

# **650.445: Practical Cryptographic Systems**

## **Hardware Security & Tamper Resistance\***

**\* Much of this lecture based on  
Anderson, Chap 14**

**Instructor: Matthew Green**

# Housekeeping: A2

- Server bug fixed
- Client issue fixed!
- Don't RE the Java or you'll be sad
- Any questions?

# Reading and Midterm

- 19th or 26th
- Do the reading, please
  - Anderson, Physical Tamper Resistance
  - Gutmann, Lessons Learned
  - Adam Langley, GotoFail
  - Cache timing attacks on AES
  - Kocher: Timing attacks
  - Bardou et al.: Efficient Padding Oracle Attacks

# Kocher's Timing Attack

- Assume that for some values of  $(a * b)$ , multiplication takes unusually long
- Given the first  $b$  bits, compute intermediate value “result” up to that point
- If the next bit of  $d = 1$ , then calc is  $(\text{result} * c)$
- If this is expected to be slow, but response is fast then the next bit of  $d \neq 1$



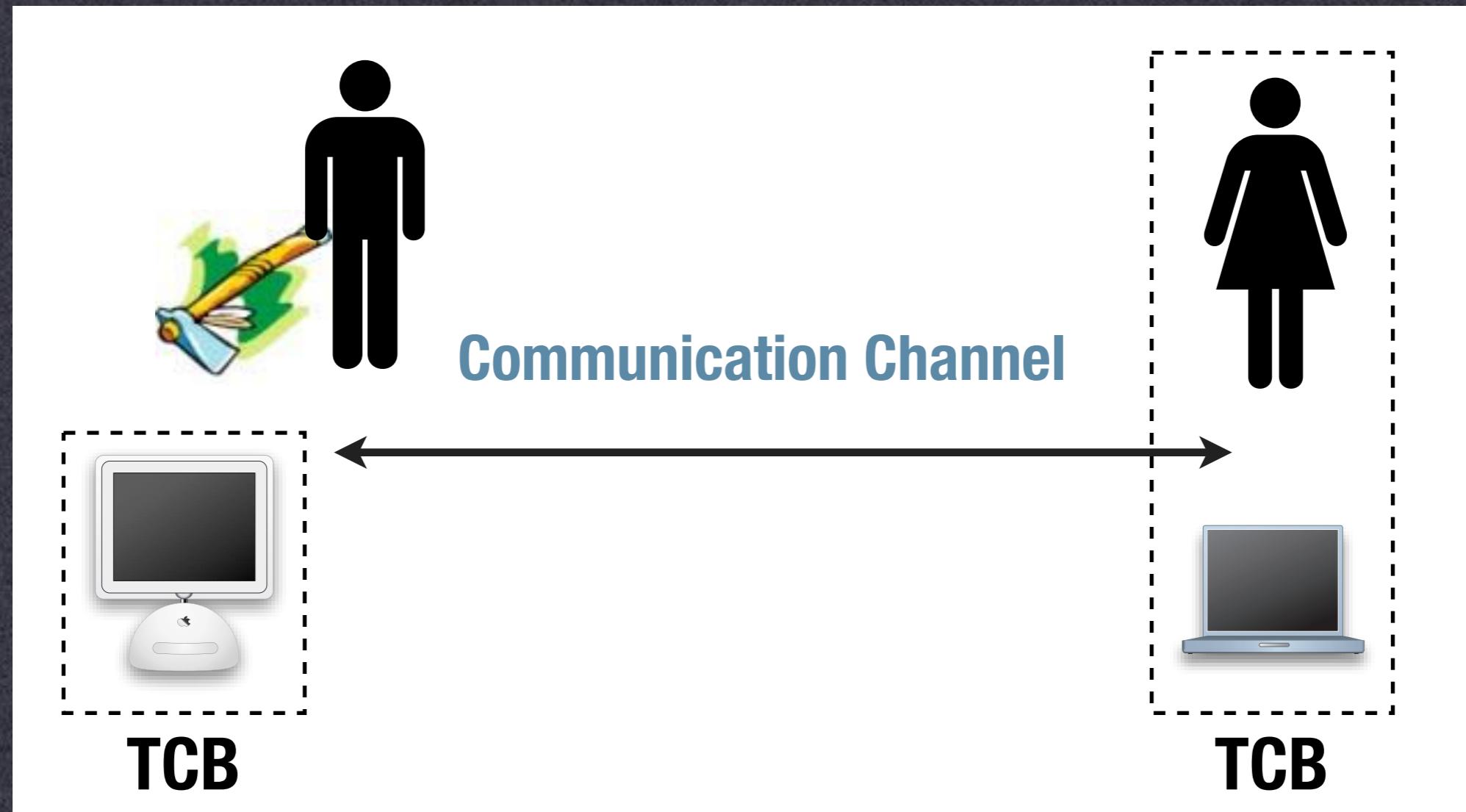
by Michael Mimoso

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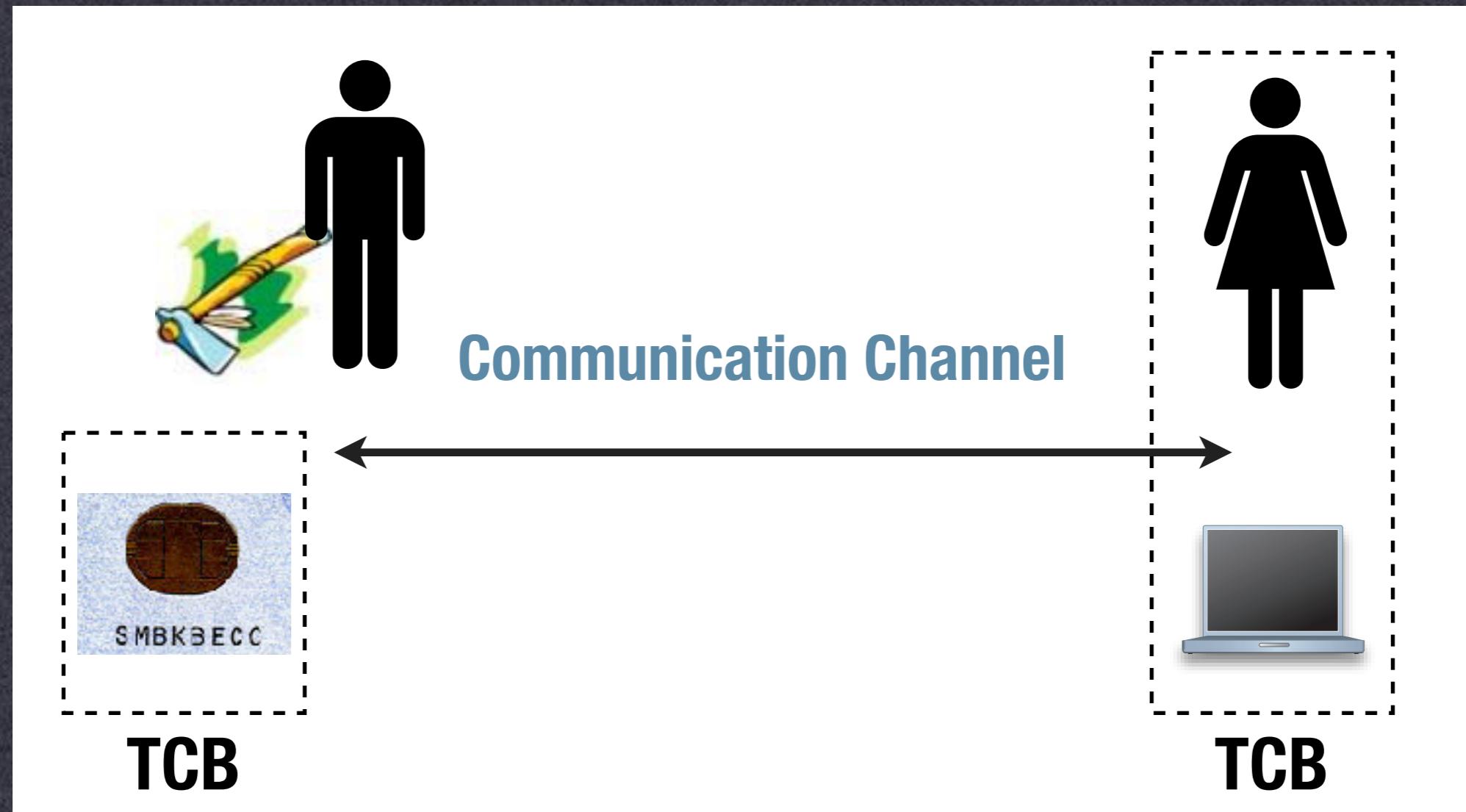
October 3, 2016 , 8:45 am

Logjam was one of several downgrade attacks discovered in the last 18 months that

# Today



# Today



# Physical Security

- Devices in a hostile environment
  - Military cryptoprocessors
  - Financial services
- ATM machines
- Credit-card smartchips
  - Digital Rights Management devices
- Trusted Computing



Image of IBM Cryptoprocessor: [www.cl.cam.ac.uk/~rnc1/descrack](http://www.cl.cam.ac.uk/~rnc1/descrack)

# Threat Models

- Various levels of sophistication
  - **Class 1: Clever Outsiders**  
Moderate knowledge of system, will usually attack via a known weakness
  - **Class 2: Knowledgeable Insiders**  
Specialized technical education & experience  
Access to the system & tools to exploit it
  - **Class 3: Funded Organizations**  
Team of attackers backed by significant funding,



# FIPS Levels

- FIPS 140-2: Cryptographic Modules
  - FIPS 140, Level 1
    - Software only, no physical security
    - FIPS 140, Level 2
  - Tamper evidence or pick-resistant locks
    - FIPS 140, Level 3
  - Tamper resistance
    - FIPS 140, Level 4
  - Strong physical security around device

# System Examples

- Classical ATM machine:
  - Armor, temperature sensors, tilt sensors
  - Attacker has to drill through the shell, defeat any tamper sensors, avoid setting off alarms
  - Might lose \$\$, but can often protect cryptographic secrets



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# System Examples

- Modern ATM machine:
  - No armor, limited physical security
  - Owner/operator might be untrustworthy
  - Limited \$\$ amounts, still worry about loss of key material
  - Interface based on commodity OS (Windows CE?)



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# System Examples

- Back-end server:
  - Strong physical security around server room
  - Performance is critical
  - Insider attacks a major concern
  - Large potential \$\$ losses if key material compromised
  - Linux/Windows/Legacy



# System Examples

- Client-side smartcard:
  - User/owner is potentially hostile
  - Worse if card is stolen
  - Attacker-supplied power source



# Two approaches

- Tamper-evidence
  - Make tampering obvious
  - Allow for recovery/renewability  
(e.g., re-generate cryptographic keys)
- Tamper-resistance:
  - Keep attackers out
  - Wipe cryptographic key material



# A General Approach

- Minimize the size of the “T” in our TCB
  - i.e., putting an ATM in a safe is expensive
  - Anchor trust in this area, build a secure system from there
  - Might involve untrusted storage/RAM/ROM/processing, all connected to one trusted component



# A General Approach

- Might also be necessary for practical reasons:
  - Support multiple “untrusted” manufacturers
  - E.g., SIM chips
  - E.g., CableCARD



# Protecting Cryptoprocessors

- Metal
  - Can be cut/drilled
- Epoxy
  - Can be scraped off, penetrated with a logic analyzer probe



# IBM 4758



# IBM 4758

- **High-security Cryptoprocessor**
  - RAM, CPU, cryptographic circuitry
  - Dedicated SRAM for key memory
  - Battery powered
  - All wrapped in:
- Aluminum EM shielding
- Tamper-sensing mesh
- Potting material



Source: Anderson Chap 14

# IBM 4758

- Tamper sensing mesh:
  - Thousands of small wires wrapped around device
  - Interrupting any circuit (i.e., drilling) wipes the contents of key SRAM
- v1: copper wires
- v2: printed circuits



# IBM 4758

- Memory remanence attacks:
  - Key “burn in”
  - After storing keys for too long, they may become permanent default states of RAM
  - NSA Forest Green Book has guidelines for this
  - Solution: “RAM savers”



# IBM 4758

- Memory remanence attacks:
  - Attacker might try to freeze the device
  - Thus keys would survive wipe
  - Bursts of X-Rays can “lock” RAM in
  - Protections: temperature sensor, radiation sensor
- Gets too cold, keys go away
- Though what if we ship UPS!



# Capstone/Clipper

- Proposed national voice encryption device
  - Designed as a compromise between need for strong crypto, and US's need to eavesdrop
  - Contained a secret cipher (Skipjack) w/80-bit key
  - Tamper-resistance:
    - Difficult to extract embedded secret keys
    - Difficult to R.E. Skipjack design
    - Difficult to alter operation
    - Currently used in Fortezza card



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# Capstone/Clipper

- Threat model & design considerations
  - Extremely hostile environment
  - Range of well-funded adversaries (probably non-military)
  - Protecting secrets & design & operation
  - Very small device



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# Clipper/Capstone

- Tamper-resistance:
  - Extremely sophisticated
  - Metal/epoxy top
  - Vialink Read-Only Memory (VROM)  
- Bits set by blowing antifuses using electrical charges



# Clipper/Capstone

- Attacking Clipper & QuickLogic:
  - Remove upper metal layer (difficult)
  - Use an electron microscope to read VROM (expensive & difficult, requires extra analysis)
  - Monitor circuit while chip is in use (more promising)



# Capstone/Clipper

- Operation:
  - Each ciphertext accompanied by LEAF (Law Enforcement Access Field)
  - Essentially, key escrow under gov't key
  - LEAF contains a “checksum” (MAC) to prevent tampering/removal
- Break:
  - Matt Blaze - found that LEAF bound to message w/ 16-bit checksum

# Smartcards

- Very widely used
  - Contact/Contactless varieties
  - Small microprocessor/RAM/Serial bus
  - Became major targets of attack due to:
    - Satellite TV
    - GSM phones
    - Lately: Payment Cards



# Attacking Smartcards

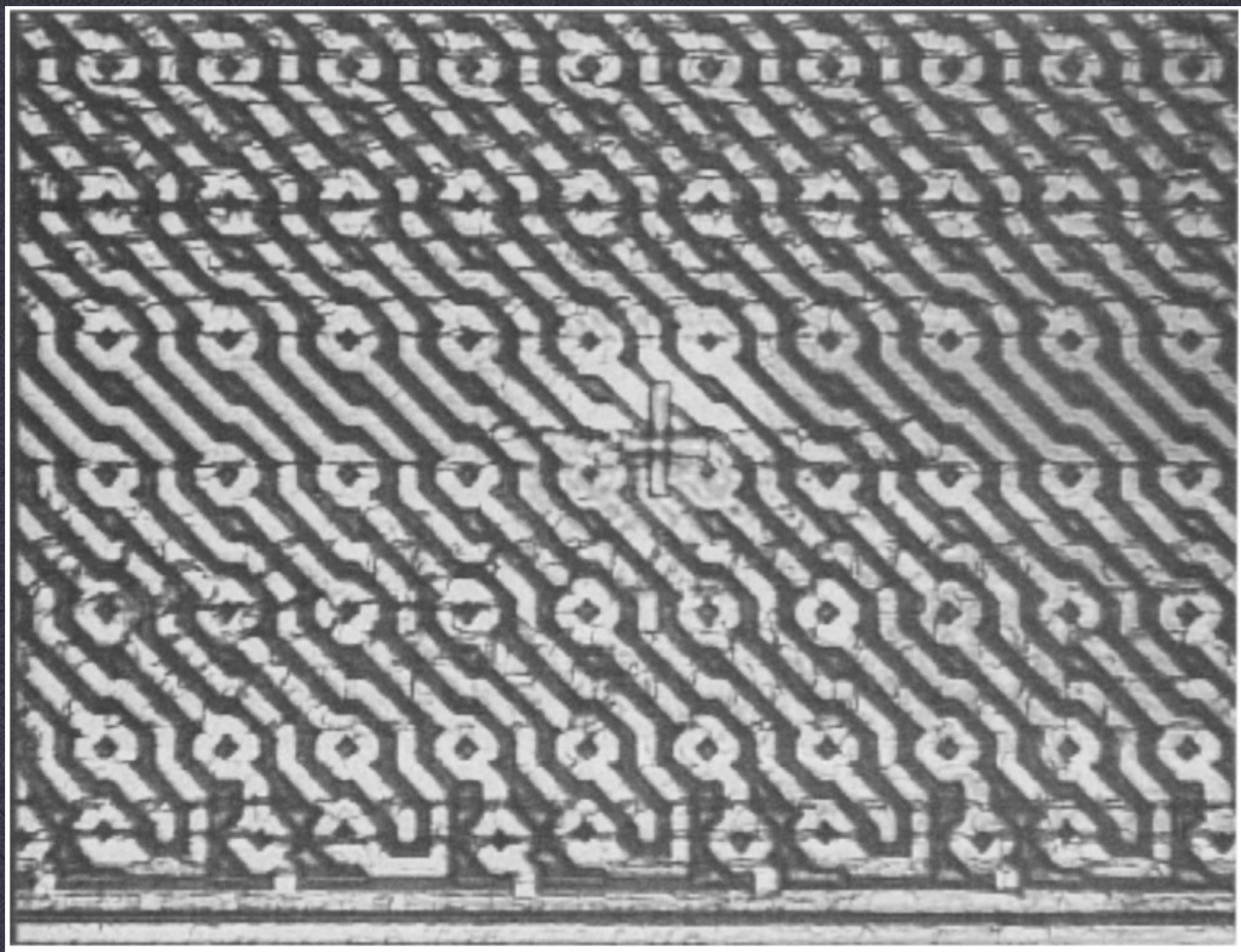
- Protocol-level attacks
  - Intercept messages, control access
- Side-channel attacks
  - Attacker controls the power source
  - DPA countermeasures introduced in 1990s



# Attacking Smartcards

- Attacks on voltage supply
  - Memory read/write attacks
  - Fault injection
- Attacks on hardware
  - Take it apart, use an electron microscope
  - Same countermeasures, though:  
-protective mesh, potting





# Tamper-evidence

- **Seals/locks**
  - Make sure you can detect and renew security after an attack occurs
- Can even be implemented in software (under certain assumptions)



# Trusted Computing

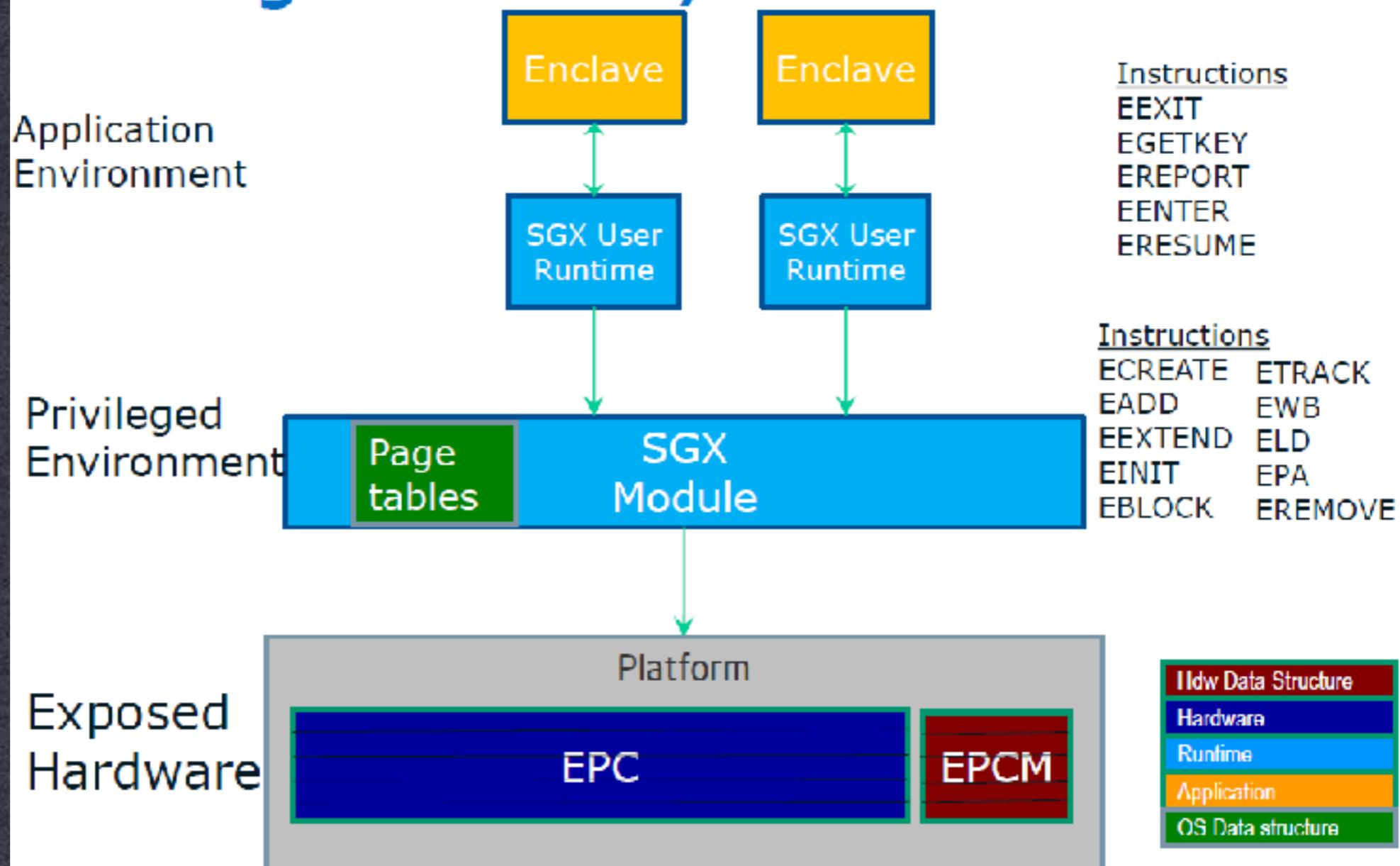
- Effort to put a tamper-resistant security processor into every PC
  - Useful to verify software integrity
  - Key management for access control & DRM
  - Minimize co-processor footprint by bootstrapping secure software
- Newest incarnation: Intel SGX

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- Effort to put a tamper-resistant security processor into every PC
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# SGX

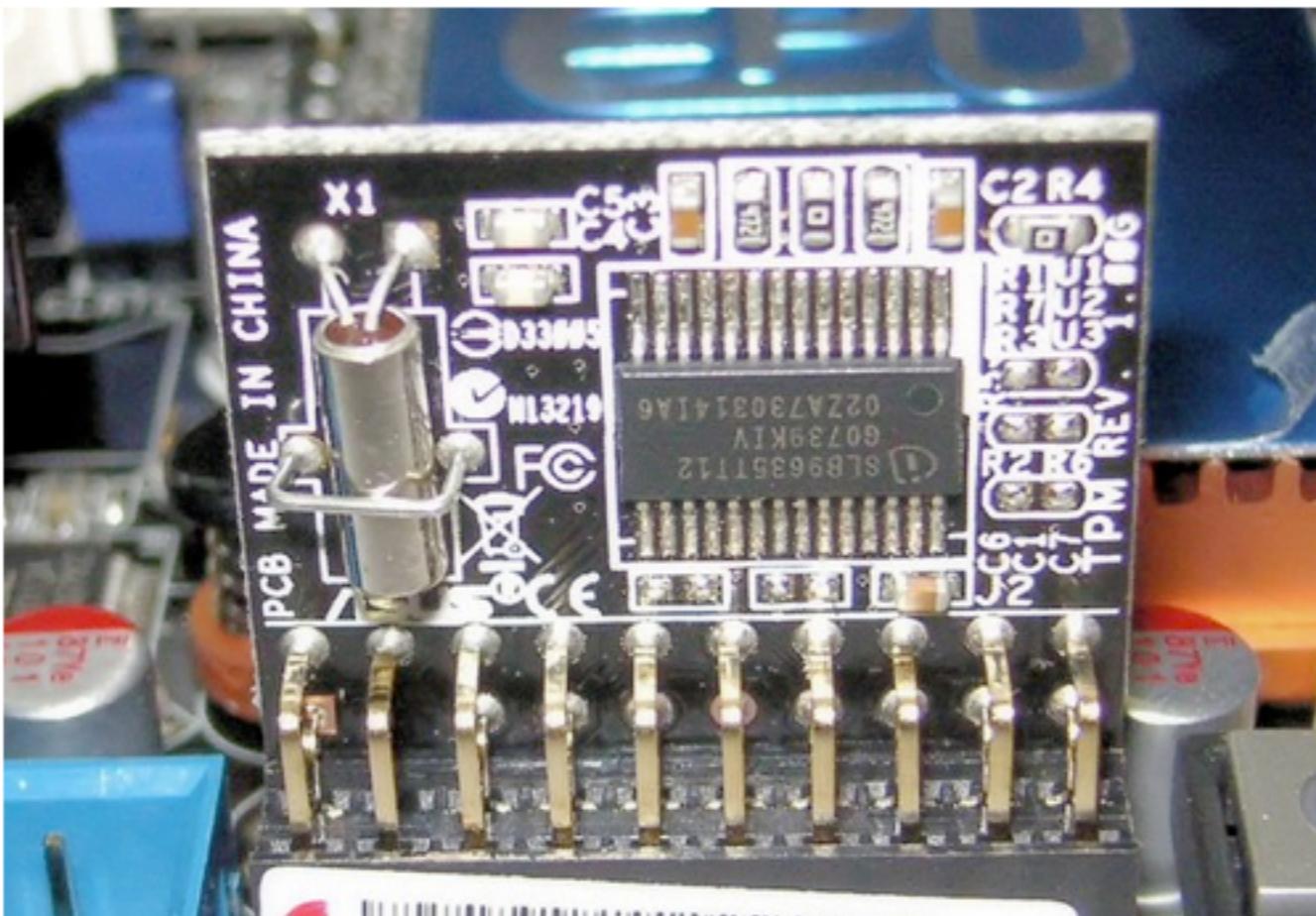
## SGX High-level HW/SW Picture



FILED UNDER [Desktops](#), [Laptops](#)

## Christopher Tarnovsky hacks Infineon's 'unhackable' chip, we prepare for false-advertising litigation

By Tim Stevens  posted Feb 12th 2010 10:31AM



As it turns out, [Infineon](#) may have been a little bit... *optimistic* when it said its SLE66 CL PE was "unhackable" — but only a little. The company should have put an asterisk next to the word, pointing to a disclaimer indicating something to the effect of: "Unless you have an electron microscope, small conductive needles to intercept the chip's internal circuitry, and the acid necessary to expose it." Those are some of the tools available to researcher Christopher Tarnovsky, who perpetrated the hack and presented his findings at the Black Hat DC Conference earlier this month. Initially, Infineon claimed what he'd done was impossible, but now has taken a step back and said "the risk is manageable, and you are just attacking one computer." We would tend to agree in this case, but Tarnovsky still deserves serious respect for this one. Nice work, [Big Gun](#).

# Trusted Computing

- Implications

- Same chip used in the XBox 360 (allegedly, Tarnovsky offered \$100k to hack it)
- Illustrates the most important lesson of tamper resistant systems:
  - Individual devices can and will be hacked
  - Must ensure that single-device hack (or easily replicable attack) does not lead to system-wide compromise!