Hacking PGP

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Overview

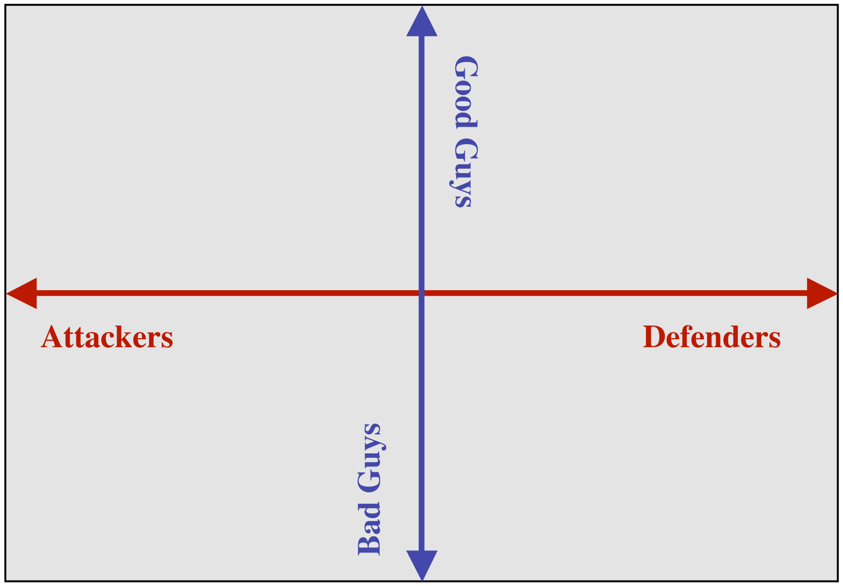
- OpenPGP is the most widely-used cryptosystem today
- There ain’t a lock that can’t be picked
- There ain’t a system that can’t be broken

- What is possible? What is not?
- What can we learn from years of experience?
- How do we make things better?
- How do we sanely defend ourselves

- Paranoia is the *unwarranted* fear they’re out to get you

Attackers and Defenders

- There are different axes
  - Good Guys and Bad Guys
  - Attackers and Defenders
- In cryptography, there are only attackers and defenders
  - Some attackers are the good guys
  - Some defenders are the good guys
- Today, we're concerned only with attacks and defense



Getting the Right Mind-Set

- Typically we think like defenders
  - Look at where we can defend
  - Look at where we can block
- To be a good defender, you need to think like an attacker
  - Imagine what’s possible
  - Imagine what’s out of scope
- Pick your favorite bad guy, and think about how to attack
  - Think about what’s possible with different capabilities, effort levels, threat models
  - If we have X, what can we do?

This Isn’t *Just* Interesting Gossip

- It is important to attack your own system
- It is important to learn how your system is attacked
- It is important to be open about how your system works
- It is important to be open about what your system doesn’t do

- Learn to do this to your own systems
  - You don’t *have* to give a Black Hat talk on it
  - It is good to have a Risks and Threats document at the least
  - I’ve done this for other companies as well.

Assumptions

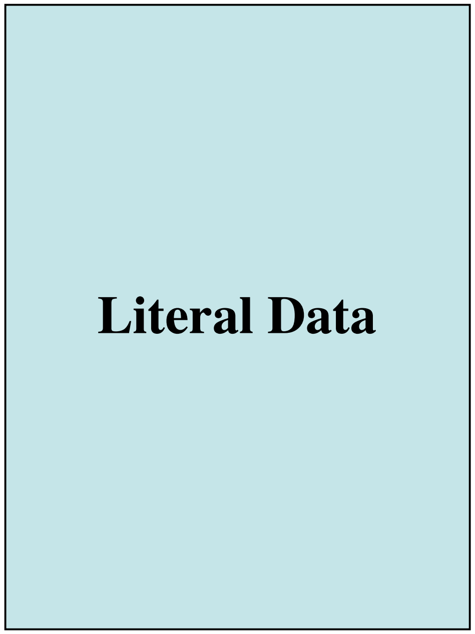
- I am assuming you know
  - What PGP is
  - Some basic bits of cryptography
    - Crypto scrambles things to make them unreadable
    - There’s such a thing as public and private keys
  - Some basic networking
    - Networks carry data from one computer to another magically
    - Reading this data is easier than we’d like, but harder than some people think
  - Some basic OS security
    - Letting someone write onto your disk is bad
- There are no stupid questions; ask, but I may defer

Terms

- OpenPGP
  - IETF standard for cryptographic data and certificates
  - RFC 2440 -- OpenPGP Formats
  - RFC 3156 -- OpenPGP/MIME
- PGP®
  - PGP Corporation software, implements OpenPGP for messages
  - PGP Disk®
  - PGP AIM encryption
- Other OpenPGP systems
  - Hushmail, GNU Privacy Guard, etc.

Cryptographic Message Structure

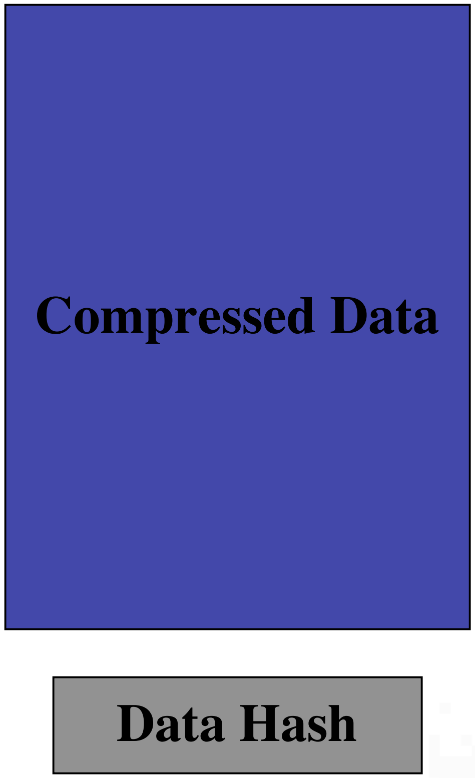
- Start with plaintext
- Ordinary data
  - Binary
  - Text



Literal Data

Cryptographic Message Structure

- Compress the Data
- Start hashing if you want to sign

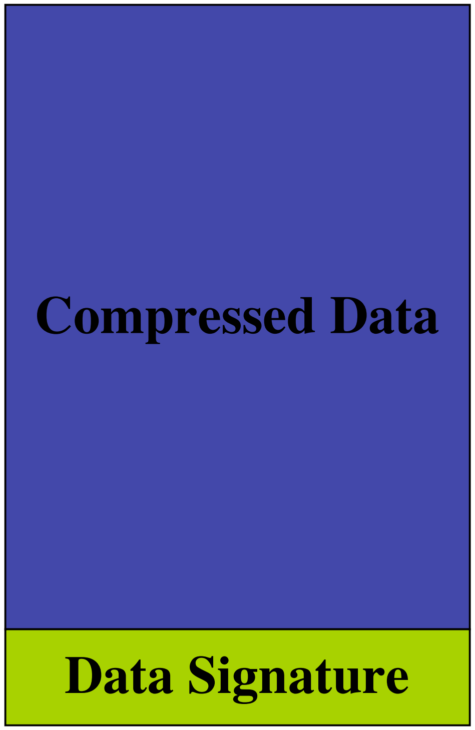


Compressed Data

Data Hash

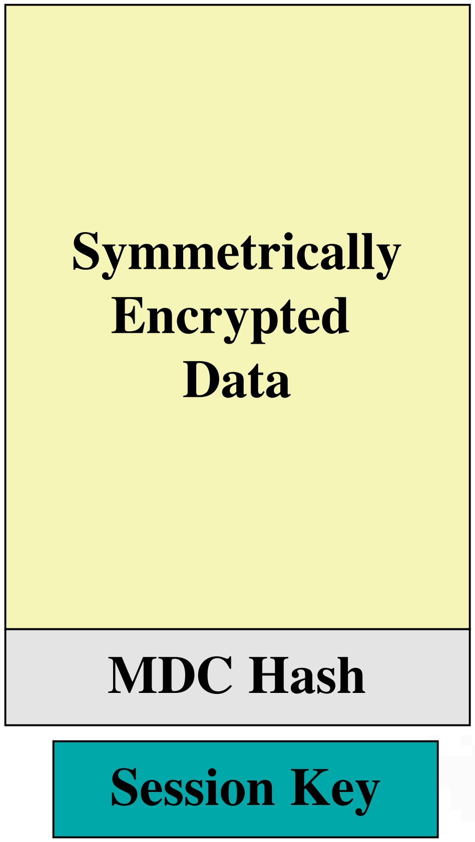
Cryptographic Message Structure

- Create a signature



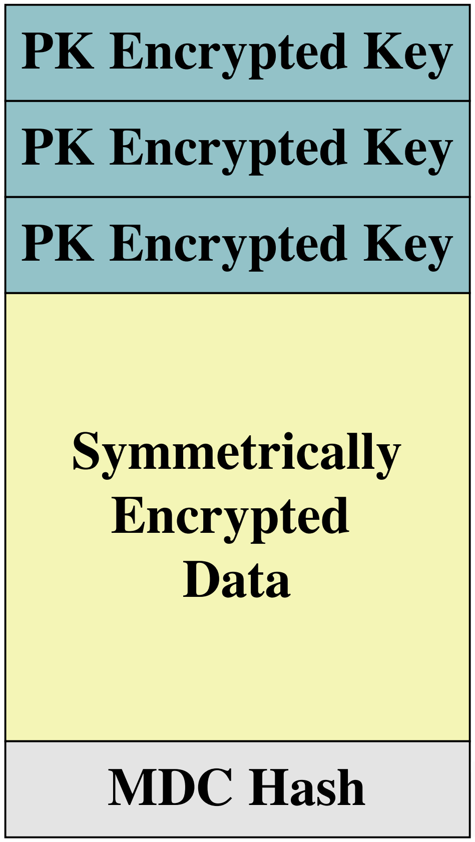
Cryptographic Message Structure

- Encrypt the data and signature
  - “Negotiate” a symmetric algorithm
  - Select a sesson key
  - Start computing a hash for Modification Detection
  - Add MDC packet at the end



Cryptographic Message Structure

- Encrypt the symmetric key to Crypto Recipients
  - All Crypto Recipients get the session key
  - Might be "speculative"
    - Key id is 0
    - Receiving system must try all possible public keys
- Decryption unwinds in reverse order



Public Key Weaknesses

- RSA
  - RSA keys can be found if ~1/4 the bits of the private key are leaked
  - A number of attacks (padding attacks, etc.) are based on this
  - Timing attacks, power analysis attacks can leak private key bits
- DSA
  - Heavily reliant on random numbers
    - Random number in signature can have covert channels
    - Interesting uses for this, but not relevant to an attack
    - If random number leaks, trivially leaks the private key!
    - This was a key in Defcon '04 RootFu

Public Key Weaknesses (cont'd)

- Elgamal
  - Can be used for signatures and encryption, but signatures are fussy, and have been discontinued
- All
  - There is parallelism between factoring and discrete logs
  - If one can be done "easily" then so can the other
  - However, this doesn't mean we know what the solution is!
  - This may not matter anyway
    - Suppose factoring is found to be polynomial
    - If the polynomial is a big polynomial, it would still be impractical to solve

Factoring Advances

- Directly applies to RSA
  - Mathematically, if RSA is easily factored, there’s an easy discrete log solver
  - No math tells us what it is, just that it exists.
- Adi Shamir estimates that machine to break 1024-bit RSA key in one year can be made for US$10M
  - Easy mitigation -- get a 1025 bit (or larger) key.
  - I’ll be happy to give mine up for a mere US$1M. Such a bargain!
- Bottom line:
  - Even if someone has such a machine(s), are you on the list?
  - If so, get a new key, you’ll be glad you did.

Symmetric Key Weakness

- 8-byte blocks
  - Birthday-attacks after 2^64 message blocks -- 2^67 bytes
  - Only an issue with extended, high-speed transfers
  - This is why AES etc. have 16-byte blocks
- AES
  - Been found to be a large algebraic equation
  - If that equation can be solved, then --- ?
- Encryption Modes
  - CFB mode can be transparently truncated
  - CBC mode (not used in OpenPGP) can be front-truncated
  - Modification Detection Codes (MDC) created to solve this

Symmetric Key Weakness (cont’d)

- Existential Forgeries
  - It is in theory possible to create a message that has the same MDC value as another message
  - Using an HMAC would prevent this
  - Real solution is to sign the message
  - Completely theoretic
  - Easier attack -- just make a new message
    - “I can say I love you just as easily as your SO can.”

Hash Algorithm Weaknesses

- Hash functions falling like flies
  - MD4, MD5, SHA-1, others like RIPE-MD, Haval, etc.
- Going to get worse before it gets better
- However:
  - Not a single real collision (pre-image collision) has been found even with MD5
  - Present attacks of no practical value
  - With 2^69 work, I can create two blobs that hash to the same value
  - These blobs will be arbitrary? Random?

Cryptographic Strength

- It is easy to forget the power of exponentials
- Every 10 bits is ~1000
- A mole (Avogadro's Number) is about 79 bits
- Are 128-bit keys good enough?

How big is 2^128?

- Imagine a processor the size of a grain of sand
- Assume it can test one key in the amount of time it takes light to cross it
- Make a parallel system by covering the Earth with these to the height of one meter

- How long (on average) does it take to break a 128-bit key?

- Answer: ~1000 years
  - This metaphor courtesy Burt Kaliski

What about Quantum Computers?

- No one knows
- But we think that quantum computers will halve the effective bit size of a key.
- This is why AES has 256-bit keys, as a hedge against quantum computers (or equivalent)

Traffic Analysis

- Encrypted messages stand out
- We can easily see encrypted messages
- Crypto recipients are in plain sight
  - Speculative key ids can hide this
  - Transmission probably makes it obvious, anyway
- If signatures are “outside the envelope” then the signer key id is evident

Anonymized Transmissions

- Even anonymous remailer networks, onion routers, etc. have limits
- If we can see inputs and outputs, they can be correlated
- Fighting correlation introduces latency, and only requires more statistics

Conclusions about Cryptography

- If you find a message *in situ*, there’s not a lot you can do with it
- Key identifiers leak data about recipient
- Hash functions are weakest point, but still ridiculously secure
- Traffic analysis trivially easy, but no eavesdropper can read a message

- None of this is PGP-specific -- everything is affected by these issues

Real-World Example: Accidental RAID on Data

- Locking yourself out
  - Victim did backups of disk -- started playing with a striping array of disks
  - Disks go bad, backup of 15 years of data is encrypted
  - Private key is in the backup
- Situation
  - Without the private key, you’re out of luck
  - Recommended victim look for another backup with the private key in it
  - Fortunately, victim had such a backup from three years past
- Note how he got out of the problem

A Quick Slide on Steganography

- Hide the message in -- something
  - Pictures
  - Sounds
  - Fake spam
- Still subject to traffic analysis correlation
- Severe bandwidth loss
- Works least well against the most obnoxious adversaries
  - An attacker who might just whack you will see stego as proof of guilt
  - Even civilized attackers will see it as admission of being up to no good

What we need is -- the private key

- The way you get at a message is to get the private key
- The private key is encrypted symmetrically with a key derived from the passphrase
- Getting the private key requires getting key data and getting the password

- Hold that thought -- let’s talk a bit more about the network

Oracle-based attacks

- Requires participation of entity that can decrypt message
- Jallad-Katz-Schneier attack
  - Construct damaged version of a message
  - Send to someone who can decrypt
  - Get them to send back erroneously decrypted data
  - Compression, MDC can thwart
- Mister-Zuccherato Attack
  - Construct damaged version of a message
  - Send to someone who can decrypt
  - Get them to report whether quick-check worked
  - ~32K transactions can yield 2 bytes of crypto block
  - Compression makes even less practical

Oracles, cont'd

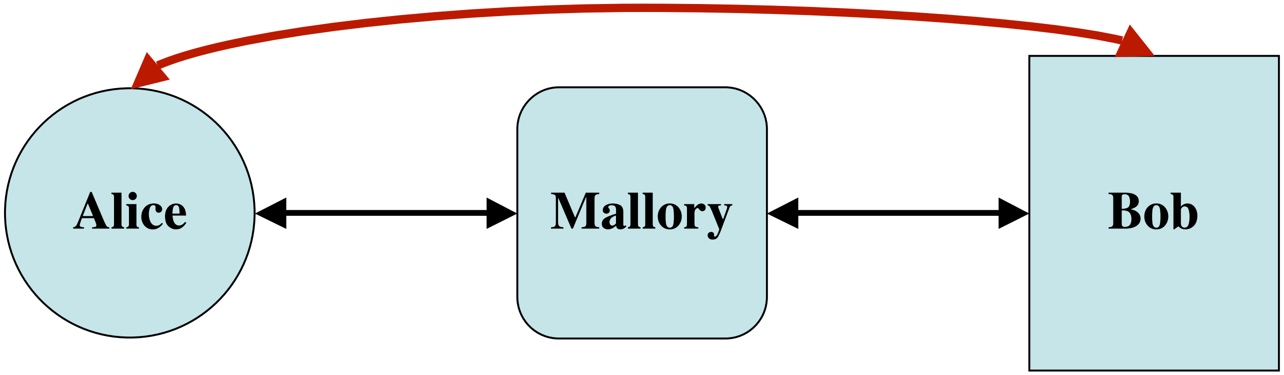
- With sufficiently stupid recipient, and just the right message, can be a real, effective attack
- Unlikely that humans are sufficiently stupid, but servers could be stupid enough because computers are like that
- Software work-arounds make not viable

- Bottom line: requires unpatched systems, uncompressed messages, badly built servers

- Protocol discussions in OpenPGP for revisions

Man-in-the-Middle Attack

- Many people mis-characterize MITM attacks
- Here’s what one is:



- Alice and Bob think they are talking to each other
  - Mallory (in the middle) pretends to be Bob when talking to Alice
  - Mallory pretends to be Alice when talking to Bob
- This is ***NOT*** a simple eavesdropper nor impersonation!

MITM Attacks (more)

- Thwarting MITMs is easy and hard
  - Certificates (including PGP keys)
  - Pre-established relationship (like SSH)
- MITMs are easy to do once, hard to do over the long term
  - If Alice and Bob talk on a channel Mallory doesn’t control, it’s likely to come out
- Not all MITMs are bad!
  - Proxy firewalls, network scan shims (anti-virus, anti-spam, etc.) are all in the middle
- My first PGP Universal paper was called “The Man-in-the-Middle Defense”
- Systems need to differentiate between types of middles (and ends)

Impersonation Attacks

- Mallory pretends to be Bob when talking to Alice, leaving Bob out.
- Phishing, other attacks are impersonation attacks
- Has both technical and psychological components
- Can be very effective in the short run
- Lasts until Alice talks to the real Bob enough
- Alice and Bob can effectively turn the tables on Mallory

Real-World Example: “Voldemort” Incident

- Voldemort tries to find out about a zero-day exploit
- Development team is distributed between Europe (Alice) and US (Bob)
- Voldemort spoofs mail from Alice to Bob
  - Claims to need zero-day fix right away
  - Manages to persuade Alice to “update” PGP to “latest version”
- Voldemort’s insistence on getting information tees off Alice, who phones Bob to chew him out
  - “Look, I told you I’d have the fix by Tuesday, give me a *%$@! Break!”
- Bob says, “Huh?”
- Alice and Bob figure out impersonation, involve the cops

Hacking the Passphrase

- Presumes you have someone’s private key file
  - Snarfed off someone’s computer, computer stolen or seized, insider gets file….
- Now what?
- Start hacking the passphrase
  - Use some cracker
  - Call specialists in this (Access Data, etc.)
  - Major governments have their own clusters to do this
  - Use psychological modeling based upon browser caches, searches of plaintext
  - Can generate over 2^40 hypotheticals per second

Passphrase Hacking (cont’d)

- Things that can help us:
  - Passphrase is in the dictionary
  - 7h3 \/1c7im 1z 1336
  - Relates to a hobby or something in the browser cache
- However, this is still a hard task
  - OpenPGP has built-in countermeasures
  - “Iterated and Salted String-To-Key”
  - Hashes passphrase+salt many times to slow down dictionary attacks
  - Cuts rate from millions, billions per second to tens

Physical Access

- "*I love cryptography, it tells me what part of the system not to bother attacking*" -- Dr Andrew Gross
- Physical Access Is All
- Discussions are now moving away from crypto into systems
- The attacks can get absurdly easy or amazingly clever

Keyloggers

- Hardware or Software
- Hardware keyloggers
  - Might be inserted in serial keyboard cable
  - Might be part of keyboard
  - I know of no USB keylogger
    - This doesn't mean they don't exist, and a USB keyboard might be bugged
- Software systems
  - Many spyware systems have them
  - PGP products have some anti-keylogger software
  - Virtualization *could* make this ultimately impossible to detect

Real World Example: Scarfo Case

- Nicodemo Scarfo was a bookie in the US, used PGP
- FBI black-bagged him, installed a keylogger on his system
- Keylogger yielded his passphrase, which was his father’s prison ID #

- We don’t know if it was hardware or software
- Keylogger only worked when he was connected to the Internet

Black bag: spy slang for breaking into a building and stealing things, leaving bugs, cameras, etc..

Other Ways to Get Keys With Physical Access

- Broken random number generator
  - All crypto relies on random numbers for keys, etc.
  - If seeded with (e.g.) time-of-day, makes for easy searches
    - This was a real bug in Netscape Navigator years ago
  - Could be genuinely bogus
    - Suppose it gave out 0-255 -- or was a constant
    - How would you know?
- This is so easy to do I would worry about someone finding it

Other Software Attacks

- Math Games
  - Random fault in RSA signature could release bogus signature that would yield key
  - Malicious blinding or padding could leak information
  - Restricted exponents in discrete logs
  - DSS signatures could release information in covert channel
    - Suppose sig mod 16411 leaked 1 byte of passphrase or key + 6-bit length
  - These software faults would imbed information that an eavesdropper could pick up
- Differential analysis
  - Timing, etc, in non-crypto process.
  - In-machine microphone uses acoustic analysis on computer, keyboard

More Outré and Silly Attacks

- Leak crypto information in other systems things
  - Take 4-bits of data and nibble count. Leak in:
    - TCP/IP sequence numbers
    - Cookies in common web sites
- Think MD5, SHA-1 checksums will help?
  - Hack the ‘md5’ command to return the right value
- While we’re at it, hack the digital signature code to verify what we want

- This is basic rootkit track-covering, just applied to crypto.

Out of Scope But Realistic

- Communications partner compromised, bribed, etc.
- Human intelligence on cleaning staff, repairman, neighbors, self
- Van Eck (TEMPEST)?
- Pinhole cameras in the ceiling, behind a picture, …..
- All depends on threat model

- Don’t forget rubber hose cryptanalysis

Real World Example: The Latvian Incident

- All that is known is from Internet report by purported victim
- Supposedly a whistle-blower in Latvian government
- Snuck out information from government offices
- Information stored on PGP Disk
- Claims that when he was caught, authorities knew things that could only have come from the PGP Disk
- What happened?
  - Is he a troll? Is he wrong? Insane?
  - Was he black bagged? Slipped bogus software? Camera in his house?
  - Merely caught out? Friend, lover suborned?

Back Down To Earth: Mitigation

- Check fingerprints, digital signatures
- Consider your threat model
- Practice good operational security
  - Don’t install things you don’t need
  - Get a laptop, lock it up
  - Store important data encrypted
  - Worry about backups, data warehousing

Trusting your Software

- Published source is good! That’s why we publish it.
- Published protocols are good
  - Even they end up with issues
  - Secret protocols, source are especially vulnerable to attacker who beats on your system
- External threat assessment, testing is good.
- Hire people to do this.
  - Not even we can rely on beta testing.
- This is like looking under the hood of a car, or visiting the kitchen of a restaurant.
  - All developers should be doing this
  - All users should be insisting on it

Who Built The Software?

- Paradox of open/published source
  - The more available the source is, the easier to hack
  - The more controlled the source, the more the origin is known
- How do you know the verified source is what made the binary?
  - How do you know the waiter didn't sneeze on your food?
- It is hard to do this retail
  - At PGP, we make desktop sources available, but not installers, etc.
  - For large customers we make full build systems available
  - Ultimately, all developers have to make tradeoffs because there are only 86,400 seconds in a day

The Bottom Line

- What is your threat model?
  - Who is your attacker?
  - What resources do they have?
  - This includes time, money, skills, access to people, software, computers
- What are you defense resources?
  - What can you afford to to defend against?
  - What personal resources can you bring to bear?
  - This also includes time, money, skills, allies….
- PGP was originally designed for activists using BBS systems

Summary

- Cryptography is hard to hack, systems are easy
- The further you are from the victim, the harder it is to hack them
- Weak point is the passphrase
- Information leaks are limited to traffic analysis

- How to hack PGP:
  - Root them
  - Bribe, suborn, compromise someone
  - Black-bag them
  - Steal a private key, break the passphrase

Questions?