Covert and Side Channels

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Spring 2022

Based on slides from Christopher W. Fletcher

Before We Start

- Recitation Prize
- HotCRP Demo
  - Review submission interface
  - Bid papers
- Announce 3 Talks

What is Covert and Side Channel?

- Gather information by measuring or exploiting **indirect** effects of the system or its hardware -- rather than targeting the program or its code directly.

- Covert channel:
  - **Intended** communication between two or more security parties
- Side channel:
  - **Unintended** communication between two or more security parties

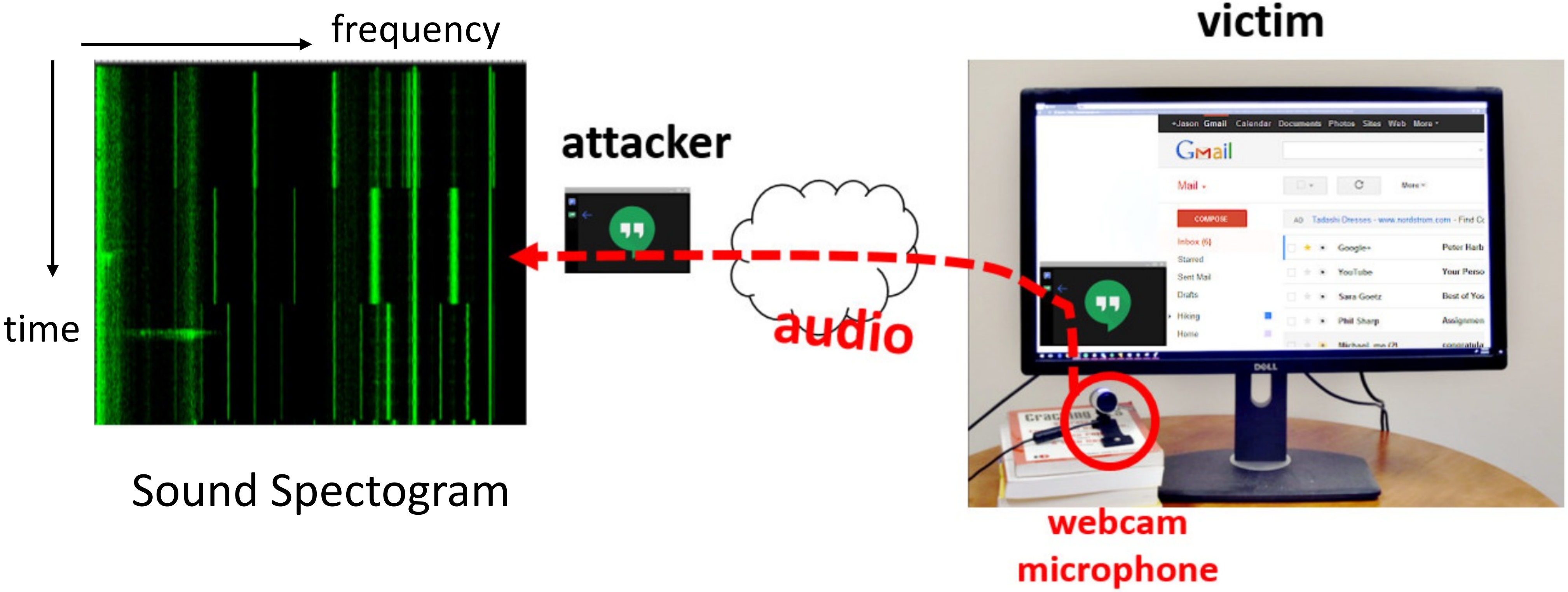
- In both cases:
  - Communication should not be possible, following system semantics
  - The communication medium is not designed to be a communication channel

Side Channels Are Almost Everywhere

Daily Life Examples

- Acoustic side channels
  - Monitor keystrokes
  - You only need: a cheap microphone + an ML model
- Network traffic contention side channel
  - If you want to be an active attacker, try stress test

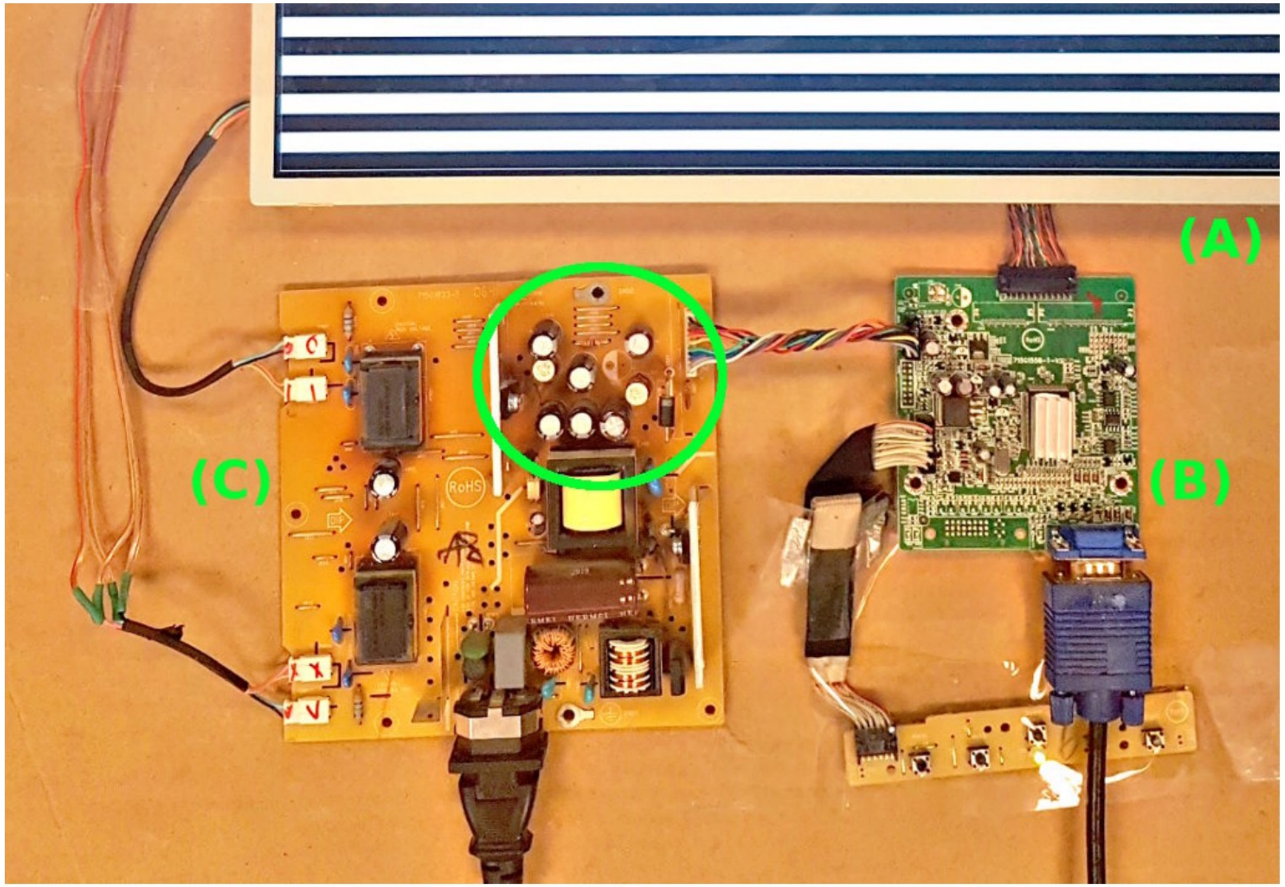
“Hear” The Screen



Sound Spectogram

Genkin et. al. Synesthesia: Detecting Screen Content via Remote Acoustic Side Channels. S&P’19

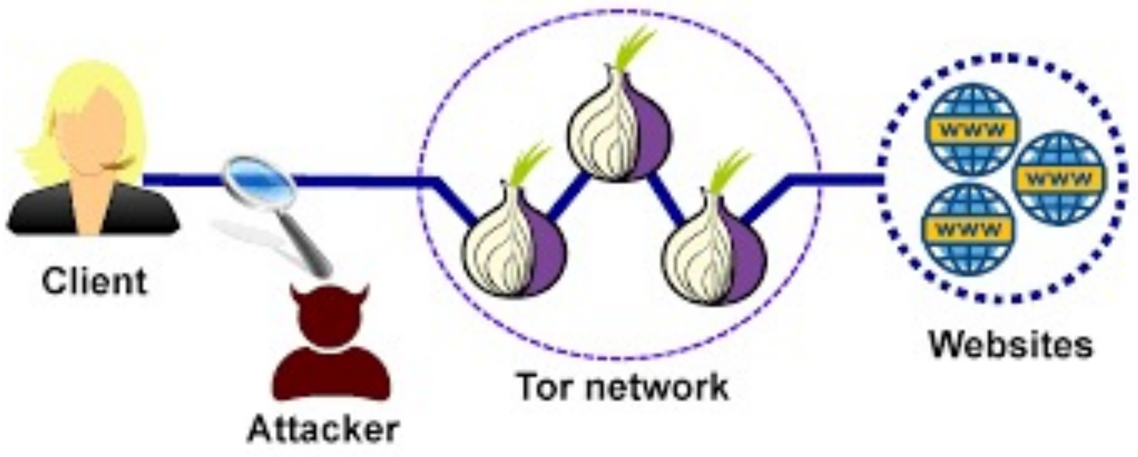
“Hear” The Screen



(A) is the LCD panel, (B) is the screen’s digital logic and image rendering board and, (C) is the screen’s power supply board.

Network Side Channels

- Website Fingerprinting

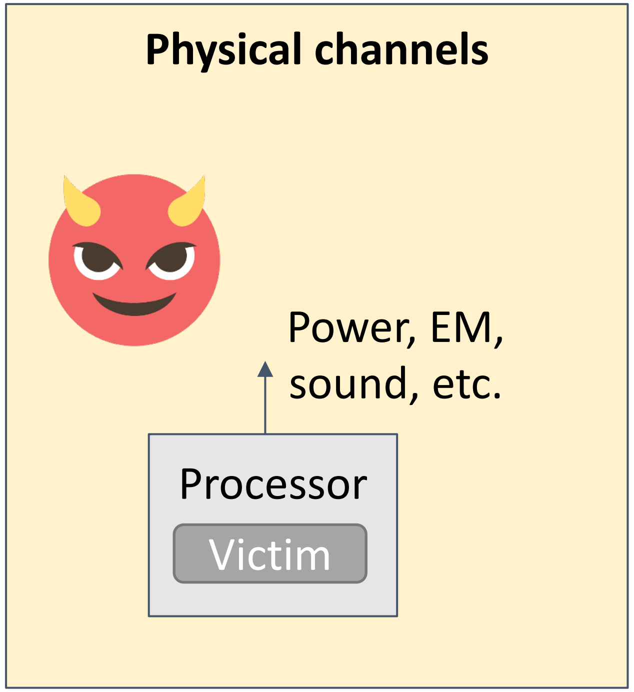


- Response dependent:
    - iSideWith.com
- Real-time feedback:
    - Google Search auto-complete

Lescisin et. al. Tools for Active and Passive Network Side-Channel Detection for Web Applications. WOOT'18
Cai et. al. Touching from a distance: Website fingerprinting attacks and defenses. CCS'12.

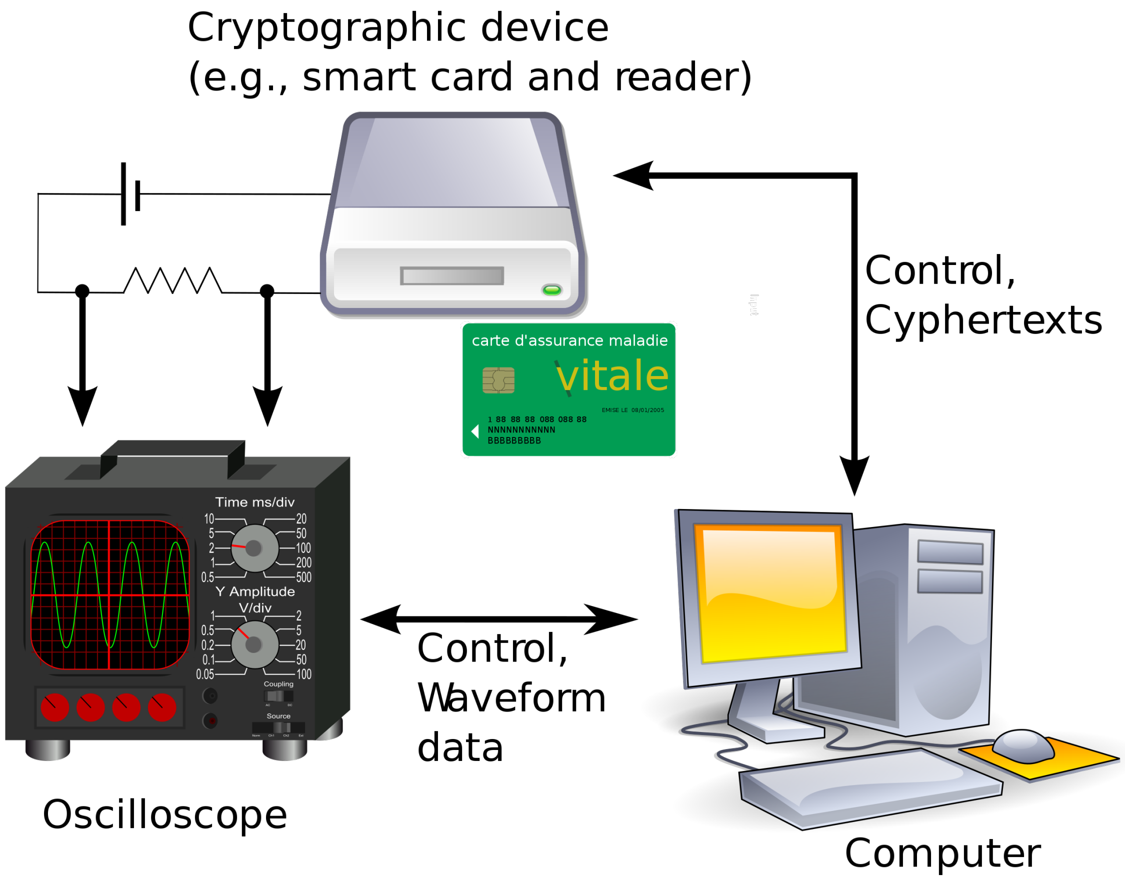
Physical v.s. Timing v.s. uArch Channel

- What can the adversary observe?



Attacker requires measurement equipment → physical access

Power Analysis



from https://en.wikipedia.org/wiki/Power_analysis

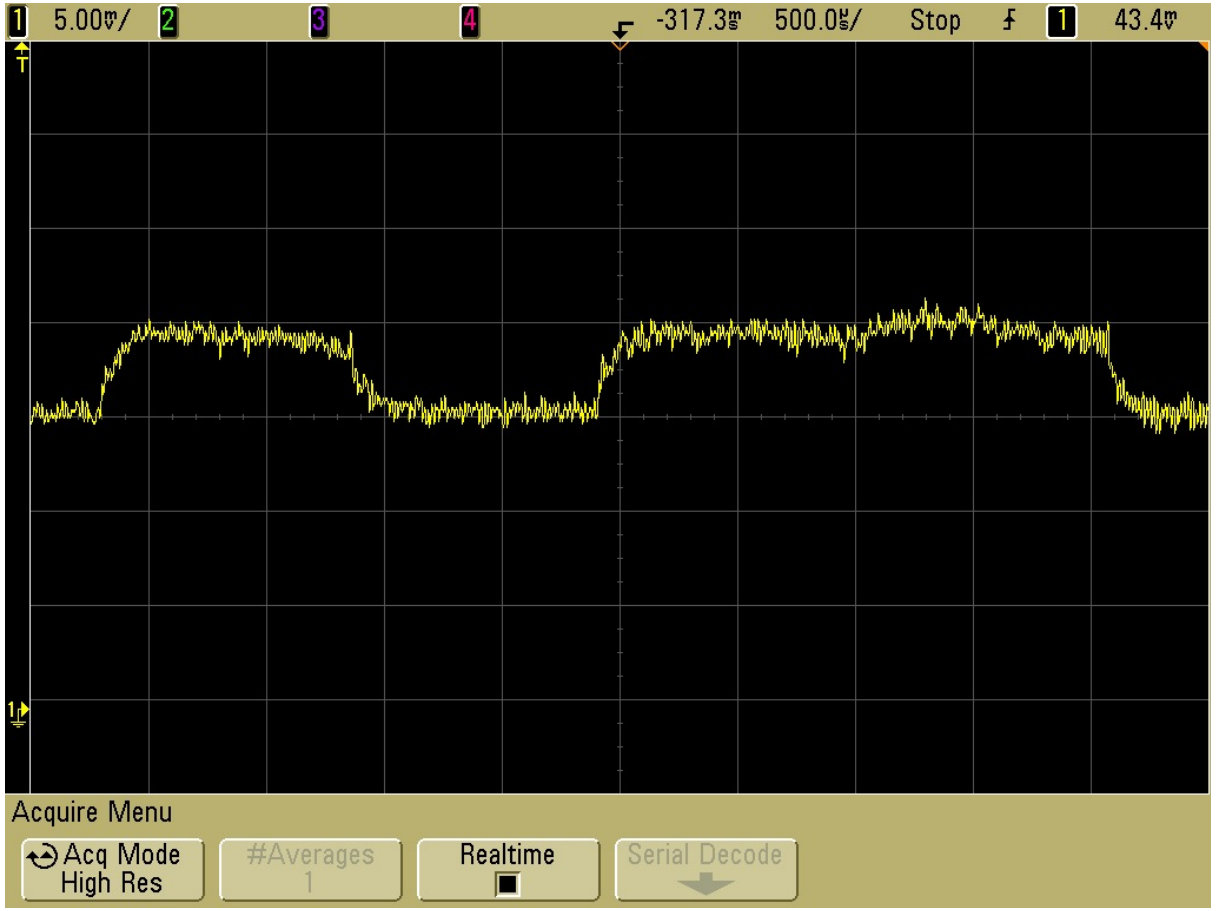
Victim Application: RSA

- Square-and-multiply based exponentiation

Input : base b, modulo m, exponent $e = (e_{n-1} \ldots e_0)_2$
Output: $b^e \bmod m$

$r = 1$
for $i = n-1$ *down to* 0 **do**
    $\boxed{r = sqr(r)}$
    $r = mod(r,m)$
    if $e_i == 1$ **then**
        $\boxed{r = mul(r,b)}$
        $r = mod(r,m)$
    end
end
return r

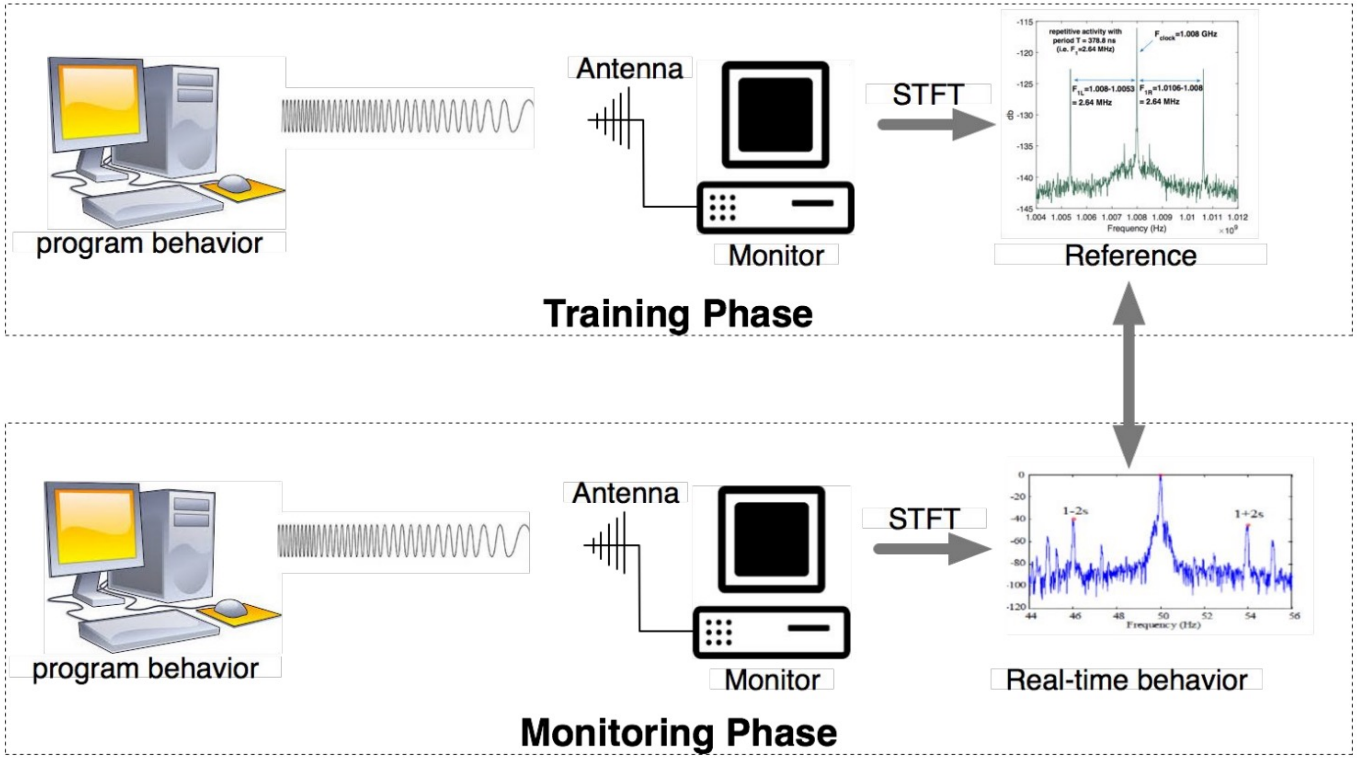
Power Analysis



- Various signal processing techniques to de-noise.
- More advanced: differential power analysis (DPA)

Benign Usage: Non-intrusive Software Monitoring

- How to efficiently monitor application for anomaly detection?
- EM side channel can trace back to Van Eck phreaking in 1985



Sehatbakhsh et al. *Spectral Profiling: Observer-Effect-Free Profiling by Monitoring EM Emanations. MICRO'16*
Van Eck phreaking *https://en.wikipedia.org/wiki/Van_Eck_phreaking*

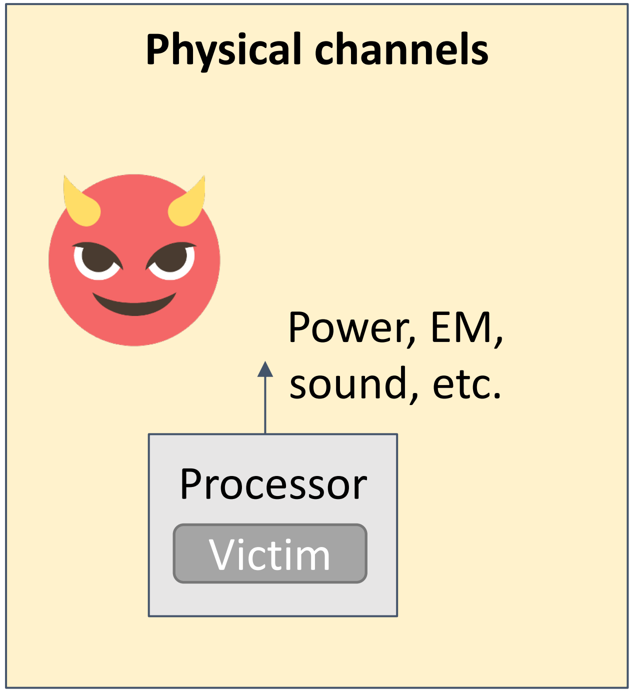
What can you do with these channels?

- Violate privilege boundaries
  - Inter-process communication
  - Infer an application’s secret
- (Semi-Invasive) application profiling

- What makes it more threatening compared to traditional software or physical attacks?
  - Stealthy. Sophisticated mechanisms needed to detect channel
  - Usually no permanent indication one has been exploited

Physical v.s. Timing v.s. uArch Channel

- What can the adversary observe?



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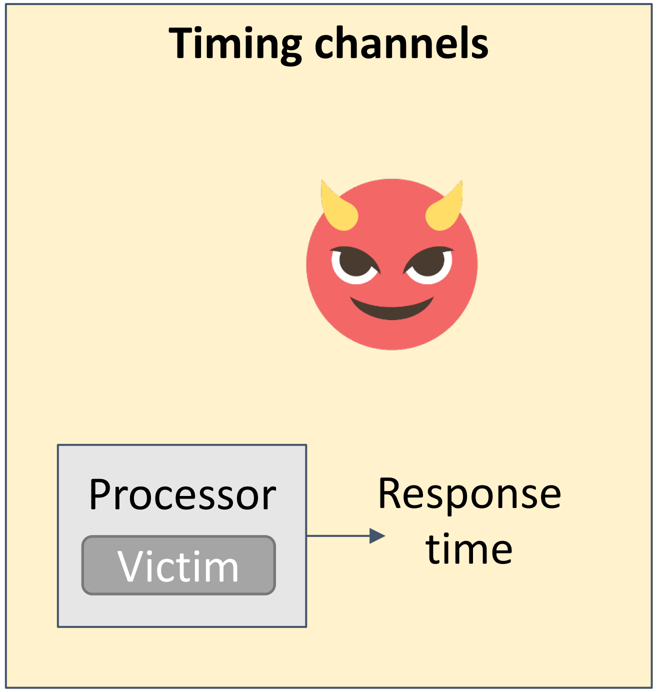
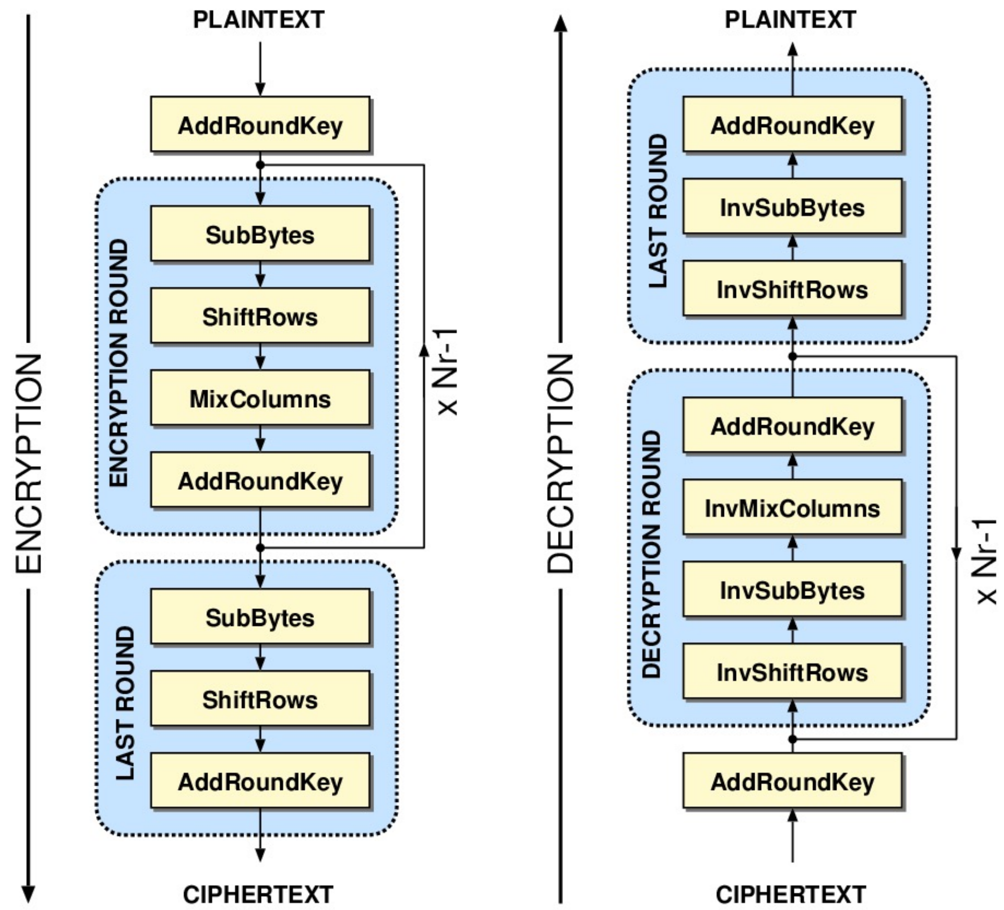


Attacker may be remote (e.g., over an internet connection)

Victim Application: AES

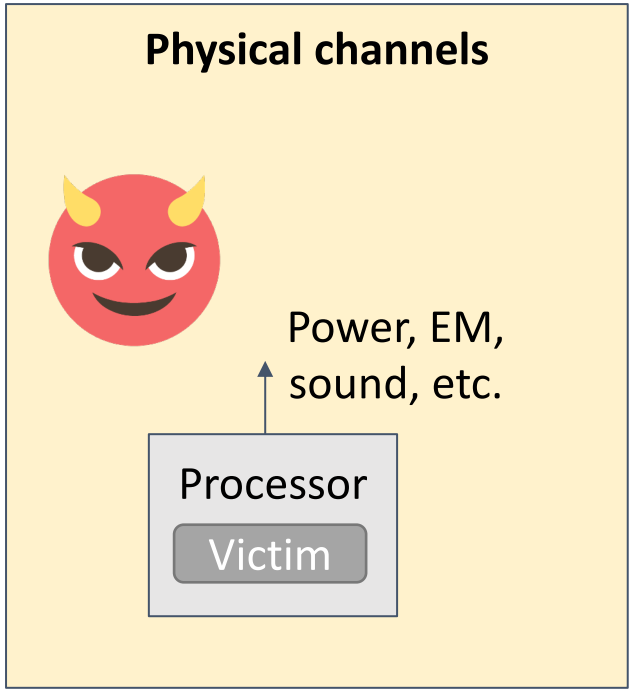


- SubBytes:

  `S[i] = Ttable[S[i]]`

Physical v.s. Timing v.s. uArch Channel

- What can the adversary observe?



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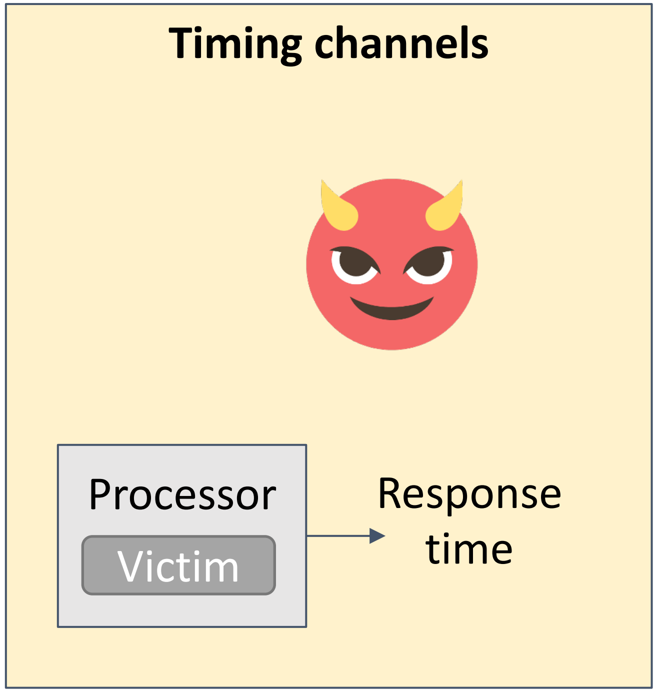

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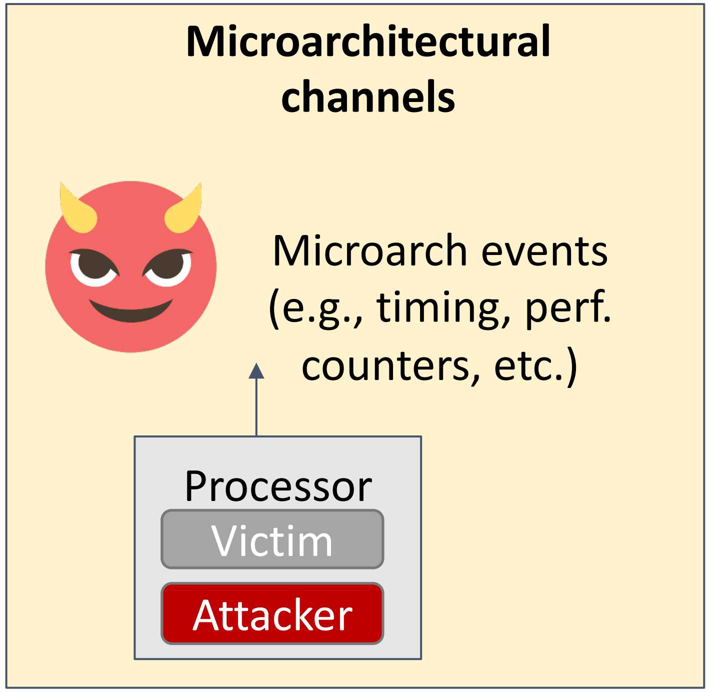
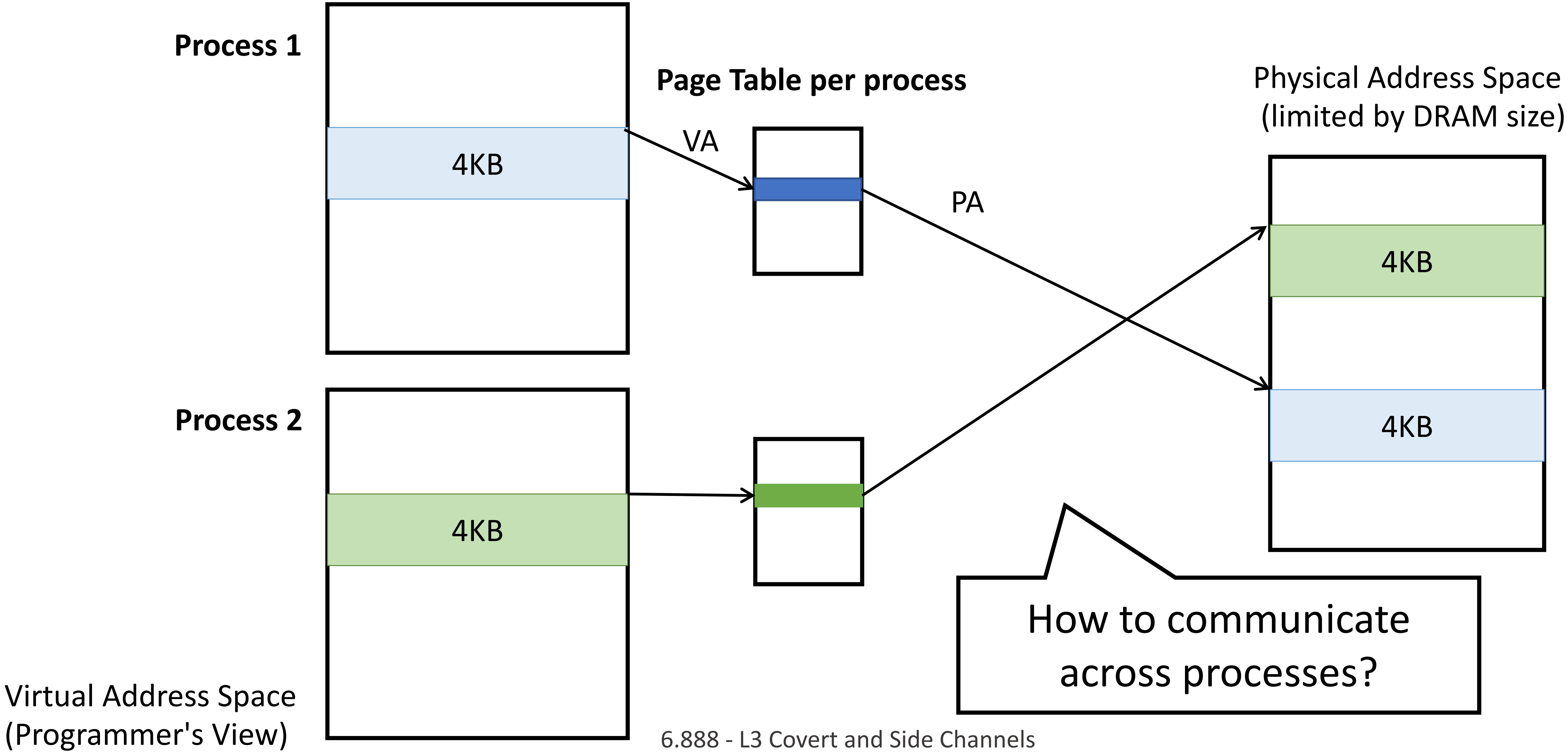


Attacker may be remote, or be co-located

uArch Side Channels

Recap: Process Isolation



How to communicate across processes?

Inter-process communication

- File
- Socket
- Pipe
- Shared memory (shm in Linux)
- …

All of these communication approaches are monitored by OS.

Normal Cross-process Communication

```
include <socket.h>

void send(bit msg) {
  socket.send(msg);
}

bit recv() {
  return socket.recv(msg);
}
```

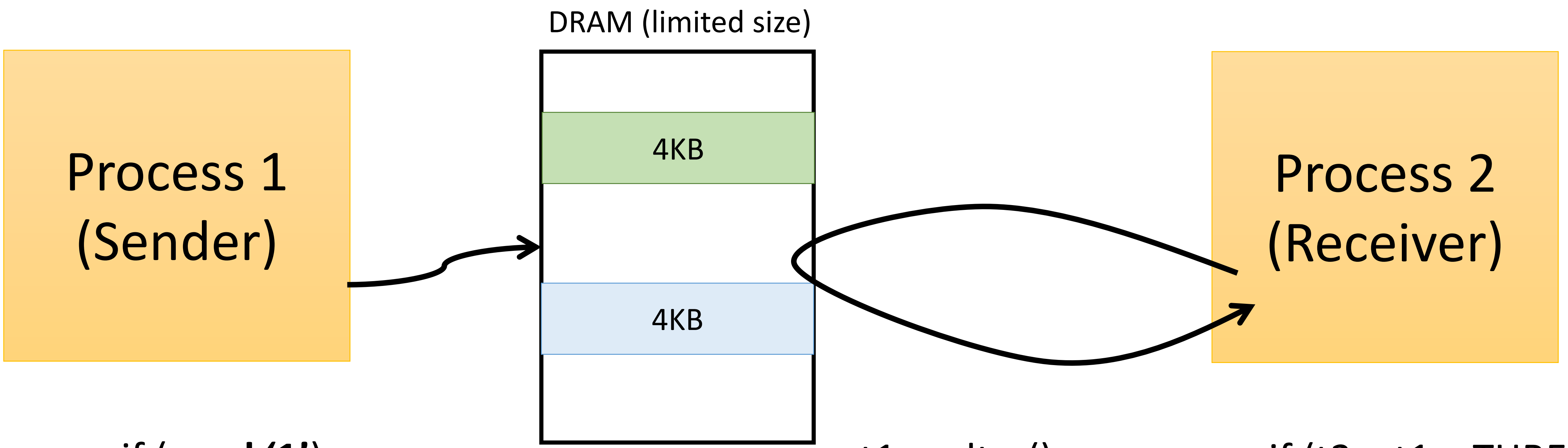
How to communication without letting OS know?

--> Use HW contention

Covert Channels 101: Through the Page Fault

Blackboard: page fault, on-demand paging

Covert Channels 101: Through the Page Fault

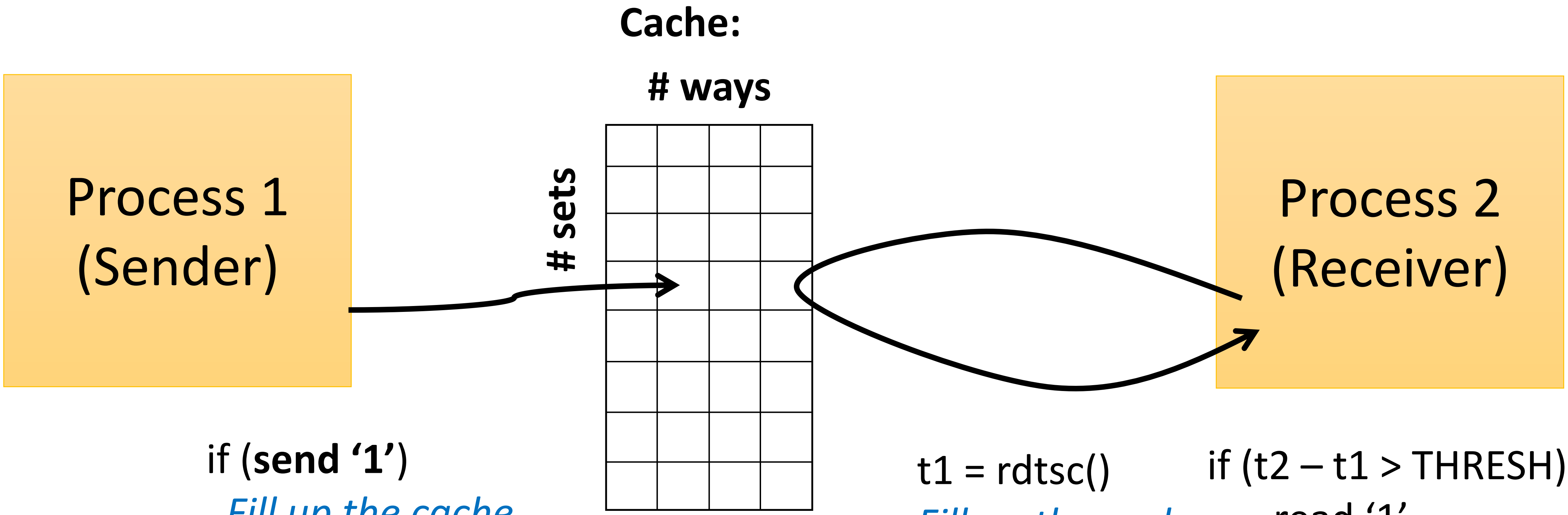


if (**send ‘1’**)
  accesses many pages
else
  idle

t1 = rdtsc()
Accesses many pages
t2 = rdtsc()

if (t2 – t1 > THRESH)
    read ‘1’
else
    read ‘0’

Another Example of Using Caches



if (**send ‘1’**)
  Fill up the cache
else
  idle

t1 = rdtsc()
Fill up the cache
t2 = rdtsc()

if (t2 – t1 > THRESH)
    read ‘1’
else
    read ‘0’

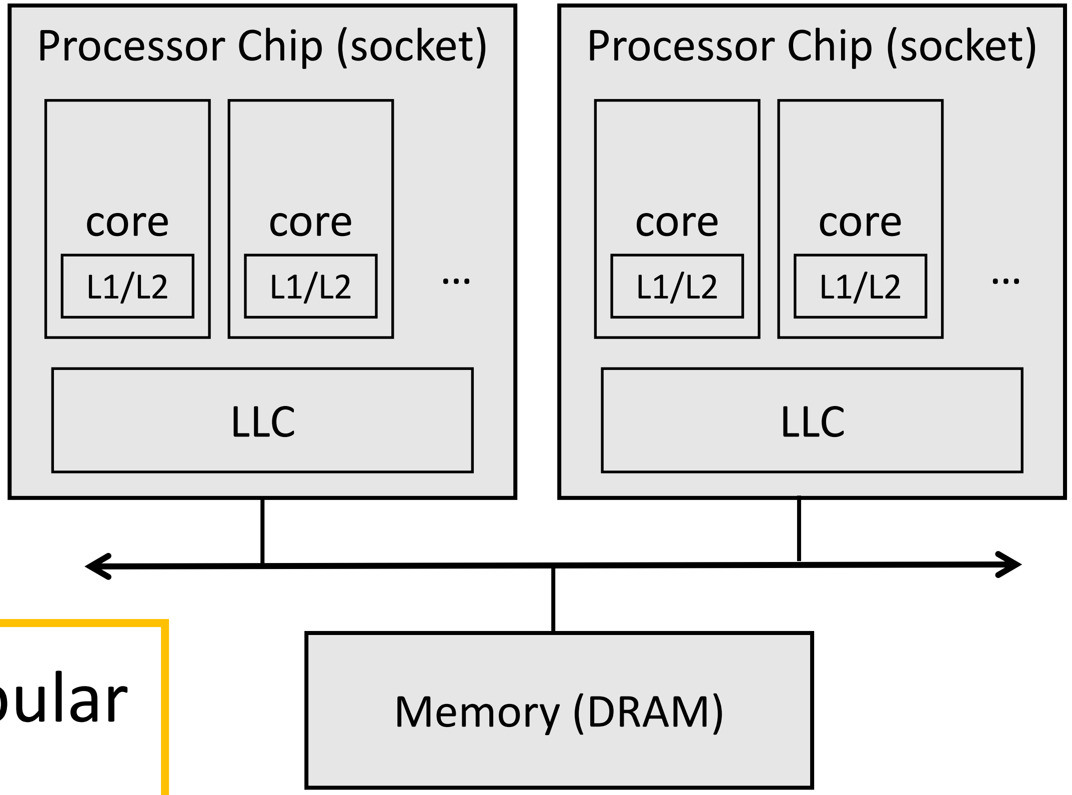
Potential Covert Channel Medium?

- Functional units inside the pipeline/core
- Main memory
- Network interface card (NIC)
- Hard disk drive
- GPUs
- PCIe bus

The Memory Hierarchy

- L1, L2
  - Shared by threads on the same core
- LLC:
  - Shared by threads on different cores
- DRAM row buffer:
  - Shared by …..

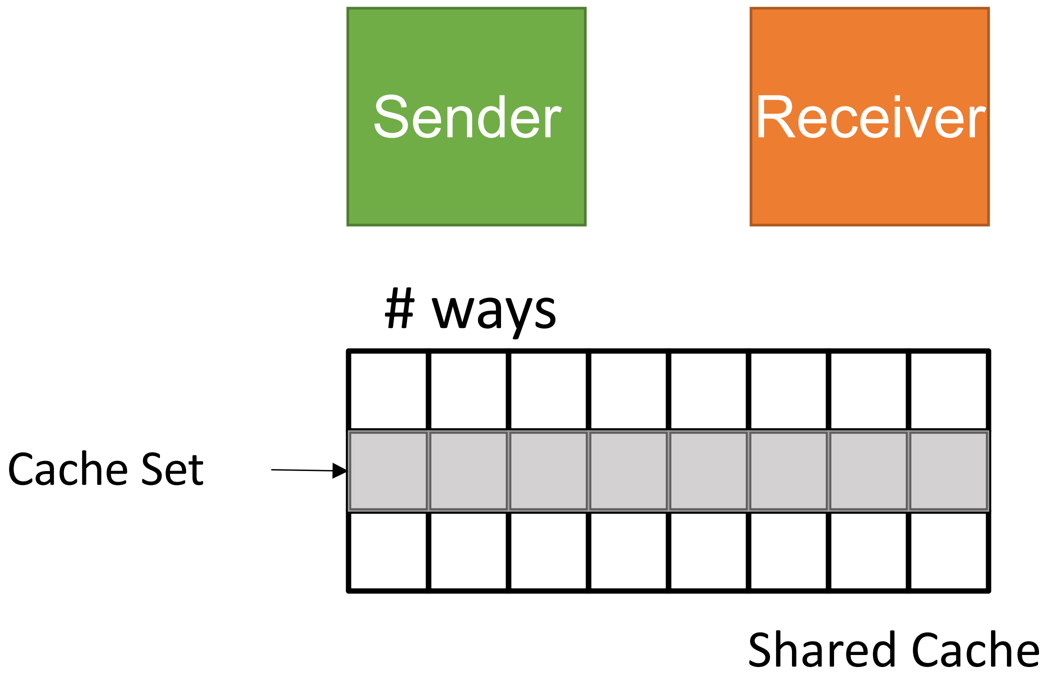
Last-level cache is a popular attack target. Why?



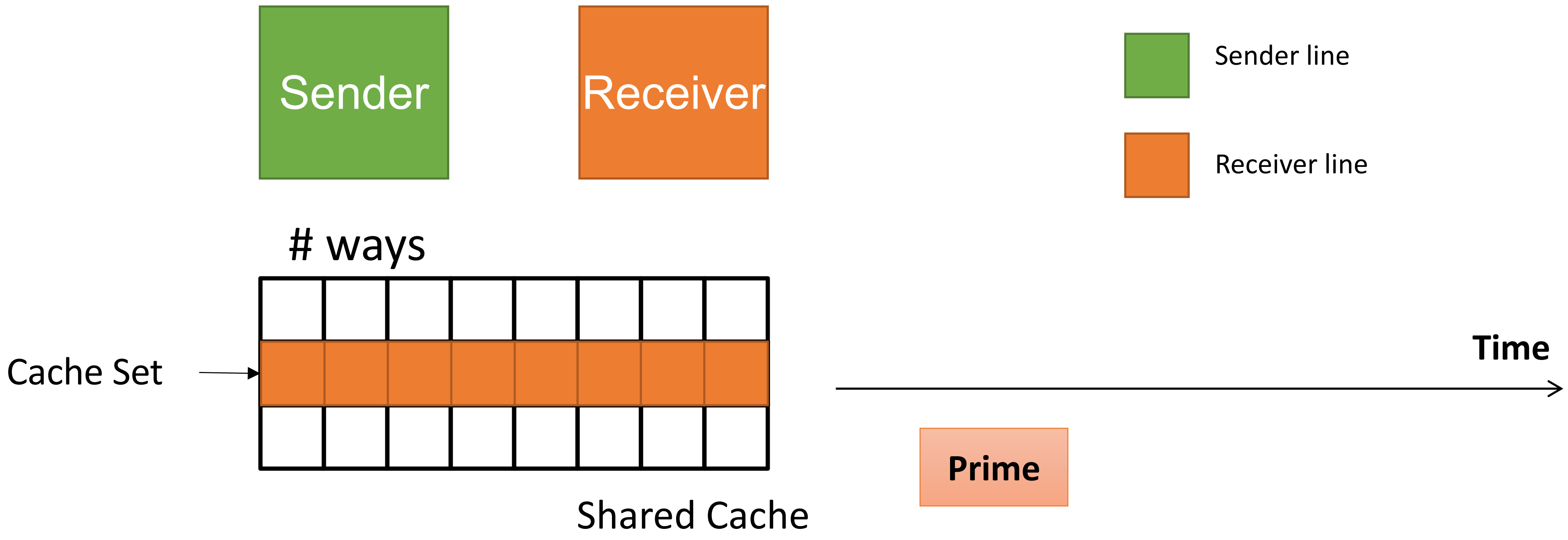
Flush+Reload in the Cache

- On blackboard: page deduplication, clflush

Protocol 101: Prime+Probe in the Cache

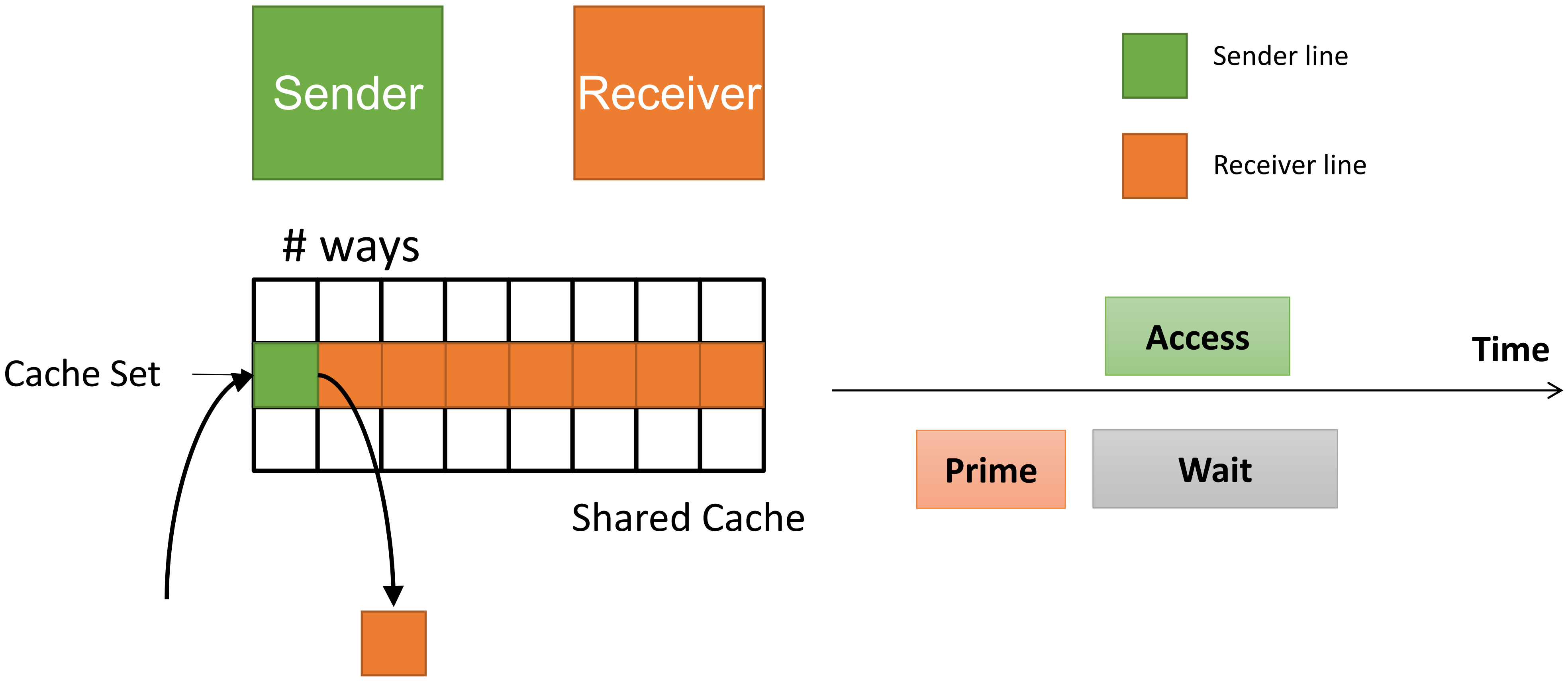


Prime+Probe

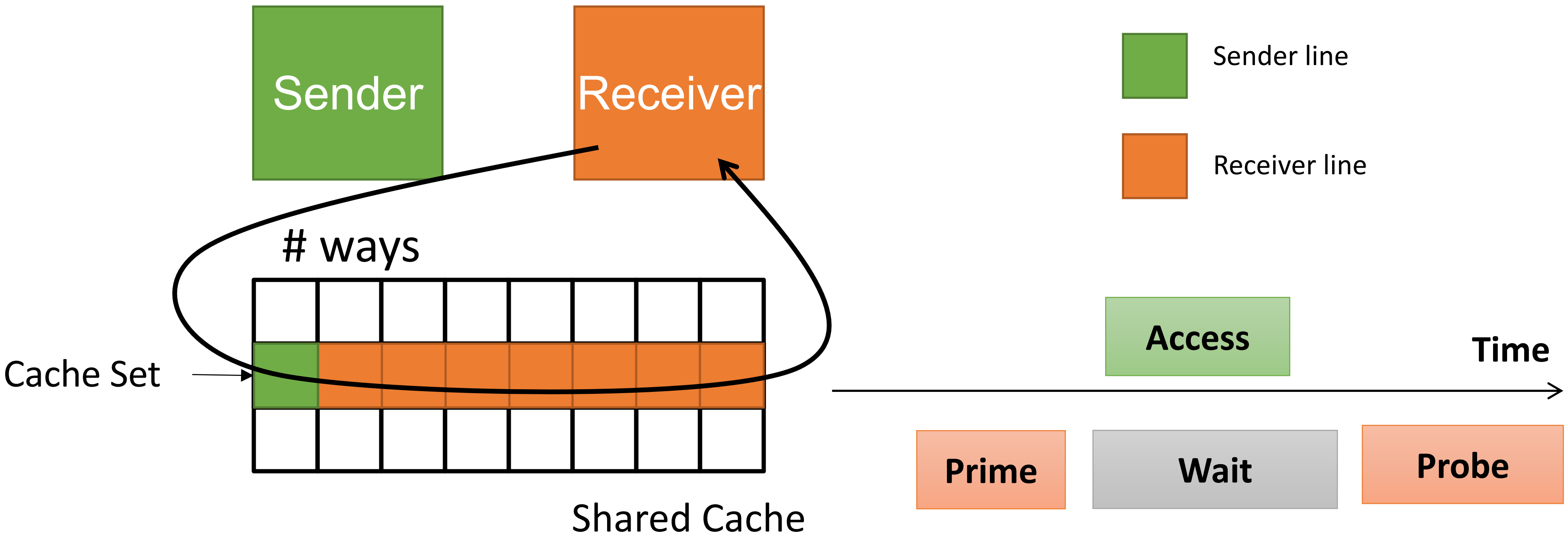


Sender
Receiver
Sender line
Receiver line
ways
Cache Set
Time
Prime
Shared Cache

Prime+Probe – Send “1”

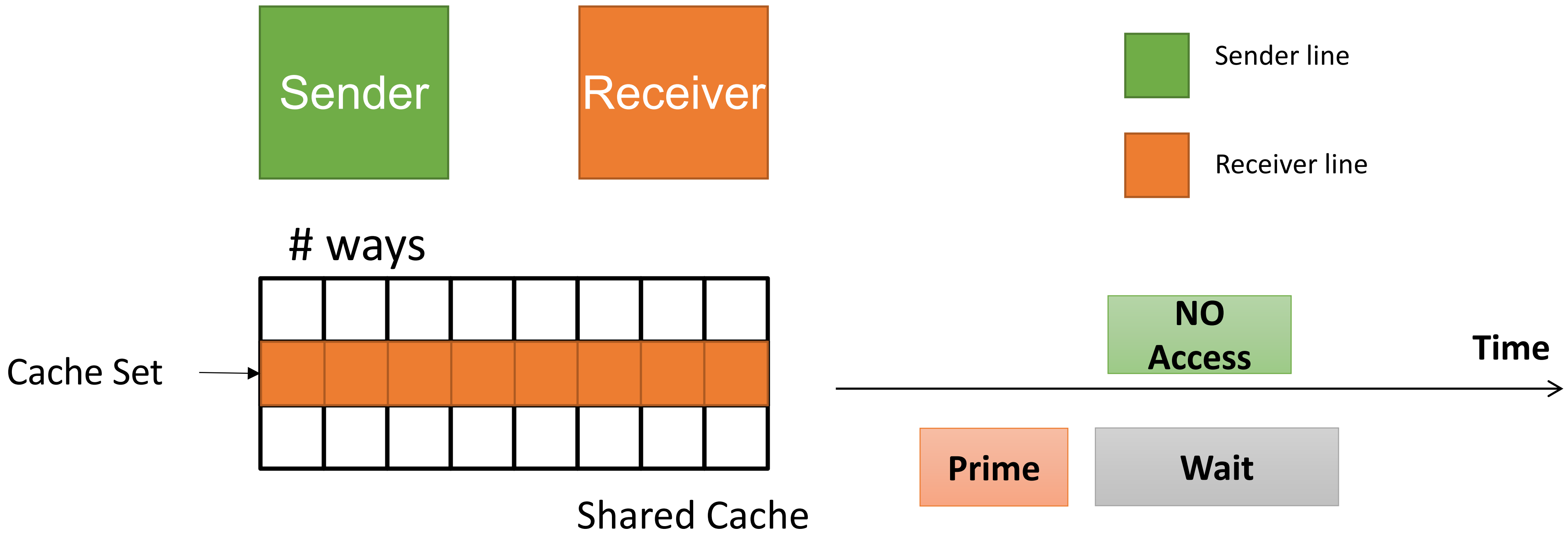


Prime+Probe – Receive “1”

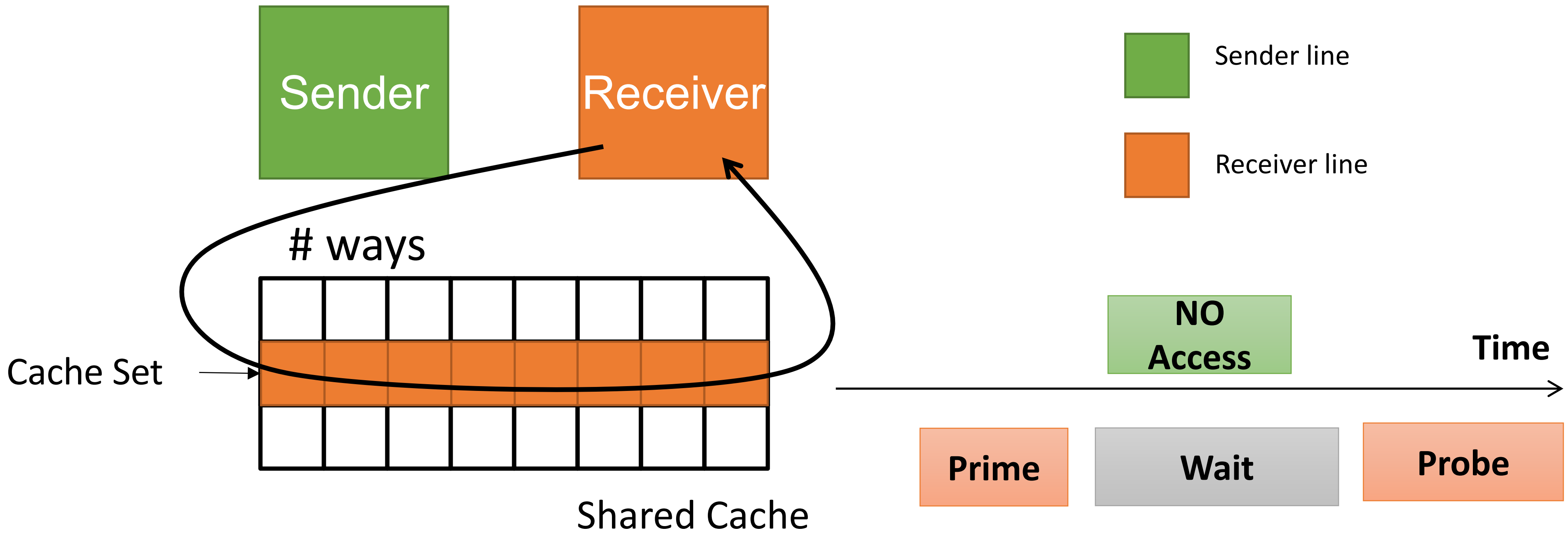


Receive “1” = 8 accesses → 1 miss

Prime+Probe – Send “0”

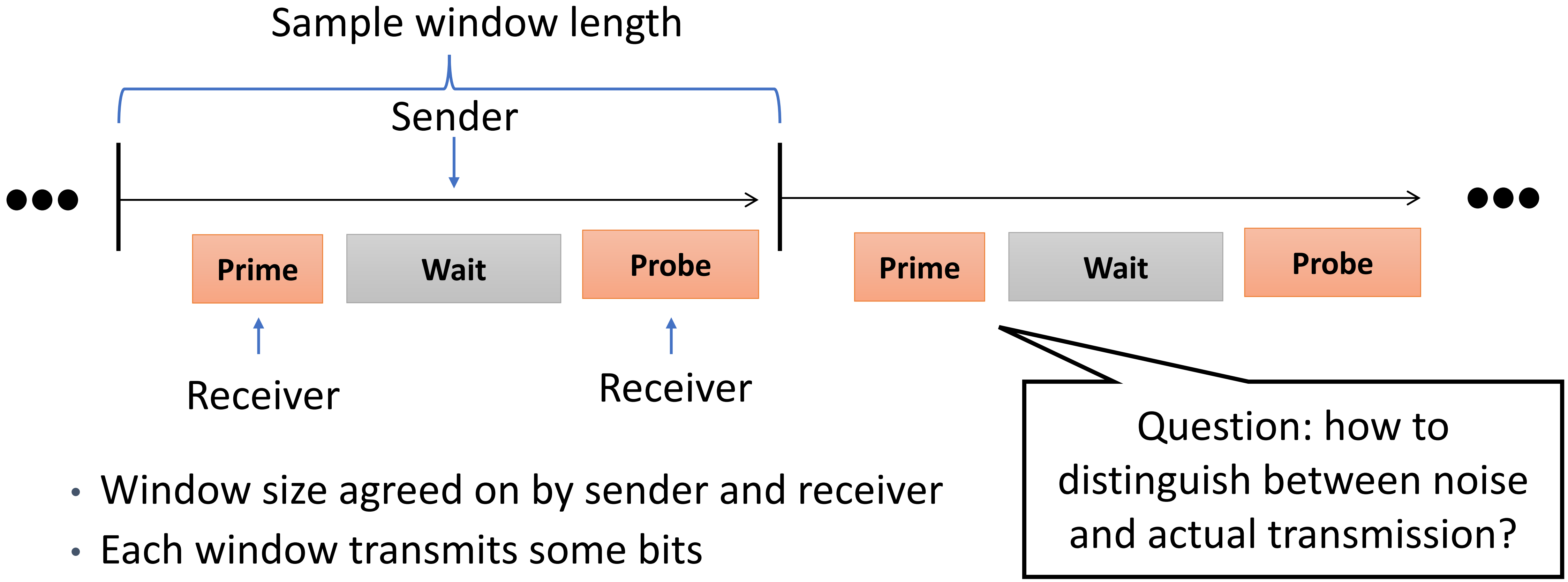


Prime+Probe – Receive “0”



Receive “0” = 8 accesses → 0 miss

A Complete Protocol -- Synchronization

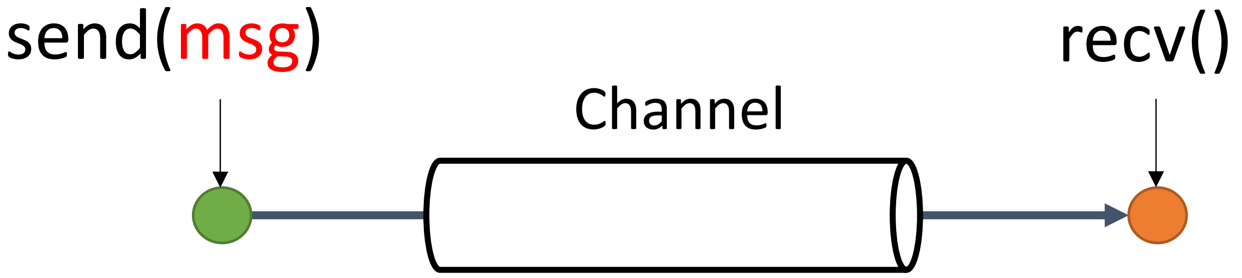


- Window size agreed on by sender and receiver
- Each window transmits some bits

- Sender & receiver need to perform an window alignment at the start

Bandwidth

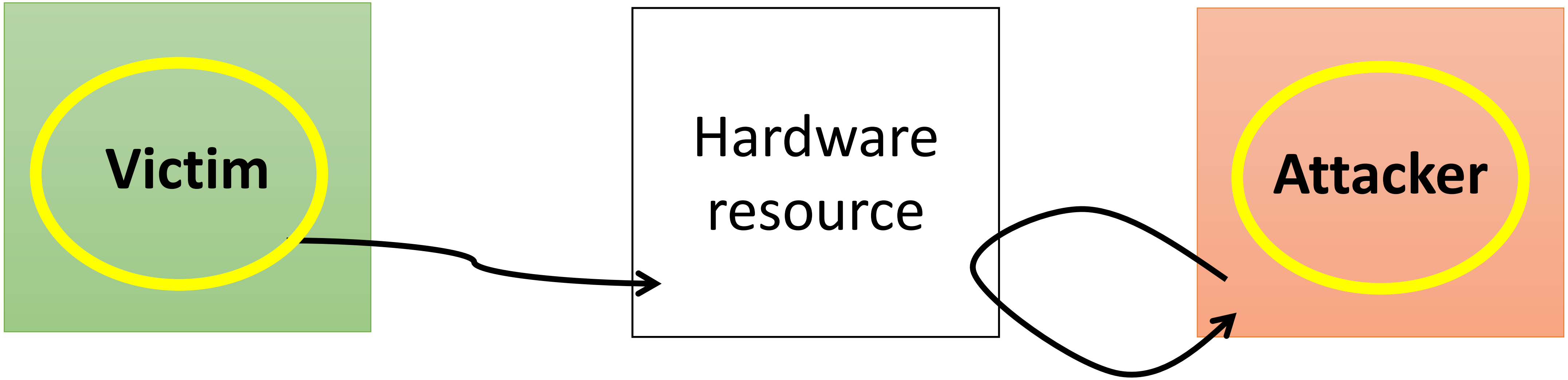
Error-free bitrate of send() → recv()



Depends on what hardware structure is used to build the channel.

- RDRAND unit:
- MemBus/AES-NI contention:
- LLC:
- Various structures on GPGPU:

From Covert → Side Channels



Covert channel:

if (**send ‘1’**)
  Use resource
else
  idle

Side channel:

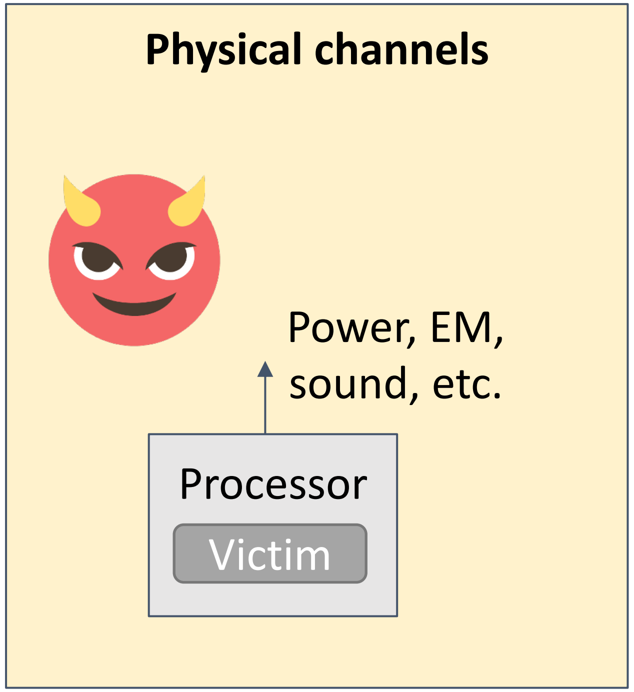
if (**secret**)
  Use resource
else
  idle

t1 = rdtsc()
Use resource
t2 = rdtsc()

if (t2 – t1 > THRESH)
    read ‘1’
else
    read ‘0’

Summary

- What can the adversary observe?



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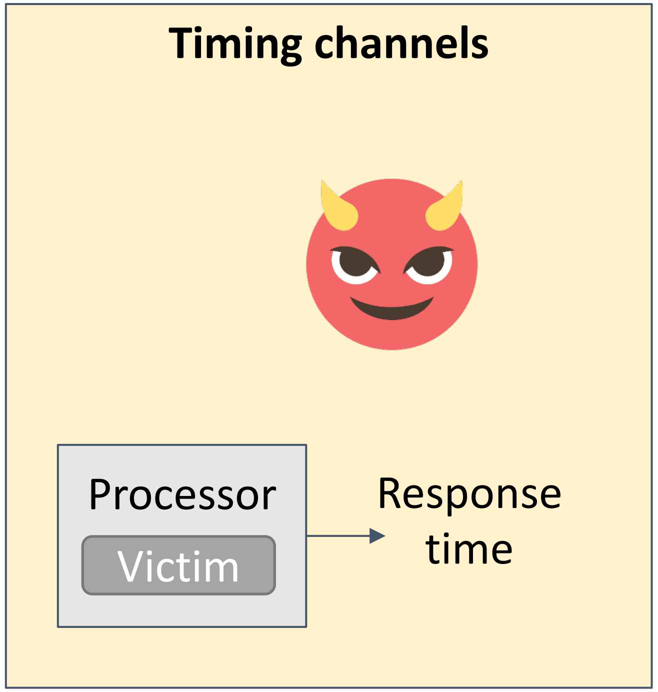

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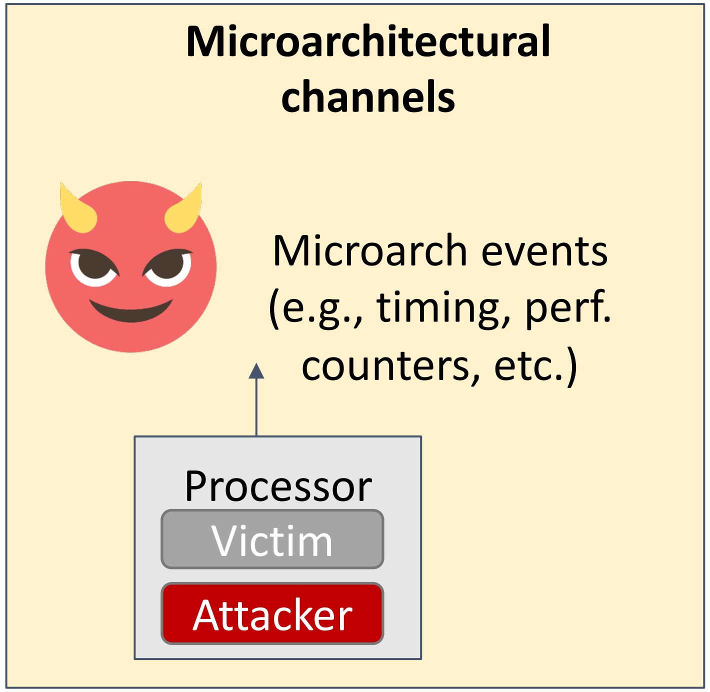

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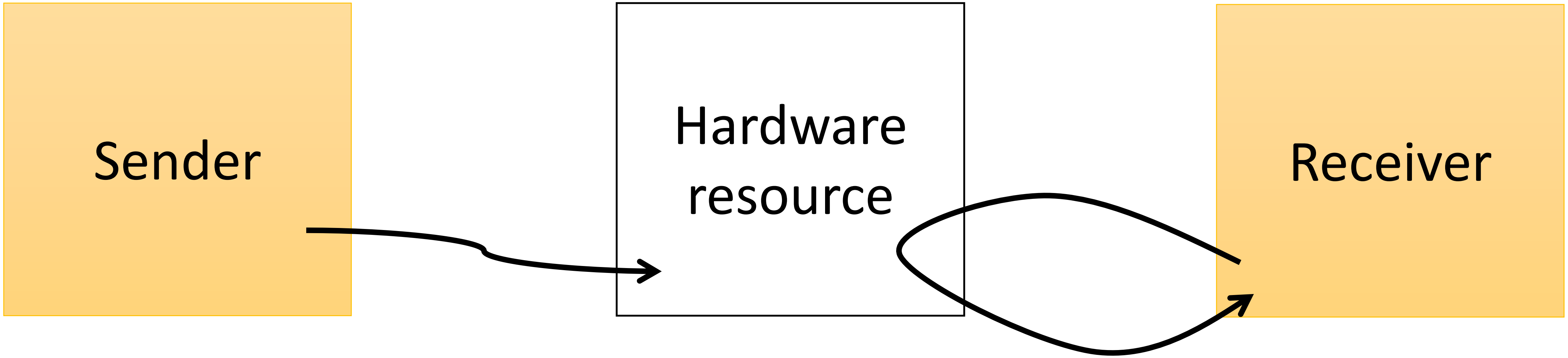
Micro-arch Side Channel Generalization



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else
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t1 = rdtsc()
Use resource
t2 = rdtsc()

if (t2 – t1 > THRESH)
    read '1'
else
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Next Lecture:
Practical Cache Side Channel Examples