Cache-based attack on AES

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Contribution of this paper

- Get the secret key from AES in 3s + 3min
- Very weak assumptions
- No known plaintext needed
- No special rights needed, only to be able to spawn and control threads

Side-channel attack

- **Goal: attack the implementation instead of brute force or theoretical weaknesses**
  - Timing attacks
  - Power-monitoring attacks
  - Electromagnetic attack
  - Acoustic cryptanalysis

CPU Cache

- **The CPU is way faster than the RAM, so we add caches so that we don't have to interact with the RAM**
  - The caches are divided in blocks (64-128 bytes)
  - L1 ~10kb
  - L2 ~1M
  - L2 14x slower than L1
  - RAM 20x slower than L2, 200x slower than L1

AES

$$X = \begin{pmatrix} x_0 & x_4 & x_8 & x_C \\ x_1 & x_5 & x_9 & x_D \\ x_2 & x_6 & x_A & x_E \\ x_3 & x_7 & x_B & x_F \end{pmatrix} = (\underline{\mathbf{x}}_0 \ \underline{\mathbf{x}}_1 \ \underline{\mathbf{x}}_2 \ \underline{\mathbf{x}}_3)$$

$$\text{ShiftRows}(X) = \tilde{X} = \begin{pmatrix} x_0 & x_4 & x_8 & x_C \\ x_5 & x_9 & x_D & x_1 \\ x_A & x_E & x_2 & x_6 \\ x_F & x_3 & x_7 & x_B \end{pmatrix}$$

$$s(\tilde{X}) = \begin{pmatrix} s(x_0) & s(x_4) & s(x_8) & s(x_C) \\ s(x_5) & s(x_9) & s(x_D) & s(x_1) \\ s(x_A) & s(x_E) & s(x_2) & s(x_6) \\ s(x_F) & s(x_3) & s(x_7) & s(x_B) \end{pmatrix}$$

$$\text{MixColumns}(s(\tilde{X})) = M \bullet s(\tilde{X}) = \begin{pmatrix} 2 & 3 & 1 & 1 \\ 1 & 2 & 3 & 1 \\ 1 & 1 & 2 & 3 \\ 3 & 1 & 1 & 2 \end{pmatrix} \bullet s(\tilde{X})$$

AES implementation

- Exploit redundancy in the matrix multiplications to speedup the calculation
- Massive use of precomputed tables

→ If we know which entry is use when, we can deduce the private key

→ Each round we get a probability that a byte sequence is part of the key

Main idea

1) Fill L1 with known data
2) Let the target execute one table load (will be a miss)
3) Detect which cache line has been changed
4) Deduce which part of the table has been loaded
5) Repeat!

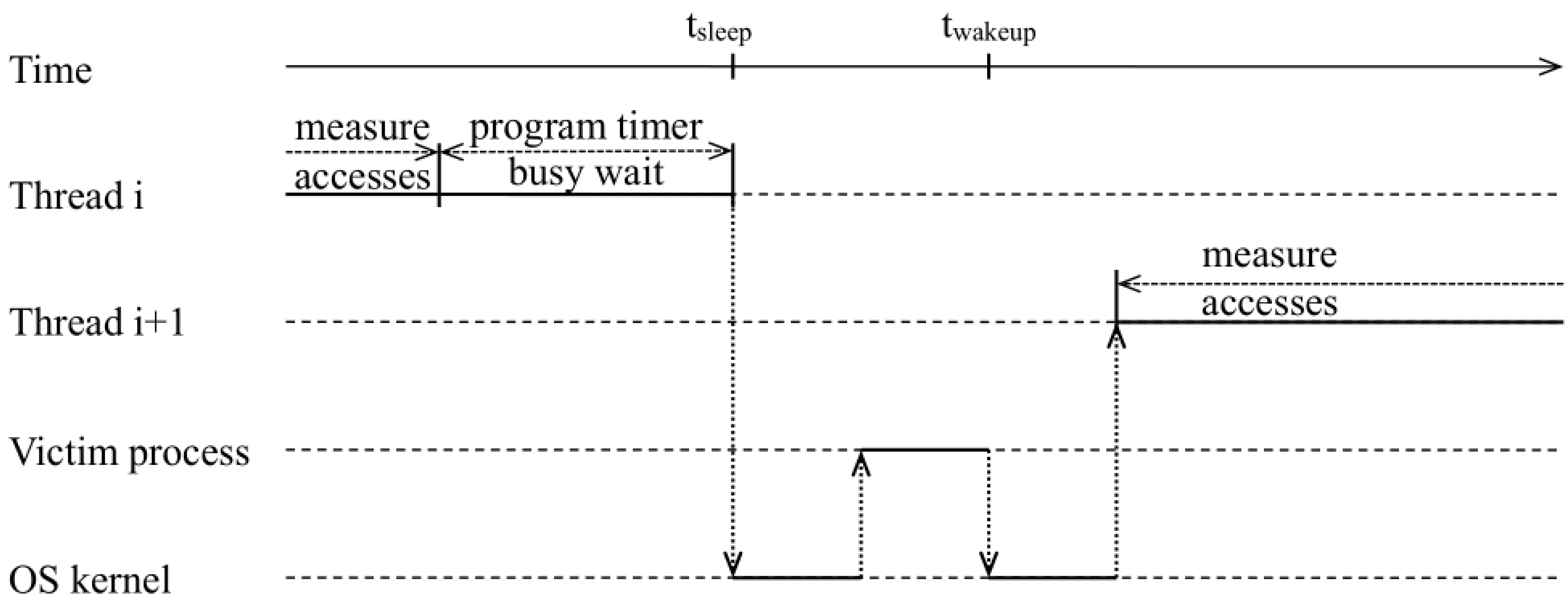
Completely fair scheduler

- Linux process scheduler
- Goal: as with n processes executing on n processors at 1/n the speed.

  → Execute first the process which had less execution time

The attack

- **DoS on CFS: hundreds of threads + one dummy thread**

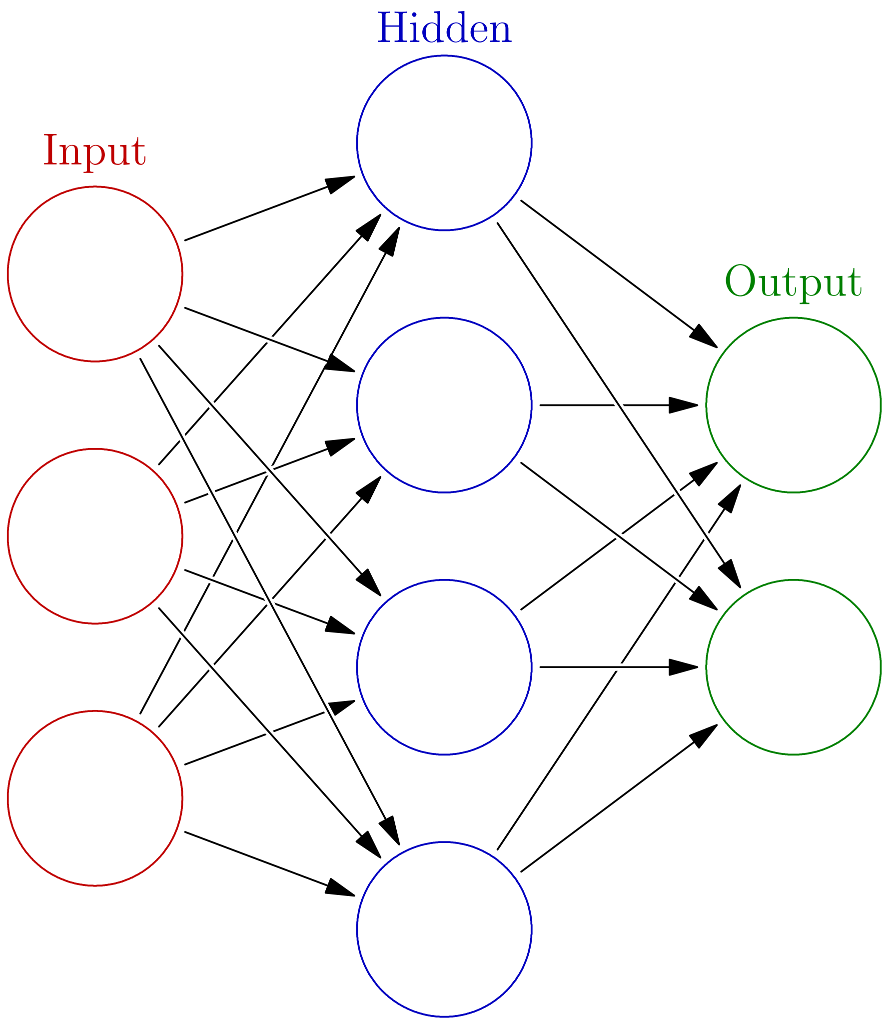


The attack - 2

- **Read a big array, if response time above a threshold → cache miss → the target process used this cache line**

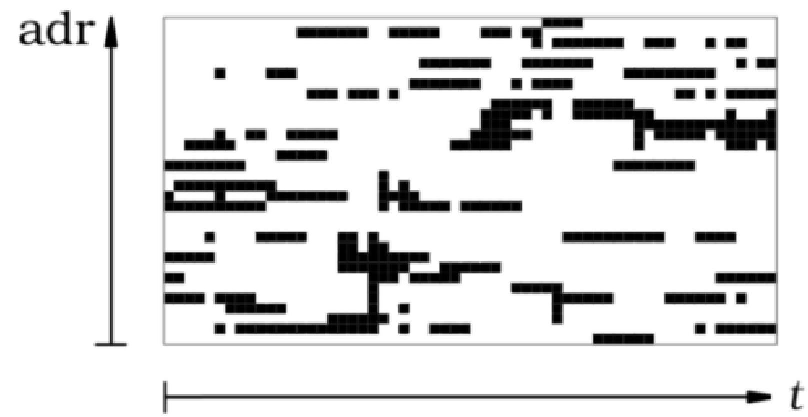
Neural networks

- One neuron has multiple inputs and one output
- Each input has an associated weight
- The networks learns by changing the weights

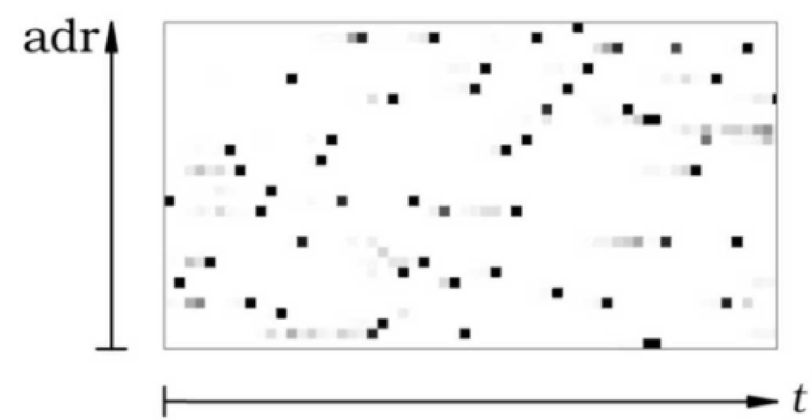


Post-processing

- **Use of two neural networks:**
  - Noise reduction (right)
  - Estimation on the number of memory access at t



(a) Input of the neural network.



(b) Output of the neural network.

Results

- **250 threads, 100 encryptions**
  - 10ms → 2.8s
- **Noise reduction: 21s, normal process**
- **Preparing key search by constructing a probability table: 63s**
- **Key search: 30-300s**

  → **3 minutes to find the key**

  → **60kB to transfer for post-processing**

Countermeasures (general)

- **Don't use the cache**
  - Not possible in real life
- **Don't let process access high-res timers**
  - A lot of legitimate apps use it
- **Cache preloading by the OS**
- **Mark table as uncachable**
- **Limit the minimum time between context switch**

Contermeasures (AES)

- Use more efficient instructions to reduce table size
- Use hardware-supported encryption (Intel AES-NI)

References

- Paper: https://eprint.iacr.org/2010/594.pdf
- Wikipedia: https://en.wikipedia.org/wiki/Artificial_neural_network