The Need for Speed: Applications of HPC in Side Channel Research

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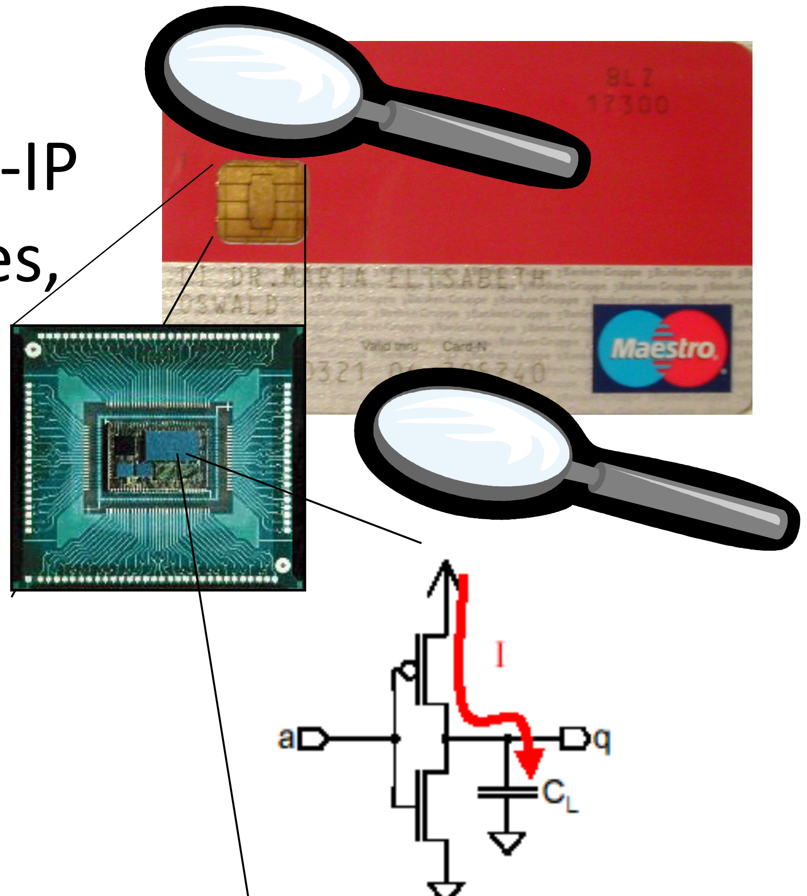
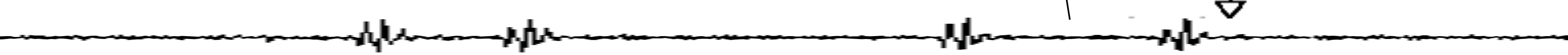
Roadmap

- Background: side channels, practical angles for research
- The BIG question: how much does my device leak?
- Summary

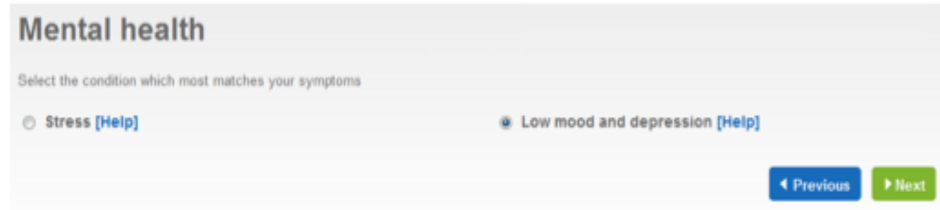
In case you haven't heard of side channels ....

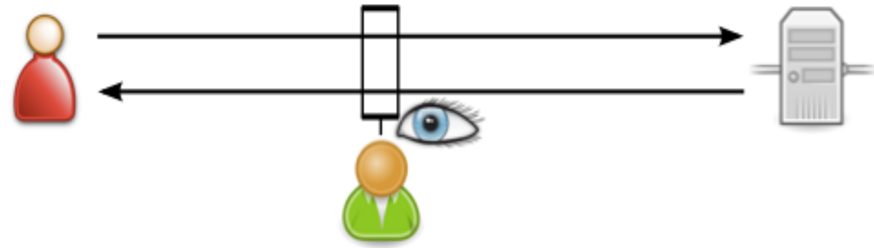
- Known side channels:
  - timing, power, EM
  - acoustics, de-duplication, TCP-IP traffic features, error messages, cache behaviour, ...
- Used for
  - Key recovery
  - Plaintext recovery
  - Device fingerprinting

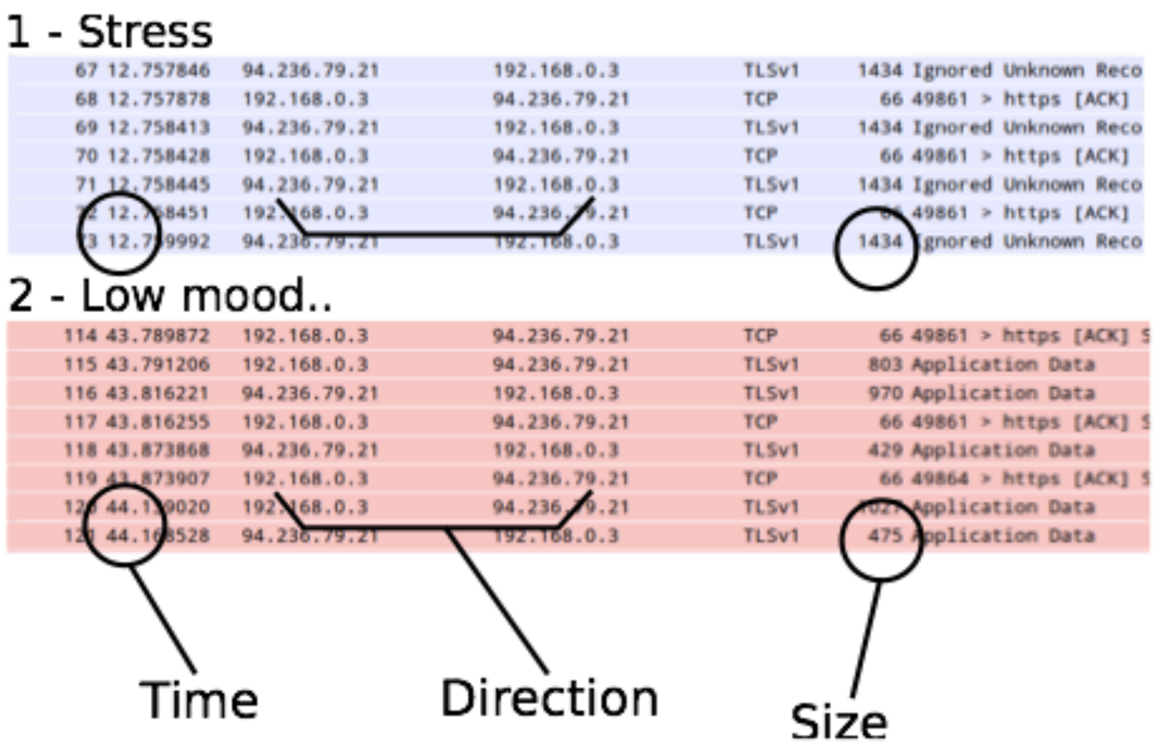




E.g. Web traffic analysis



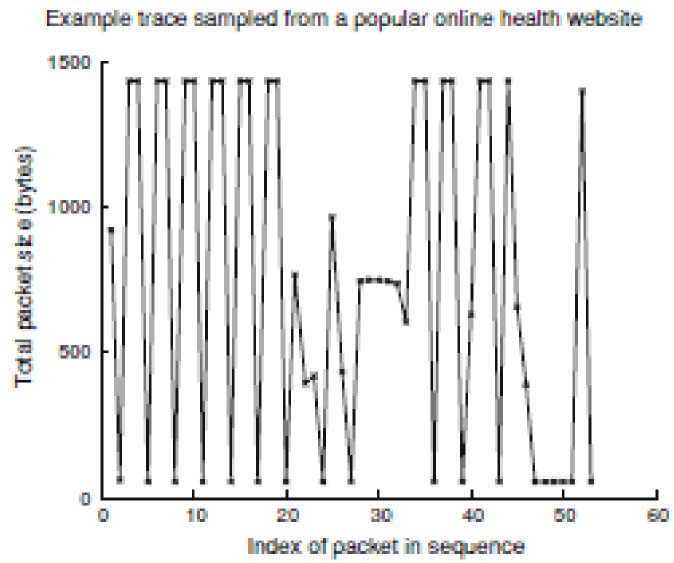


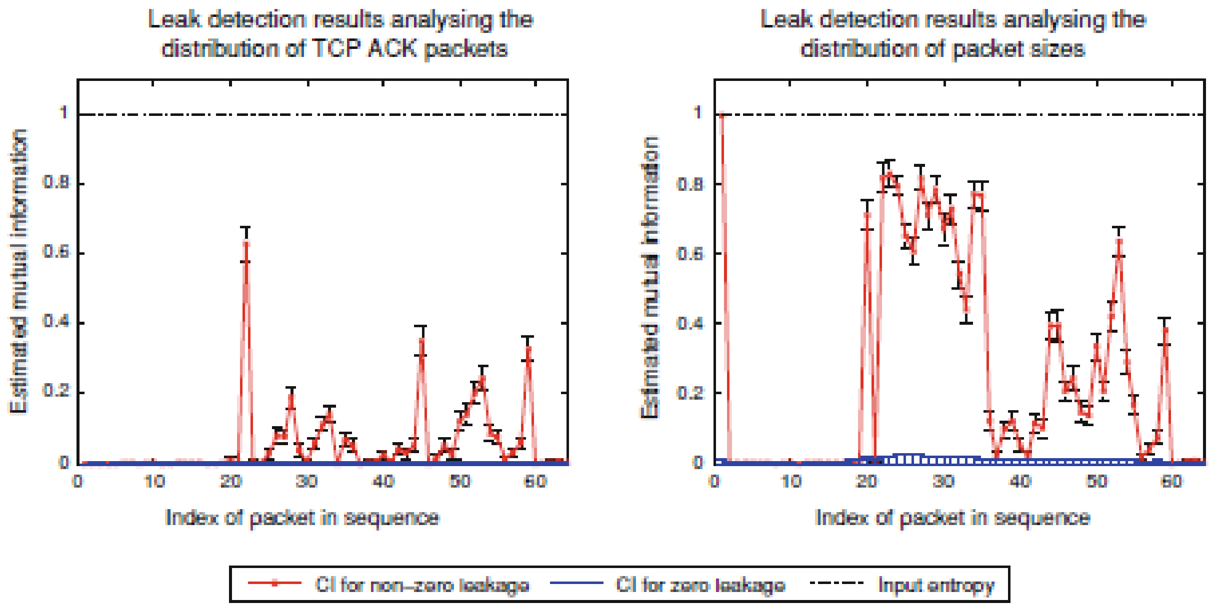


Profiling of web traffic allows to recover user choices even through encrypted traffic.

(Chen et al., IEEE S&P, 2010)

E.g. Web traffic analysis: features which leak





Features that leak are:

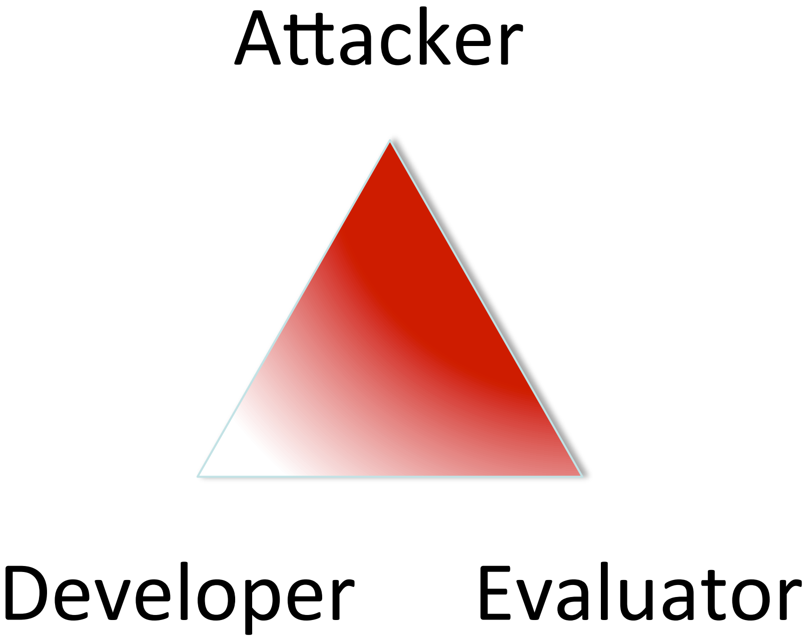
- Packet size
- Direction
- Arrival time
- TLS record lengths
- TCP acknowledg. flag
- TCP handshaking flags

Details: Mather & O., JCEN 2012 (2)

Side channel research questions …

- Are there leaks? If so what leaks? If not how can we be sure?
- How many side channel observations are needed to exploit the leaks …?
  - One?
  - Many? (What is many?)
  - What does exploit mean? (Key recovery, partial key recovery, lambda leakage?)
- (New attacks, new countermeasures, leakage resilient crypto)

Different practical 'angles' for (SC) research



Distinguished by:

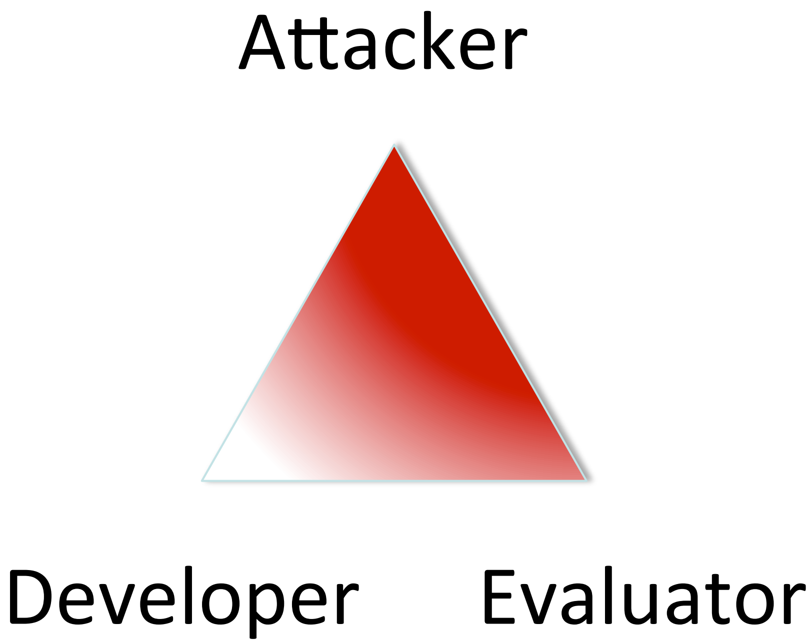
Degree/extent of knowledge:

- Leakage points (within a trace)
- Leakage model

Computational capabilities:

- How many leakage traces
- How much computation

Different practical 'angles' for (SC) research



Evaluator should be at least as good as best 'practical' attacker …

But computational capabilities are increasing fast:

- Attack using a 32-bit key guess took just over 8 minutes in 2012 using 4 state of the art GPUs
- Same attack now takes 15 sec!

Roadmap

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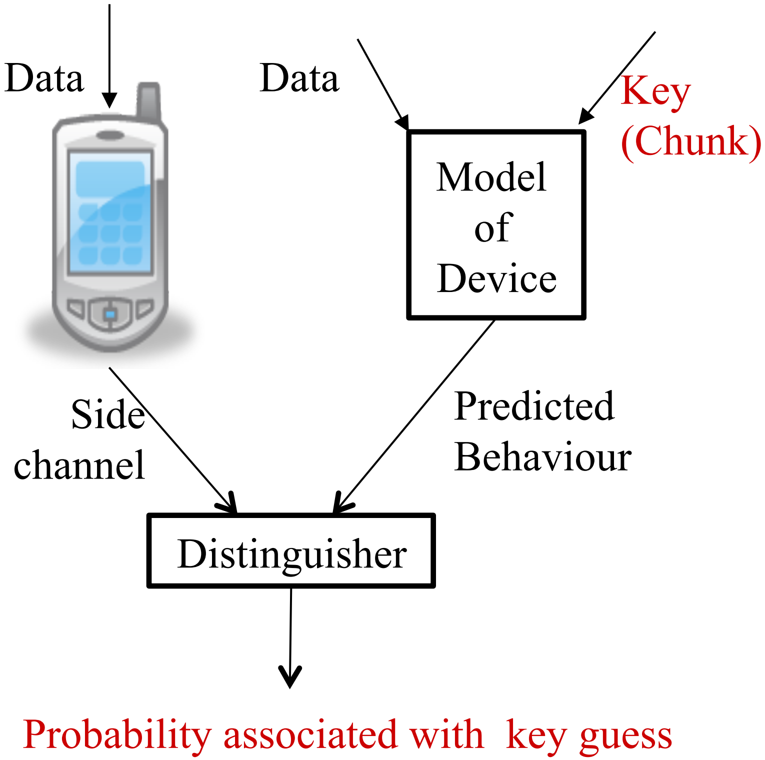
- **The BIG question: how much does my device leak?**
- Summary

How to determine λ



1. Measure side channels for N encryptions
2. Extract relevant data: leakage detection
3. Analyse relevant data to extract probabilities for chunks of key: leakage exploitation
4. Sift through key space using probabilities: key enumeration/ rank estimation

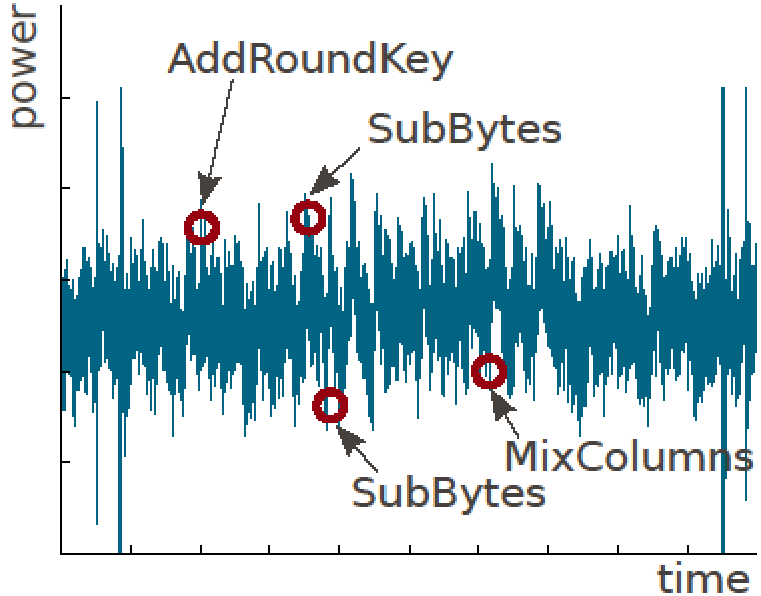
Research question:
Given N observations, how much effort is required (in 4.) to find the secret key.

→ **Leakage bound λ**

Leakage detection

Given a vector of side channel points (aka a trace, see below), determine which of the points contain leakage about a (specific) secret.

- What statistical test to use? (t-test, continuous MI, or discrete MI):
  - Genericity (i.e. it captures all sorts of leaks)
  - Computational requirements; time
  - Number of leakage traces (aka sample size)



(Power traces of AES encryption)

Leakage detection, cont.

The **better test** can spot information leakage **faster and more reliable**—it requires less data; whilst maintaining a high statistical power (i.e. probability a test correctly rejects a null hypothesis).

Can we estimate the minimum sample sizes required to achieve sufficient statistical power?

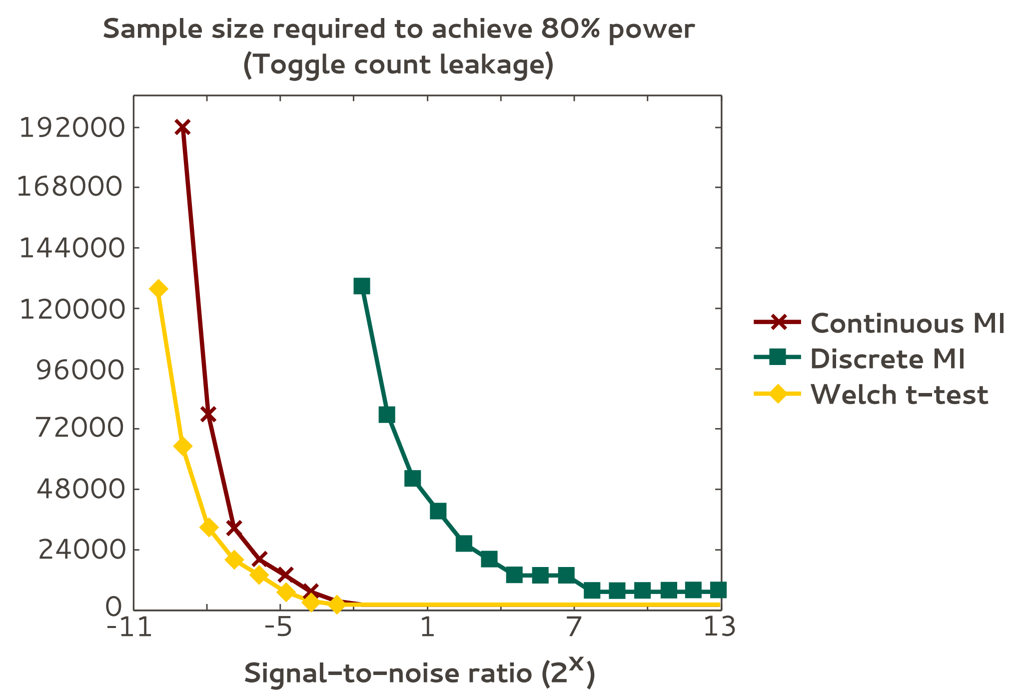
- Need to vary leakage models, noise levels, and sample sizes!!
- This is research is computationally very expensive.

Leakage detection, cont.

Heavily lifting required to evaluate effectiveness of e.g. CMI:

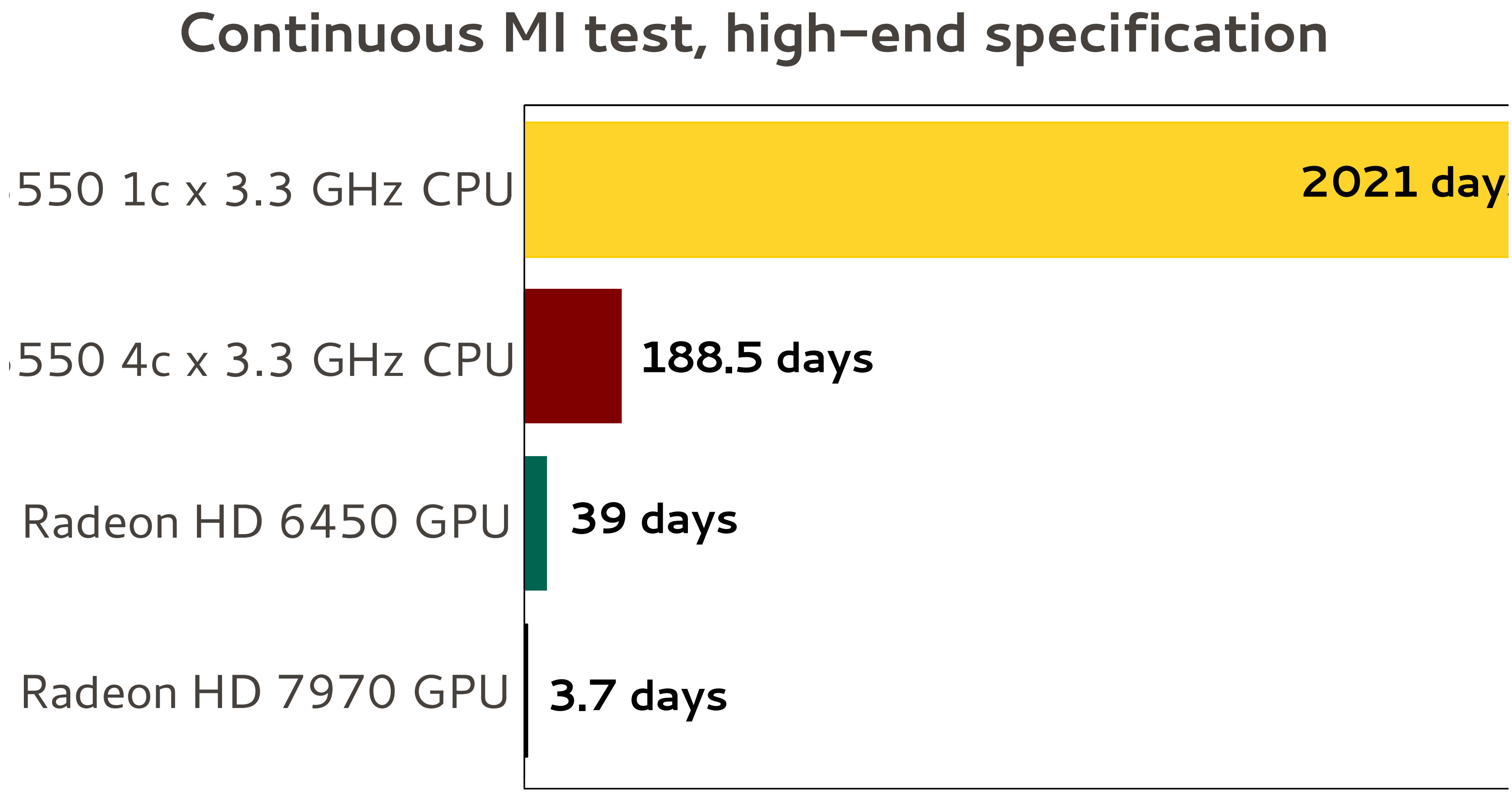
- Estimate MI(K;T)
- Estimate 'zero MI', by randomly permuting traces T (need at least around 100 permutations)
- Repeatedly ….

$$\hat{\mathrm{I}}(K;T) = \sum_{k \in \mathcal{K}} \int_T \hat{p}(k,t) \log_2 \left(\frac{\hat{p}(k,t)}{p(k)\hat{p}(t)} \right) dt.$$



Even heavy for a single application: CMI applied to our real world AES traces demanded 2^51 calls to the kernel function!

Leakage detection, cont.



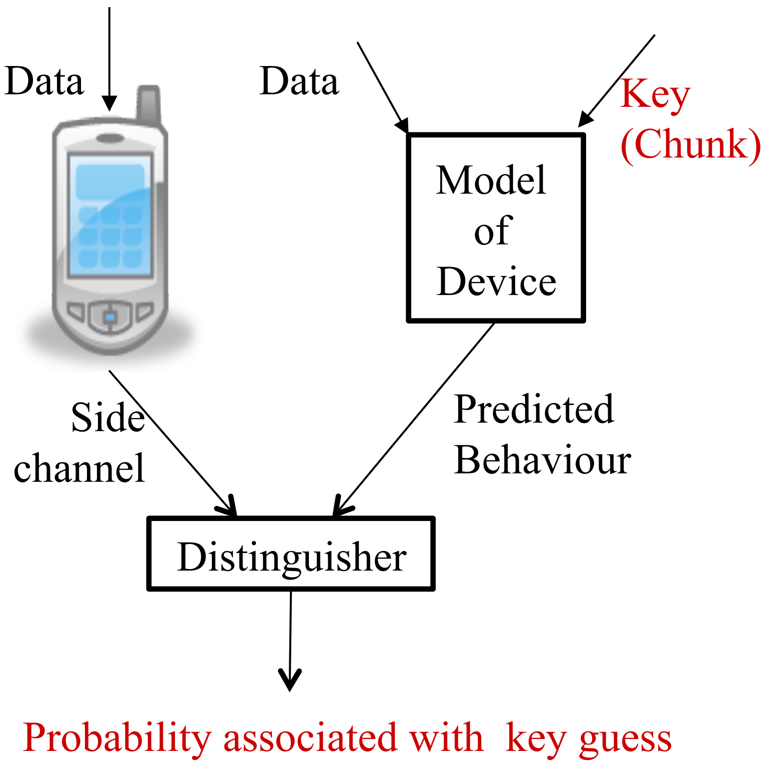
Switching to a GPU based implementation on our HPC cluster was the only way to conduct this research.

Leakage detection summary

- T-test is a good baseline test, but obviously cannot capture higher-order leaks
- CMI can be used in practice if implemented appropriately

- Bottom line: we can now assess general information leaks with some rigour!
  - See Mather & O. (et al.) Asiacrypt 2013

How to determine λ



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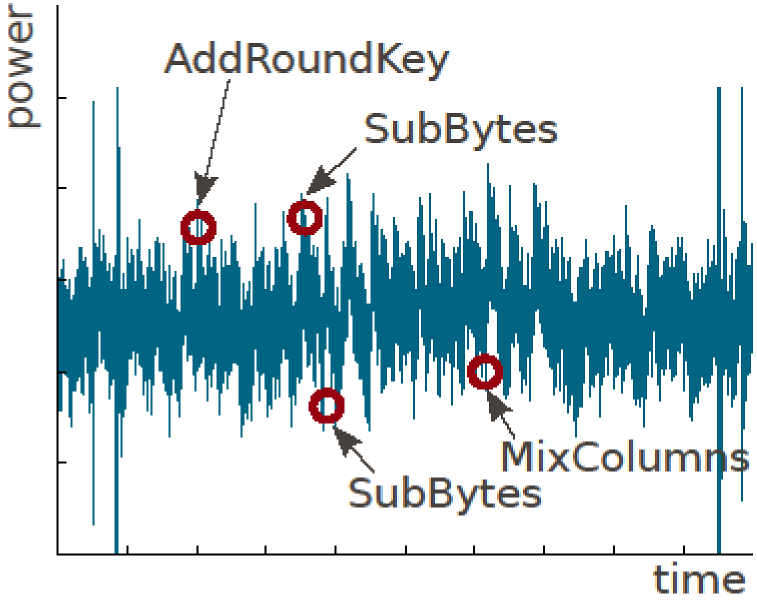
Leakage bound λ

Leakage exploitation

- Given a set of known leakage points what is the best strategy to exploit the leakage?
  - (How to select among the known leakage points)
  - How to combine the selected leakage points



(AES power trace)

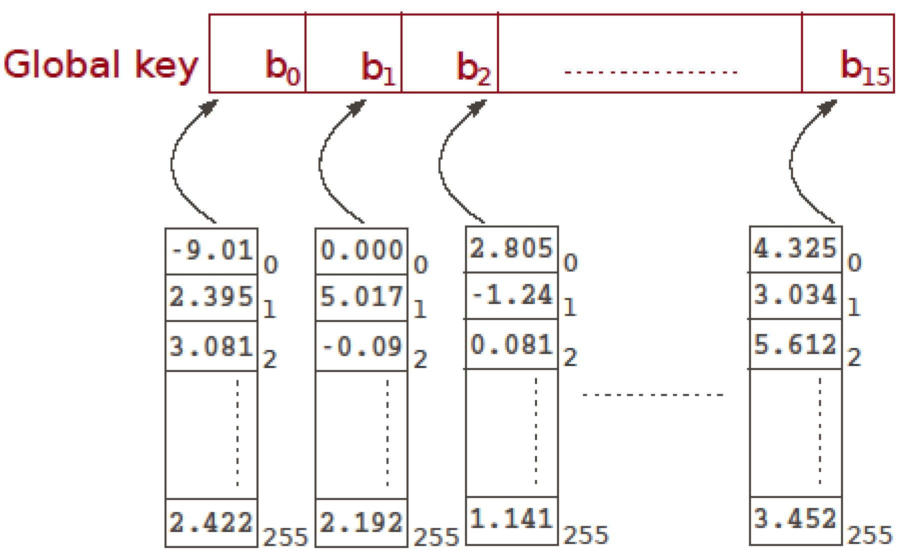
Leakage exploitation: combining attack outcomes (AES)

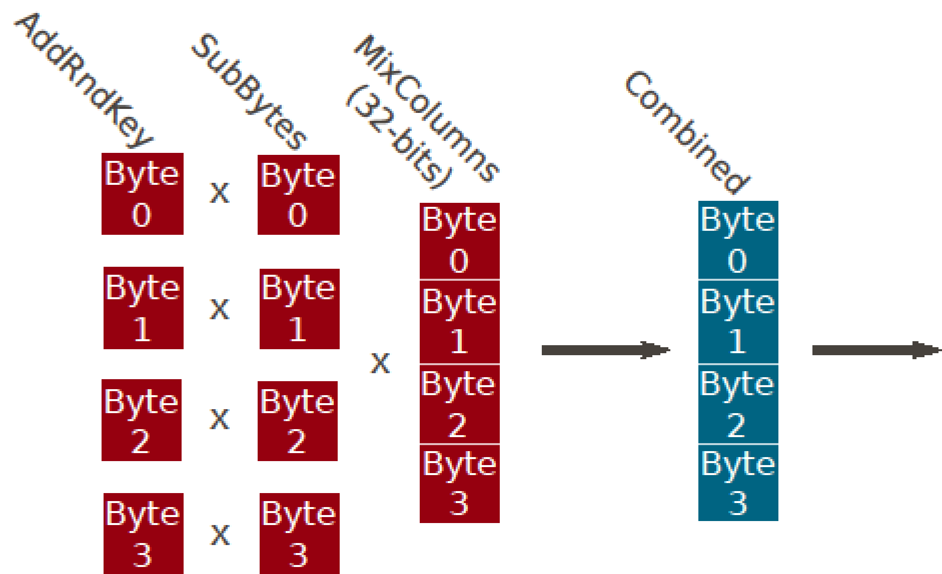
Single point attack

- AES has 16 state bytes, assume you attack them individually:

Combining outcomes

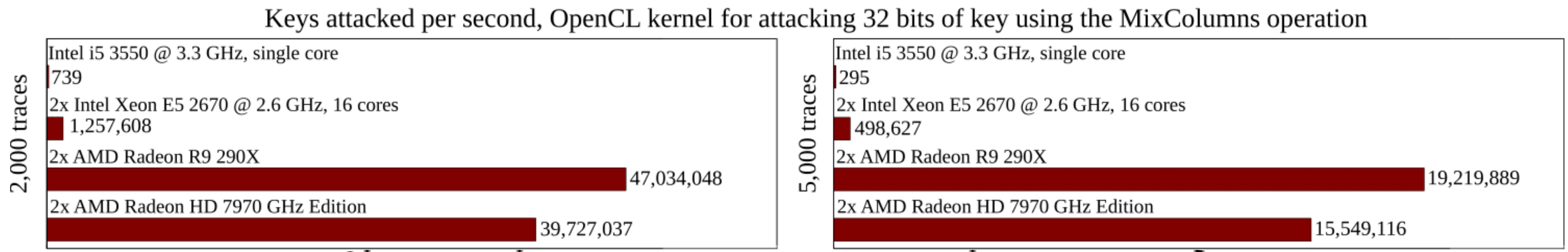
- But you can attack different intermediate values, so these should be combined



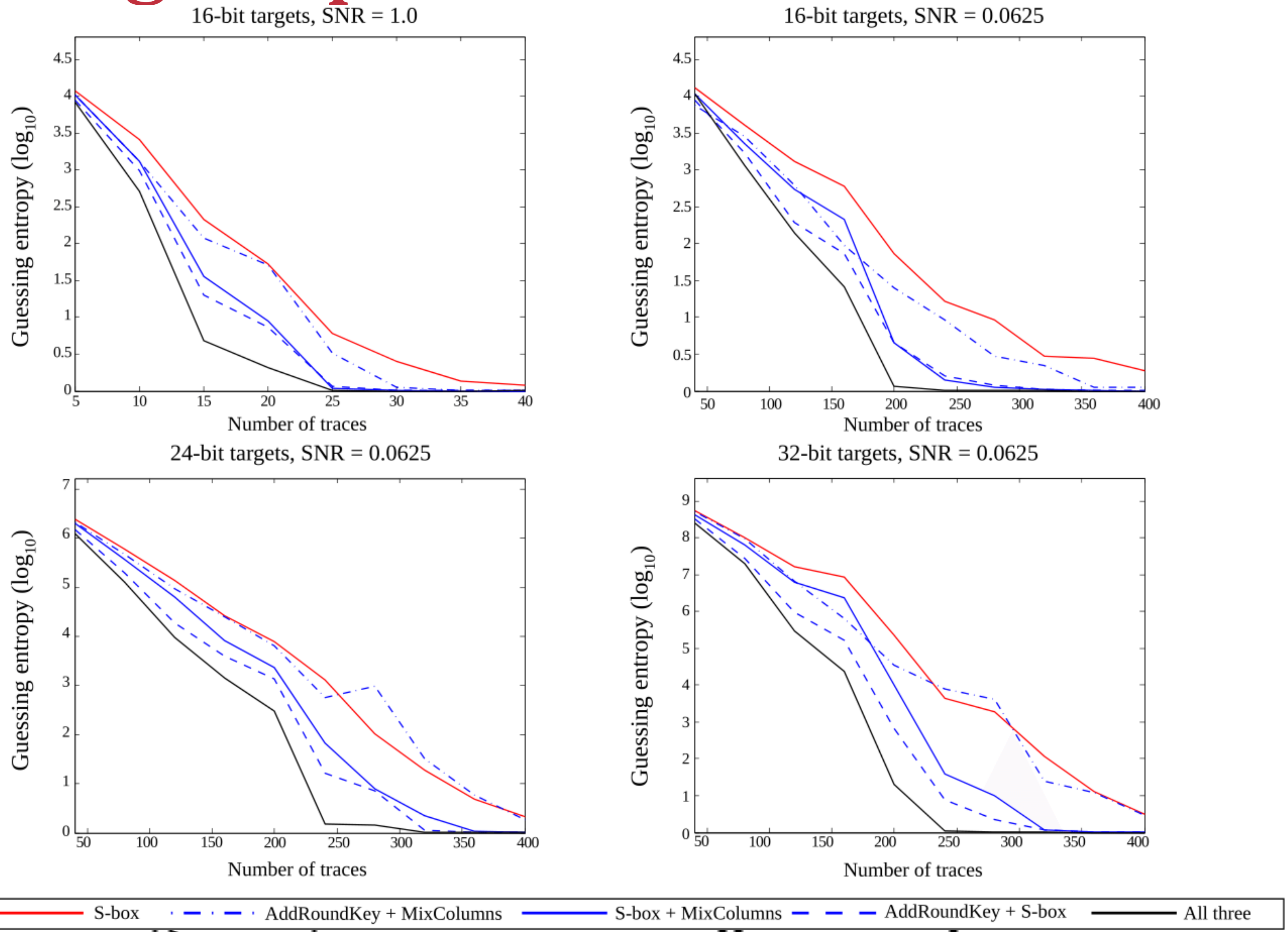


Leakage exploitation, cont.

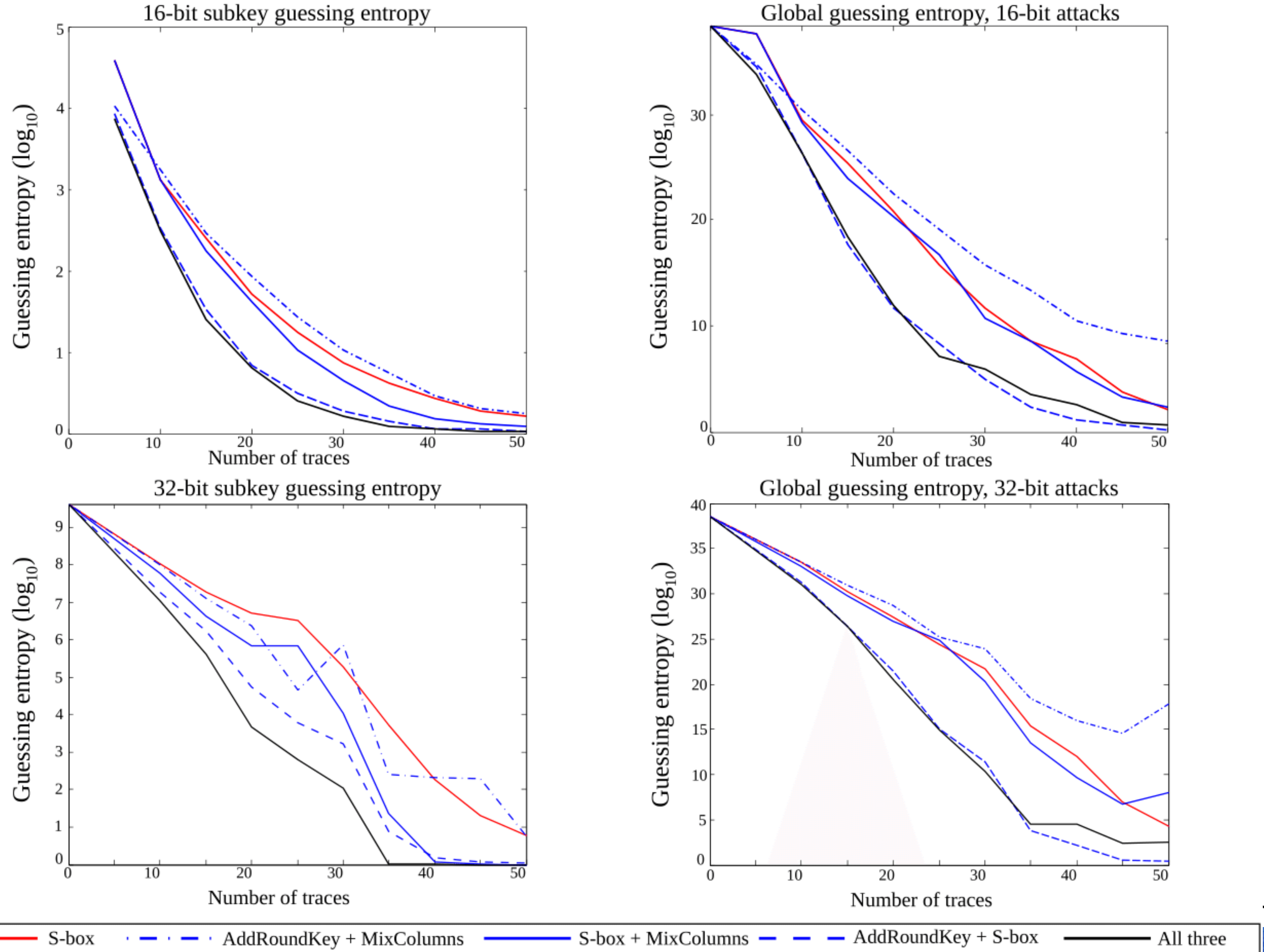
- It turned out that amalgamating distinguishing scores by `directly´using them as probabilties is a very efficient strategy
- But working with MixColumns means we need to work with 32 bits of the key at a time. We used again a GPU based implemenation, and switched to an HPC platform to do repeat experiments.



Leakage exploitation: AES column



Leakage exploitation: real device



Leakage exploitation: experimental setup

- Used up to 6 workstations with 2 high end GPUs each (cost per machine around 2k GBP)
  - Both Nvidia cards and AMD
- Developed Baikal which efficiently distributes attacks across workstations and within nodes (hand threaded) utilising OpenCL
- Completed just over 2^50 operations on combined distinguishing vectors in about 2 weeks
  - Details in Mather & O. (et al.) Asiacrypt 2014

Leakage exploitation summary

- Multi target attacks effectively amalgamate distinguisher outcomes of different (independently) computed attacks.
  - They can exploit multiple leakage points effectively
  - (Template attacks do not scale and so cannot be applied across large portions of leakage traces)
- Implementation is practical when appropriate hardware is used (GPUs)

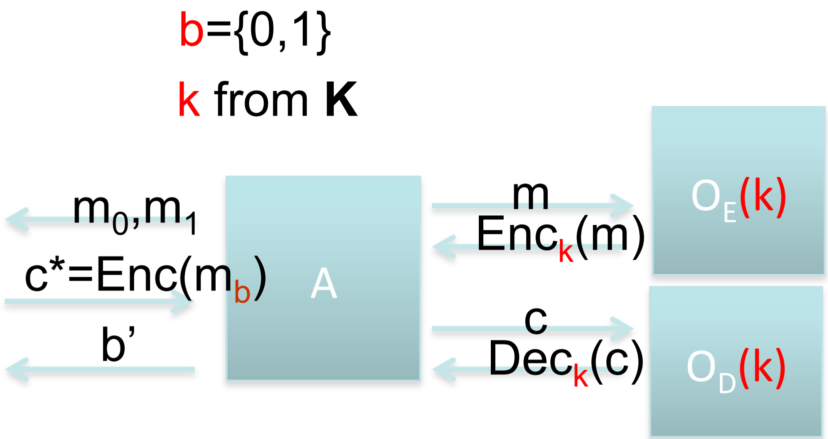
Conclusion

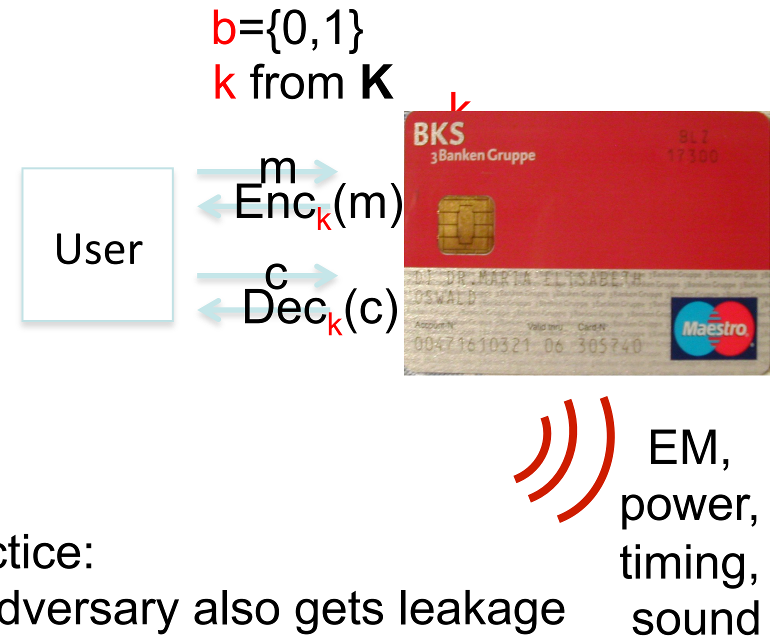
HPC inspired computing is a game changer for practical side channel research:

- Can work on asserting sound leakage bounds
- Have ability to produce scalable implementations:
  - Research perspective: to compute SR and GE curves and so exlain the effectiveness of attack strategies accross different leakage models, and SNRs
  - Practical perspective: To `emulate´the best real world attackers, to be used in evaluations & testing

All research done thanks to the University of Bristol HPC platform Blue Crystal.

Crypto Theory vs. Crypto Practice





Theory:
- A scheme is secure if a game is 'hard' to win
- (example above relates to symmetric encryption)

Practice:
- adversary also gets leakage
- (how do we include this in the theoretical game?)

O1: How to define and model leakage
O2: How to measure key entropy loss due to leakage
O3: How to build practical leakage resilient crypto