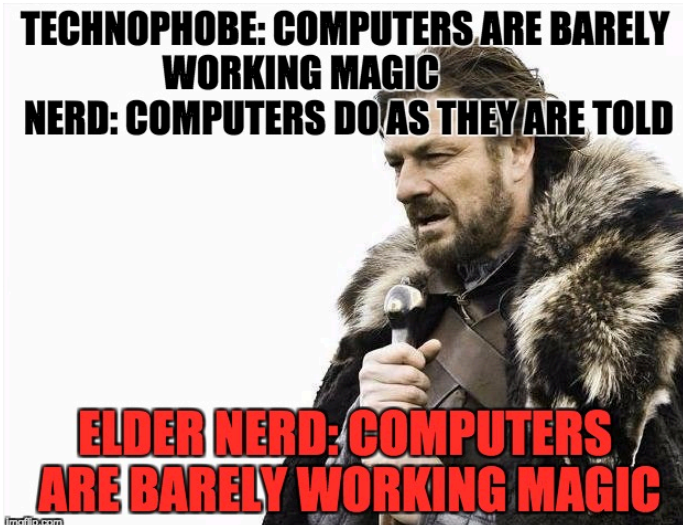
Key (mis)Management
Applied
Crypto
and Crapto



How Can We Communicate With Someone New?

- Public-key crypto gives us amazing capabilities to achieve confidentiality, integrity & authentication without shared secrets …
- But how do we solve MITM attacks?
- How can we trust we have the true public key for someone we want to communicate with?

- Ideas?

Trusted Authorities

- Suppose there's a party that everyone agrees to trust to confirm each individual's public key
  - Say the Governor of California

- Issues with this approach?
  - How can everyone agree to trust them?
  - Scaling: huge amount of work; single point of failure …
    - ... and thus Denial-of-Service concerns
  - How do you know you're talking to the right authority??

Trust Anchors

- Suppose the trusted party distributes their key so everyone has it …


UNITED STATES OF AMERICA
IN GOD WE TRUST
LIBERTY
D
QUARTER DOLLAR


CALIFORNIA
1850
JOHN MUIR
YOSEMITE VALLEY
2005
E PLURIBUS

CALIFORNIA REPUBLIC


CALIFORNIA
1850
JOHN
MUIR
YOSEMITE
VALLEY
2005
E PLURIBUS UNUM


CALIFORNIA REPUBLIC


CALIFORNIA
1850
Gavin Newsom's Public Key is
0x6a128b3d3dc67edc74d690b19e072f64.
JOHN
MUIR
YOSEMITE
VALLEY
2005
E PLURIBUS UNUM


CALIFORNIA REPUBLIC

Trust Anchors

- Suppose the trusted party distributes their key so everyone has it …
- We can then use this to bootstrap trust
  - As long as we have confidence in the decisions that that party makes

Digital Certificates

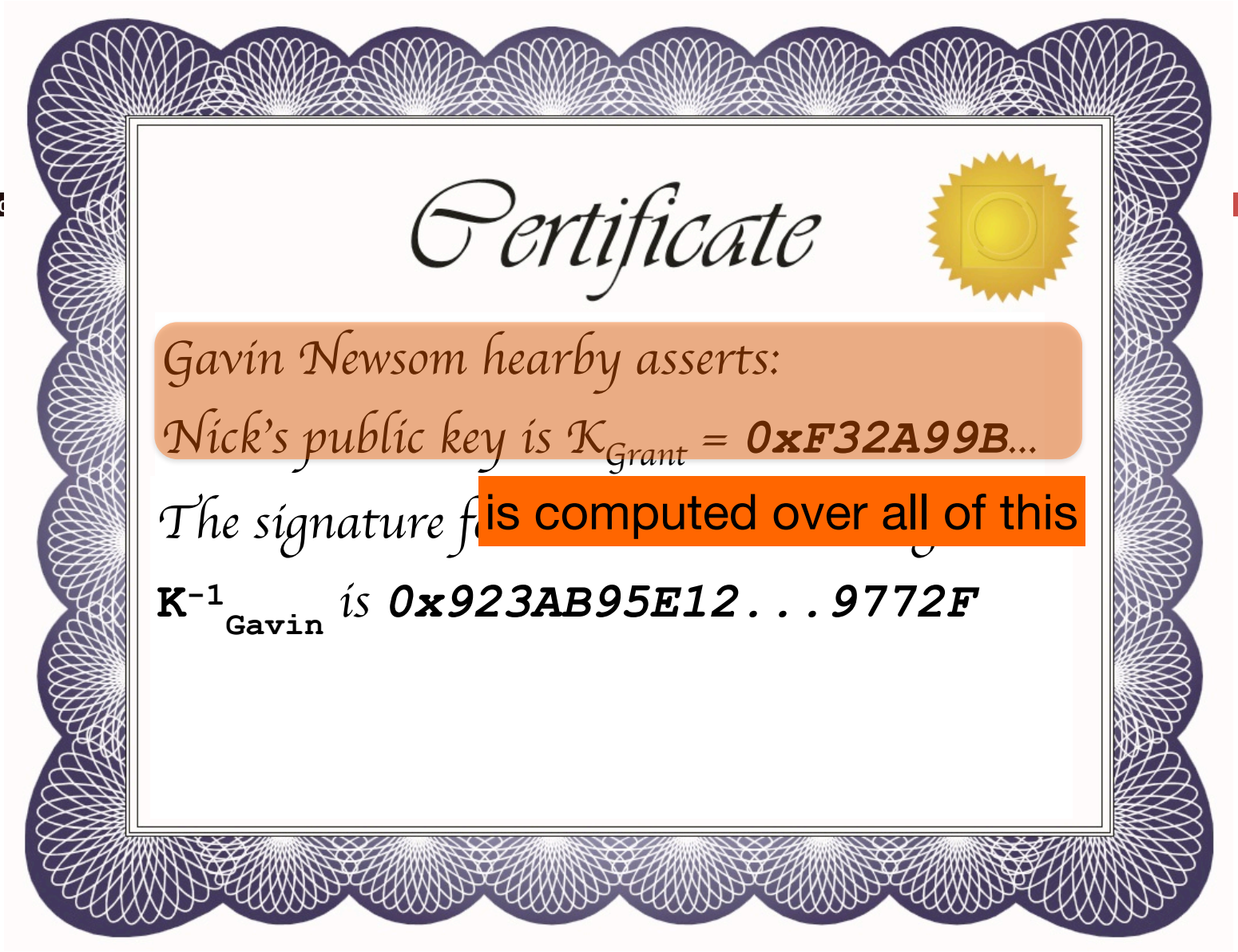
- Certificate ("cert") = signed claim about someone's public key
  - More broadly: a signed *attestation* about some claim

- Notation:
  $\{ M \}_K$ = "message M encrypted with public key k"
  $\{ M \}_{K^{-1}}$ = "message M signed w/ private key for K"

- E.g. M = "Nick's public key is K_{Nick} = ***0xF32A99B***..."
  Cert: M,
  $\{$ "Nick's public key … ***0xF32A99B***..." $\}_{K^{-1}Gavin}$
  = ***0x923AB95E12...9772F***


Certificate
Gavin Newsom hearby asserts:
Nick's public key is K_{Grant} = 0xF32A99B...
The signature for this statement using
K^{-1}_{Gavin} is 0x923AB95E12...9772F


Certificate
Gavin Newsom hearby asserts:
Nick's public key is K_{Grant} = 0xF32A99B...
The signature for this statement using
K^{-1} This is 0x923AB95E12...9772F


Certificate
Gavin Newsom hearby asserts:
Nick's public key is K_{Grant} = 0xF32A99B...
The signature f
is computed over all of this
K^{-1}_{Gavin} is 0x923AB95E12...9772F


Certificate
Gavin Newsom hearby asserts:
Nick's public key is K_{Grant} = 0xF32A99B...
The signature for this statement using
K^{-1}_{Gavin} is 0x923AB95E12...9772F
and can be
validated using:

Certificate

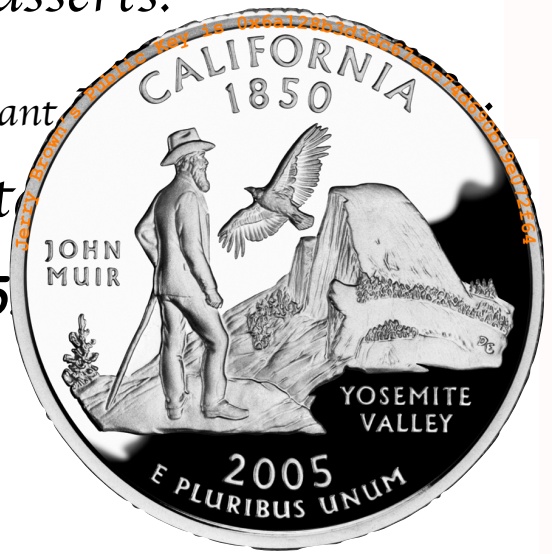
This:

Gavin Newsom hearby asserts:

Nick's public key is K_{Grant}

The signature for this st

K^{-1}_{Gavin} is **0x923AB95**



If We Find This Cert Shoved Under Our Door …

- What can we figure out?
  - If we know Gavin's key, then whether he indeed signed the statement
  - If we trust Gavin's decisions, then we have confidence we really have Nick's key

- Trust = ?
  - Gavin won't willy-nilly sign such statements
  - Gavin won't let his private key be stolen

Analyzing Certs Shoved Under Doors …

- ***How*** we get the cert doesn't affect its utility
- ***Who*** gives us the cert doesn't matter
  - They're not any more or less trustworthy because they did
  - Possessing a cert doesn't establish any identity!
- However: if someone demonstrates they can decrypt data encrypted with K_{nick}, then we have high confidence they possess K^{-1}_{Nick}
  - Same for if they show they can sign "using" K^{-1}_{Nick}

Scaling Digital Certificates

- How can this possibly scale? Surely Gavin can't sign everyone's public key!
- Approach #1: Introduce hierarchy via delegation
  - { "Janet Napolitano's public key is 0x... and I trust her to vouch for UC" }K^{-1}_{Gavin}
  - { "Carol Christ's public key is 0x... and I trust him to vouch for UCB" }K^{-1}_{Janet}
  - { "John Canny's public key is 0x... and I trust him to vouch for EECS" }K^{-1}_{Carol}
  - { "Nick Weaver's public key is 0x..." }K^{-1}_{John}

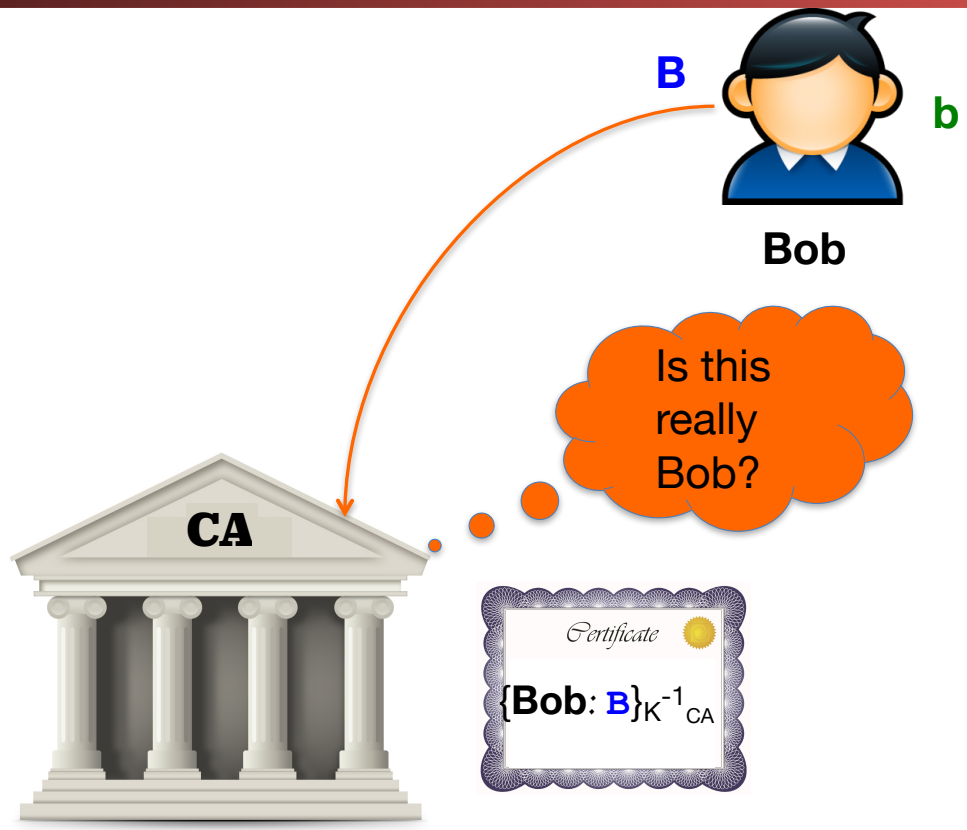
Scaling Digital Certificates, con't

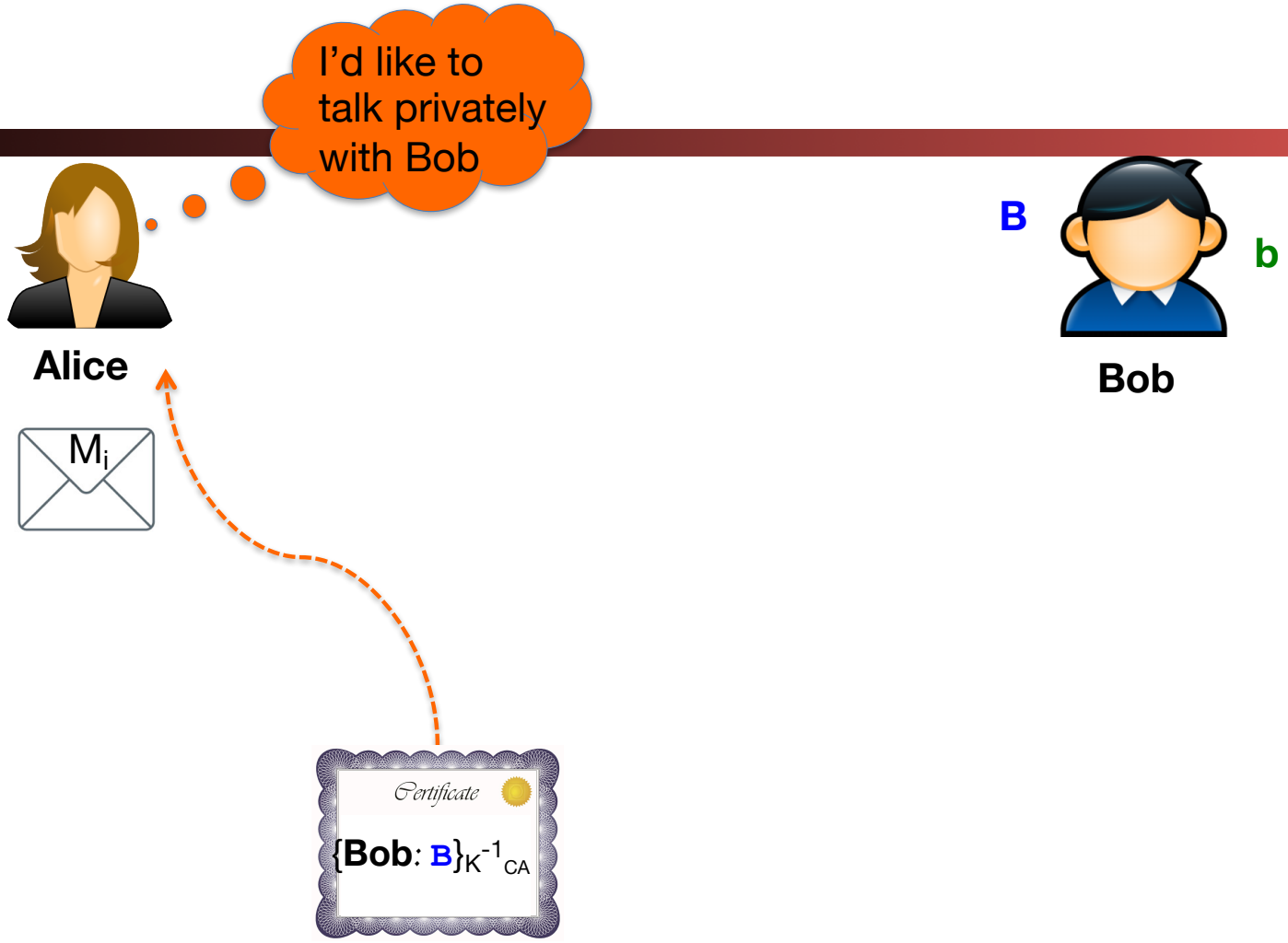
- Nick puts this last on his web page
  - (or shoves it under your door)
- Anyone who can gather the intermediary keys can validate the chain
  - They can get these (other than Gavin's) from anywhere because they can validate them, too

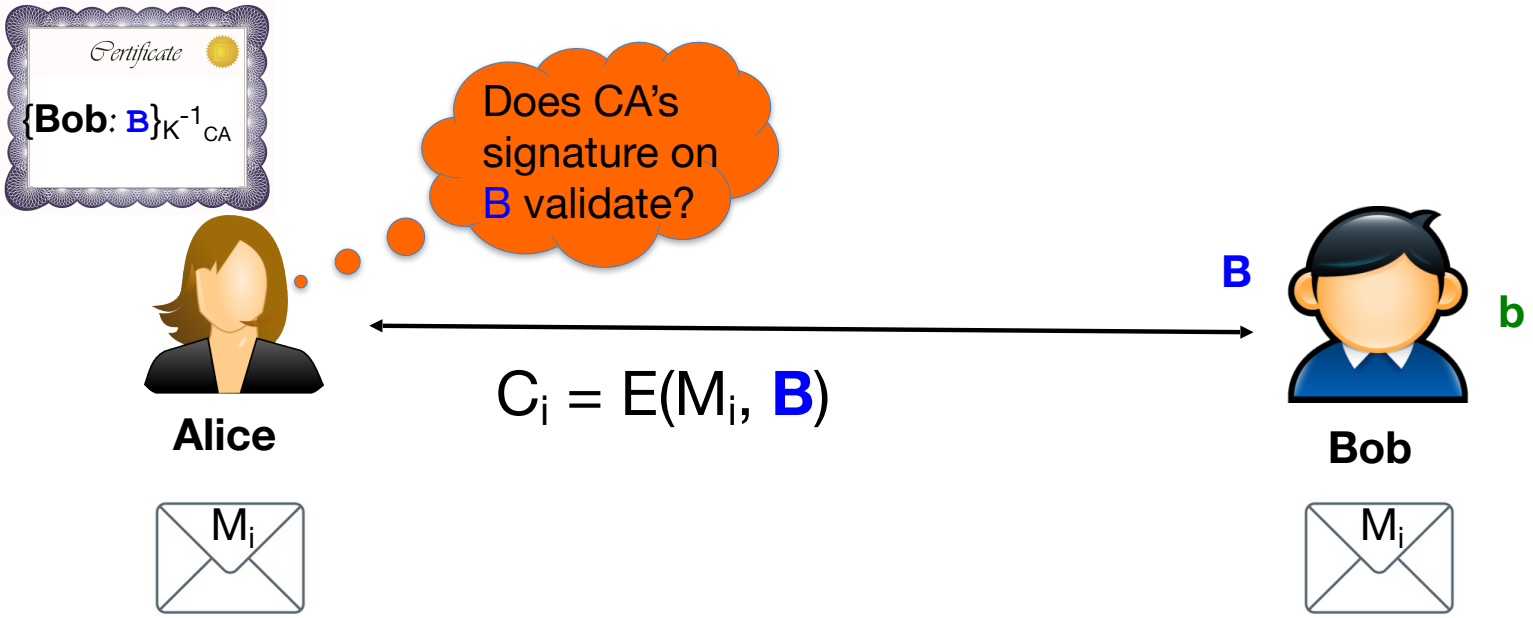
- Approach #2: have multiple trusted parties who are in the business of signing certs …
  - (The certs might also be hierarchical, per Approach #1)

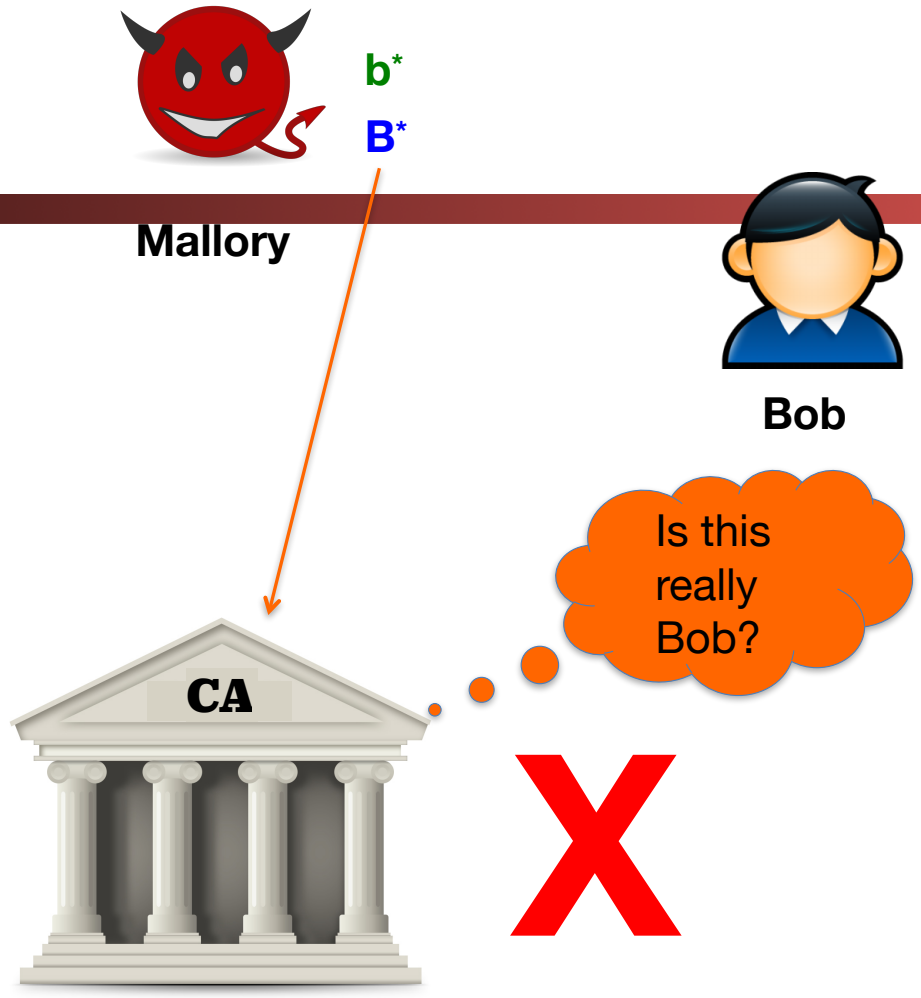
Certificate Authorities

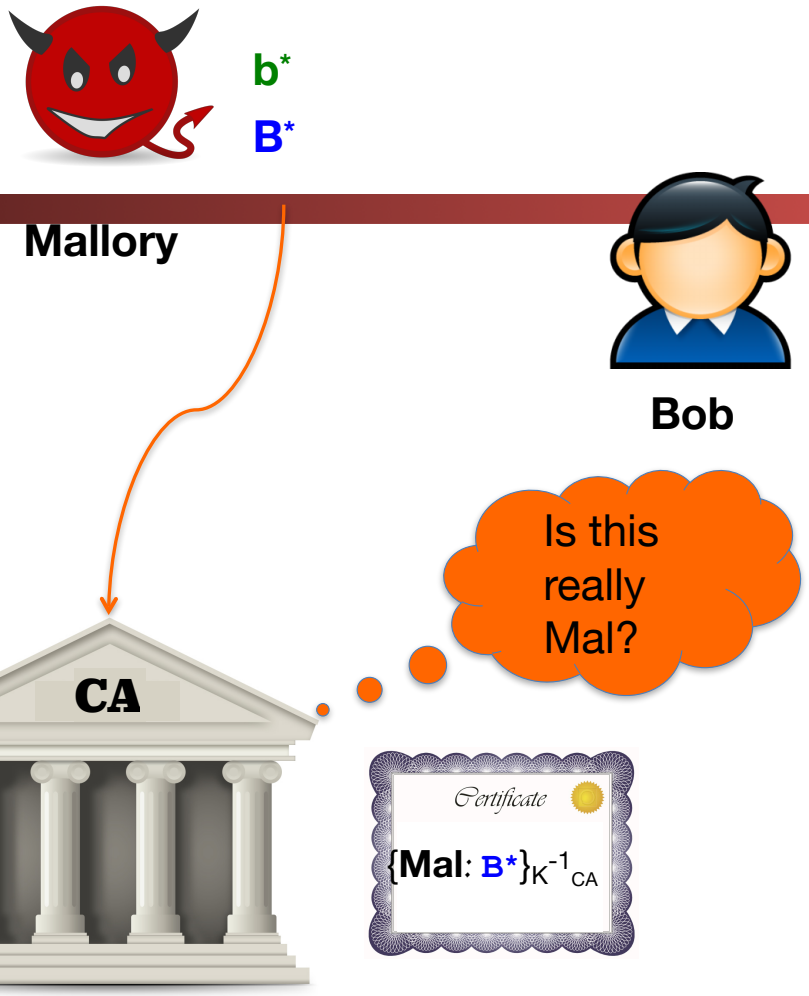
- CAs are trusted parties in a Public Key Infrastructure (PKI)
- They can operate offline
  - They sign ("cut") certs when convenient, not on-the-fly (… though see below ...)
- Suppose Alice wants to communicate confidentially w/ Bob:
  - Bob gets a CA to issue {Bob's public key is B} K^{-1}_{CA}
  - Alice gets Bob's cert any old way
  - Alice uses her known value of K_{CA} to verify cert's signature
  - Alice extracts B, sends $\{M\}K_B$ to Bob

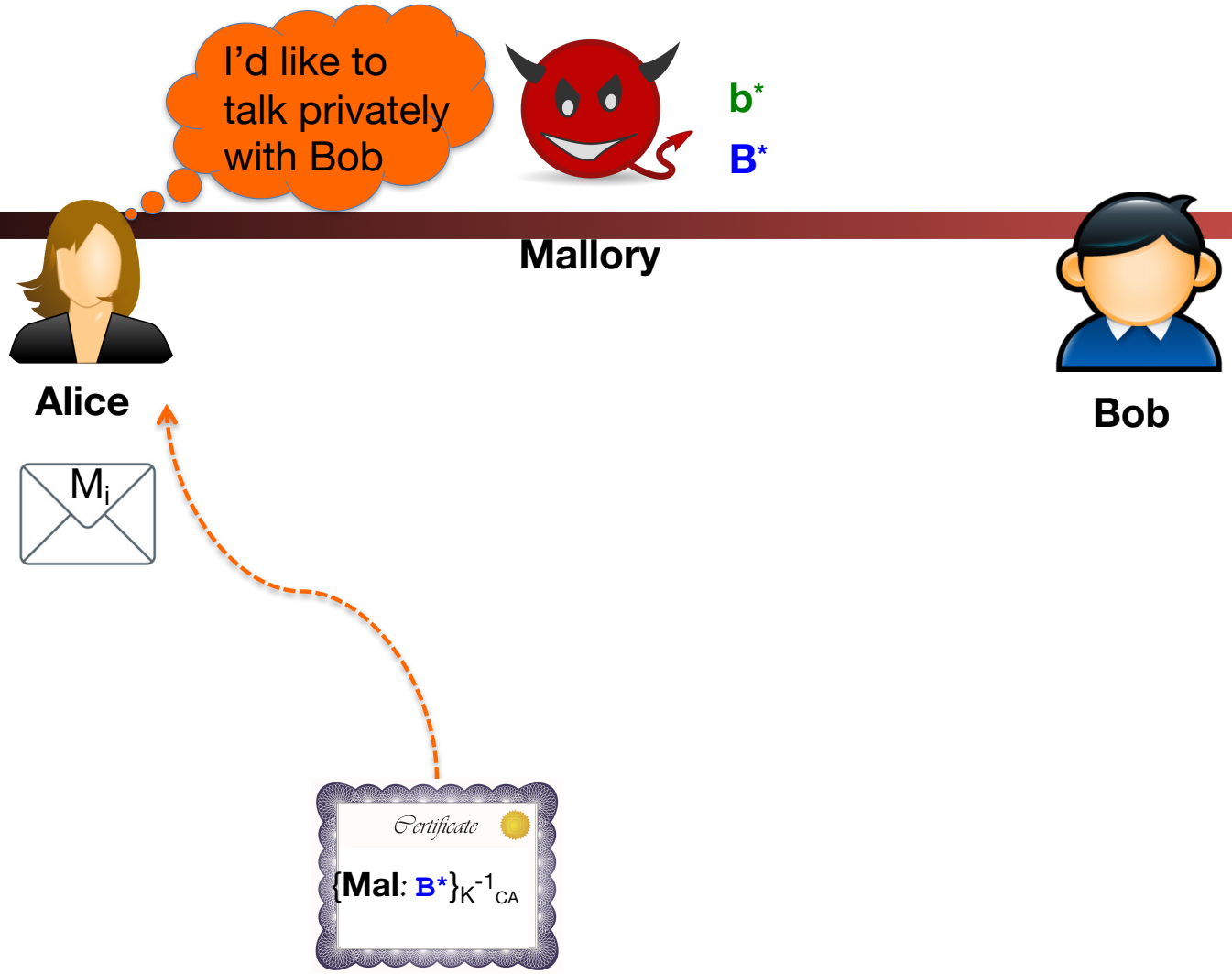

B
b
Bob
Is this really Bob?
CA
Certificate
{Bob: B}K-1CA

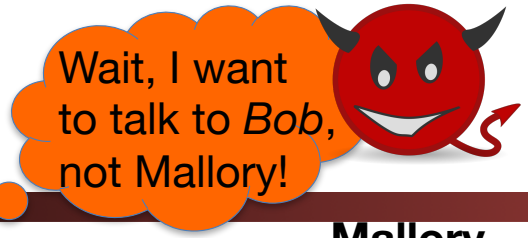

I'd like to talk privately with Bob
Alice
M_i
B
b
Bob
Certificate
{Bob: B}K^{-1}_{CA}


Certificate
{Bob: B}K-1CA
Does CA's signature on B validate?
B
b
Ci = E(Mi, B)
Alice
Bob
Mi
Mi


b*
B*
Mallory
Bob
Is this really Bob?
CA
X


b*
B*
Mallory
Bob
Is this really Mal?
CA
Certificate
{Mal: B*}K-1CA


I'd like to talk privately with Bob
b*
B*
Mallory
Alice
Bob
M_i
Certificate
{Mal: B*}$_{K^{-1}_{CA}}$



b*

B*

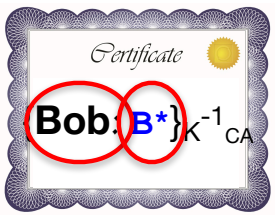
Mallory

Alice

Bob

Revocation

- What do we do if a CA screws up and issues a cert in Bob's name to Mallory?



I'd like to talk privately with Bob

b*

B*

Mallory

Alice

Bob

Revocation

- What do we do if a CA screws up and issues a cert in Bob's name to Mallory?
  - E.g. Verisign issued a **`Microsoft.com`** cert to a *Random Joe*
  - (Related problem: Bob realizes b has been stolen)
- *How do we recover from the error?*
- Approach #1: expiration dates
  - Mitigates possible damage
  - But adds management burden
    - Benign failures to renew will break normal operation

Revocation, con't

- Approach #2: announce revoked certs
  - Users periodically download cert revocation list (CRL)

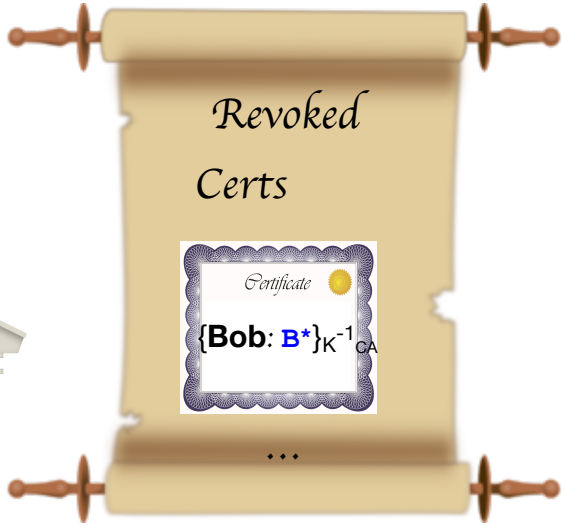
b*

B*

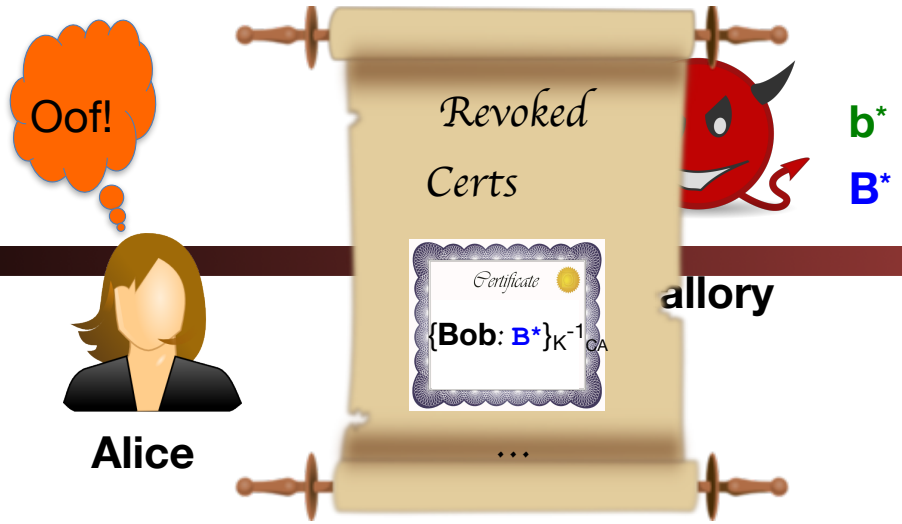
Mallory

Alice

Bob



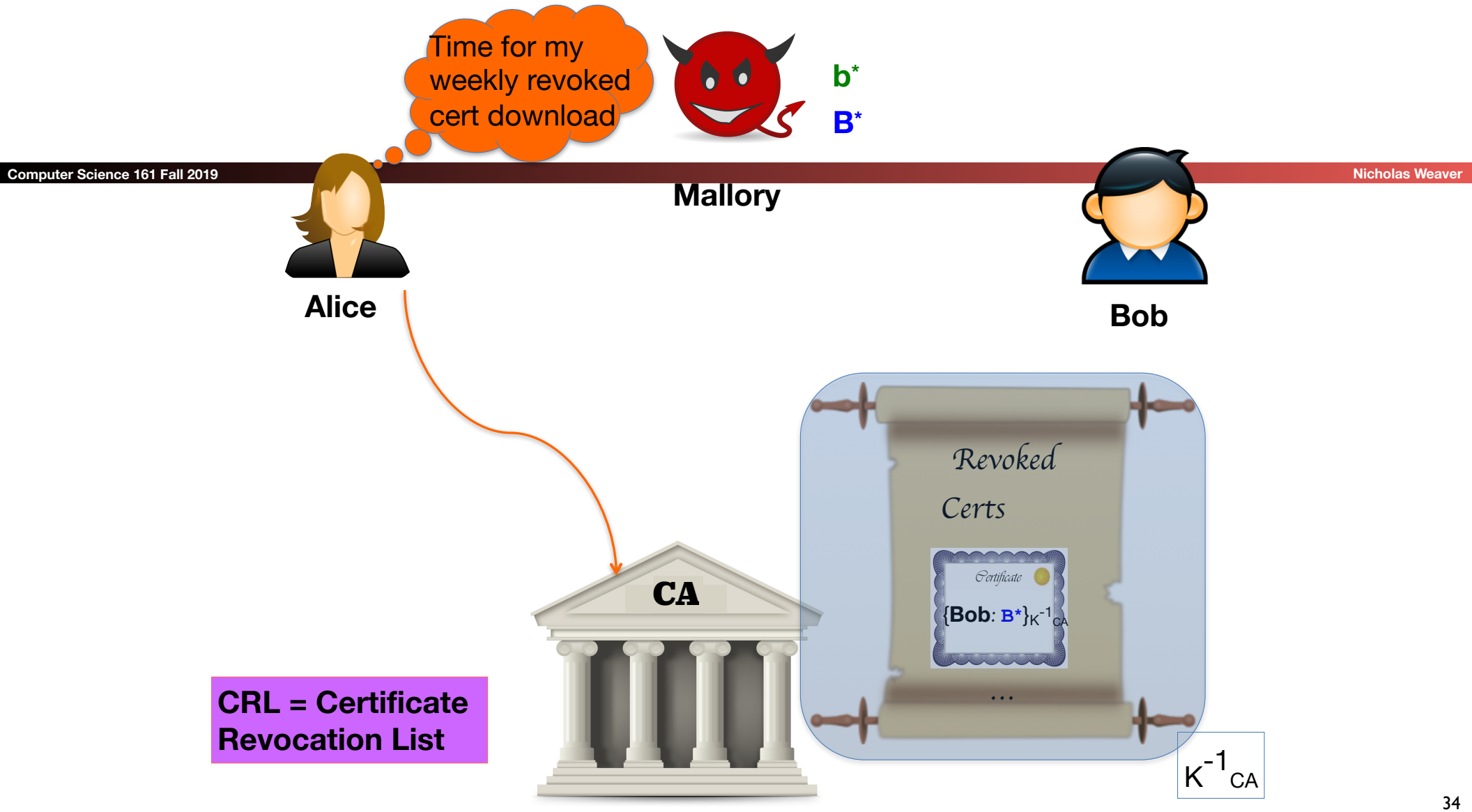
CRL = Certificate Revocation List



CRL = Certificate Revocation List

Revocation, con't

- Approach #2: announce revoked certs
  - Users periodically download cert revocation list (CRL)
- Issues?
  - Lists can get large
  - Need to authenticate the list itself – how?



CRL = Certificate Revocation List

Revocation, con't

- Approach #2: announce revoked certs
  - Users periodically download cert revocation list (CRL)
- Issues?
  - Lists can get large
  - Need to authenticate the list itself – how? Sign it!
  - Mallory can exploit download lag
  - What does Alice do if can't reach CA for download?
    - Assume all certs are invalid (fail-safe defaults)
      - Wow, what an unhappy failure mode!
    - Use old list: widens exploitation window if Mallory can "DoS" CA (DoS = denial-of-service)

The (Failed) Alternative: The "Web Of Trust"

- Alice signs Bob's Key
  - Bob Sign's Carol's
- So now if Dave has Alice's key, Dave can believe Bob's key and Carol's key…
  - Eventually you get a graph/web of trust…
- PGP started out with this model
  - You would even have PGP key signing parties
  - But it proved to be a disaster:
    Trusting central authorities can make these problems so much simpler!

The Facebook Problem: Applied Cryptography in Action

- Facebook Messenger now has an encrypted chat option
  - Limited to their phone application
- The cryptography in general is very good
  - Used a well regarded asynchronous messenger library (from Signal) with many good properties, including forward secrecy
- When Alice wants to send a message to Bob
  - Queries for Bob's public key from Facebook's server
  - Encrypts message and send it to Facebook
  - Facebook then forwards the message to Bob
- Both Alice and Bob are using encrypted and authenticated channels to Facebook

Facebook's Unique Messenger Problem: Abuse

- Much of Facebook's biggest problem is dealing with abuse...
  - What if either Alice or Bob is a stalker, an a-hole, or otherwise problematic?
    - Aside: A huge amount of abuse is explicitly gender based, so I'm going to use "Alex" as the abuser and "Bailey" as the victim through the rest of this example
- Facebook would expect the other side to complain
  - And then perhaps Facebook would kick off the perpetrator for violating Facebook's Terms of Service
- But fake abuse complaints are also a problem
  - So can't just take them on face value
- And abusers might also want to release info publicly
  - Want sender to be able to ***deny to the public*** but not to Facebook

Facebook's Problem Quantified

- Unless Bailey forwards the unencrypted message to Facebook
  - Facebook ***must not*** be able to see the contents of the message
- If Bailey does forward the unencrypted message to Facebook
  - Facebook ***must ensure*** that the message is what Alex sent to Bailey
- Nobody ***but*** Facebook should be able to verify this: No public signatures!
  - Critical to prevent abusive release of messages to the public being verifiable

The Protocol In Action

Alex

Bailey

What Is Bailey's Public Key?

Aside: Key Transparency...

- Both Alex and Bailey are trusting Facebook's honesty...
  - What if Facebook gave Alex a different key for Bailey? How would he know?
- Facebook messenger has a ***nearly*** hidden option which allows Alex to see Bailey's key
  - If they ever get together, they can manually verify that Facebook was honest
- The mantra of central key servers: ***Trust but Verify***
  - The simple option is enough to force honesty, as each attempt to lie has some probability of being caught
- This is the biggest weakness of Apple iMessage:
  - iMessage has (fairly) good cryptography but there is no way to verify Apple's honesty

The Protocol In Action

Alex

Bailey

$\{message=E(K_{pub\_b},$
$M=\{$"Hey Bailey, my zipper has a problem, see photo", $k_{rand}\}),$
$mac=HMAC(k_{rand}, M),$
$to=Bailey\}$

$\{message=E(K_{pub\_b},$
$M=\{$"Hey Bailey, my zipper has a problem, see photo", $k_{rand}\}),$
$mac=HMAC(k_{rand}, M),$
$to=Bailey,$
$from=Alex,$
$time=now,$
$fbmac=HMAC(K_{fb},\{mac, from, to, time\})\}$

Some Notes

- Facebook ***can not*** read the message or even verify Alex's HMAC
  - As the key for the HMAC is in the message itself
- Only Facebook knows their HMAC key
  - And its the only information Facebook ***needs*** to retain in this protocol:
    Everything else can be discarded
- Bailey upon receipt checks that Alex's HMAC is correct
  - Otherwise Bailey's messenger silently rejects the message
    - Forces Alex's messenger to be honest about the HMAC, ***even thought Facebook never verified it***
- Bailey trusts Facebook when Facebook says the message is from Alex
  - Bailey does ***not verify*** a signature, because there is no signature to verify…
    But the Signal protocol uses an ephemeral key agreement so that implicitly verifies Alex as well

Now To Report Abuse

Alex

Bailey

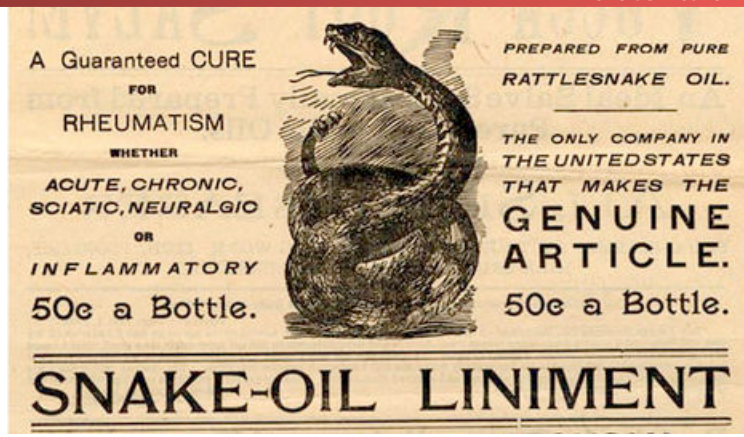
$\{Abuse\{$
$M=\{$"Hey Bailey, my zipper ha
a problem, see photo",
$k_{rand}\}\}$,
$mac=HMAC(k_{rand}, M)$,
$to=Bailey$,
$from=Alex$,
$time=now$,
$fbmac=HMAC(K_{fb},\{mac, from,$
$to, time\})\}$

Facebook's Verification

- First verify that Bailey correctly reported the message sent
  - Verify $\mathbf{fbmac=HMAC(K_{fb},\{mac,from,to,time\})}$
    - Only Facebook can do this verification since they keep $\mathbf{K_{fb}}$ secret
  - This enables Facebook to confirm that this is the message that it relayed from Alex to Bailey
- Then verify that Bailey didn't tamper with the message
  - Verify $\mathbf{mac=HMAC(k_{rand},\{M,\ k_{rand}\})}$
- Now Facebook knows this was sent from Alex to Bailey and can act accordingly
  - But Bailey ***can't prove*** that Alex sent this message to anyone ***other than Facebook***
  - And Bailey ***can't tamper with the message*** because the HMAC is also a hash

Snake Oil Cryptography: Craptography

- "Snake Oil" refers to 19th century fraudulent "cures"
  - Promises to cure practically every ailment
  - Sold because there was no regulation and no way for the buyers to know



- The security field is practically ***full*** of Snake Oil Security and Snake Oil Cryptography
  - https://www.schneier.com/crypto-gram/archives/1999/0215.html#snakeoil

Anti-Snake Oil:
NSA's CNSA cryptographic suite

- Successor to "Suite B"
  - Unclassified algorithms approved for Top Secret:
    - There is nothing higher than TS, you have "compartments" but those are access control modifiers
    - https://www.iad.gov/iad/programs/iad-initiatives/cnsa-suite.cfm
  - Symmetric key, AES: 256b keys
  - Hashing, SHA-384
  - RSA/Diffie Helman: >= 3072b keys
  - ECDHE/ECDSA: 384b keys over curve P-384
- In an ideal world, I'd only use those parameters,
  - But a lot of "strong" commercial is 128b AES, SHA-256, 2048b RSA/DH, 256b elliptic curves, plus the DJB curves and cyphers (ChaCha20)
  - NSA has a requirement where a Top Secret communication captured today should not be decryptable by an adversary 40 years from now!

Snake Oil Warning Signs...

- Amazingly long key lengths
  - The NSA is super paranoid, and even they don't use >256b keys for symmetric key or >4096b for RSA/DH public key
  - So if a system claims super long keys, be suspicious
- New algorithms and crazy protocols
  - There is ***no reason*** to use a novel block cipher, hash, public key algorithm, or protocol
    - Even a "post quantum" public key algorithm should not be used alone:
      Combine it with a conventional public key algorithm
  - Anyone who roles their own is asking for trouble!
  - EG, Telegram
    - "It's like someone who had never seen cake but heard it described tried to bake one.
      With thumbtacks and iron filings." Matthew D Green
    - "Exactly! GLaDOS-cake encryption.
      Odd ingredients; strange recipe; probably not tasty; may explode oven. :)" Alyssa Rowan

Lots in the Cryptocurrency Space…

- The biggest being IOTA (aka IdiOTA), a “internet of Things” cryptocurrency…
  - That doesn’t use public key signatures, instead a hash based scheme that means you can ***never*** reuse a key…
    - And results in 10kB+ signatures! (Compared with RSA which is <450B, and those are big)
  - That has created their own hash function…
    - That was quickly broken!
  - That is supposed to end up distributed…
    - But relies entirely on their central authority
  - That uses ***trinary math!?!***
    - Somehow claiming it is going to be better, but you need entirely new processors…

Snake Oil Warning Signs...

- "One Time Pads"
  - One time pads are secure, if you actually have a true one time pad
  - But almost all the snake oil advertising it as a "one time pad" isn't!
  - Instead, they are invariably some wacky stream cypher
- Gobbledygook, new math, and "chaos"
  - Kinda obvious, but such things are never a good sign
- Rigged "cracking contests"
  - Usually "decrypt this message" with no context and no structure
    - Almost invariably a single or a few unknown plaintexts with nothing else
  - Again, Telegram, I'm looking at you here!

Unusability:
No Public Keys

- The APCO Project 25 radio protocol
  - Supports encryption on each traffic group
    - But each traffic group uses a single ***shared*** key
- All fine and good if you set everything up at once...
  - You just load the same key into all the radios
  - But this totally fails in practice: what happens when you need to coordinate with s who doesn't have the same keys?
- Made worse by bad user interface and users who think rekeyin frequently is a good idea
  - If your crypto is good, you shouldn't need to change your crypto keys
- "Why (Special Agent) Johnny (Still) Can't Encrypt
  - http://www.crypto.com/blog/p25

Unusability: PGP

- I ***hate*** Pretty Good Privacy
  - But not because of the cryptography...
- The PGP cryptography is decent...
  - Except it lacks "Forward Secrecy":
    If I can get someone's private key I can decrypt all their old messages
- The metadata is awful...
  - By default, PGP says who every message is from and to
    - It makes it much faster to decrypt
  - It is hard to hide metadata well, but its easy to do things better than what PGP does
- It is never transparent
  - Even with a "good" client like GPG-tools on the Mac
  - And I don't have a client on my cellphone

Unusability:
How do you find someone's PGP key?

- Go to their personal website?
- Check their personal email?
- Ask them to mail it to you
  - In an unencrypted channel?
- Check on the MIT keyserver?
  - And get the old key that was mistakenly uploaded and can never be removed?

Search results for 'nweaver icsi edu berkeley'

```
Type bits/keyID     Date       User ID
pub  4096R/8A46A420 2013-06-20 Nicholas Weaver <nweaver@icsi.berkeley.edu>
                               Nicholas Weaver <n_weaver@mac.com>
                               Nicholas Weaver <nweaver@gmail.com>
pub  2048R/442CF948 2013-06-20 Nicholas Weaver <nweaver@icsi.berkeley.edu>
```

Unusability:
openssl libcrypto and libssl

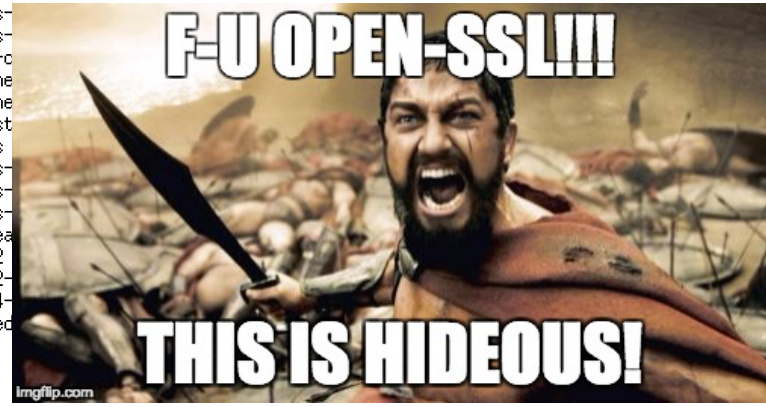
- OpenSSL is a nightmare...
  - A gazillion different little functions needed to do anything
- So much of a nightmare that I'm not going to bother learning it to teach you how bad it is
  - This is why last semester's python-based project didn't give this raw
- But just to give you an idea:
  The command line OpenSSL utility options:

```
OpenSSL> help
openssl:Error: 'help' is an invalid command.

Standard commands
asn1parse         ca                ciphers           cms
crl               crl2pkcs7         dgst              dh
dhparam           dsa               dsaparam          ec
ecparam           enc               engine            errstr
gendh             gendsa            genpkey           genrsa
nseq              ocsp              passwd            pkcs12
pkcs7             pkcs8             pkey              pkeyparam
pkeyutl           prime             rand              req
rsa               rsautl            s_client          s_server
s_time            sess_id           smime             speed
spkac             srp               ts                verify
version           x509

Message Digest commands (see the `dgst' command for more details)
md4               md5               mdc2              rmd160
sha               sha1

Cipher commands (see the `enc' command for more details)
aes-
aes-
bf-c
came
came
cast
des
des-
des-
des-
idea
rc2
rc2-
rc4-
seed
```

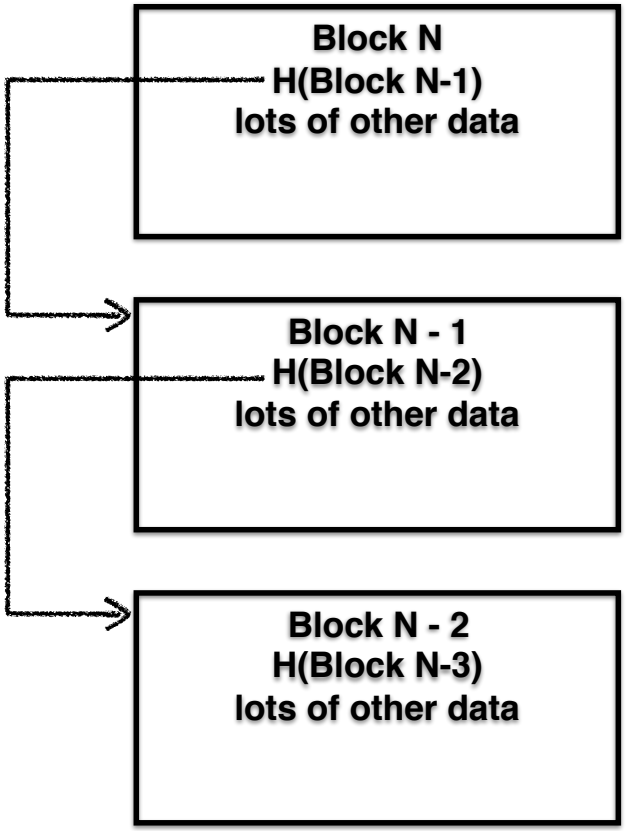


And On To ~~Linked Lists~~ Blockchains And CryptoCurrencies

- "Blockchain Technology"
  - A fancy word for "Append-Only Data Structure"
    - That causes people's eyes to glaze over and them to throw money at people
  - "Private/Permissioned Blockchain":
    - A setup where only one or a limited number of systems are authorized to append to the log
    - AKA 20 year old, well known techniques
  - "Public/Permissionless Blockchain":
    - Anybody can participate as appenders so there is supposedly no central authority: Difficulty comes in removing "sibyls"
- Cryptocurrencies
  - Things that don't actually work as currencies…
    More on Monday (which will be a 'fun' lecture and not covering stuff on the midterm, but will cover all the problems with public blockchains & cryptocurrencies)

Hash Chains

- If a data structure includes a hash of the previous block of data: This forms a “hash chain”
- So rather than the hash of a block validating just the block:
  The inclusion of the previous block’s hash validates all the previous blocks
- This also makes it easy to add blocks to data structures
  - Only need to hash block + hash of previous block, rather than rehash everything:
    How you can efficiently hash an "append only" datastructure
- Now just validate the head (e.g. with signatures) and voila!
  - All a “blockchain” is is a renamed hashchain!
    Linked timestamping services used this structure and were proposed back in 1990!



Merkle Trees

- Lets say you have a lot of elements
  - And you want to add or modify elements
- And you want to make the hash of the set easy to update
- Enter hash trees/merkle trees
  - Elements 0, 1, 2, 3, 4, 5...
  - H(0), H(1), H(2)...
  - H(H(0) + H(1)), H(H(2)+H(3))...
  - The final hash is the root of the top of the tree.
- And so on until you get to the root
  - Allows you to add an element and update lg(n) hashes Rather than having to rehash all the data
  - Patented in 1979!!

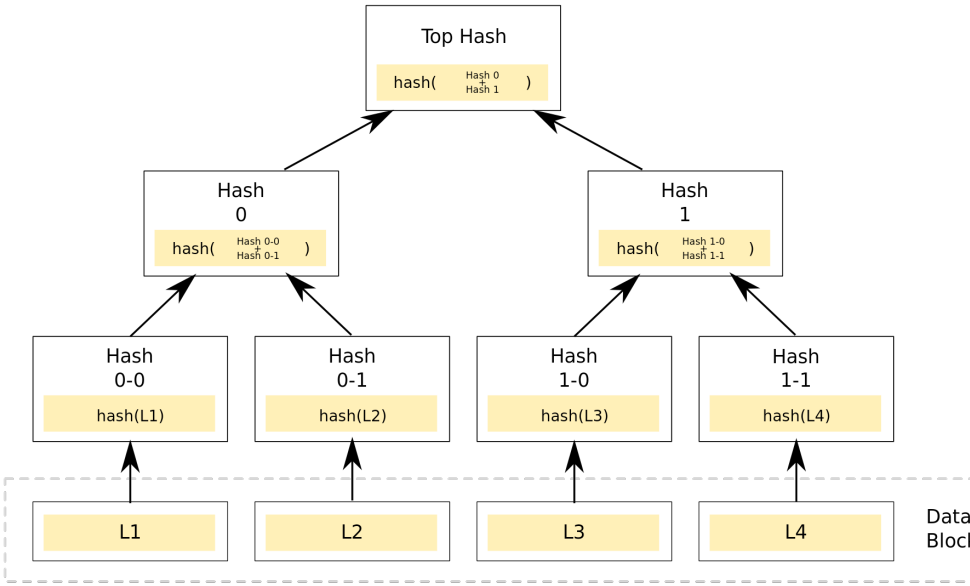


Image Stolen from Wikipedia

A Trivial Private Blockchain…

- We have a single server ***s***, with keys K_{pub} and K_{priv}…
  - And a git archive ***g***…
- Whenever we issue a pull request…
  - The server validates that the pull request meets the allowed criteria
  - Accepts the pull request
  - Signs the head…
- And that is it!
  - Git is an append only data structure, and by signing the new head, we have the server authenticating the ***entire archive!***
- This is why "private" blockchain is ***not*** a revolution!!!
  - Anything that would benefit from an append-only, limited writer database already has one!