Cracking Cryptocurrency Brainwallets

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DISCLAIMER

- Don’t blame the victim
- Don’t be a jerk

Introduction

- Brainwallets aren’t a good idea - If you want something similar but actually secure, use WarpWallet with eight diceware words
- Don’t use brainwallets.
- Move your money out of any brainwallets you’re using. Please. Don’t get robbed.
    - Somebody just lost $14K last week. Here’s how.

What is a Cryptocurrency?

- Electronic money, secured with cryptography
- Bank and/or gov support not required
- Transfers are like checks, but signed cryptographically instead of with ink
- All transaction history is public and pseudonymous
- Bitcoin, Litecoin, Dogecoin, Defcoin, etc
- Control of private key == Control of money

What is a Brainwallet?

- Passphrase -> Private key & Address
- Knowledge of passphrase == Control of money

Why a Brainwallet?

- What people are thinking
  - “Plausible deniability”
  - “Possible 5th amendment protection against government seizure”
  - “Meat is a better random number generator than silicon because it can’t be backdoored”
- Philosophy can be admirable, but it’s technology that determines what works
  - This… doesn’t work.

Things you should remember:

- Cryptocurrency transactions are public
- Brainwallet addresses are in the transactions
- The same passphrase always results in the same address
- Guess-and-check cracking is possible
- **A weak passphrase can be guessed**
    - That $14K was sent to the passphrase of “”
    - Yes, an empty string

How a typical brainwallet tool works

"correct horse battery staple"   Passphrase

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```
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v   v   v   v   v   v   v   v    SHA256
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db963f0fe106f483d9afa73bd4e39a8a
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v   v   v   v   v   v   v   v   v   v   v   v   v   v   v   v   v   v   v     privateToPublic
           (UNCOMPRESSED)                          (COMPRESSED)
04 78d430274f8c5ec1321338151e9f27f4 -> 03 78d430274f8c5ec1321338151e9f27f4    Public key
   c676a008bdf8638d07c0b6be9ab35c71       c676a008bdf8638d07c0b6be9ab35c71
   a1518063243acd4dfe96b66e3f2ec801
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   3c8e072cd09b3834a19f81f659cc3455       |   |   |   |   |   |   |   |       SHA256
   v   v   v   v   v   v   v   v          v   v   v   v   v   v   v   v
   b57443645468e05a15302932b06b05e0       7c7c6fae6b95780f7423ff9ccf0c552a
   580fa00ba5f5e60499c5c7e7d9c7f50e       8a5a7f883bdb1ee6c22c05ce71c1f288
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   3c8e072cd09b3834a19f81f659cc3455       |   |   |   |   |   |   |   |       SHA256
   v   v   v   v   v   v   v   v          v   v   v   v   v   v   v   v
   b57443645468e05a15302932b06b05e0       7c7c6fae6b95780f7423ff9ccf0c552a
   580fa00ba5f5e60499c5c7e7d9c7f50e       8a5a7f883bdb1ee6c22c05ce71c1f288
   v   v   v   v   v   v                  v   v   v   v   v   v               RIPEMD160
   c4c5d791fcb4654a1ef5                   79fbfc3f34e7745860d7                Hash160
   e03fe0ad3d9c598f9827                   6137da68f362380c606c                (used for tx)
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   3c8e072cd09b3834a19f81f659cc3455       |   |   |   |   |   |   |   |       SHA256
   v   v   v   v   v   v   v   v          v   v   v   v   v   v   v   v
   b57443645468e05a15302932b06b05e0       7c7c6fae6b95780f7423ff9ccf0c552a
   580fa00ba5f5e60499c5c7e7d9c7f50e       8a5a7f883bdb1ee6c22c05ce71c1f288
   v   v   v   v   v   v                  v   v   v   v   v   v               RIPEMD160
   c4c5d791fcb4654a1ef5                   79fbfc3f34e7745860d7                Hash160
   e03fe0ad3d9c598f9827                   6137da68f362380c606c                (used for tx)
   v   v   v   v   v   v                  v   v   v   v   v   v               Base58Check
   1JwSSubhmg6iPtRjtyqhUYYH7bZg3Lfy1T     1C7zdTfnkzmr13HfA2vNm5SJYRK6nEKyq8  Address
```

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(What questions do we ask when a password database leaks?)

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- Were the passwords salted? No
- Is the hash slow to crack? Kinda
- Bonus: Cracking yields money

My original cracker

- C + OpenSSL
- Reads a file of hash160s, looks for passphrases passed on STDIN
- ~10,000 guesses/second
- I’ll feed it a bunch of wordlists I have - It’ll be fun!

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- I’ll feed it a bunch of wordlists I have - It’ll be fun!
- I was not prepared for the result

WTF!?

- “how much wood could a woodchuck chuck if a woodchuck could chuck wood”
- 250 BTC - $20k at the time
- Mine for the taking, but ethics
- With great power comes great responsibility
- Don’t want someone else to steal it either
- What to do?

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- What to do?
- Call Dan Kaminsky (a friend and admitted whitehat)

How to prevent a pwning

- All I have is a Bitcoin address - how to warn?
- Send “Chuck” a few cents, then take it back
    - “Oh no! Somebody must have my private key! I better move my money somewhere else while I still can!”
- Vanitygen -> address with chosen prefix
- What prefix?
- Must be short, exponentially harder w/ length

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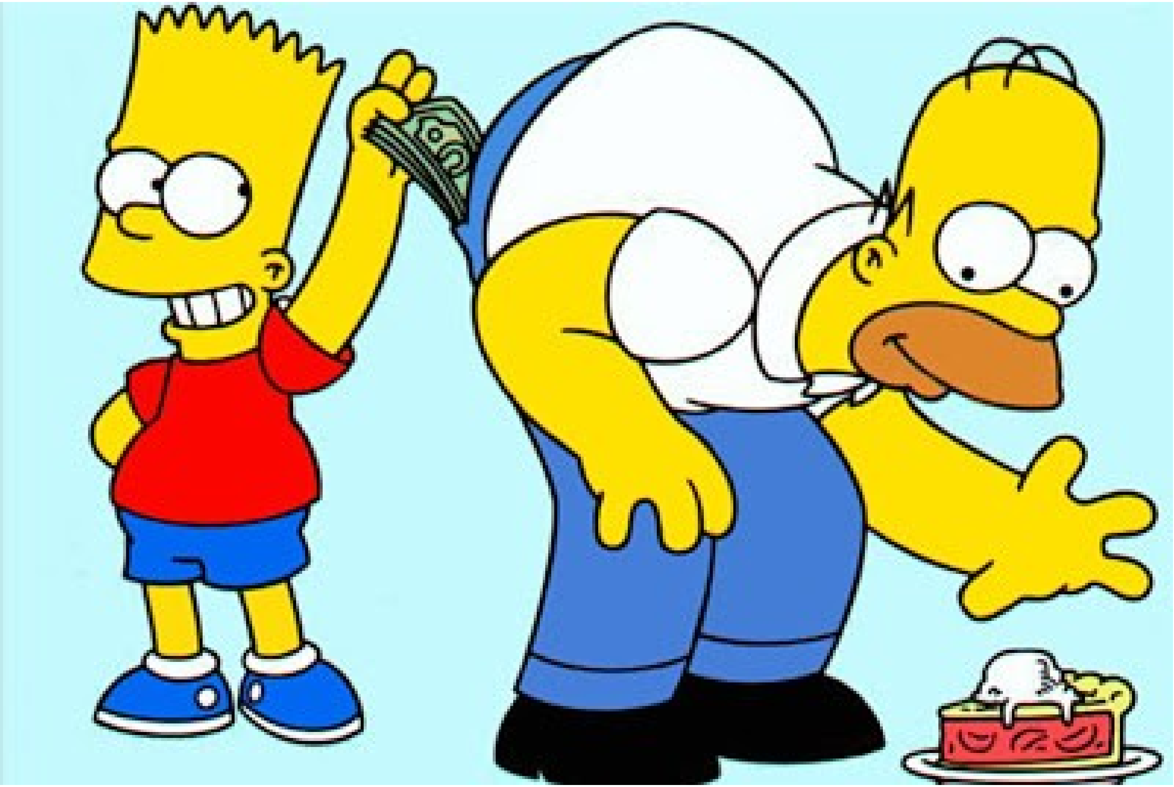
- My wife suggested “yoink”

Yoink!



The Plan

- Send a little money to Chuck
- Take that money back
  - There’s no “Balance” on an address
  - Just a collection of previous TX outputs
  - The 250BTC output is separate from the little output
- Hope Chuck worries why a “yoink” address can take money back

What actually happened

- Send a little money to Chuck
- Try to take specifically that money back
  - Not a thief!
- **Actually** draw from the 250BTC at risk
  - Took 0.00031337 BTC, sent it to “Yoink”
  - Took 249.99968663 BTC, sent it Somewhere Else
- WHERE DID THE MONEY GO!?
- WHAT IS THIS ADDRESS!?

Change Addresses

- I thought exact change would be used
- Big, old outputs are prioritized
- Bitcoin software made up a new address
- Sent the “change” from the 250BTC to it
- Found it, sent the money back

How to prevent a pwning

- New strategy: follow the BTC
- DeepBit mining pool owner passed on my email
    - After convincing him of no malicious intent
- Hilarious conversation ensues

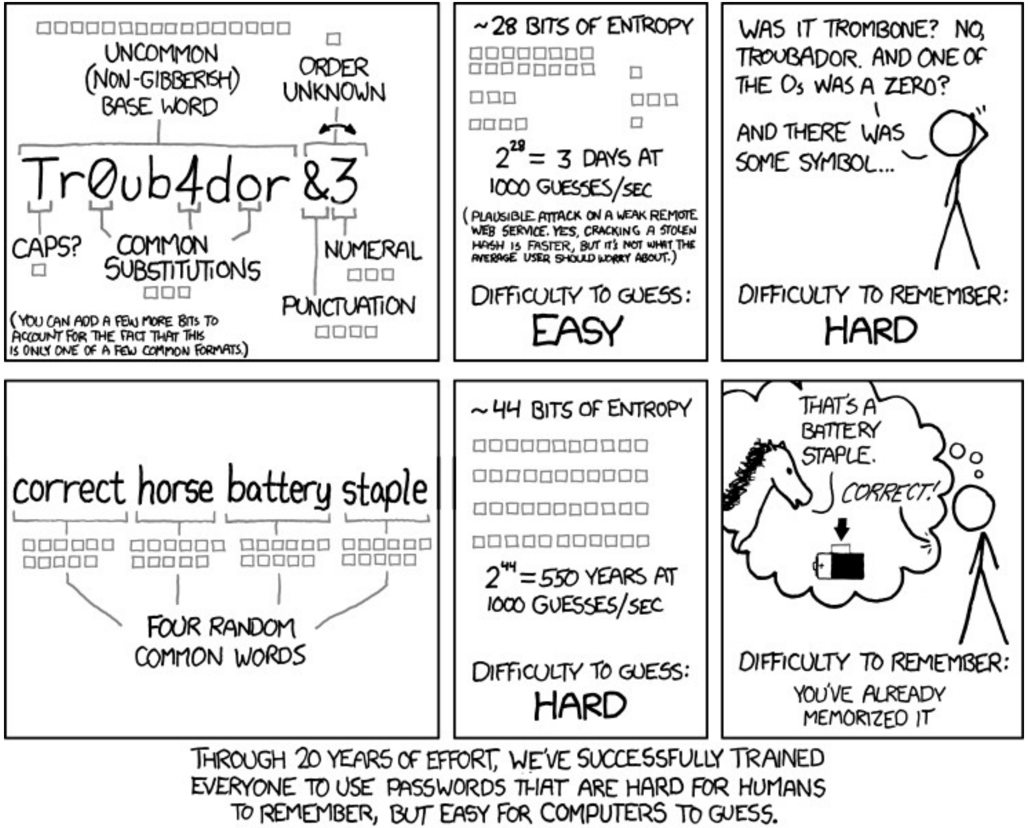
Smart people pick can bad passphrases too

- Chuck wasn’t stupid
- How many people understand how effective cracking tools are?

Meet Brainflayer

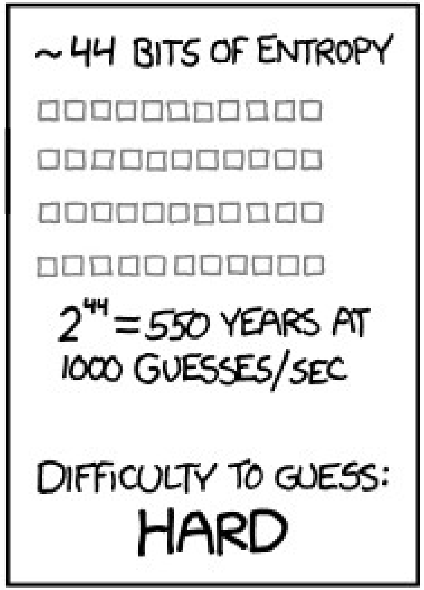
- Speed improvements - now uses libsecp256k1
- Does 130k guesses/second on my machine
- Running on EC2, $1 checks 560 million passphrases.
- With 1,000 instances, $175 will check one trillion passphrases in 9 hours

Remember this?


UNCOMMON (NON-GIBBERISH) BASE WORD
ORDER UNKNOWN
Tr0ub4dor &3
CAPS?
COMMON SUBSTITUTIONS
NUMERAL
PUNCTUATION
(YOU CAN ADD A FEW MORE BITS TO ACCOUNT FOR THE FACT THAT THIS IS ONLY ONE OF A FEW COMMON FORMATS.)
~28 BITS OF ENTROPY
2^28 = 3 DAYS AT 1000 GUESSES/SEC
(PLAUSIBLE ATTACK ON A WEAK REMOTE WEB SERVICE. YES, CRACKING A STOLEN HASH IS FASTER, BUT IT'S NOT WHAT THE AVERAGE USER SHOULD WORRY ABOUT.)
DIFFICULTY TO GUESS: EASY
WAS IT TROMBONE? NO, TROUBADOR. AND ONE OF THE Os WAS A ZERO?
AND THERE WAS SOME SYMBOL...
DIFFICULTY TO REMEMBER: HARD
correct horse battery staple
FOUR RANDOM COMMON WORDS
~44 BITS OF ENTROPY
2^44 = 550 YEARS AT 1000 GUESSES/SEC
DIFFICULTY TO GUESS: HARD
THAT'S A BATTERY STAPLE.
CORRECT!
DIFFICULTY TO REMEMBER: YOU'VE ALREADY MEMORIZED IT
THROUGH 20 YEARS OF EFFORT, WE'VE SUCCESSFULLY TRAINED EVERYONE TO USE PASSWORDS THAT ARE HARD FOR HUMANS TO REMEMBER, BUT EASY FOR COMPUTERS TO GUESS.

XKCD: Not Always Right

- Brainflayer could cover that search space in less than a week on EC2
- ...and, bad guys use botnets, probably capable of checking 2^{48} passphrases per day



Want it faster?

- Low level optimization and fancy math are possible
- GPU acceleration is possible
- FPGA acceleration is possible
- ASIC acceleration is possible, but unlikely
    - Mining BTC != Calculating Brainwallets

How does Brainflayer work?

1. Download entire blockchain
2. Extract all the unique addresses
3. Pre-process for high-speed lookups
4. Generate candidate passphrases and calculate corresponding addresses
5. Check for matching addresses from the blockchain
6. Win

Analyzing the blockchain

- 80,000,000 BTC addresses
- Bloom filter can check all addresses simultaneously, providing either “no match” or “probable match”
- Second, slower check could identify any false positives

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- 80,000,000 BTC addresses
- Bloom filter can check all addresses simultaneously, providing either “no match” or “probable match”
- Second, slower check could identify any false positives
- Crack multiple blockchains a the expense of just a few more false positives

Bloom filter?

- A big bitmask - 512MiB
- Brainflayer maps each address to 20 locations in the bitmask
- Set all of them to insert
- Read to check - return false on a miss
- Normally bloom filters uses hashes, but those are slow
- hash160 -> already hashed - just bitslice

Generating candidate passphrases

- Wordlists are easy to find, but phraselists require some creativity
- Scrape song lyric sites, wikiquote, project gutenberg, forums, mailing lists, reddit, etc.
- Normalize the raw data
- Apply rules (with/without punctuation, vary capitalization, with/without spaces, etc.)

Some results

“Down the Rabbit-Hole”- held about 85 BTC in July 2012

“The Quick Brown Fox Jumped Over The Lazy Dot” - held about 85 BTC in December 2011

“” - had 50BTC last week, stolen in seconds

Some more results

- “gate gate paragate parasamgate bodhi svaha”
- “The Persistence Of Memory”
- “QTC”
- “644122178”
- “8964009”
- “que me lleve la muerte”
- “one two three four five six seven”
- “it’s a secret to everybody”
- “Ph’nglui mglw’nafh Cthulhu R’lyeh wgah’nagl fhtagn”

A few more results (for the lulz)

- “my hovercraft is full of eels”
- “Interior Crocodile Alligator”
- “No need to worry, my accountant handles that”
- “tomb-of-the-unknown-soldier-identification-badge”
- “permit me to issue and control the money of a nation and i care not who makes its laws”
- “who is john galt”
- “Live as if you were to die tomorrow. Learn as if you were to live forever.”

All together...

- I looked up the peak balances on everything I cracked - it adds up to 733 BTC
- Hard to tell what was moved away safely and what was stolen
- I didn’t take any of it

Don’t be that guy. Don’t be Chuck.

- Just about anything you can come up with can be replicated by a sufficiently clever password guessing algorithm
- If someone else came up with it, it will eventually make it into a phraselist
- There are better ways

Alternatives

- Electrum, which generates a 12-word phrase for you
- WarpWallet supports a salt and uses scrypt for key stretching
- Encrypted paper wallets

Determining passphrase strength

- Strength of a computer generated random key measured in bits
  - Adding a bit doubles the strength
  - Adding 10 increases about 1000x
- What if key is not computer generated, but chosen by a person trying to be random?
  - Need to determine how many “bits” of entropy
  - Several tools attempt this, notably Dropbox’s zxcvbn
  - Failure cases, including limited dictionary size

Strength of chosen passphrases

- “kwyjibo#” rated as having 42.2 bits of entropy - but it was on the Simpsons without the hash - and in big wordlists
- Bad estimates are rampant
  - “one two three four five six seven” rated as 92.9 bits “centuries to crack”
  - Microsoft study estimated average user’s password is ~40 bits (wat?)

Key stretching

- Makes passwords harder to crack by making passwords more expensive to test
    - Brainflayer tests 130K/sec
    - Stretching could make this 1/sec
- scrypt, bcrypt, sha512crypt, pbkdf2, etc
- Password Hashing Competition just announced their winner, “Argon2”

Extreme key stretching

- Hard to go past 1/sec and still be usable
- Could split the problem
  - Store part of the system on a hard drive
  - Without the part, both attacker and passphrase holder might be able to try 1/day
  - Default attacker does not have the “shortcut” and runs slow, default defender does and runs fast
- More research required

How to get a secure password

- Generate it randomly!
- You may not remember it, but your password manager can
- Your password manager needs a master password - and backups
- The backups could be cracked
- Doesn’t seem to be any getting around the need to remember at least one good one

A field report

- **About half a dozen active thieves**
- They’re sophisticated, and in competition
- They must be fast - they do that with bots
- Cracking with Brainflayer is not real time
- Rainbow tables aren’t instant
- Lookup tables are instant
- They have big lookup tables

How I’d do it

- Disk-backed key-value store
- Truncated hash160 key, passphrase and/or private key value
- Extract hash160s from transaction, check if private key is available
- Use private key to take the funds
- Be faster than the other guys

Estimating table size

- 64 billion on a $120 4TB disk
- My probes imply at least 10 billion
- Every 5 character password I try gets swiped in seconds
- So does anything on common wordlists
- And lyrics, and stuff on wikiquote
- 6 random characters is a bit much for a table
- Brainflayer can do that for $1,300

Cryptomnemonics

- Diceware
- Electrum’s scheme
- Pronounceable passwords
- Structured generators
- Proposal for .onion URLs
- Active area of research, many others

Remember:

- Meat is predictable. Don’t get robbed.

Let’s have some fun

- So, DEFCOIN exists
- The guys from “Crack Me If You Can” generated a bunch of passwords and passphrases for me
- Brainflayer should be online at https://rya.nc/brainflayer shortly
- Get yourselves some DEFCOIN :D
- Follow me on twitter @ryancdotorg

Questions?