KU LEUVEN

The Future of Cryptography

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2016 IACR Distinguished Lecture

TS//SI//REL to USA, FVEY

(S//REL) iPhone Location Services

(U) Who knew in 1984...

TS//SI//REL to USA, FVEY

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TS//SI//REL to USA, FVEY

(S//REL) iPhone Location Services

(U) ...that this would be big brother...

TS//SI//REL to USA, FVEY

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NSA calls the iPhone users public 'zombies' who pay for their own surveillance

TS//SI//REL to USA, FVEY

(S//REL) iPhone Location Services

(U) ...and the zombies would be paying customers?

TS//SI//REL to USA, FVEY

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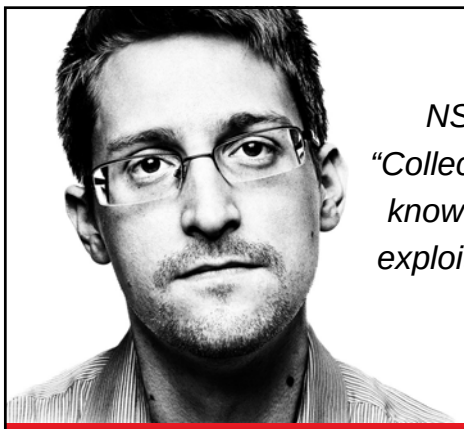

NSA:
"Collect it all, know it all, exploit it all"

www.wired.com

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Outline

- Snowden revelation and mass surveillance
- Going after crypto
- The end of crypto
- Crypto research

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Snowden revelations

most capabilities could have been extrapolated from open sources

But still…

massive scale and impact (pervasive)

level of sophistication both organizational and technical
- redundancy: at least 3 methods to get to Google's data
- many other countries collaborated (beyond five eyes)
- industry collaboration through bribery, security letters*, …
  - including industrial espionage

undermining cryptographic standards with backdoors (Bullrun) … and also the credibility of NIST

* Impact of security letters reduced by Freedom Act (2 June 2015)

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Snowden revelations (2)

Most spectacular: **active defense**
- networks
  - Quantum insertion: answer before the legitimate website
  - inject malware in devices
- devices
  - malware based on backdoors and 0-days (FoxAcid)
  - supply chain subversion

Translation in human terms: **complete control** of networks and systems, including bridging the air gaps

No longer deniable

Oversight weak

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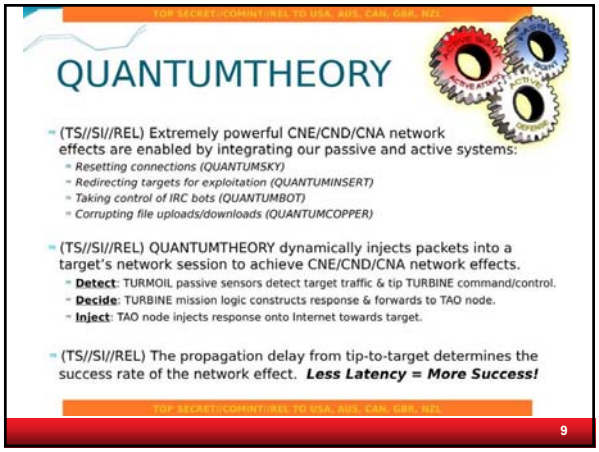

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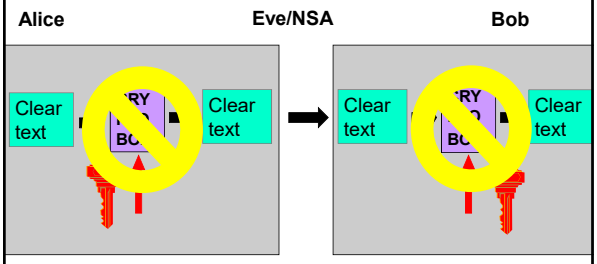
Rule #1 of cryptanalysis: search for plaintext [B. Morris]



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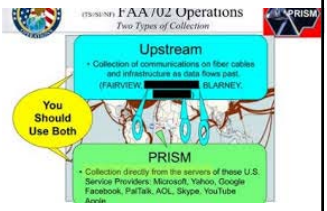
Where do you find plaintext? SSO: Special Source Operations

1. PRISM (server)

2. Upstream (fiber)



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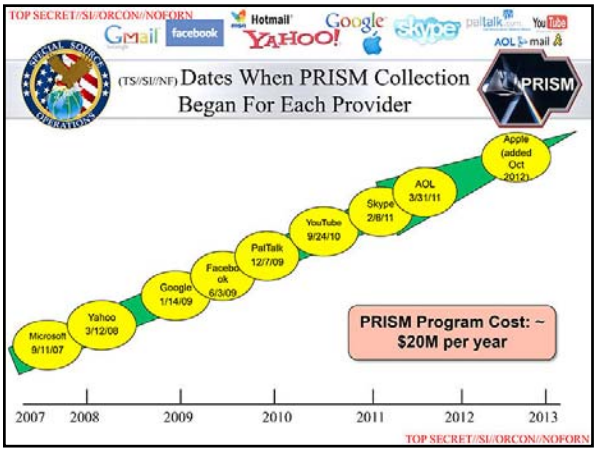

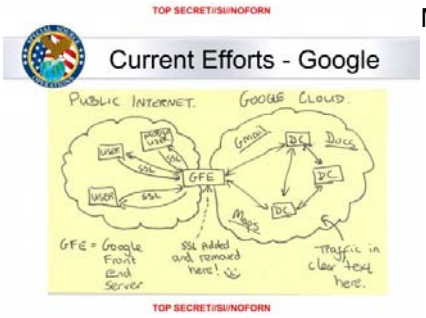

Muscular (GCHQ) help from Level 3 (LITTLE)

Jan 9 2013: In the preceding 30 days, field collectors had processed and sent back 181,280,466 new records — including "metadata," which would indicate who sent or received e-mails and when, as well as content such as text, audio and video (from Yahoo! and Google)

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3. Traffic data (meta data) (DNR)

not plaintext itself, but

- URLs of websites, MAC and IP addresses, location information,…
- it allows to map networks and reveals social relations

6 June 2013: NSA collecting phone records of millions of Verizon customers daily

- Nov. 2015: USA Freedom act: "Final temporary reauthorization of the Section 215 bulk telephony metadata data program in the US expires"
- Information stored at telcos – can be obtained via FISA court

EU: data retention directive (2006/24/EC)

- April 2014: direct is declared illegal by EU Court of Justice: disproportionate and contrary to some fundamental rights protected by the Charter of Fundamental Rights, in particular to the principle of privacy

DNR: Dial number recognition 14

3. The meta data debate

It's *only* meta data

We kill people based on meta data

… but that's not what we do with *this* metadata

Former National Security Agency (NSA) and Central Intelligence Agency (CIA) Director Michael Hayden (Reuters/Larry Downing)

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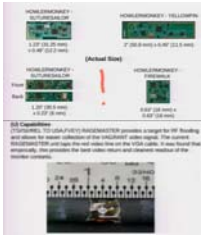
4. Client systems: Quantum + TAO

- sophisticated malware based on 0-days (or subversion of the update mechanism)
  - e.g. FOXACID – quantum insertion
- hardware devices (air-gapped machines)
  - radio interfaces and radar activation
  - supply chain interception



TAO: Tailored Access Operations 16

Which questions can one answer with mass surveillance systems/bulk data collection?

Tempora (GCHQ) ~ Deep Dive Xkeyscore (NSA)

- I have one phone number – find all the devices of this person, his surfing behavior, the location where he has travelled to and his closest collaborators
- Find all Microsoft Excel sheets containing MAC addresses in Belgium
- Find all exploitable machines in Panama
- Find everyone in Austria who communicates in French and who use OTR or Signal

BND has spied on EU (incl. German) companies and targets in exchange for access to these systems

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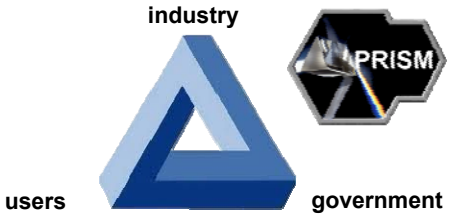
If data is the new oil, data mining yields the rocket fuel



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Mass Surveillance

panopticon
[Jeremy Bentham, 1791]

discrimination
fear
conformism - stifles dissent
oppression and abuse

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Mass Surveillance

Economy of scale

Pervasive surveillance requires pervasive collection and active attacks

- implicates everyone - also innocent bystanders
- emphasis moving from COMSEC to COMPUSEC (from network security to systems security)
- undermines integrity of and trust in computing infrastructure

Human rights do not stop at your border

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NSA foils much internet encryption

NYT 6 September 2013

The National Security Agency is winning its long-running secret war on **encryption**, using supercomputers, technical trickery, court orders and behind-the-scenes persuasion to undermine the major tools protecting the privacy of everyday communications in the Internet age

[Bullrun]

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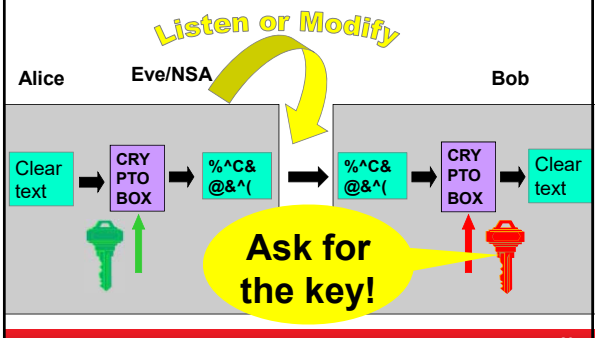
If you can't get the plaintext



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Asking for the key

- (alleged) examples – through security letters?
  - Lavabit email encryption
  - CryptoSeal Privacy VPN
  - SSL/TLS servers of large companies?
  - Silent Circle email?
  - Truecrypt??

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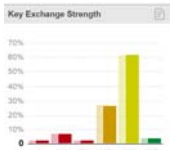
Find the Private Key (Somehow)

- Logjam: TLS fallback to 512-bit export control legacy systems
- 1024-bit RSA and Diffie-Hellman widely used default option not strong enough

- GCHQ Flying Pig program



Source: SSL Pulse

[Adrian+] Imperfect Forward Secrecy: How Diffie-Hellman Fails in Practice, CCS 2015

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If you can't get the private key, substitute the public key

12M SSL/TLS servers
fake SSL certificates or SSL person-in-the-middle as commercial product or government attack

- 650 CA certs trustable by common systems
- Comodo, Diginotar, Turktrust, ANSSI, China Internet Network Information Center (CNNIC), Symantec
- Flame: rogue certificate by cryptanalysis

Let's Encrypt life since November 2015
https://letsencrypt.org/isrg/

[Holz+] TLS in the Wild, NDSS 2016
[Stevens] Counter-cryptanalysis, Crypto'13

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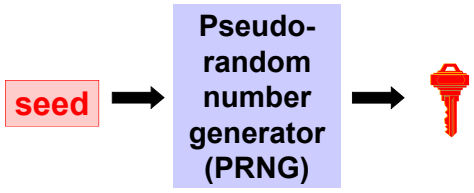
If you can't get the key

make sure that the key is generated using a random number generator with trapdoor



trapdoor allows to predict keys

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Dual_EC_DRBG

Dual Elliptic Curve Deterministic Random Bit Generator

- ANSI and ISO standard
- 1 of the 4 PRNGs in NIST SP 800-90A
  - draft Dec. 2005; published 2006; revised 2012

- Two "suspicious" parameters P and Q
- Many warnings and critical comments
  - before publication [Gjøsteen05], [Schoenmakers-Sidorenko06]
  - after publication [Ferguson-Shumov07]

Appendix: The security of Dual_EC_DRBG requires that the points P and Q be properly generated. To avoid using potentially weak points, the points specified in Appendix A.1 should be used.

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Dual_EC_DRBG

- 10 Sept. 2013, NYT: "internal memos leaked by a former NSA contractor suggest that [..] the Dual EC DRBG standard […] contains a **backdoor** for the NSA."
- 16 Sept. 2013: NIST **"strongly recommends" against the use of Dual_EC_DRBG**, as specified in SP 800-90A (2012)
- Nov. 2013: RSA's BSAFE library chooses DUAL_EC as default
- Dec. 2015: Juniper announces Dual_EC problems for Netscreen
  - 08: 6.2.r01 uses Dual_EC in a way it can be exploited
  - 12: someone changed the backdoor (6.2.r015)

[Checkoway+] On the Practical Exploitability of Dual EC in TLS Implementations, Usenix Security 2014

[Checkoway+] A Systematic Analysis of the Juniper Dual EC Incident, Cryptology ePrint Archive, Report 2016/376

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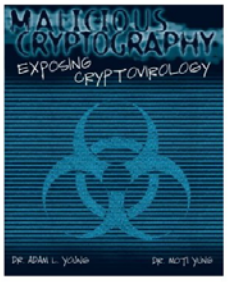
Cryptovirology [Young-Yung]

http://www.cryptovirology.com/cryptovfiles/research.html



Title: Malicious Cryptography – Exposing Cryptovirology

Authors: Adam Young
Moti Yung

Date: February, 2004

Publisher: John Wiley & Sons

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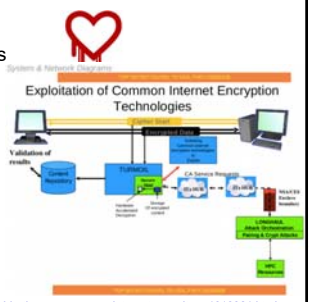
NSA can (sometimes) break SSL/TLS, IPsec, SSH, PPTP, Skype

- ask for private keys
- implementation weaknesses
- weak premaster secret (IPsec)
- end 2011: decrypt 20,000 secure VPN connections/hour



- http://www.spiegel.de/international/germany/inside-the-nsa-s-war-on-internet-security-a-1010361.html
- http://blog.cryptographyengineering.com/2014/12/on-new-snowden-documents.html

Fighting cryptography

- Weak implementations
- Going after keys
- Undermining standards
- Cryptanalysis

- Increase complexity of standards
- Export controls
- Hardware backdoors
- Work with law enforcement to promote backdoor access and data retention

We are going dark

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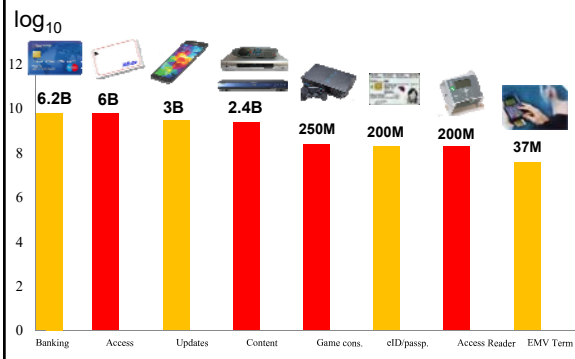
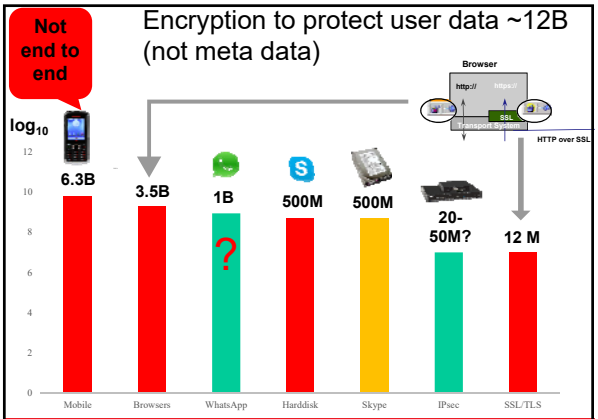
Encryption to protect industry ~18.3B



Encryption to protect user data ~12B (not meta data)



Deployment of cryptography

- most crypto in volume and market serves for data and entity authentication
  - code updates
  - payments: credit/debit/ATM/POS and SSL/TLS
  - access cards
- confidentiality
  - government/military secrets
  - DRM/content protection
  - telco: not end-to-end or with a backdoor
  - hard disk encryption: backdoored?
  - most data in the cloud is not encrypted
- Metadata: only for the happy few (million)

[Narayan13] What Happened to the Crypto Dream? IEEE Security & Privacy

Cryptography that seems to work


Active User [redacted]
Active User IP Address [redacted]
Target User [redacted]
Target User IP Address [redacted]
Start Mar 16, 2012 13:35:35 GMT
Stop Mar 16, 2012 13:39:53 GMT

Other User IP Addresses [redacted]

Time (GMT) From To Message
Mar 16, 2012 13:37:51 [redacted]
Mar 16, 2012 13:37:59 [OC: No decrypt available for this OTR encrypted message.]
Mar 16, 2012 13:38:08 [OC: No decrypt available for this OTR encrypted message.]
Mar 16, 2012 13:38:12 [OC: No decrypt available for this OTR encrypted message.]
Mar 16, 2012 13:38:24 [OC: No decrypt available for this OTR encrypted message.]

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Cryptography that seems to work

difficulty decrypting certain types of traffic, including
- Truecrypt
- GPG
- Tor* ("Tor stinks") – likely that a lot of progress is being made
- ZRTP from implementations such as RedPhone (but downgrade problem)

commonalities
- RSA (≥ 2048), Diffie-Hellman (≥ 2048), ECDH and AES
- open source
- end-to-end
- limited user base

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COMSEC - Communication Security

Secure channels
- authenticated encryption studied in CAESAR http://competitions.cr.yp.to/caesar.html
- downgrade attacks
- forward secrecy
- denial of service

Simplify internet protocols with security by default: DNS, BGP, TCP, IP, http, SMTP,…

Or start from scratch: SCION [Perrig+]

Limited fraction (a few %) of traffic is protected. A very small fraction of traffic is protected end-to-end with a high security level

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COMSEC - Communication Security
meta data

Hiding communicating identities
- few solutions – need more
- largest one is TOR with a few million users
- well managed but known limitations
  - e.g. security limited if user and destination are in same country

Location privacy: problematic

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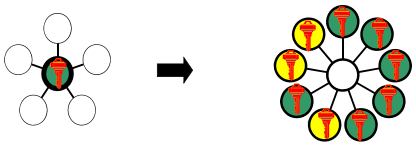
COMSEC - Communication Security

Do **not** move problems to a single secret key
- example: Lavabit email
- solution: threshold & proactive cryptography

Do **not** move problems to the authenticity of a single public key



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COMPUSEC - Computer Security

Complex ecosystem developed over 40 years by thousands of people that has many weaknesses

- **Errors** at all levels leading to attacks (think)
  - governments have privileged access to those weaknesses
- Continuous remote **update** needed (implies weakness)
- Current **defense technologies** (firewall, anti-virus) not very strong with single point of failure
- Not designed to resist **human factor** attacks: coercion, bribery, blackmail
- **Supply chain** of software and hardware vulnerable and hard to defend (backdoors or implants)

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COMPUSEC - Computer Security

Protecting data at rest

- well established solutions for local encryption: Bitlocker, Truecrypt
- infrequently used in cloud
  - Achilles heel is key management
  - territoriality

But what about computations?

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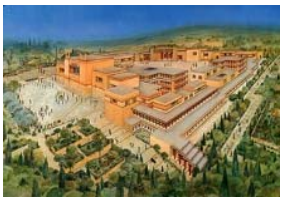
Architecture is politics [Mitch Kaipor'93]

Control:

avoid single point of trust that becomes single point of failure



Stop massive data collection

big data yields big breaches (think pollution)

this is both a privacy and a security problem (think OPM)

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Legal dimension

06/10/2015 Court of Justice of the European Union invalidates Safe Harbour US

replacement: Privacy Shield

04/05/2016 General Data Protection Regulation (GDPR) 2016/69 published

28/05/2018 GDPR comes into force

"Privacy by Design"

Fines up to 4% of global turnover

Excludes national security

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Distributed systems with local data

Many services can be provided based on local information processing

- advertising
- proximity testing
- set intersection
- road pricing and insurance pricing

Cryptographic building blocks: ZK, OT, PIR, MPC, (s)FHE

Almost no deployment:

- massive data collection allows for other uses and more control
- fraud detection may be harder
- lack of understanding and tools

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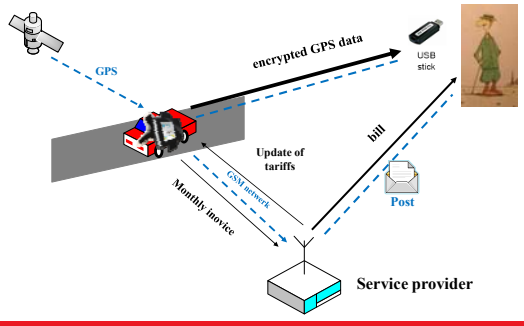
Privacy-friendly insurance pricing

[Troncoso+11]



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Centralization for small data

exceptional cases such as genomic analysis
- pseudonyms
- differential privacy
- searching and processing of encrypted data
- strong governance: access control, distributed logging

fascinating research topic but we should
favor local data
not oversell cryptographic solutions

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Transparency
Open/Free Software and Hardware

Effective governance

Increased transparency for service providers, privacy for the normal users

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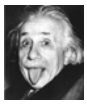
Academic freedom

[Rogaway15: The moral character of cryptographic work]

- free choice of problems you work on
  - but pressure for publication and/or impact
- very hard to predict what will be valuable
  - even harder to predict what will be valuable to society
  - but sometimes one can tell when it will likely not be

If we knew what it was we were doing, it would not be called research, would it?



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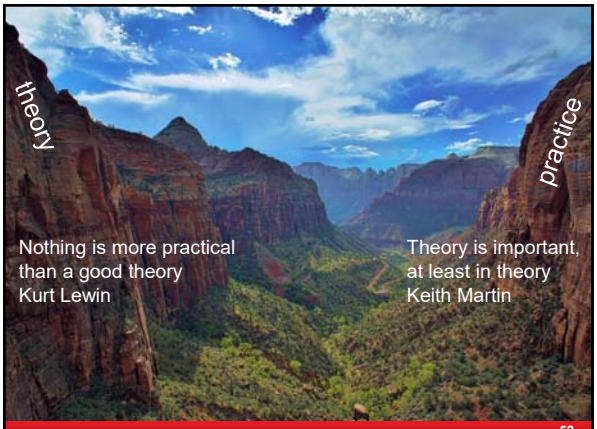

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The Crypto Stack

Implementations
Specifications
Standards
Protocols
Modes
Primitives
Assumptions

reduction proofs are very valuable
more automation needed
question models
be careful with assumptions

It is possible to build a cabin with no foundations, but not a lasting building.
Eng. Isidor Goldreich (1906-1995)

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The Crypto Stack

Implementations
Specifications
Standards
Protocols
Modes
Primitives
Assumptions

much more work needed here: automation
e.g. miTLS

which problems are hard?

A hard problem is a problem no one works on
James L. Massey

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Crypto Life Cycle

Crypto design	Kleptography
Hardware/software design	Hardware backdoors
Hardware production	
Firmware/sw impl.	Software backdoors
Device assembly	Adding/modifying hardware backdoors
Device shipping	
Device configuration	Configuration errors
Device update	Backdoor insertion

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What are real problems?

PRNGs
secure messaging
post-quantum cryptography
location-based services
cliptography
….

understand the problems
evaluate deployed or standardized systems
contribute towards creating solutions
– if possible go beyond paper designs

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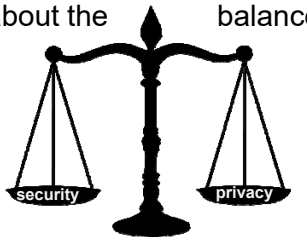
What about the balance?



- privacy is a security property: not 0-sum
- privacy is multi-dimensional, e.g. both individual and collective

- intelligence agencies have used technology to tilt the balance
- law enforcement agencies may loose out on some fronts
- can we design better solutions?

http://www.juliansanchez.com/2011/02/04/the-trouble-with-balance-metaphors/ 58

Conclusions

- New threat models
- Shift from network security to system security
- Rethink architectures: distributed
- Help build open technologies and contribute to review by open communities

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It's all about choices

You are (part of) the future of cryptography

Thank you for your attention

"Optimism is a moral duty" [Immanuel Kant]

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Further reading

Books

- Glenn Greenwald, No place to hide, Edward Snowden, the NSA, and the U.S. Surveillance State, Metropolitan Books, 2014

Documents:

- https://www.eff.org/nsa-spying/nsadocs
- https://cjfe.org/snowden

Articles

- Philip Rogaway, The moral character of cryptographic work, Cryptology ePrint Archive, Report 2015/1162
- Bart Preneel, Phillip Rogaway, Mark D. Ryan, Peter Y. A. Ryan: Privacy and security in an age of surveillance (Dagstuhl perspectives workshop 14401). Dagstuhl Manifestos, 5(1), pp. 25-37, 2015.

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More information

Movies

- Citizen Four (a movie by Laura Poitras) (2014) https://citizenfourfilm.com/
- Edward Snowden - Terminal F (2015) https://www.youtube.com/watch?v=Nd6qN167wKo
- John Oliver interviews Edward Snowden https://www.youtube.com/watch?v=XEVlyP4_11M

Media

- https://firstlook.org/theintercept/
- http://www.spiegel.de/international/topic/nsa_spying_scandal/

Very short version of this presentation:

- https://www.youtube.com/watch?v=uYk6yN9eNfc

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