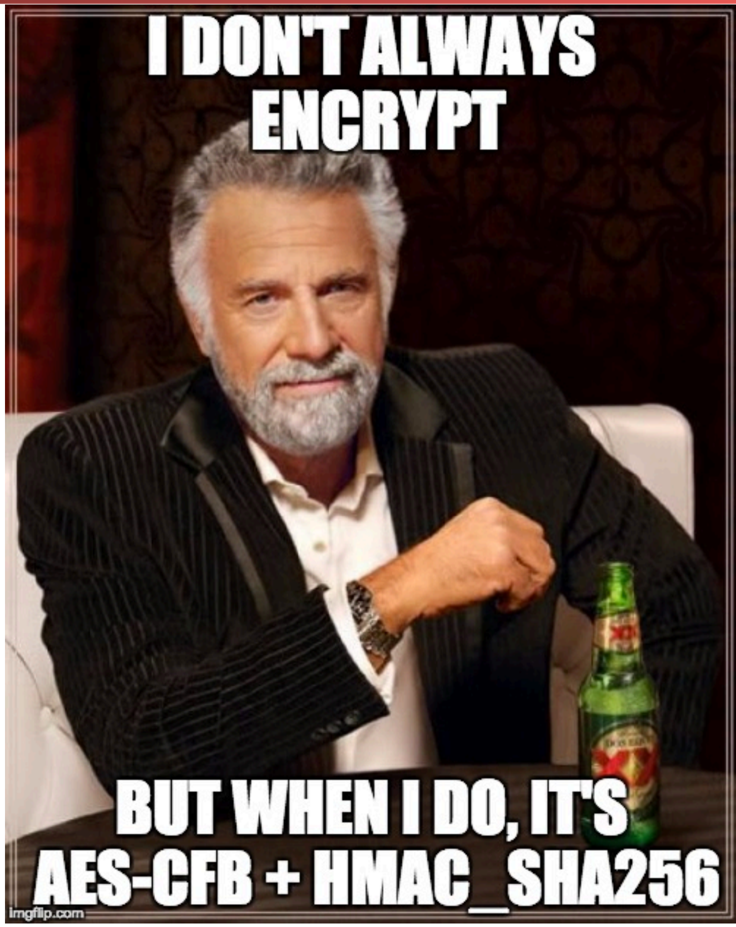
Integrity, Hashes, & "Random" Numbers



Announcements

- Midterm 1: September 23rd, 7-9pm
  - Hearst Field Annex Room 1A
  - Wheeler Auditorium
- How to know which room?
  - Take your student ID in a text file with a single newline at the end
  - Apply sha256 to it
  - Write down the first 8 hex digits and bring them with you to the exam
    (You will be asked to provide them on the exam,
    so put them on your single-page, double sided, handwritten cheat sheet)
    - DSP students, you still need to bring this with you even though you are going to a DSP room...
  - If the first 2 hex digits are less than 0x38, go to Hearst Field Annex Room 1A
  - Otherwise go to Wheeler
- No class on the 23rd
- Review session TBA

Mallory the Manipulator

- Mallory is an active attacker
  - Can introduce new messages (ciphertext)
  - Can “replay” previous ciphertexts
  - Can cause messages to be reordered or discarded
- A “Man in the Middle” (MITM) attacker
  - Can be much more powerful than just eavesdropping

Encryption Does Not Provide Integrity

- Simple example: Consider a block cipher in CTR mode...
- Suppose Mallory knows that Alice sends to Bob "Pay Mal $0100". Mallory intercepts corresponding C
  - M = "Pay Mal $0100". C = "r4ZC#jj8qThMK"
  - $M_{10..13}$ = "0100". $C_{10..13}$ = "ThMK"
- Mallory wants to replace some bits of C...

Encryption Does Not Provide Integrity

- Mallory computes
  - "0100" $\oplus$ $C_{10..13}$
    - Tells Mallory that section of the counter XOR:
      Remember that CTR mode computes $E_k(IV||CTR)$ and XORs it with the corresponding part of the message
  - $C'_{10..13}$ = "9999" $\oplus$ "0100" $\oplus$ $C_{10..13}$
- Mallory now forwards to Bob a full $C' = C_{0..9}||C'_{10..13}||C_{14...}$
- Bob will decrypt the message as "Pay Mal $9999"...
  - For a CTR mode cipher, Mallory can in general replace any ***known*** message M with a message M' of equal length!

Integrity and Authentication

- Integrity: Bob can confirm that what he's received is exactly the message M that was originally sent
- Authentication: Bob can confirm that what he's received was indeed generated by Alice
- Reminder: for either, confidentiality may-or-may-not matter
  - E.g. conf. not needed when Mozilla distributes a new Firefox binary
- Approach using symmetric-key cryptography:
  - Integrity via MACs (which use a shared secret key **K**)
  - Authentication arises due to confidence that only Alice & Bob have **K**
- Approach using public-key cryptography (later on):
  - "Digital signatures" provide both integrity & authentication together
- Key building block: cryptographically strong hash functions

Hash Functions

- Properties
  - Variable input size
  - Fixed output size (e.g., 256 bits)
  - Efficient to compute
  - Pseudo-random (mixes up input extremely well)

- Provides a “fingerprint” of a document
  - E.g. “**`shasum -a 256 <exams/mt1-solutions.pdf`**” prints **`0843b3802601c848f73ccb5013afa2d5c4d424a6ef477890ebf8db9bc4f7d13d`**

Cryptographically Strong Hash Functions

- A collision occurs if **x≠y** but **Hash(x) = Hash(y)**
  - Since input size > output size, collisions do happen
- A cryptographically strong **Hash(x)** provides three properties:
  - One-way: **h = Hash(x)** easy to compute, but not to invert.
    - Intractable to find ***any*** **x'** s.t. **Hash(x') = h**, for a given **h**
    - Also termed “preimage resistant”

H(🐮) =

Cryptographically Strong Hash Functions

- The other two properties of a cryptographically strong **Hash(x)**:
  - Second preimage resistant: given **x**, intractable to find **x'** s.t. **Hash(x) = Hash(x')**
  - Collision resistant: intractable to find any **x**, **y** s.t. **Hash(x)** = **Hash(y)**
- Collision resistant $\Longrightarrow$ Second preimage resistant
  - We consider them separately because given Hash might differ in how well it resists each
  - Also, the Birthday Paradox means that for n-bit Hash, finding **x-y** pair takes only $\approx 2^{n/2}$ pairs
    - Vs. potentially 2^n tries for **x'**: **Hash(x) = Hash(x')** for given **x**
- Plus a hash function should look "random"
  - A "PRF" or Pseudo-Random Function

Cryptographically Strong Hash Functions, con't

- Some contemporary hash functions
  - MD5: 128 bits
    - broken – lack of collision resistance
    - Collisions for the heck of it: https://shells.aachen.ccc.de/~spq/md5.gif
      An MD5 "hash quine": an animated GIF that shows its own hash
  - SHA-1: 160 bits broken spring 2017, but was known to be weak yet still used...
  - SHA-256/SHA-384/SHA-512: 256, 384, 512 bits in the SHA-2 family, at least not currently broken
  - SHA-3: New standard! Yayyy!!!! (Based on Keccak, again 256b, 384b, and 512b options)
- Provide a handy way to unambiguously refer to large documents
  - If hash can be securely communicated, provides integrity
    - E.g. Mozilla securely publishes SHA-256(new FF binary)
    - Anyone who fetches binary can use "`cat binary | shasum -a 256`" to confirm it's the right one, untampered
- Not enough by themselves for integrity, since functions are completely known – Mallory can just compute revised hash value to go with altered message

SHA-256...

- SHA-256/SHA-384 are two parameters for the SHA-2 hash algorithm, returning 256b or 384b hashes
  - Works on blocks with a truncation routine to make it act on sequences of arbitrary length
- Is vulnerable to a ***length-extension attack***: **s** is secret
  - Mallory knows **len(s)**, **H(s)**
  - Mallory can use this to calculate **H(s||M)** for an **M** of Mallory's construction
    - Works because ***all the internal state*** at the point of calculating **H(s||...)** is derivable from **H(s)** and **len(s)**
- New SHA-3 standard (Keccak) does not have this property

Stupid Hash Tricks: Sample A File...

- BlackHat Dude claims to have 150M records stolen from Equifax...
  - How can I as a reporter verify this?
- Idea: If I can have the hacker select 10 ***random*** lines...
  - And in selecting them also say something about the size of the file...
  - Voila! Verify those lines and I now know he's not full of BS
- Can I use hashing to write a small script which the BlackHat Dude can run?
  - Where I can easily verify that the 10 lines were sampled at random, and can't be faked?

Sample a File


```
#!/usr/bin/env python
import hashlib, sys
hashes = {}

for line in sys.stdin:
    line = line.strip()
    for x in range(10):
        tmp = "%s-%i" % (line, x)
        hashval = hashlib.sha256(tmp)
        h = hashval.digest()
        if x not in hashes or hashes[x][0] > h:
            hashes[x] = (h, hashval, tmp)

for x in range(10):
    h, hashval, val = hashes[x]
    print "%s=\"%s\"" % (hashval.hexdigest(), val)
```

Why does this work?

- For each x in range 0-9...
  - Calculates **H(line||x)**
  - Stores the lowest hash matching so far
- Since the hash appears random...
  - Each iteration is an ***independent*** sample from the file
  - The expected value of H(line||x) is a function of the size of the file:
    More lines, and the value is smaller
- To fake it...
  - Would need to generate fake lines, ***and see if the hash is suitably low***
  - Yet would need to make sure these fake lines semantically match!
    - Thus you can't just go "John Q Fake", "John Q Fakke", "Fake, John Q", etc...

Message Authentication Codes (MACs)

- Symmetric-key approach for integrity
  - Uses a shared (secret) key **K**
- Goal: when Bob receives a message, can confidently determine it hasn't been altered
  - In addition, whomever sent it must have possessed **K**
    (⇒ message authentication, sorta...)
- Conceptual approach:
  - Alice sends **{M, T}** to Bob, with tag **T = MAC(K, M)**
    - Note, **M** could instead be **C =** $\mathbf{E_K}$**'(M)**, but not required
  - When Bob receives **{M', T'}**, Bob checks whether **T' = MAC(K, M')**
    - If so, Bob concludes message untampered, came from Alice
    - If not, Bob discards message as tampered/corrupted

Requirements for Secure MAC Functions

- Suppose MITM attacker Mallory intercepts Alice's **{M, T}** transmission …
  - … and wants to replace **M** with altered **M***
  - … but doesn't know shared secret key **K**
- We have secure integrity if MAC function **T = MAC(M, K)** has two properties:
  - Mallory can't compute **T* = MAC(M*, K)**
    - Otherwise, could send Bob **{M*, T*}** and fool him
  - Mallory can't find **M**** such that **MAC(M**, K) = T**
    - Otherwise, could send Bob **{M**, T}** and fool him
- These need to hold even if Mallory can observe many **{M_i, T_i}** pairs, including for **M_i**'s she chose

MAC then Encrypt or Encrypt then MAC

- You should ***never*** use the same key for the MAC and the Encryption
  - Some MACs will break completely if you reuse the key
  - Even if it is ***probably*** safe (eg, AES for encryption, HMAC for MAC) its still a bad idea
- MAC then Encrypt:
  - Compute **T = MAC(M,K_{mac})**, send **C = E(M||T,$K_{encrypt}$)**
- Encrypt then MAC:
  - Compute **C = E(M,$K_{encrypt}$)**, **T = MAC(M,K_{mac})**, send **C||T**
- Theoretically they are the same, but...
  - Once again, its time for ...

HTTPS Authentication in Practice

- When you log into a web site, it sets a "cookie" in your browser
  - All subsequent requests include this cookie so the web server knows who you are
- If an attacker can get your cookie...
  - They can impersonate you on the "Secure" site
- And the attacker can create multiple tries
  - On a WiFi network, inject a bit of JavaScript that repeatedly connects to the site
  - While as a man-in-the-middle to manipulate connections

The TLS 1.0 "Lucky13" Attack: "F-U, This is Cryptography"

- HTTPS/TLS uses MAC then Encrypt
  - With CBC encryption
- The Lucky13 attack changes the cipher text in an attempt to discover the state of a byte
  - But can't predict the MAC
  - The TLS connection retries after each failure so the attacker can try multiple times
    - Goal is to determine the status each byte in the authentication cookie which is in a known position
- It detects the ***timing*** of the error response
  - Which is different if the guess is right or wrong
    - Even though the underlying algorithm was "***proved***" secure!
- So always do Encrypt then MAC since, once again, it is more mistake tolerant

The best MAC construction: HMAC

- Idea is to turn a hash function into a MAC
  - Since hash functions are often much faster than encryption
  - While still maintaining the properties of being a cryptographic hash
- Reduce/expand the key to a single hash block
- XOR the key with the i_pad
  - 0x363636... (one hash block long)
- Hash ((K ⊕ i_pad) || message)
- XOR the key with the o_pad
  - 0x5c5c5c...
- Hash ((K ⊕ o_pad) || first hash)

```
function hmac (key, message) {
    if (length(key) > blocksize) {
        key = hash(key)
    }
    while (length(key) < blocksize) {
       key = key || 0x00
    }
    o_key_pad = 0x5c5c... ⊕ key
    i_key_pad = 0x3636... ⊕ key
    return hash(o_key_pad ||
                hash(i_key_pad || message))
}
```

Why This Structure?

- i_pad and o_pad are slightly arbitrary
  - But it is necessary for security for the two values to be different
    - So for paranoia chose very different bit patterns
- Second hash prevents appending data
  - Otherwise attacker could add more to the message and the HMAC and it would still be a valid HMAC for the key
    - Wouldn't be a problem with the key at the ***end*** but at the start makes it easier to capture intermediate HMACs
- Is a Pseudo Random Function if the underlying hash is a PRF
  - AKA if you can break this, you can break the hash!

```
function hmac (key, message) {
    if (length(key) > blocksize) {
        key = hash(key)
    }
    while (length(key) < blocksize) {
       key = key || 0x00
    }
    o_key_pad = 0x5c5c... ⊕ key
    i_key_pad = 0x3636... ⊕ key
    return hash(o_key_pad ||
                hash(i_key_pad || message))
}
```

Great Properties of HMAC...

- It is still a hash function!
  - So all the good things of a cryptographic hash:
    An attacker or even the recipient shouldn't be able to calculate **M** given **HMAC(M,K)**
  - An attacker who doesn't know **K** can't even verify if **HMAC(M,K) == M**
    - Very different from the hash alone, and potentially very useful:
      Attacker can't even brute force try to find **M** based on **HMAC(M,K)**!
- Its probably safe if you screw up and use the same key for both MAC and Encrypt
  - Since it is a different algorithm than the encryption function...
  - ***But you shouldn't do this anyway***!

Considerations when using MACs

- Along with messages, can use for data at rest
  - E.g. laptop left in hotel, providing you don't store the key on the laptop
  - Can build an efficient data structure for this that doesn't require re-MAC'ing over entire disk image when just a few files change
- MACs in general provide no promise not to leak info about message
  - Compute MAC on ciphertext if this matters
  - Or just use HMAC, which ***does*** promise not to leak info if the underlying hash function doesn't
- ***NEVER*** use the same key for MAC and Encryption...
  - Known "FU-this-is-crypto" scenarios reusing an encryption key for MAC in some algorithms when its the same underlying block cipher for both

Plus AEAD Encryption Modes...

- The latest block cipher modes are "AEAD":
  - Authenticated Encryption with Additional Data
- Provides both integrity ***and*** confidentiality over the data
  - With ***integrity*** also provided for the "Additional Data"
- Used right, these are great
  - Assuming you use a library...
- Used wrong...
  - The AEAD modes are built for "performance", which means parallelization, which means CTR mode, which means IV reuse is a disaster!

Passwords

- The password problem:
  - User Alice authenticates herself with a password ***P***
- How does the site verify later that Alice knows ***P***?
- Classic:
  - Just store {**Alice, *P***} in a file...
- But what happens when the site is hacked?
  - The attacker now knows Alice's password!
- Enter "Password Hashing"

Password Hashing

- Instead of storing {**Alice, *P***}...
  - Store {**Alice, H(*P*)**}
- To verify Alice, when she presents ***P***
  - Compute **H(*P*)** and compare it with the stored value
- Problem: Brute Force tables...
  - Most people chose bad passwords...
    And these passwords are known
  - Bad guy has a huge file...
    - **H(P1), P1**
      H(P2), P2
      H(P3), P3...
  - Ways to make this more efficient ("Rainbow Tables")

A Sprinkle of Salt...

- Instead of storing {**Alice, H(P)**}, also have a user-specific string, the "Salt"
  - Now store {**Alice, Salt, H(P||Salt)**}
  - The salt ideally should be both long and random, but it isn't considered "secret"
- As long as the salt is unique...
  - An attacker who captures the password file has to ***brute force*** Alice's password on its own
- Its still an "off-line attack" (Attacker can do all the computation he wants) but...
  - At least the attacker can't ***precompute*** possible solutions

Slower Hashes...

- Most cryptographic hashes are designed to be ***fast***
  - After all, that is the point: they should not only turn **H(🐮)** to hamburger... they need to do it quickly
- But for password hashes, we ***want*** it to be slow!
  - Its OK if it takes a good fraction of a second to ***check*** a password
    - Since you only need to do it once for each legitimate usage of that password
  - But the attacker needs to do it for each password he wants to try
- Slower hashes don't change the ***asymptotic difficulty*** of password cracking but can have huge practical impact
  - Slow rate by a factor of 10,000 or more!

PBKDF2

- "Password Based Key Derivation Function 2"
  - Designed to produce a long "random" bitstream derived from the password
- Used for both a password hash and to generate keys derived from a user's password
  - PKBDF(PRF, P, S, c, len):
    - **PRF** == Pseudo Random Function (e.g. HMAC-SHA256)
    - **P** == Password
    - **S** == Salt
    - **c** == Iteration count
    - **len** == Number of bits/bytes requested
    - **DK** == Derived Key

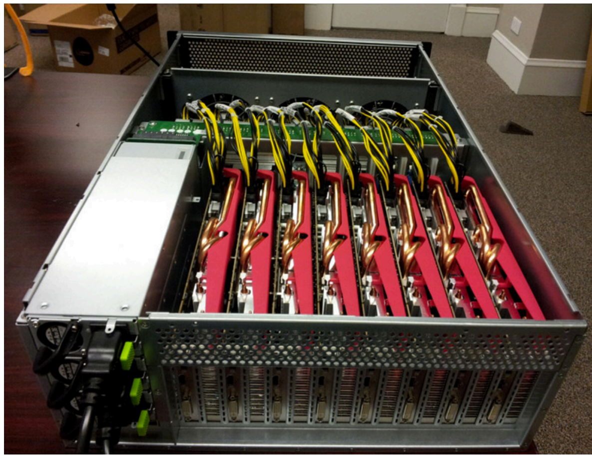
```
PKBDF(PRF,P,S,c,len){
  DK = ""
  for i = 1,range(len/blocksize)+1){
    DK = DK || F(PRF,P,S,c,i)
  }
  return DK[0:len]
}

F(PRF,P,S,c,i){
  UR = U = PRF(P, S||INT_32(i))
  for j = 2; j <= c; ++j {
    U = PRF(P, U)
    UR = UR ^ U
  }
  return UR
}
```

Comments on PBKDF2

- Allows you to get effectively an arbitrary long string from a password
  - ***Assuming*** the user's password is strong/high entropy
- Very good for getting a bunch of symmetric keys from a single password
  - You can also use this to seed a pRNG for generating a "random" public/private key pair
- Designed to be slow in computation...
  - But it does ***not*** require a lot of memory:
    Other functions are also expensive in memory as well, e.g. scrypt.

Passwords...

- If an attacker can do an ***offline*** attack, your password must be ***really good***
  - Attacker simply tries a huge number of passwords in parallel using a GPU-based computer
  - So you need a ***high entropy*** password:
    - Even xkcd-style is only 10b/word, so need a 7 or more ***random word*** passphrase to resist a determined attacker
- Life is far better is if the attacker can only do ***online*** attacks:
  - Query the device and see if it works
  - Now limited to a few tries per second and ***no parallelism!***



... and iPhones

- Apple's security philosophy:
  - In your hands, the phone should be everything
  - In anybody else's, it should (ideally) be an inert "brick"
- Apple uses a small co-processor in the phone to handle the cryptography
  - The "Secure Enclave"
- The rest of the phone is untrusted
  - Notably the memory: ***All*** data must be encrypted:
    The CPU requests that the Secure Enclave unencrypt data and some data (e.g., your credit card for ApplePay) is only readable by the Secure Enclave
- They also have an ability to effectively erase a small piece of memory
  - "Effaceable Storage": this takes a good amount of EE trickery

Crypto and the iPhone Filesystem

- A lot of keys encrypted by keys...
  - But there is a random master key, $\mathbf{k}_{\mathbf{phone}}$, that is the root of all the other keys
- Need to store $\mathbf{k}_{\mathbf{phone}}$ encrypted by the user's password in the flash memory
  - PBKDF2(P,...) = $\mathbf{k}_{\mathbf{user}}$
- But how to prevent an off-line brute-force attack?
  - Also have a 256b ***random*** secret burned into the Secure Enclave
    - Need to take apart the chip to get this!
- Now the user key is not just a function of P, but P||secret
  - Without the secret, ***can not*** do an offline attack
- All ***online*** attacks have to go through the secure enclave
  - After 5 tries, starts to slow down
  - After 10 tries, can (optionally) nuke $\mathbf{k}_{\mathbf{phone}}$!
    - Erase just that part of memory -> effectively erases the entire phone!

Backups...

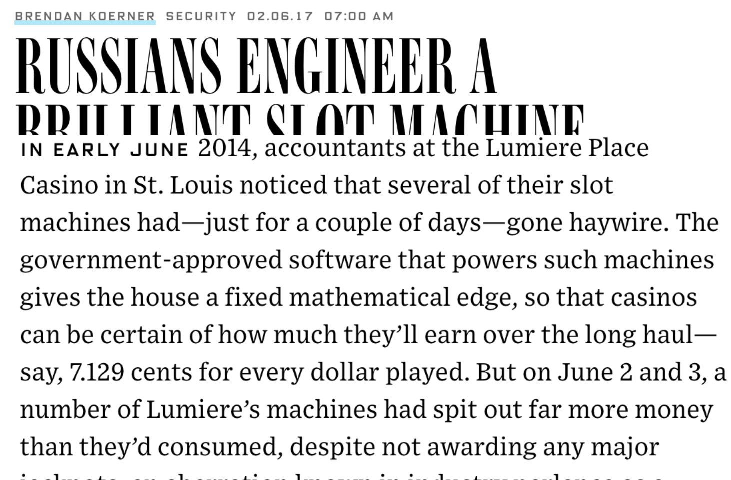
- Of course there is a ***necessary*** weakness:
  - Backing up the phone copies all the data off in a form not encrypted using the in-chip secret
    - After all, you need to be able to recover it onto a new phone!
- So someone who can get your phone...
  And can somehow managed to have it unlocked
  - Thief, abusive boyfriend, cop...
    - Hold it up to your face (iPhone X) or Fingerprint (5s or beyond)
    - And then sync it with a new computer
- Change of policy for iOS-11:
  - Now you also need to put in the passcode to trust a new computer:
    Can't create a backup without knowing the passcode

But A Lot More Uses for Random Numbers...

- The key foundation for all modern cryptographic systems is often not encryption but these "random" numbers!
- So many times you need to get something random:
  - A random cryptographic key
  - A random initialization vector
  - A "nonce" (use-once item)
  - A unique identifier
  - Stream Ciphers
- If an attacker can ***predict*** a random number things can catastrophically fail

Breaking Slot Machines

- Some casinos experienced unusual bad "luck"
  - The suspicious players would wait and then all of a sudden try to play
- The slot machines have ***predictable*** pRNG
  - Which was based on the current time & a seed
- So play a little...
  - With a cellphone watching
  - And now you know when to press "spin" to be more likely to win
- Oh, and this ***never*** effected Vegas!
  - ***Evaluation standards*** for Nevada slot machines specifically designed to address this sort of issue



BRENDAN KOERNER SECURITY 02.06.17 07:00 AM

RUSSIANS ENGINEER A BRILLIANT SLOT MACHINE

IN EARLY JUNE 2014, accountants at the Lumiere Place Casino in St. Louis noticed that several of their slot machines had—just for a couple of days—gone haywire. The government-approved software that powers such machines gives the house a fixed mathematical edge, so that casinos can be certain of how much they'll earn over the long haul—say, 7.129 cents for every dollar played. But on June 2 and 3, a number of Lumiere's machines had spit out far more money than they'd consumed, despite not awarding any major

Breaking Bitcoin Wallets

- blockchain.info supports "web wallets"
  - Javascript that protects your Bitcoin
- The private key for Bitcoin needs to be random
  - Because otherwise an attacker can spend the money
- An "Improvment" [sic] to the RNG reduced the entropy (the actual randomness)
  - Any wallet created with this improvment was brute-forceable and could be stolen

TRUE Random Numbers

- True random numbers generally require a physical process
- Common circuit is an unusable ring oscillator built into the CPU
  - It is then sampled at a low rate to generate true random bits which are then fed into a pRNG on the CPU
- Other common sources are human activity measured at very fine time scales
  - Keystroke timing, mouse movements, etc
    - "Wiggle the mouse to generate entropy for a key"
  - Network/disk activity which is often human driven
- More exotic ones are possible:
  - Cloudflare has a wall of lava lamps that are recorded by a HD video camera which views the lamps through a rotating prism: It is just one source of the randomness

Combining Entropy

- The general procedure is to combine various sources of entropy
- The goal is to be able to take multiple crappy sources of entropy
  - Measured in how many bits:
    A single flip of a coin is 1 bit of entropy
  - And combine into a value where the entropy is the minimum of the sum of all entropy sources (maxed out by the # of bits in the hash function itself)
  - **N-1** bad sources and **1** good source -> good pRNG state

Pseudo Random Number Generators (aka Deterministic Random Bit Generators)

- Unfortunately one needs a ***lot*** of random numbers in cryptography
  - More than one can generally get by just using the physical entropy source
- Enter the pRNG or DRBG
  - If one knows the state it is entirely predictable
  - If one doesn't know the state it should be indistinguishable from a random string
- Three operations
  - Instantiate: (aka Seed) Set the internal state based on the real entropy sources
  - Reseed: Update the internal state based on both the previous state and ***additional entropy***
    - The big different from a simple stream cipher
  - Generate: Generate a series of random bits based on the internal state
    - Generate can also optionally add in additional entropy
- **instantiate(entropy)**
  reseed(entropy)
  generate(bits, {optional entropy})

Properties for the pRNG

- Can a pRNG be truly random?
  - No. For seed length **s**, it can only generate at most $\mathbf{2^s}$ distinct possible sequences.
- A cryptographically strong pRNG “looks” truly random to an attacker
  - Attacker ***cannot distinguish*** it from a random sequence:
    If the attacker can tell a sufficiently long bitstream was generated by the pRNG instead of a truly random source it isn't a good pRNG

Prediction and Rollback Resistance

- A pRNG should be predictable only if you know the internal state
  - It is this predictability which is why its called "pseudo"
- If the attacker does not know the internal state
  - The attacker should not be able to distinguish a truly random string from one generated by the pRNG
- It should also be rollback-resistant
  - Even if the attacker finds out the state at time T, they should not be able to determine what the state was at T-1
  - More precisely, if presented with two random strings, one truly random and one generated by the pRNG at time T-1, the attacker should not be able to distinguish between the two

Why "Rollback Resistance" is Essential

- Assume attacker, at time T, is able to obtain all the internal state of the pRNG
  - How? E.g. the pRNG screwed up and instead of an IV, released the internal state, or the pRNG is bad...
- Attacker observes how the pRNG was used
  - T_{-1} = Session key
    T_0 = Nonce
- Now if the pRNG doesn't resist rollback, and the attacker gets the state at T_0, attacker can know the session key! And we are back to...

More on Seeding and Reseeding

- Seeding should take all the different physical entropy sources available
  - If one source has 0 entropy, it ***must not*** reduce the entropy of the seed
  - We can shove a whole bunch of low-entropy sources together and create a high-entropy seed
- Reseeding ***adds*** in even more entropy
  - **F(internal_state, new material)**
  - Again, even if reseeding with 0 entropy, it ***must not*** reduce the entropy of the seed

Probably the best pRNG/DRBG: HMAC_DRBG

- Generally believed to be the best
  - ***Accept no substitutes***!
- Two internal state registers, ***V*** and ***K***
  - Each the same size as the hash function's output
- ***V*** is used as (part of) the data input into HMAC, while ***K*** is the key
- If you can break this pRNG you can ***either break the underlying hash function*** or ***break a significant assumption about how HMAC works***
  - Yes, security proofs sometimes are a very good thing and actually do work

HMAC_DRBG Generate

- The basic generation function
- Remarks:
  - It requires one HMAC call per blocksize-bits of state
  - Then two more HMAC calls to update the internal state
- Prediction resistance:
  - If you can distinguish new **K** from random when you don't know old **K**:
    You've distinguished HMAC from a random function!
    Which means you've either broken the hash or the HMAC construction
- Rollback resistance:
  - If you can learn old **K** from new **K** and **V**:
    You've reversed the hash function!

```
function hmac_drbg_generate (state, n) {
  tmp = ""
  while(len(tmp) < N){
     state.v = hmac(state.k,state.v)
     tmp = tmp || state.v
  }
  // Update state with no input
  state.k = hmac(state.k, state.v || 0x00)
  state.v = hmac(state.k, state.v)
  // Return the first N bits of tmp
  return tmp[0:N]
}
```

HMAC_DRBG Update

- Used instead of the "no-input update" when you have additional entropy on the generate call
- Used standalone for both instantiate (**state.k = state.v = 0**) and reseed (keep **state.k** and **state.v**)
- Designed so that even if the attacker controls the input but doesn't know **k**: The attacker should not be able to predict the new **k**

```
function hmac_drbg_update (state, input) {
  state.k = hmac(state.k, state.v || 0x00
                          || input)
  state.v = hmac(state.k, state.v)
  state.k = hmac(state.k, state.v || 0x01
                          || input)
  state.v = hmac(state.k, state.v)
}
```