Remote Memory-Deduplication Attacks

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Motivation

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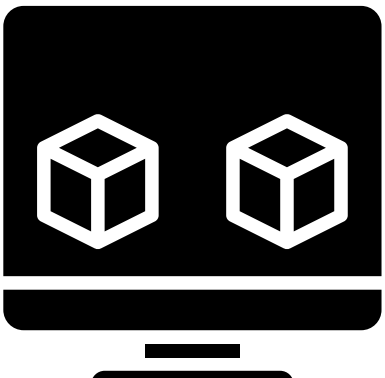
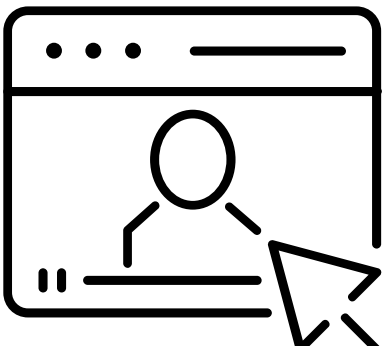
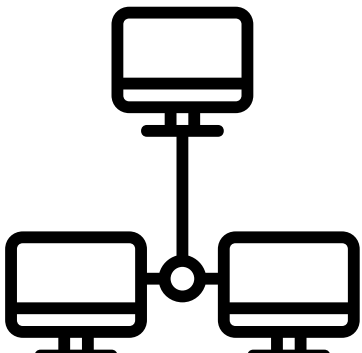
- Providers try to isolate tenants
- Need to consider side-channel attacks in both soft- and hardware
- Network throughput is increasing







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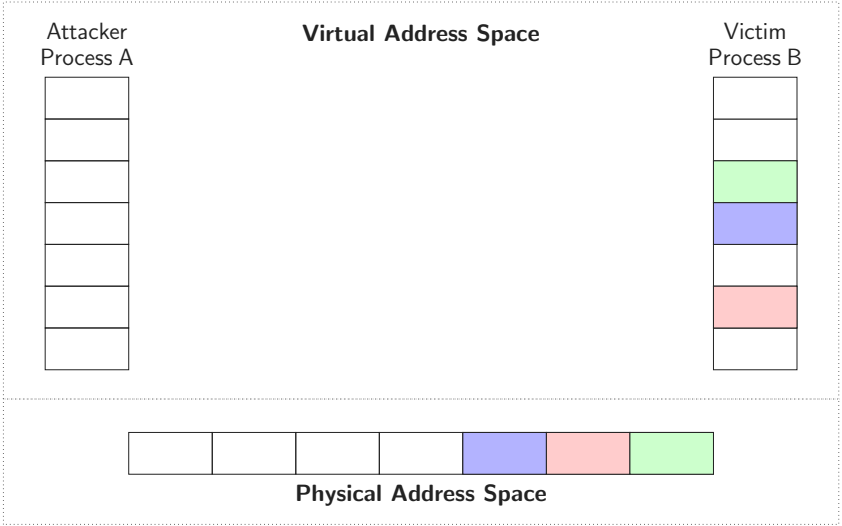
- Is used in virtual machines in the cloud
- Current active mitigations try to prevent cross-security-domain attacks
- Can memory deduplication attacks be performed on the same security domain across the internet?

Memory Deduplication



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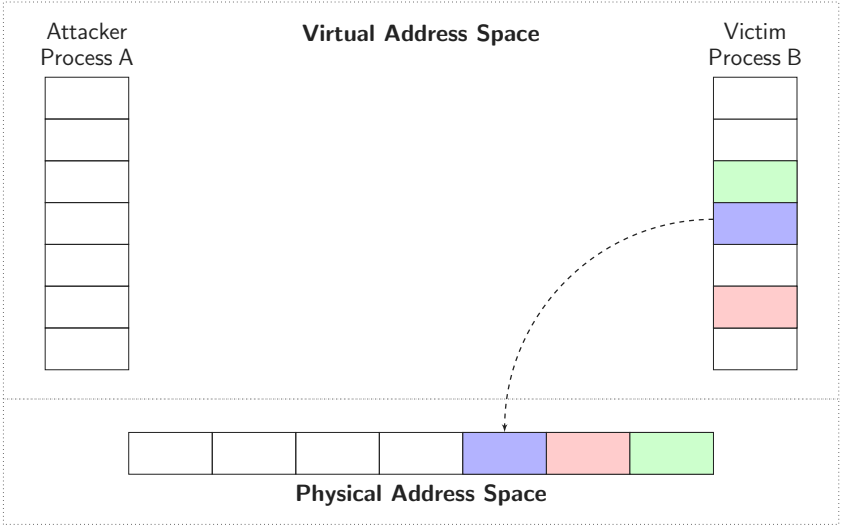

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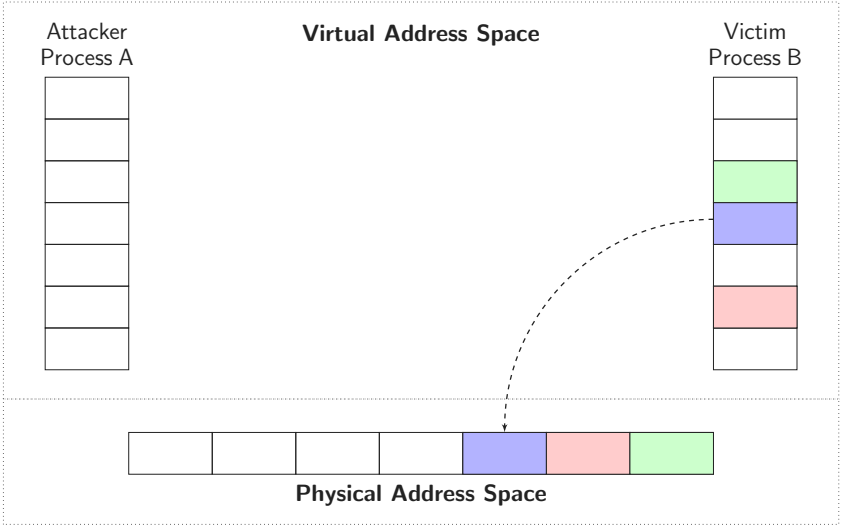

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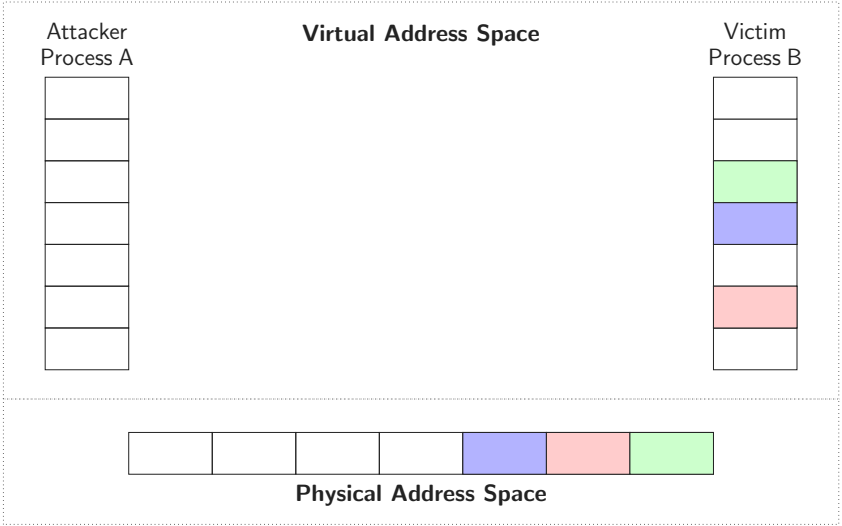

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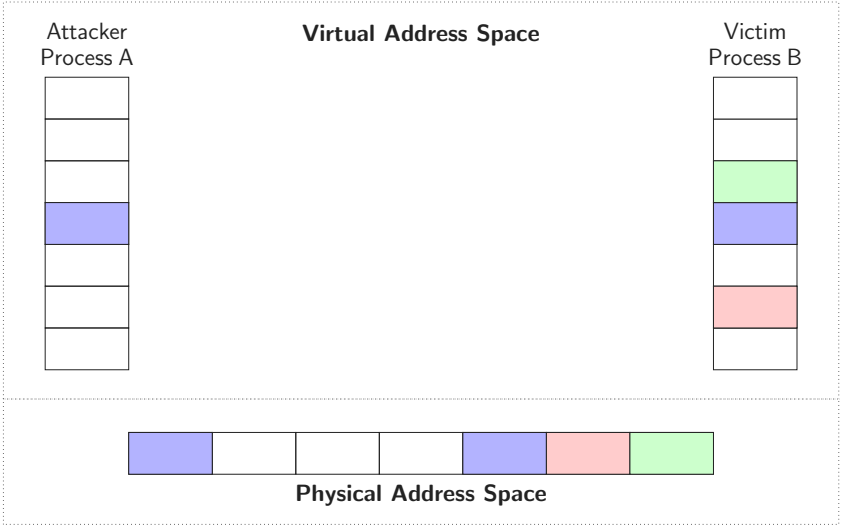

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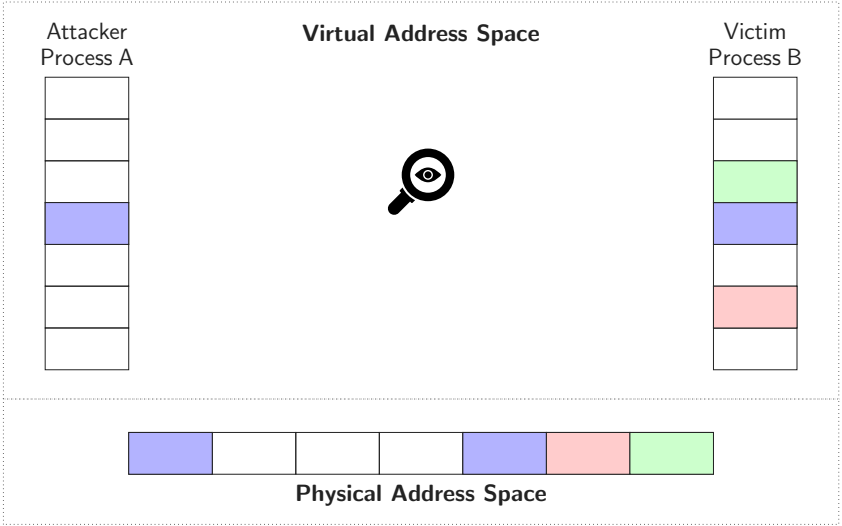

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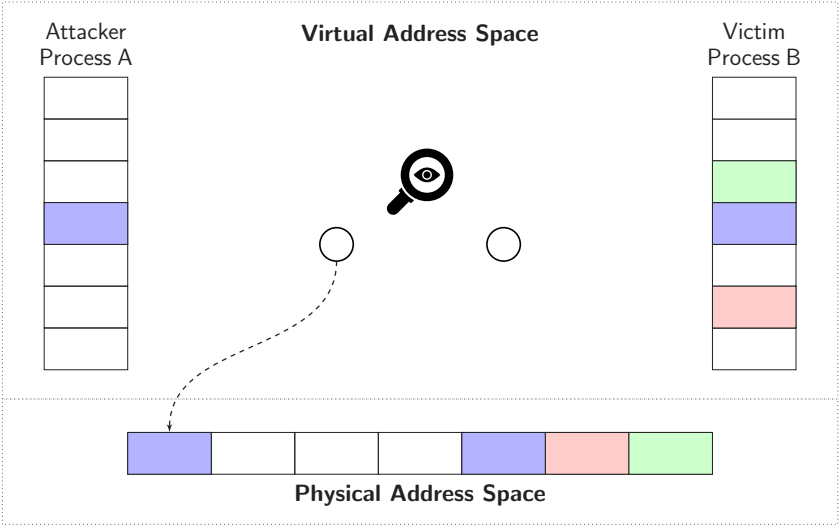

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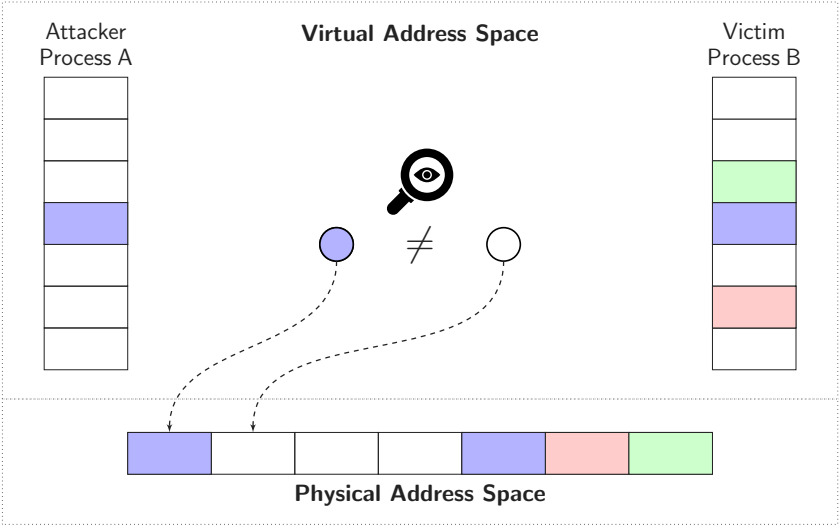

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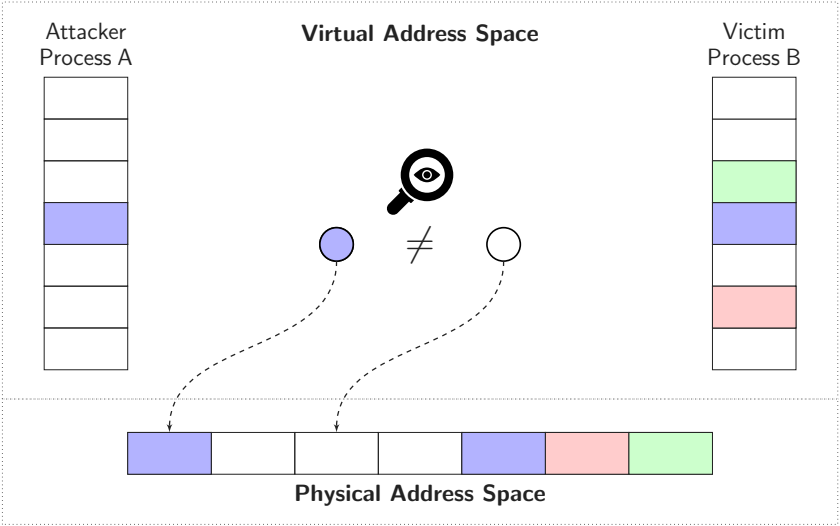

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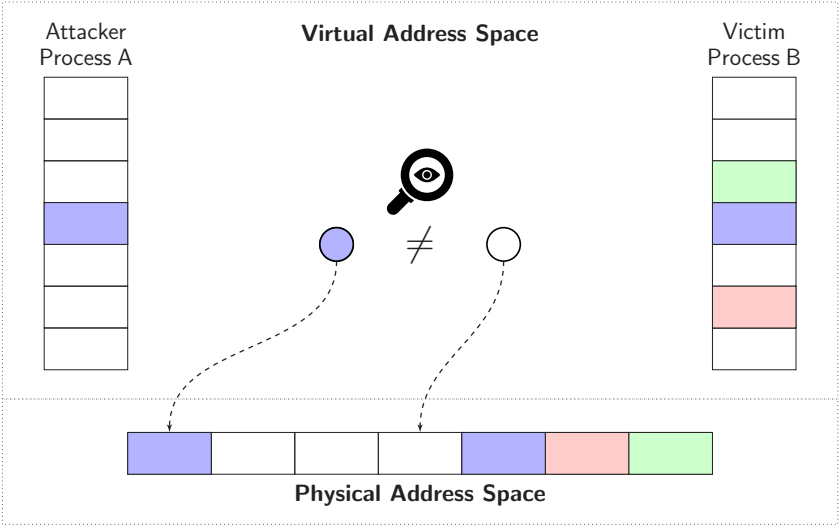

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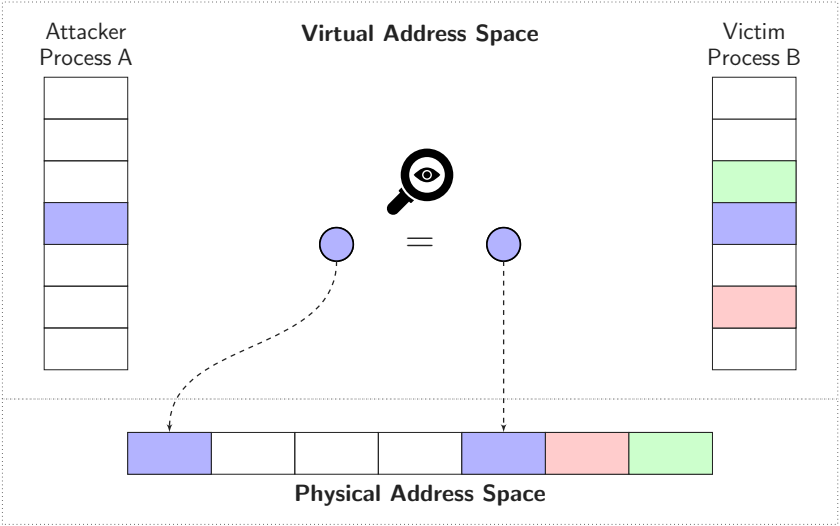

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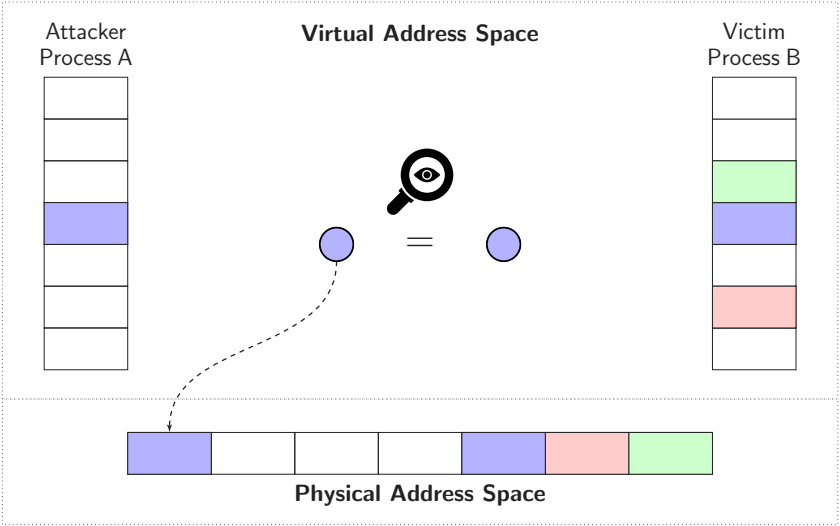

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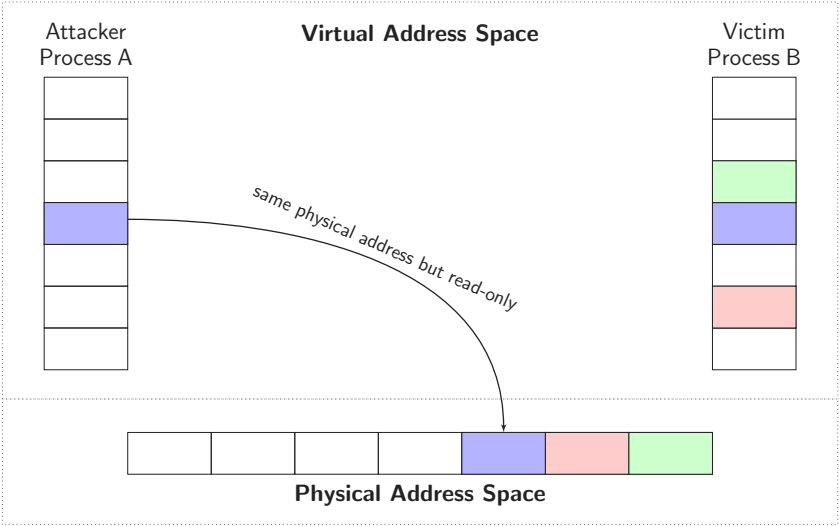

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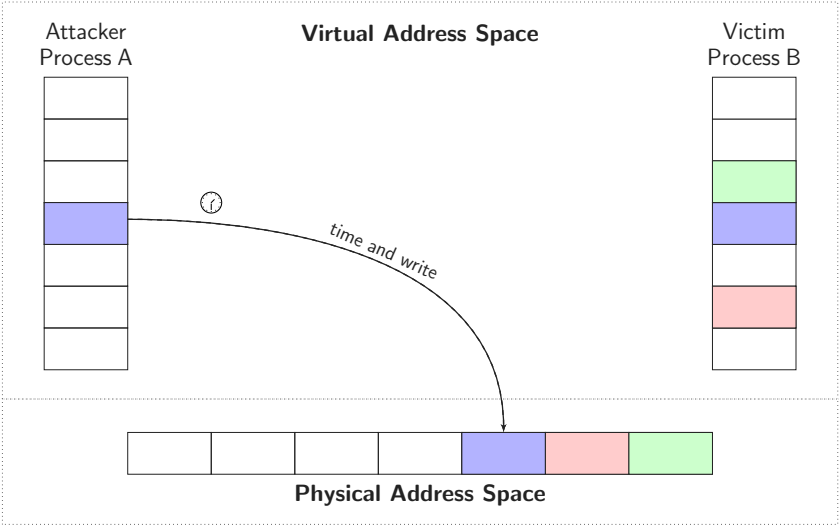

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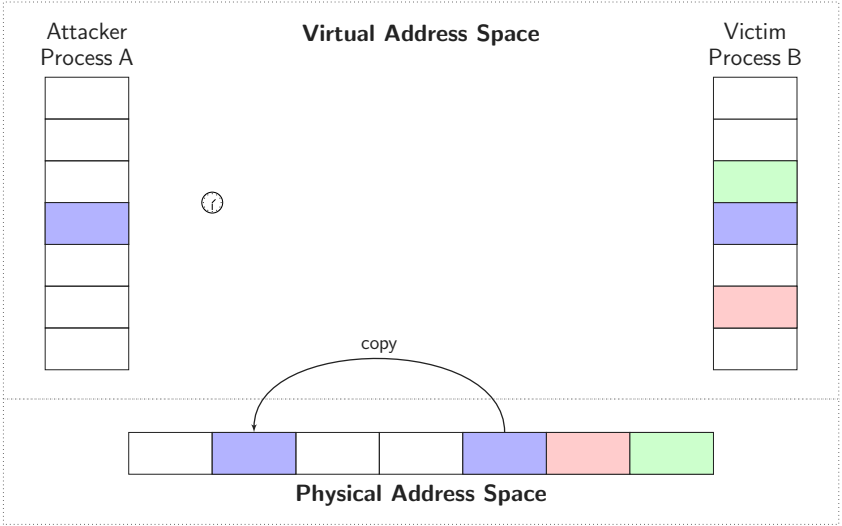

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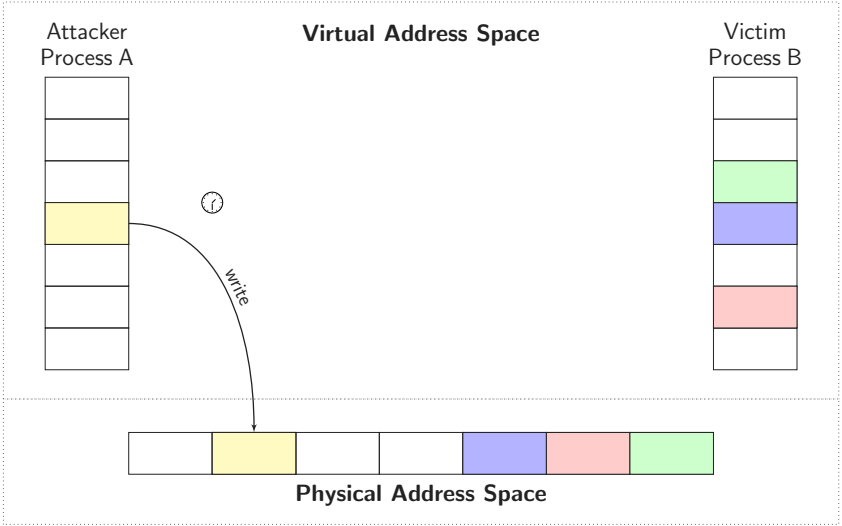

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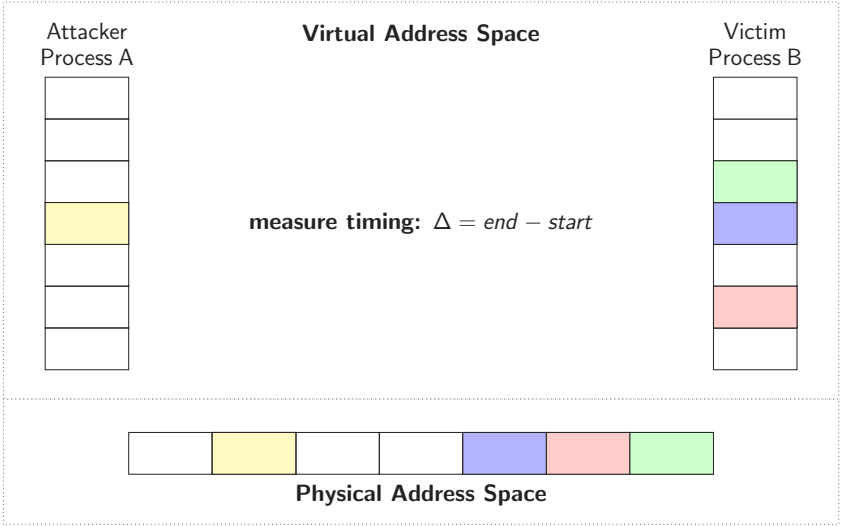
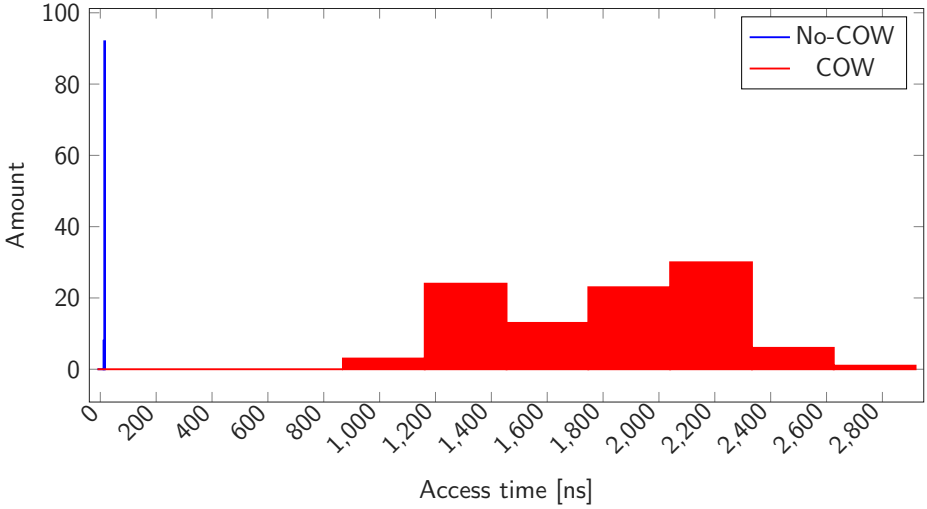
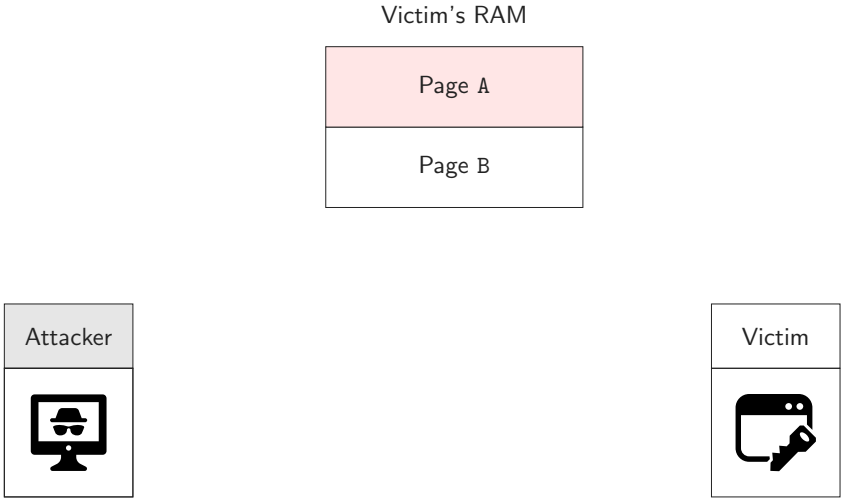


Timing Difference of COW-PF vs. Non-COW



Attack Idea



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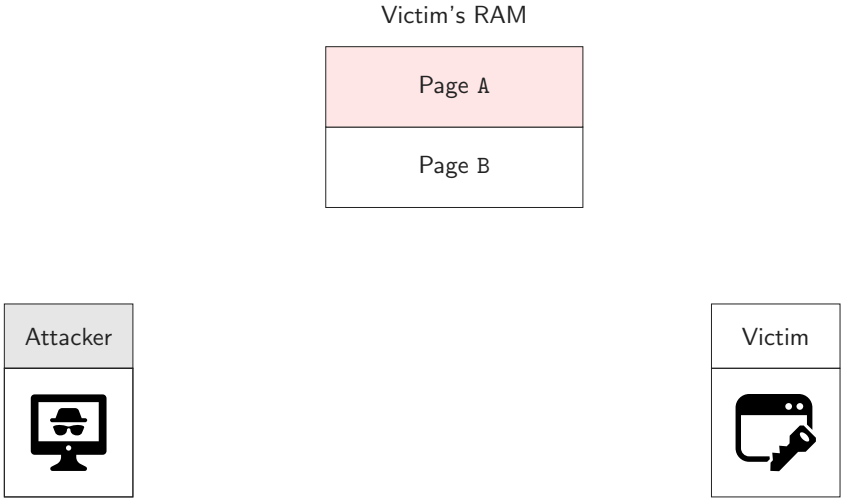

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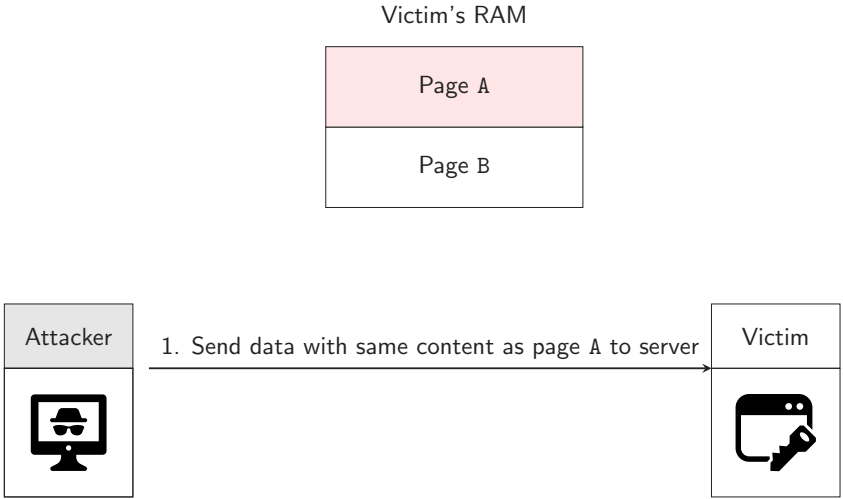
Victim's RAM
Page A
Page B
Attacker
1. Send data with same content as page A to server
Victim

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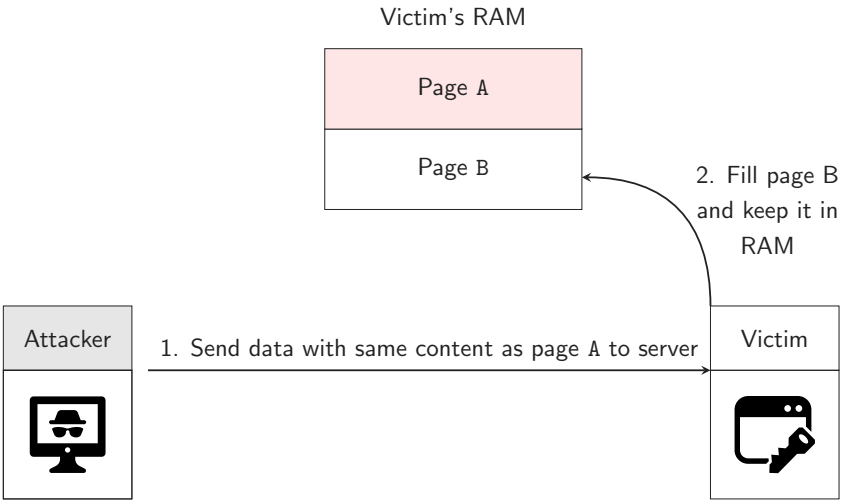
Victim's RAM
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2. Fill page B and keep it in RAM
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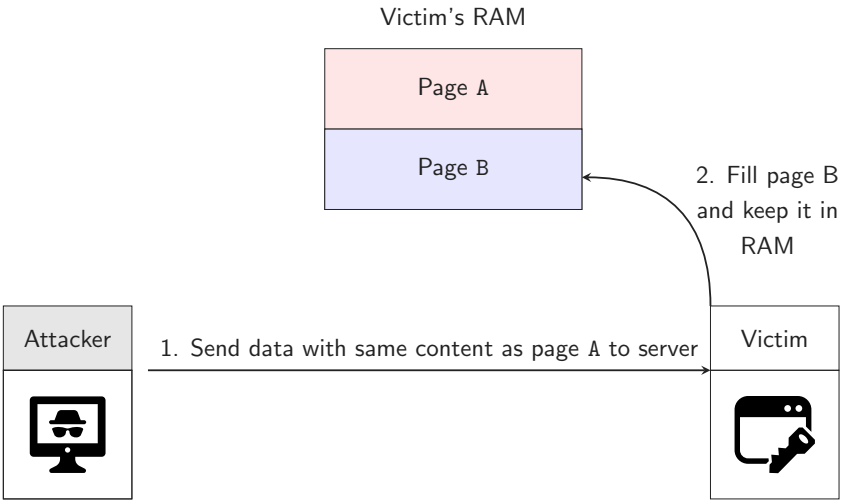
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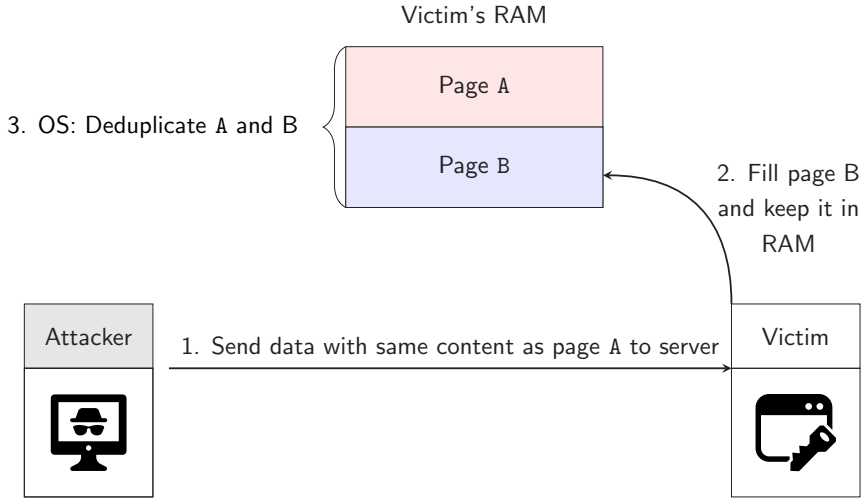
Victim's RAM
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3. OS: Deduplicate A and B
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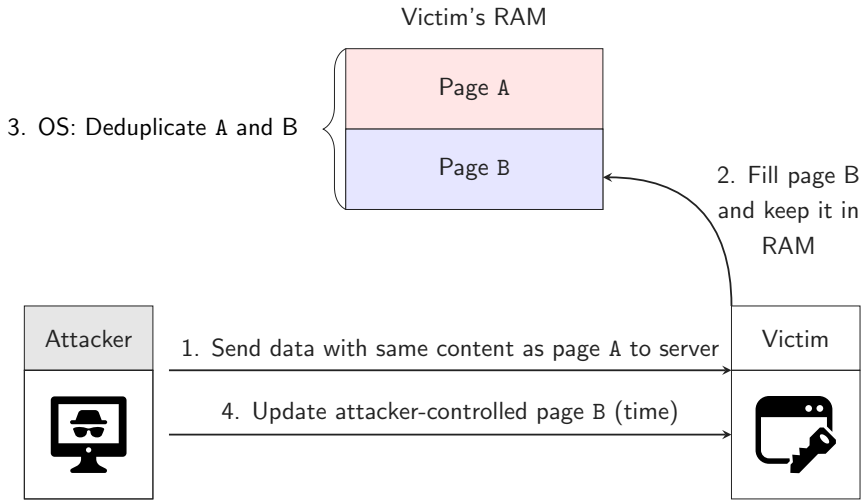
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Victim
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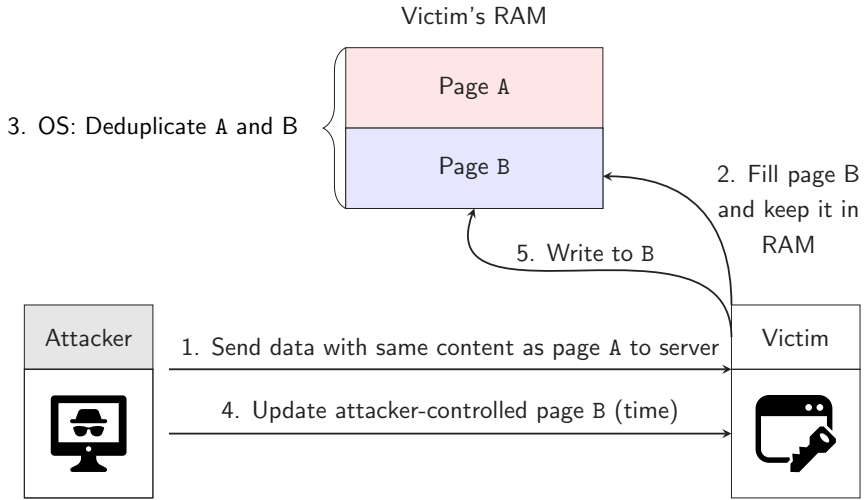
Victim's RAM
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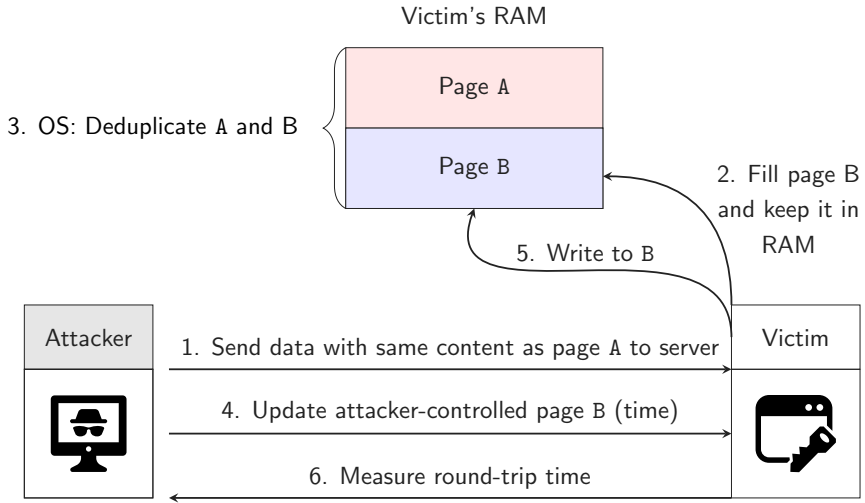
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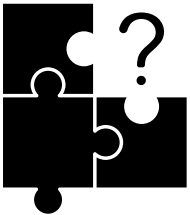
4. Update attacker-controlled page B (time)
6. Measure round-trip time

Attack Setup



- Remote Server 14 hops → high-latency

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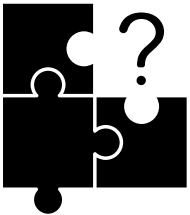

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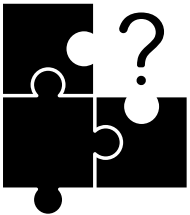

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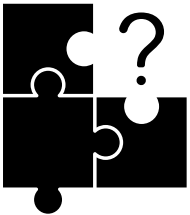
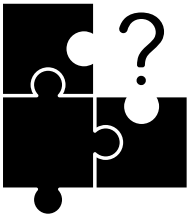


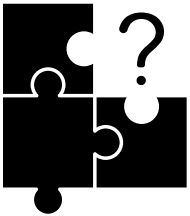
- Remote Server 14 hops → high-latency
- KVM with Ubuntu VM
- Nginx with PHP, Memcached and MySQL installed
- Use pyshark to capture web requests

Remote Covert Channel



- Use amplification across the internet

Remote Covert Channel



- Use amplification across the internet
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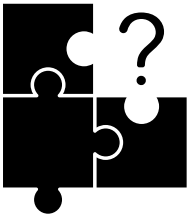
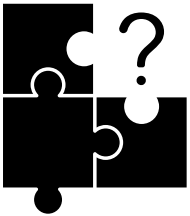


- Use amplification across the internet
- Transmit multiple bits at once
- Use asyncio
- Covert channel across internet is 34.41 B/h

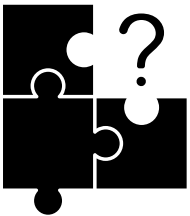
Attacks	Location	Environment	Local	Type	Attack Type	Performance
Suzaki	Co-located	Cross-VM	Yes	Native	Fingerprinting	-
Owens	Co-located	Cross-VM	Yes	Native	Fingerprinting	-
Gruss	Remote	Browser/Cross-VM	Yes	JS	Fingerprinting	-
Barresi	Remote	Cross-VM	Yes	Native	ASLR break	8.7 days
Bosman	Remote	Browser	Yes	JS	Bytewise leakage, ASLR break, Rowhammer	2.75 h
Lindemann	Co-located	Cross-VM	Yes	Native	Fingerprinting	1.8 h
Kim	Co-located	Cross-VM	Yes	Native	KASLR break	12 min
Our work	Remote	**Internet/LAN**	**No**	**None**	Bytewise leakage, KASLR break, Fingerprinting	1.5 B/h (LAN) / 4 min / 166.51 s

Challenges



- C1: Remotely amplify latencies for non-repeatable events.

Challenges



- C1: Remotely amplify latencies for non-repeatable events.
- C2: Trigger and observe COW-pagefaults in a victim domain that shares no memory with any attacker domain.

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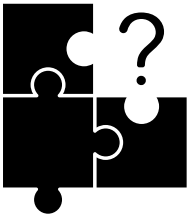
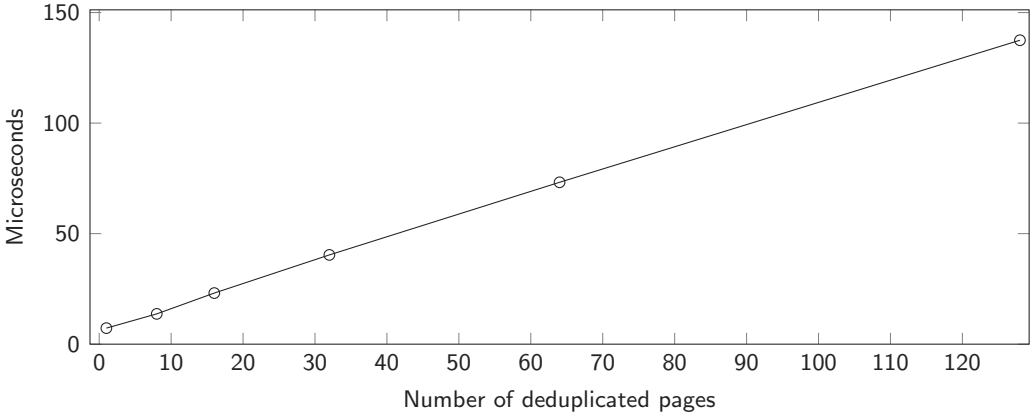
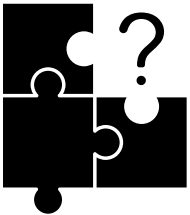


- C1: Remotely amplify latencies for non-repeatable events.
- C2: Trigger and observe COW-pagefaults in a victim domain that shares no memory with any attacker domain.
- C3: Find remote request paths that do not only keep attacker-controlled data in memory but also provide the attacker with control over alignment and in-memory representation.

C1: Amplification



C2: Trigger-COW pagefaults without shared memory



- A web application provides a file-upload

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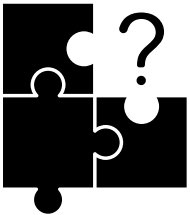

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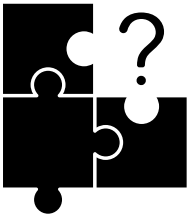
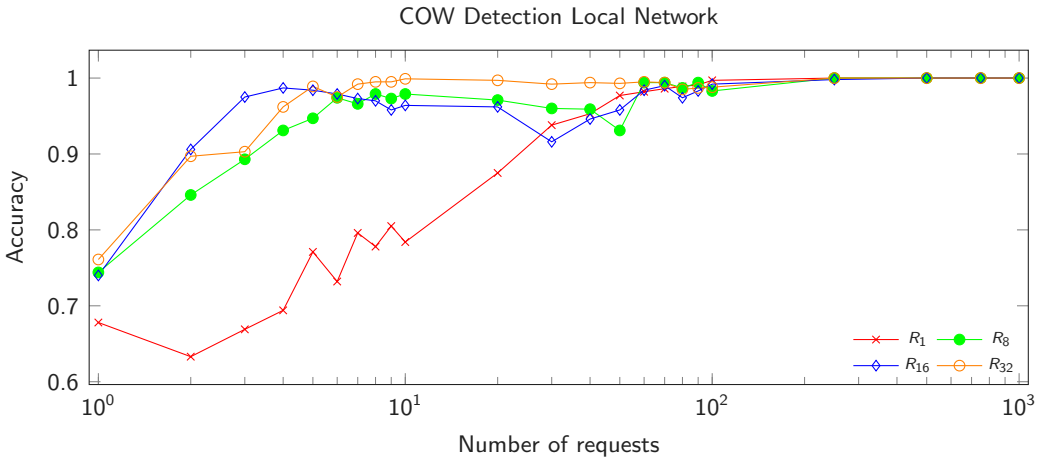
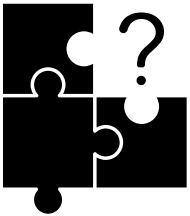


- A web application provides a file-upload
- Data is cached in RAM e.g., Memcached
- The attacker can update/overwrite the uploaded data → trigger pagefaults

C2: Trigger-COW pagefaults without shared memory



C2: Fingerprint a system library



- Fingerprint a system by uploading memory

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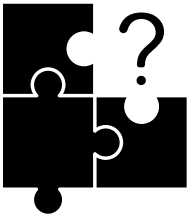

- Fingerprint a system by uploading memory
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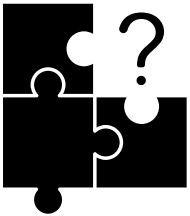

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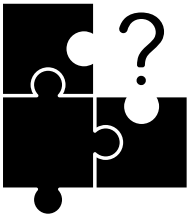

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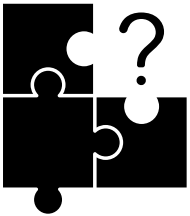

- Fingerprint a system by uploading memory
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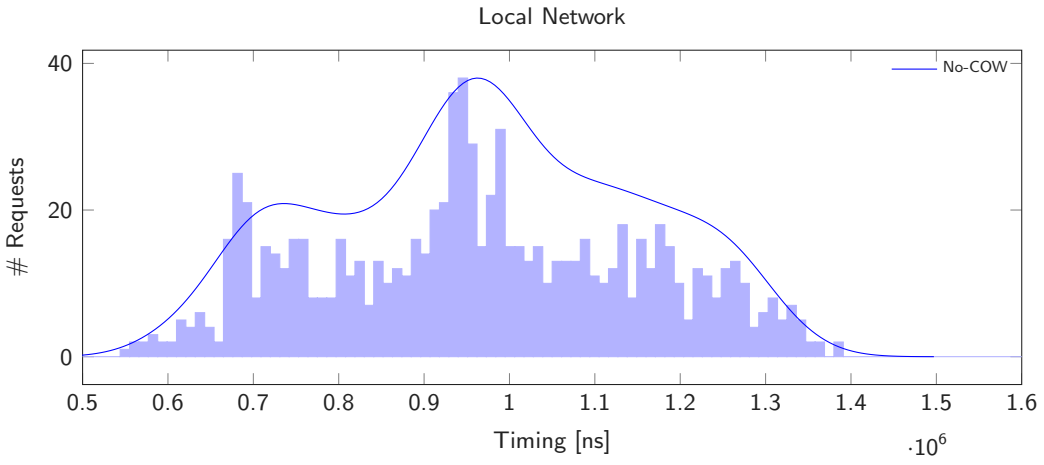
- If re-assigned overwrite page and trigger COW-pagefault

C2: Fingerprinting (LAN)



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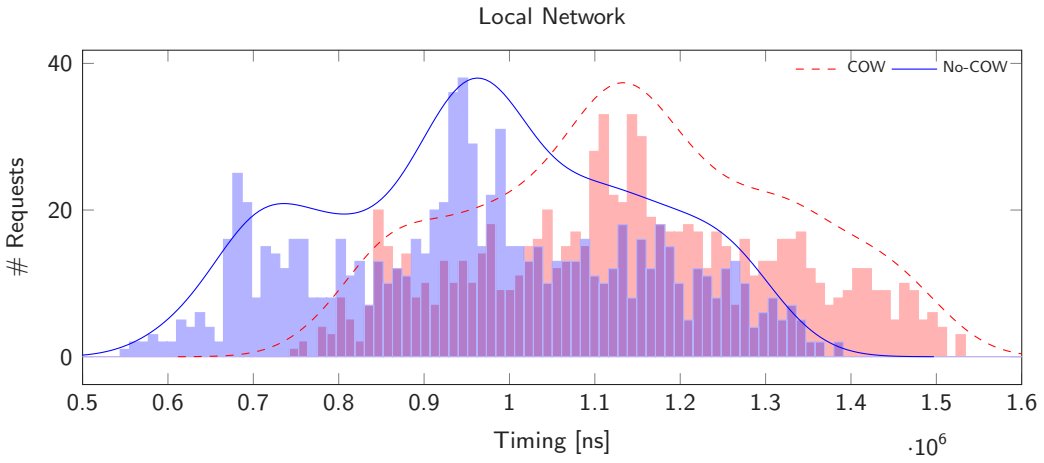

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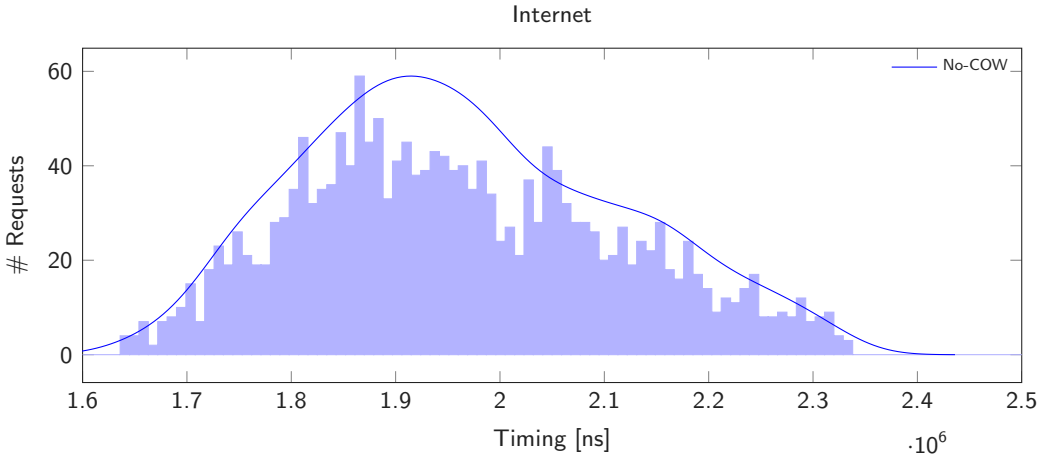

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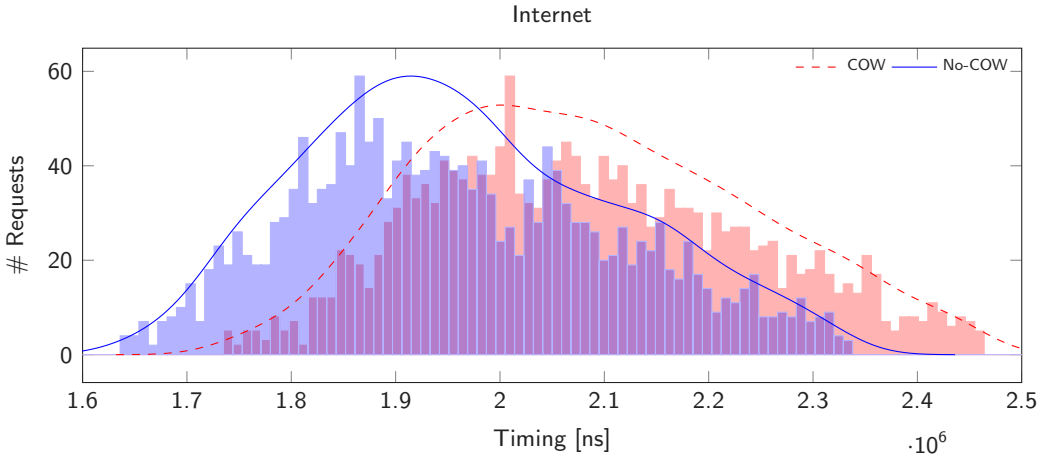
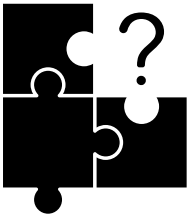


C2: Break KASLR



- Break KASLR in remote VMs

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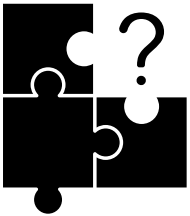

- Break KASLR in remote VMs
- Sample low-entropy pages offline pointing to kernel text

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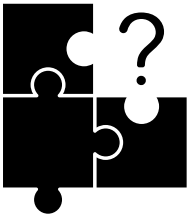

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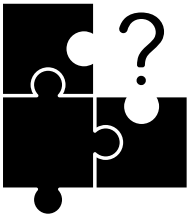
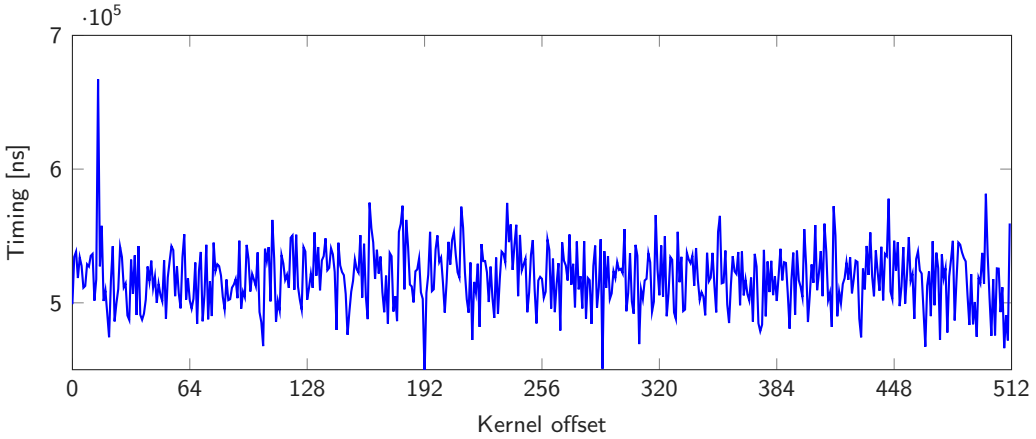
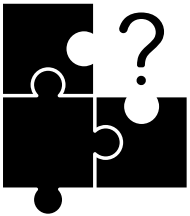


- Break KASLR in remote VMs
- Sample low-entropy pages offline pointing to kernel text
- Try all 512 different offsets
- Attacker uploads blob and triggers pagefaults

Break KASLR


·10^5
7
6
5
Timing [ns]
0
64
128
192
256
320
384
448
512
Kernel offset

C3: Control over alignment and in-memory representation



- InnoDB is a memory cache for DBMS (e.g., MySQL/MariaDB)

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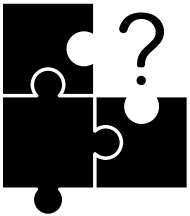

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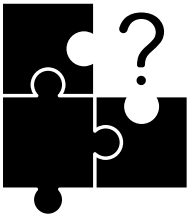
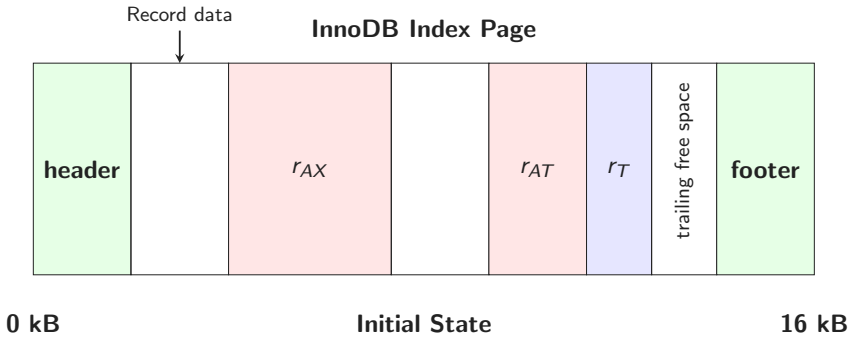
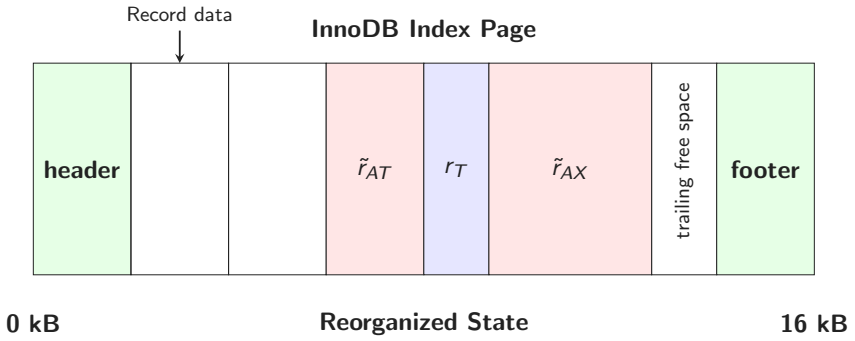


- InnoDB is a memory cache for DBMS (e.g., MySQL/MariaDB)
- Reorganization optimization in index page enables bytewise leakage
- Use Memcached as leakage primitive to leak InnoDB records

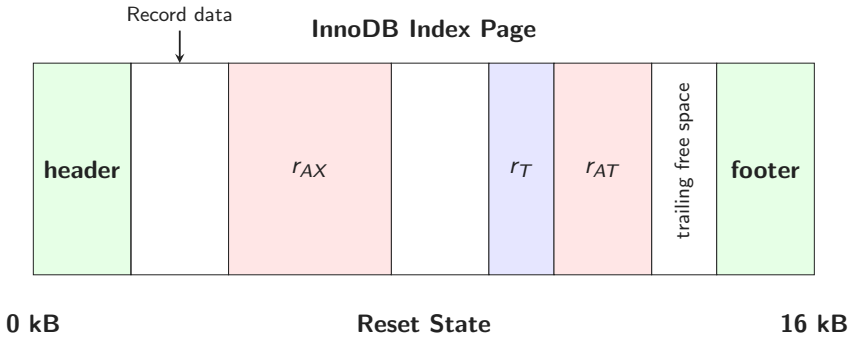
Inno-DB record



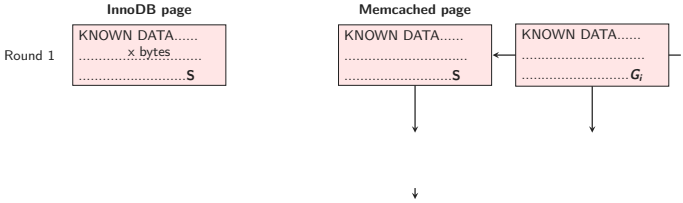
Inno-DB Reorganization



Inno-DB Reset



Inno-DB Leaking



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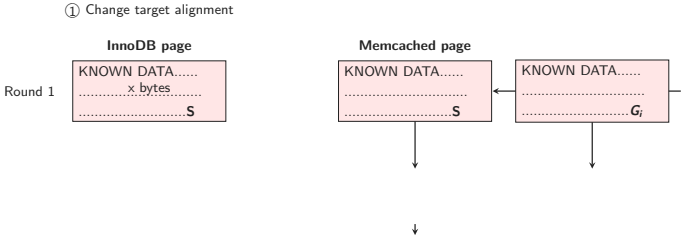

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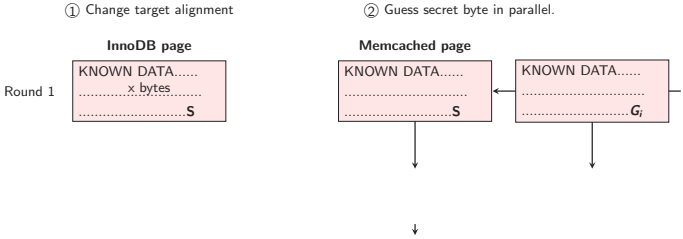

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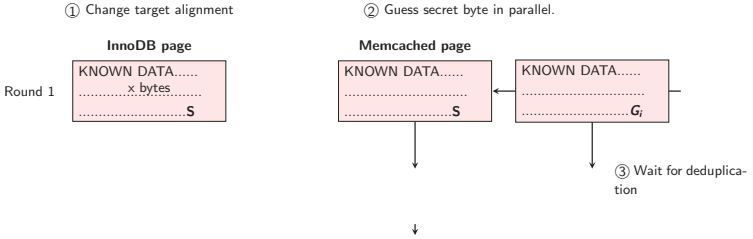

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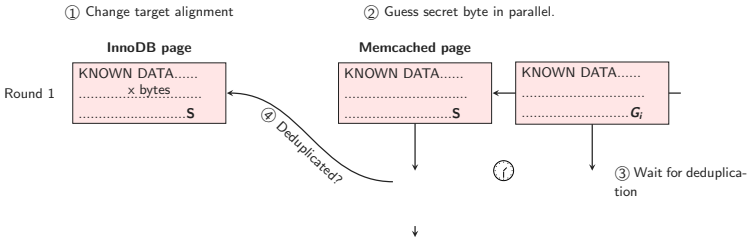

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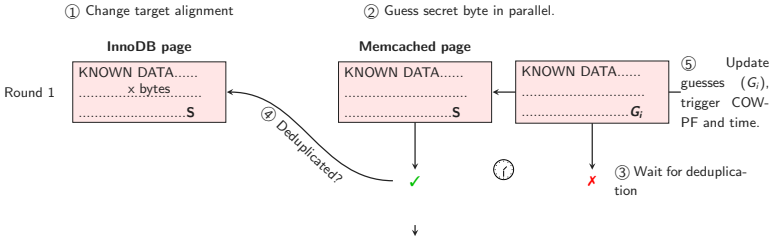

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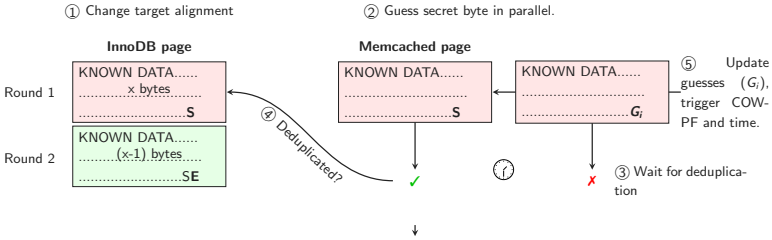

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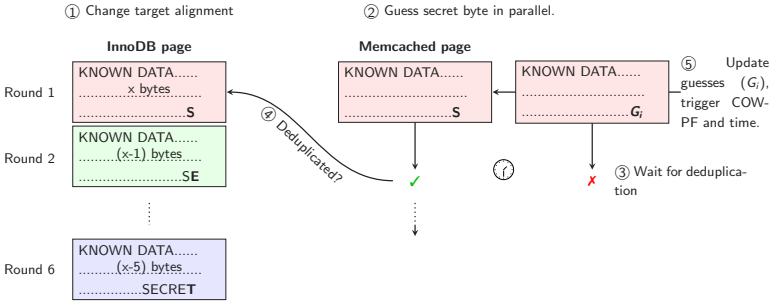

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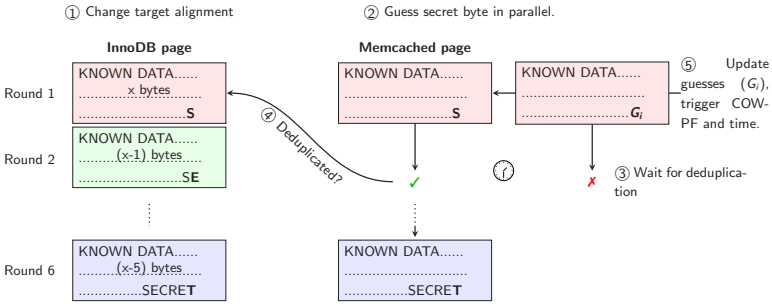


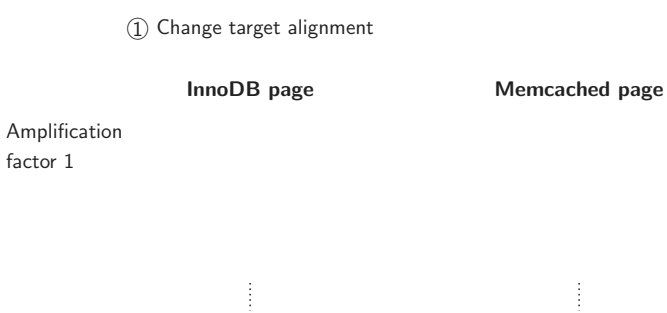
Amplification via Memcached

InnoDB page

Memcached page

Amplification via Memcached

① Change target alignment



Amplification via Memcached

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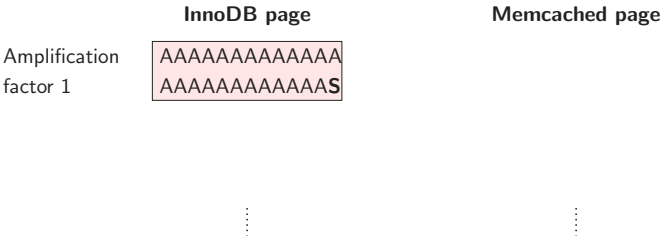
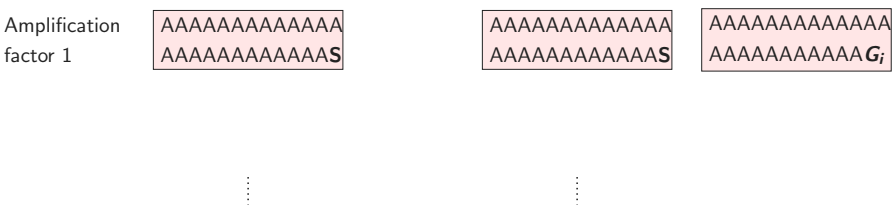


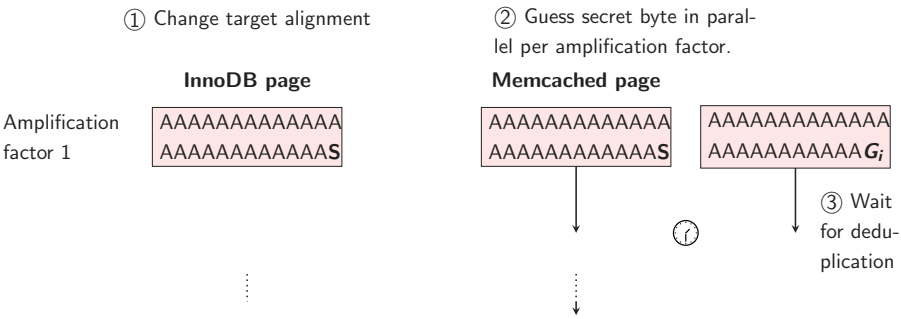
Amplification via Memcached

① Change target alignment

② Guess secret byte in parallel per amplification factor.



Amplification via Memcached



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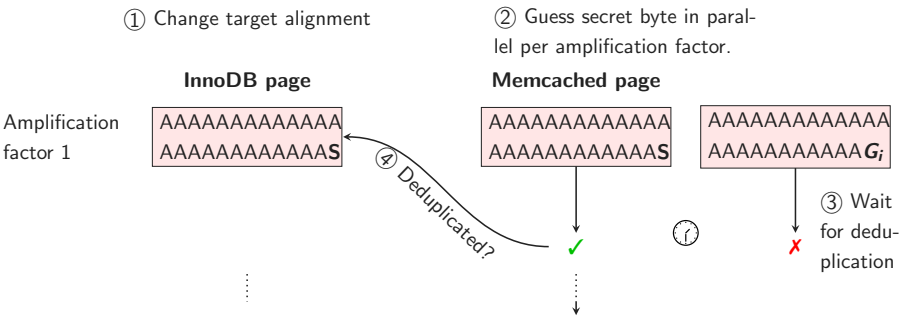
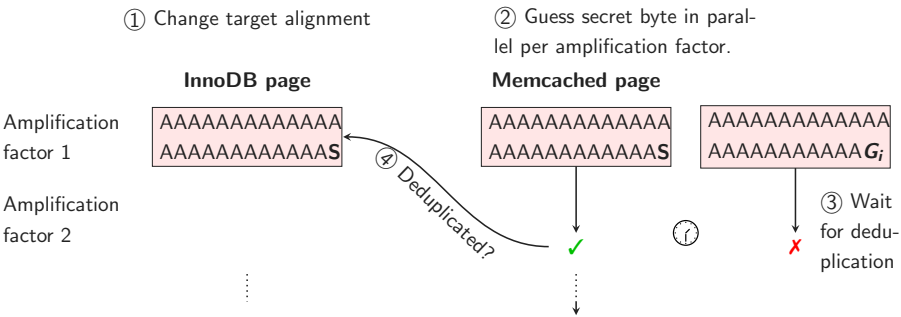


Amplification via Memcached



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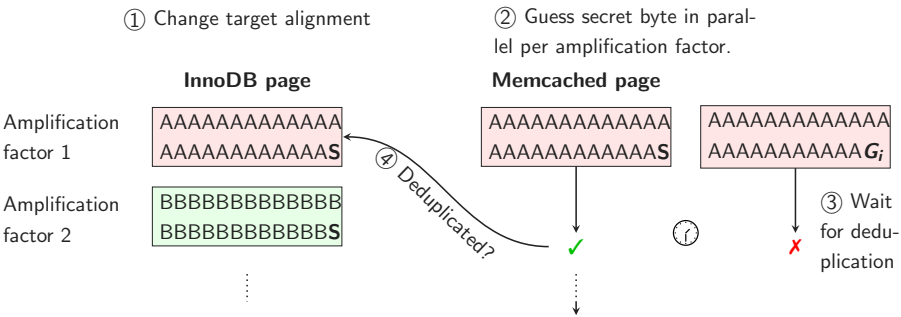

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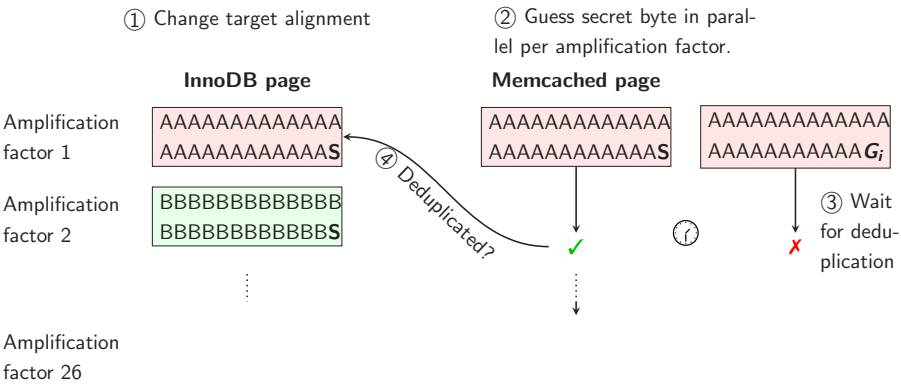

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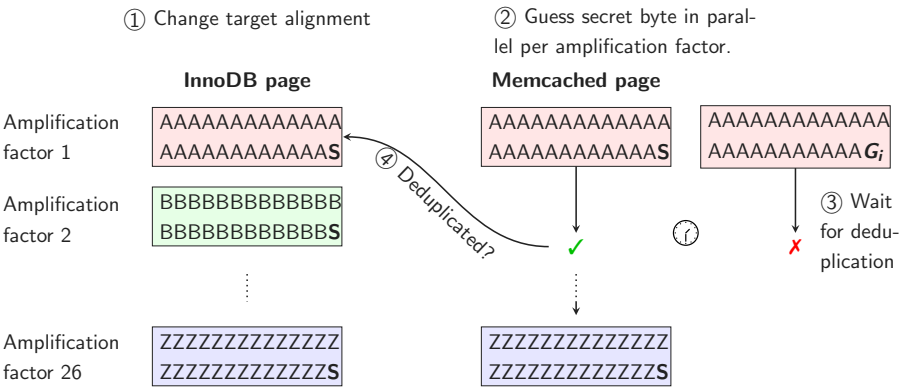
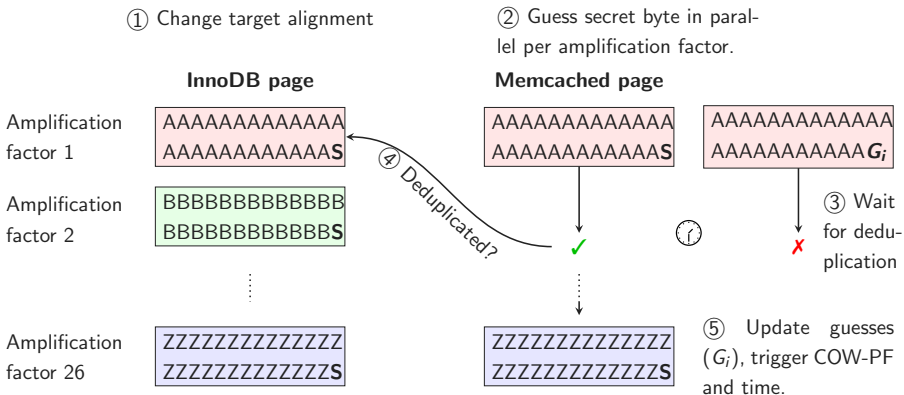


Amplification via Memcached



Mitigations

- Disable memory deduplication

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- Disable memory deduplication
- Apply same behaviour for every memory write (VUsion)

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- Disable memory deduplication
- Apply same behaviour for every memory write (VUsion)
- Only deduplicate zero pages

Mitigations

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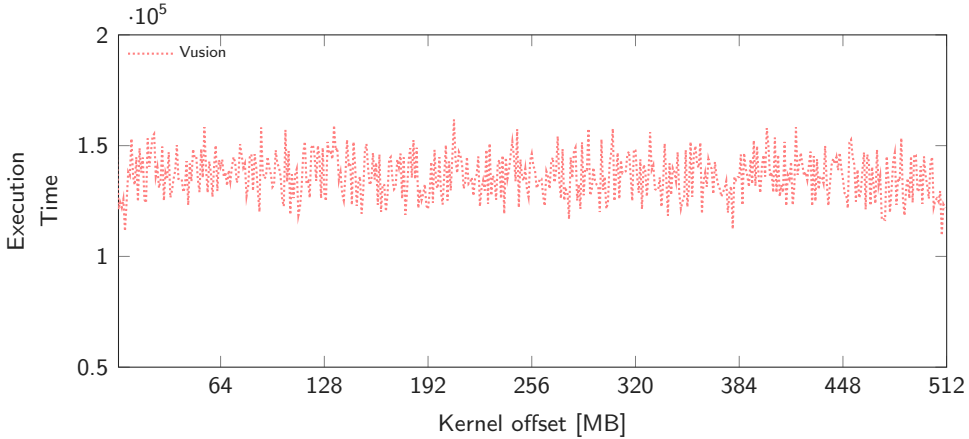
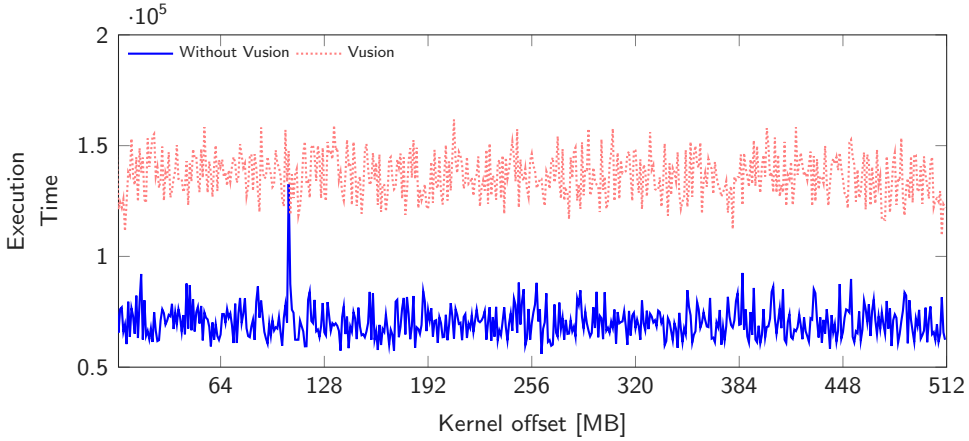
- Encode pages with different random salts

VUsion


·10^5
2
1.5
1
0.5
Vusion
Execution Time
64
128
192
256
320
384
448
512
Kernel offset [MB]

VUsion


·10^5
2
1.5
1
0.5
Without Vusion
Vusion
Execution Time
64
128
192
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- Remotely fingerprinting of libraries
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- Leak database records via InnoDB reorganization
- Red Hat developed a probabilistic mitigation as opt-in for Linux kernel

Remote Memory-Deduplication Attacks

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