Practical Memory Deduplication Attacks in Sandboxed JavaScript

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Overview

- Page deduplication not only a problem in the cloud
- Can be used to eavesdrop on browser usage

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The first page deduplication attack,

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Large scale remote attacks possible

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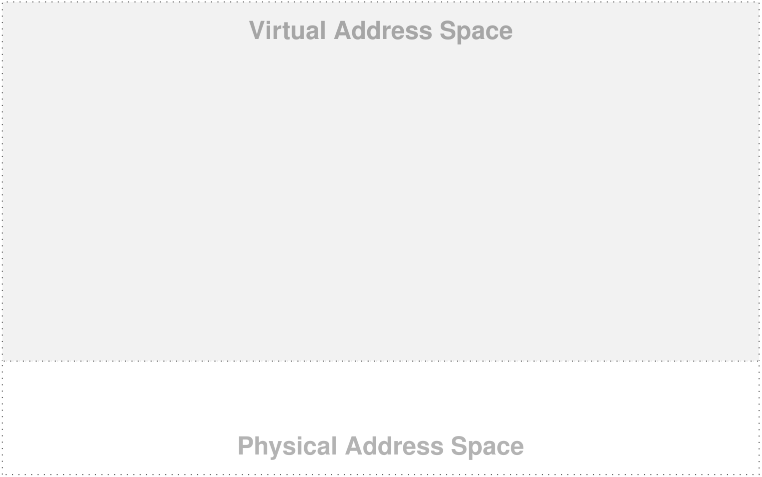

Virtual Address Space

Physical Address Space

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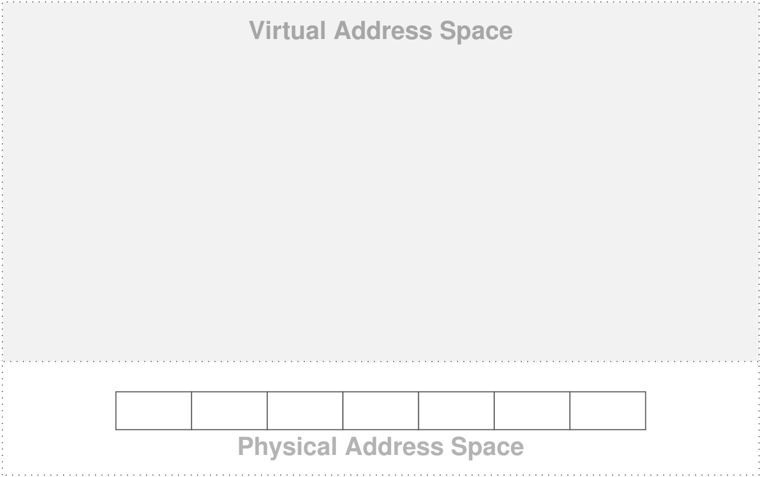

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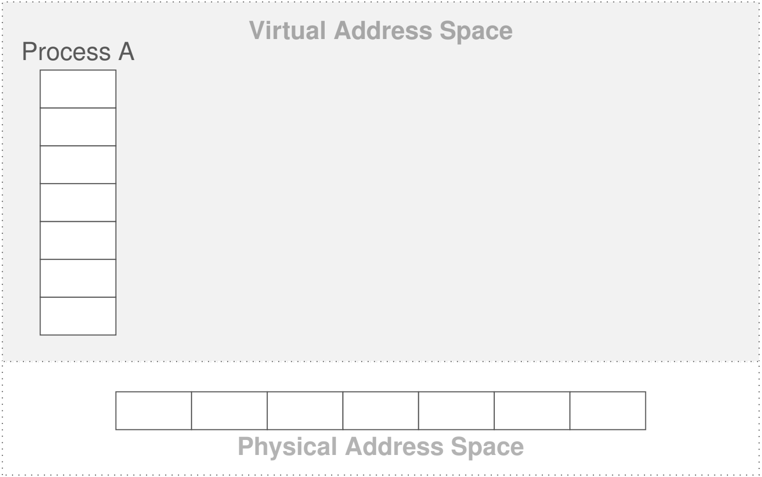

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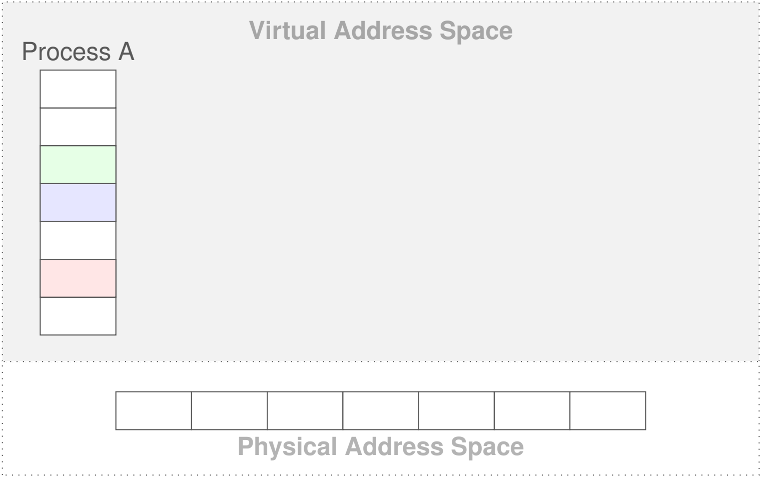

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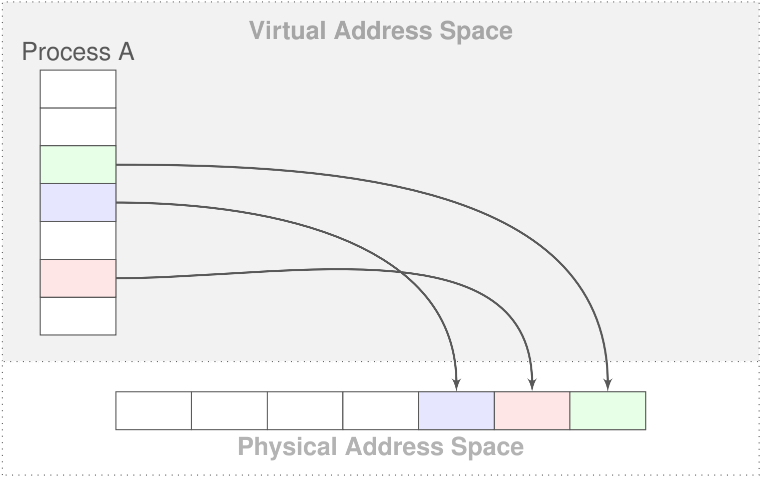

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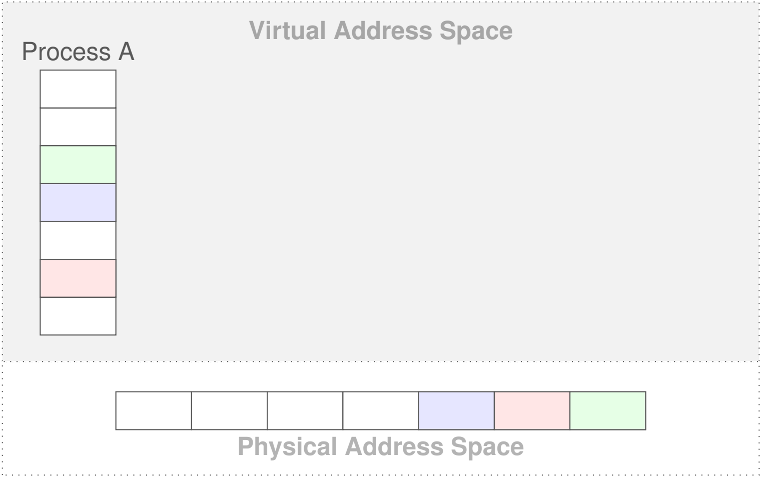

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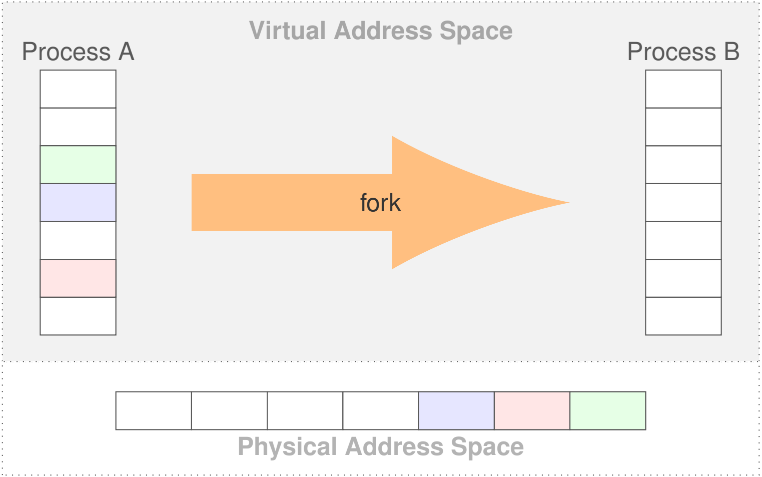

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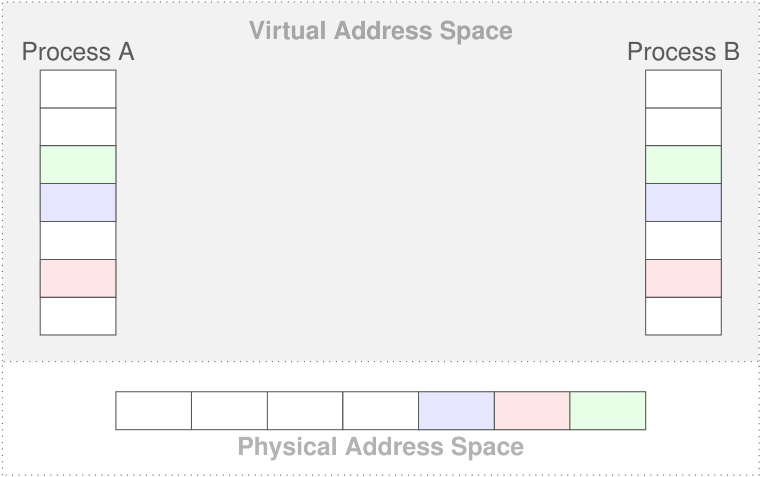

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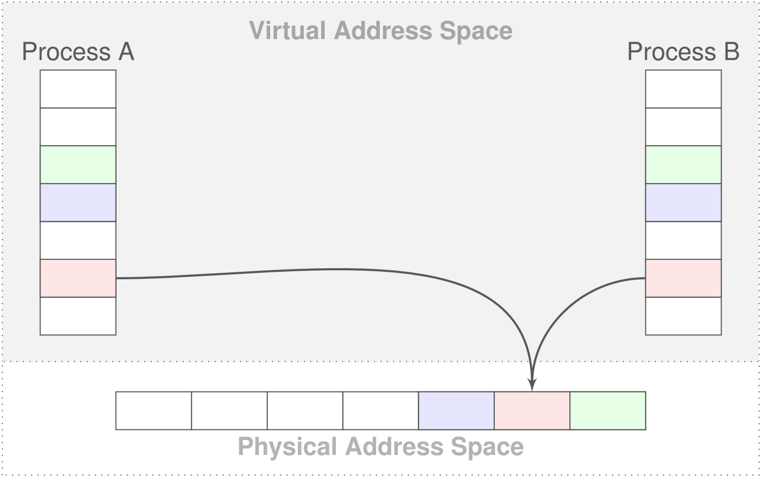

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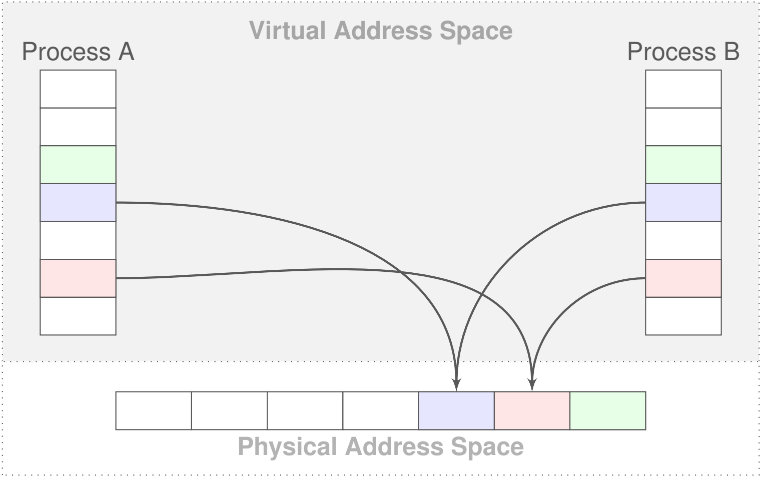

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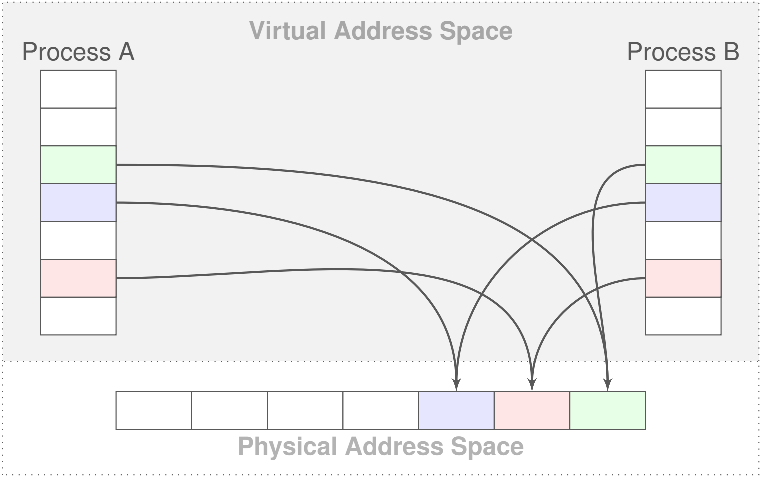

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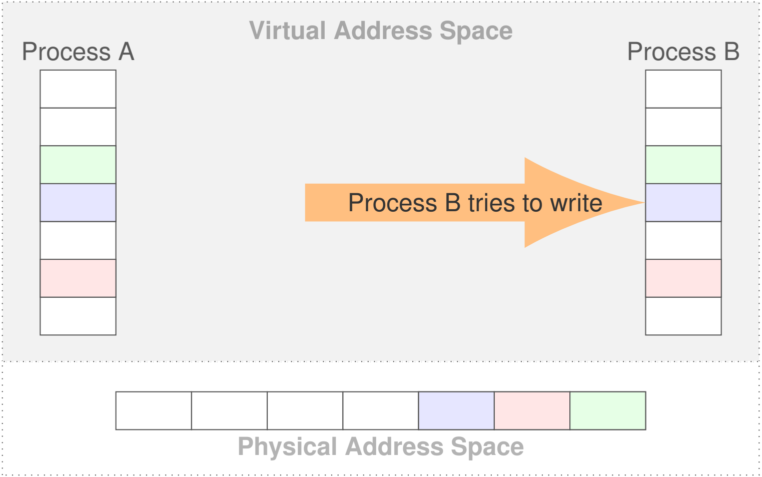

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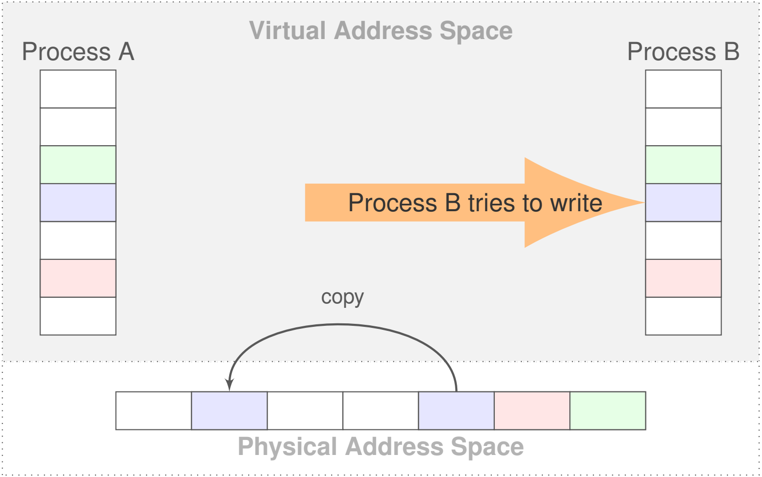

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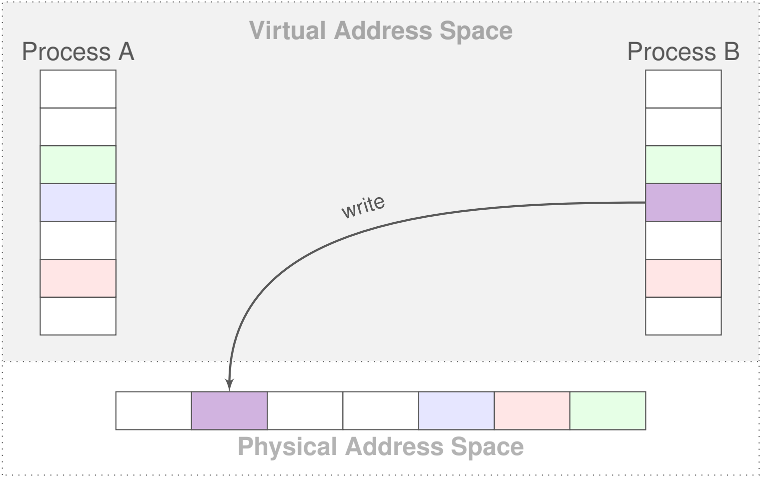
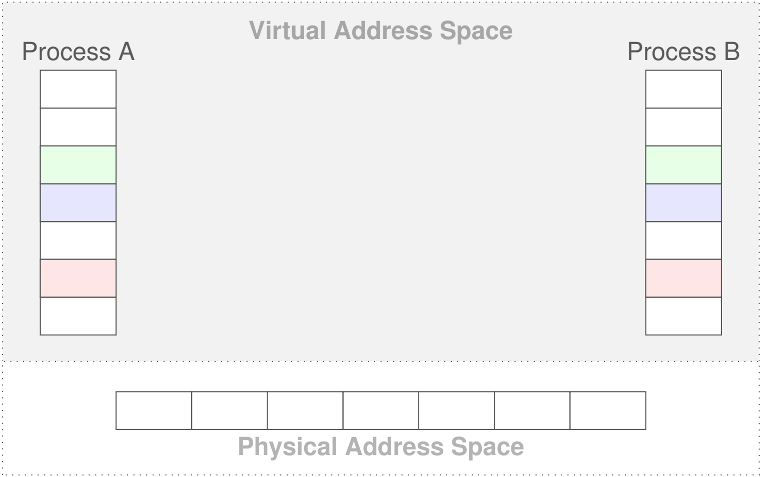


Write vs. Copy-on-Write

- Regular write access $< 0.2\mu s$
- Write access with copy-on-write pagefault $> 3.0\mu s$
- Clearly distinguishable

Page Deduplication



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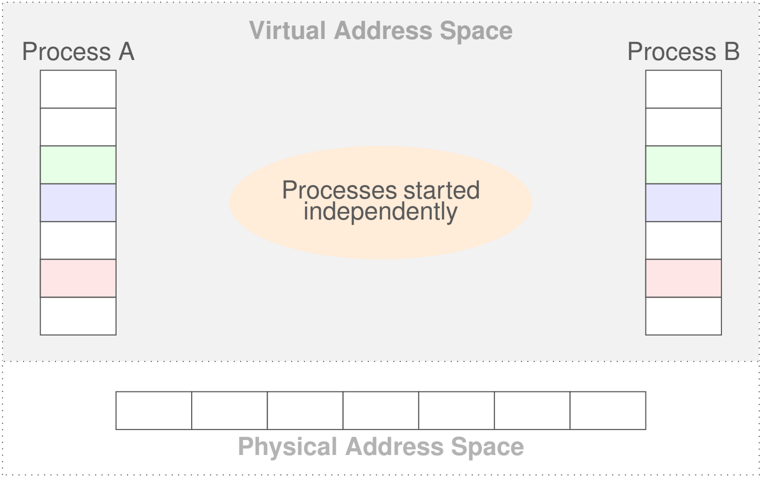

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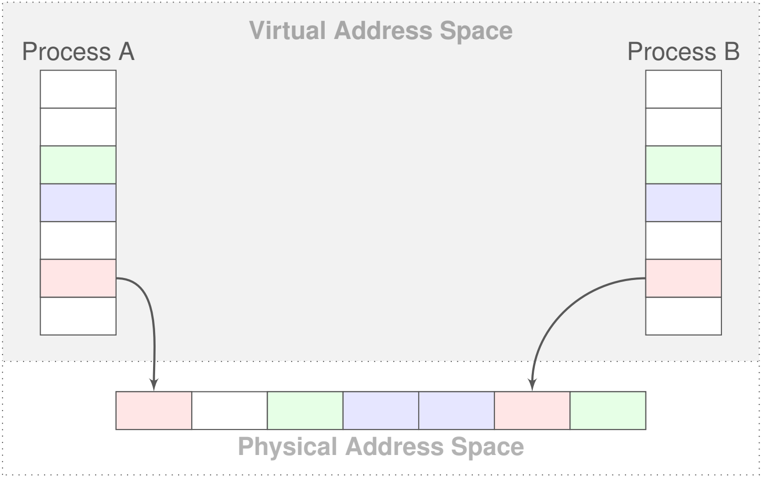

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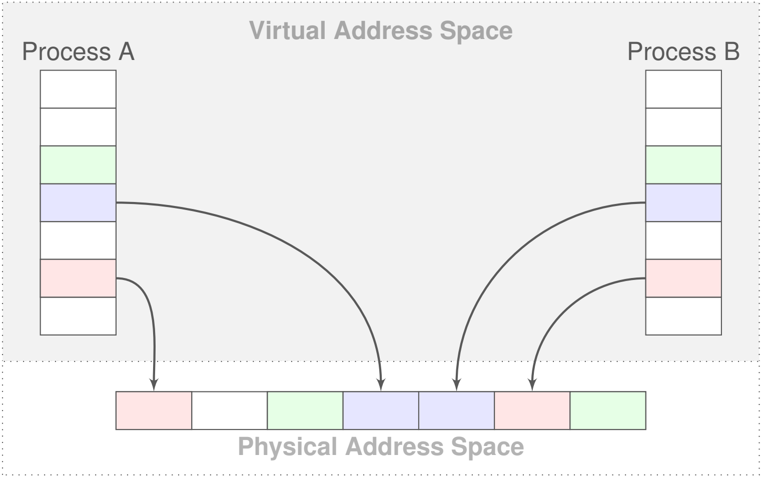

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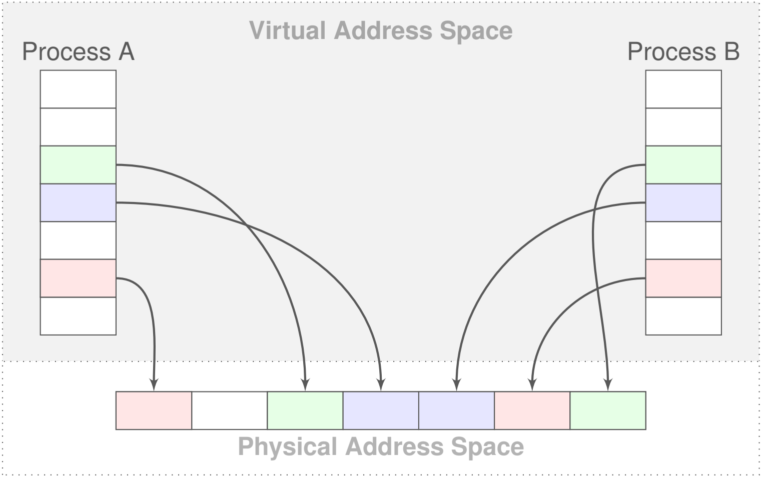

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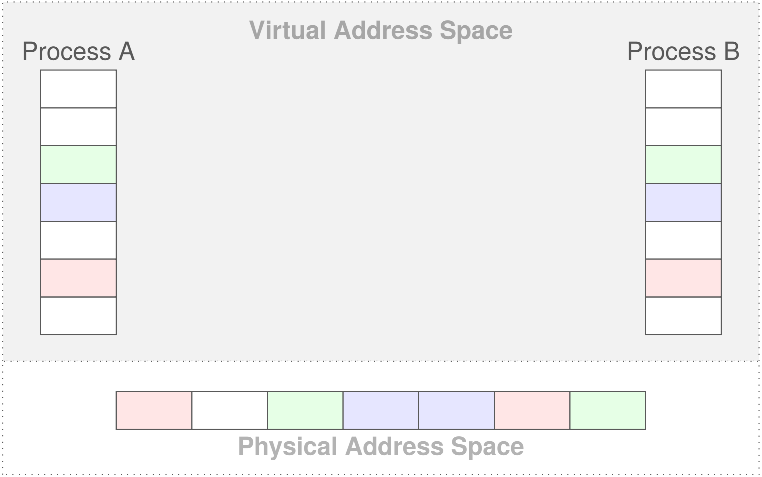

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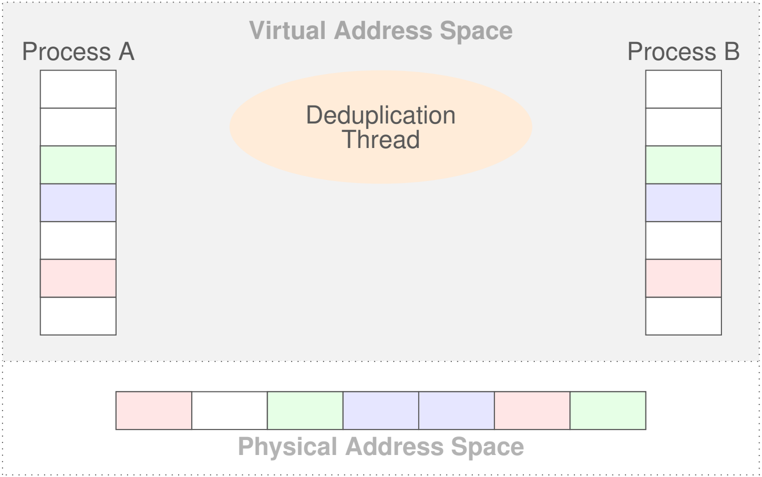

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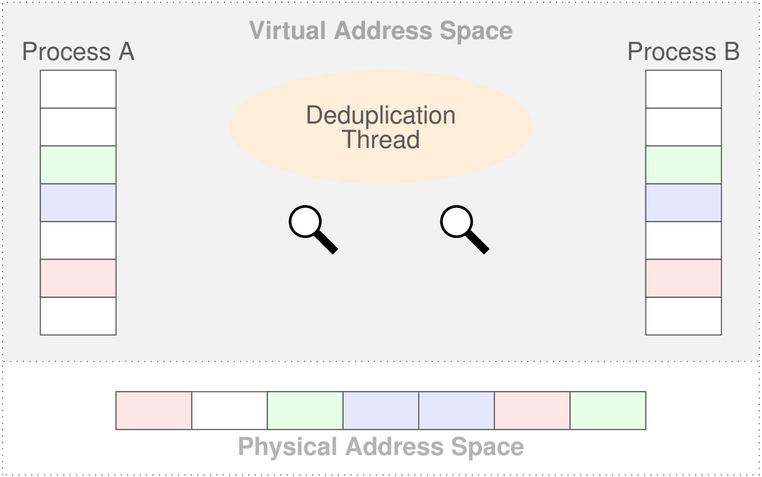

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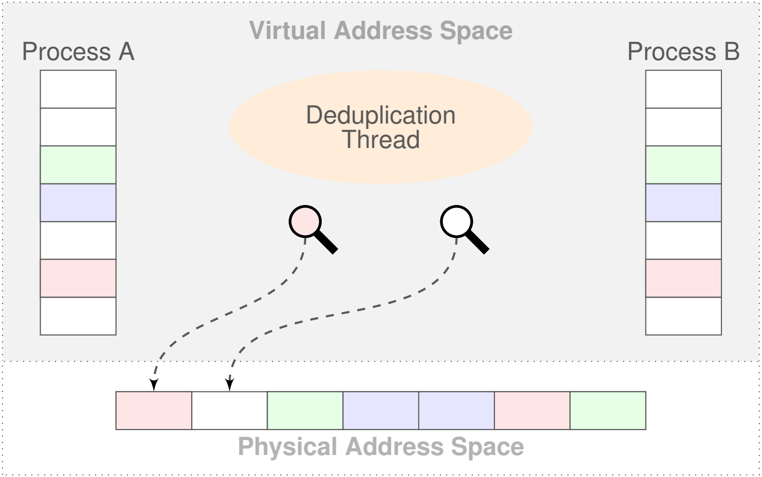

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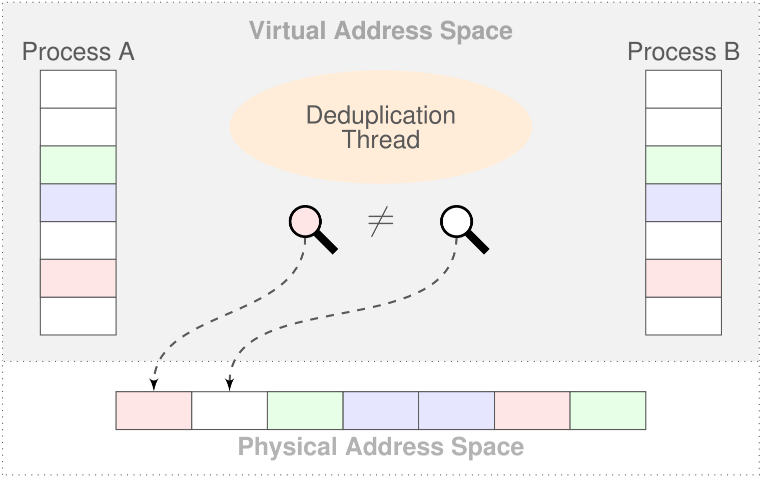

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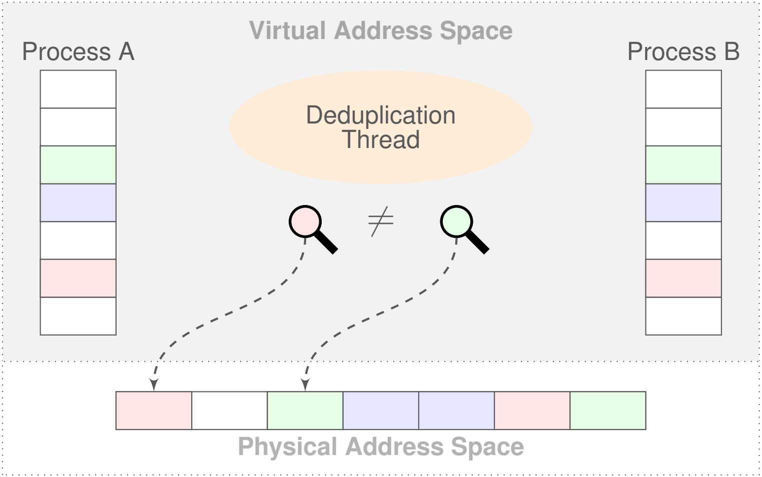

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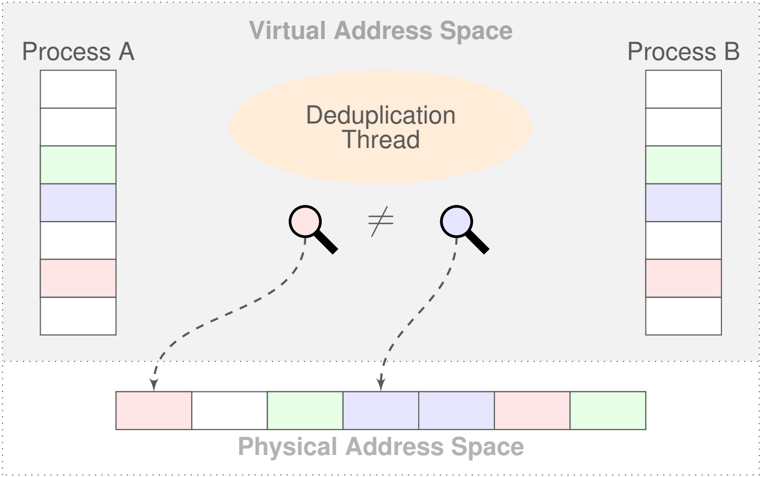

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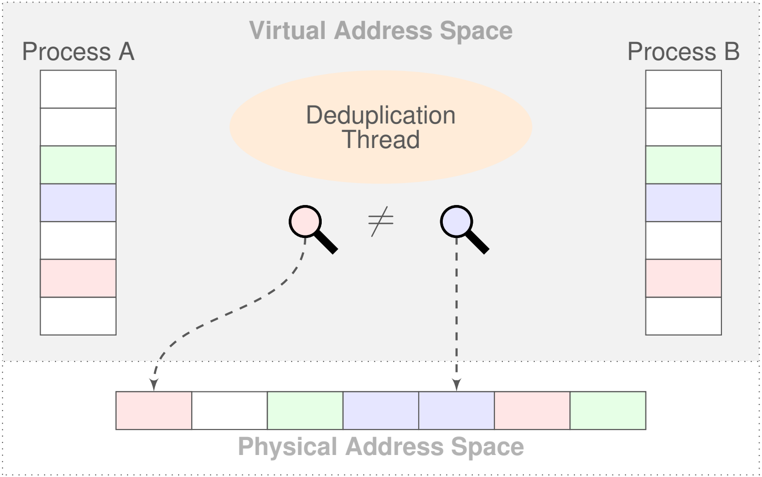

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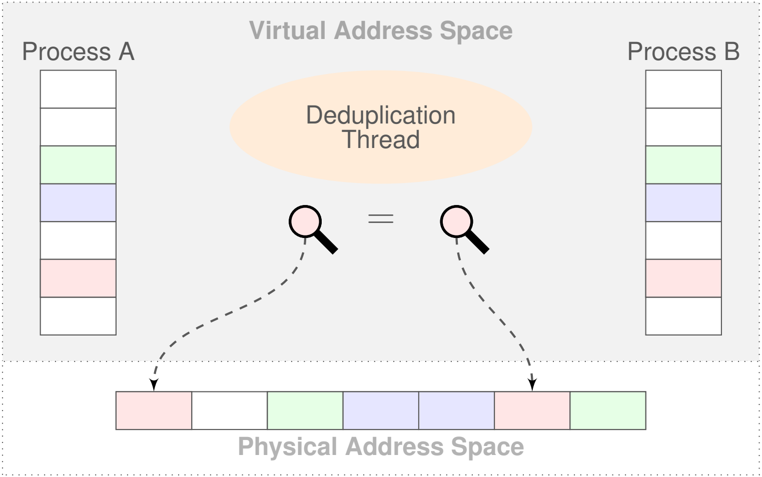

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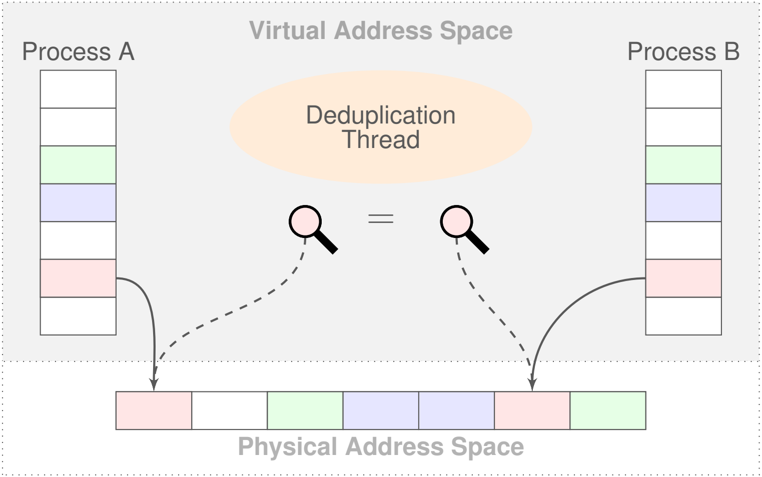

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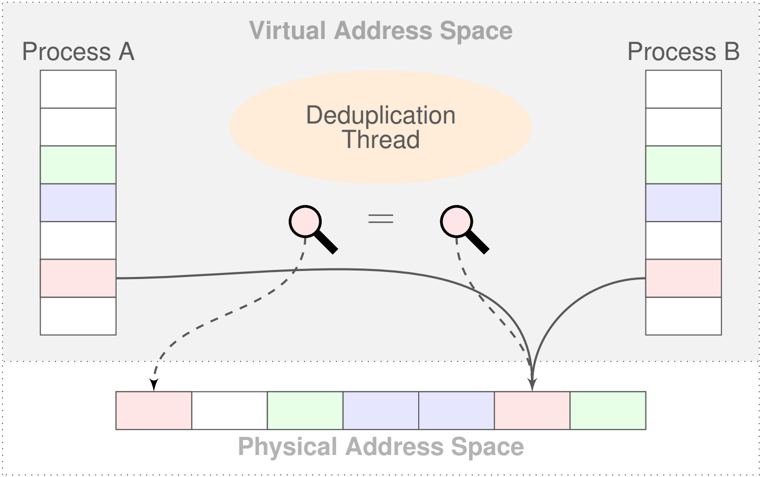

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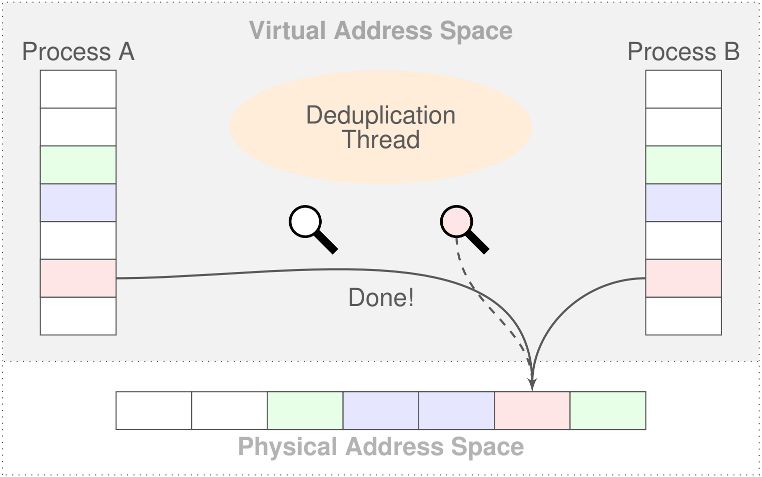

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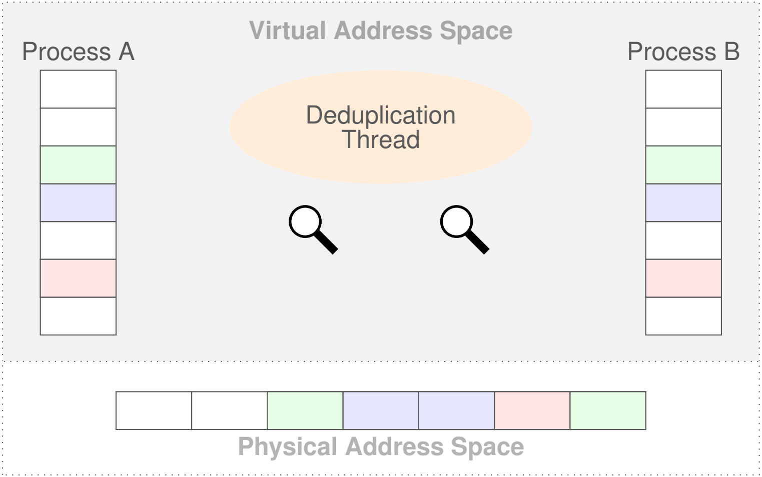
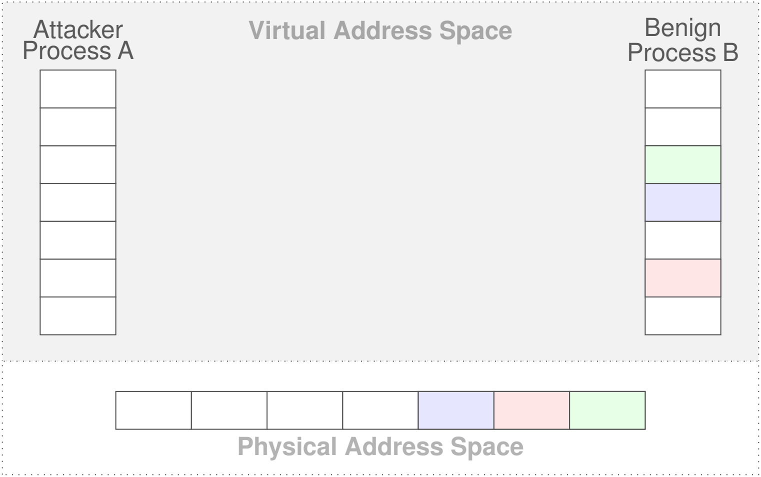


Page Deduplication

- Deduplication between processes:
    1. in same OS instance (Android, Windows)
    2. in different VMs (KVM, VMWare, ...)
- Code pages, data pages - even kernel pages
- Time until deduplication 2-45 minutes
    - depends on system configuration

Page Deduplication Attack



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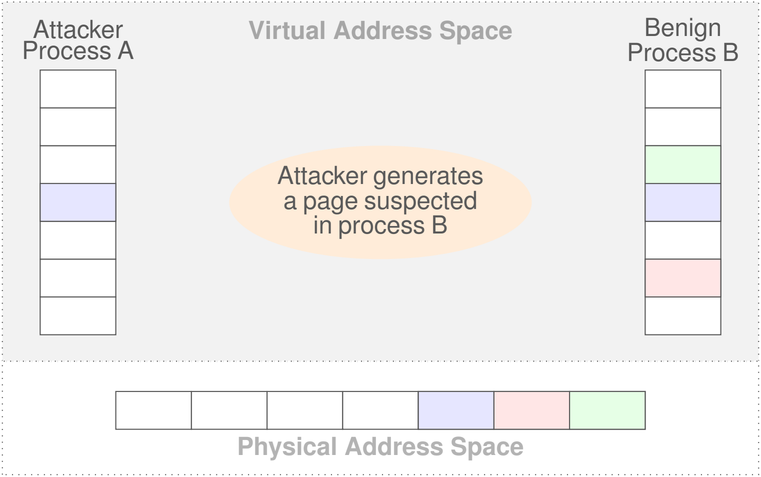

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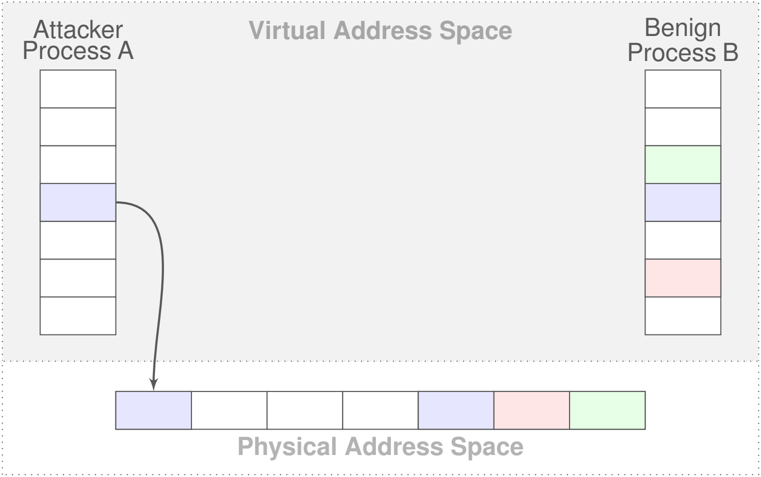

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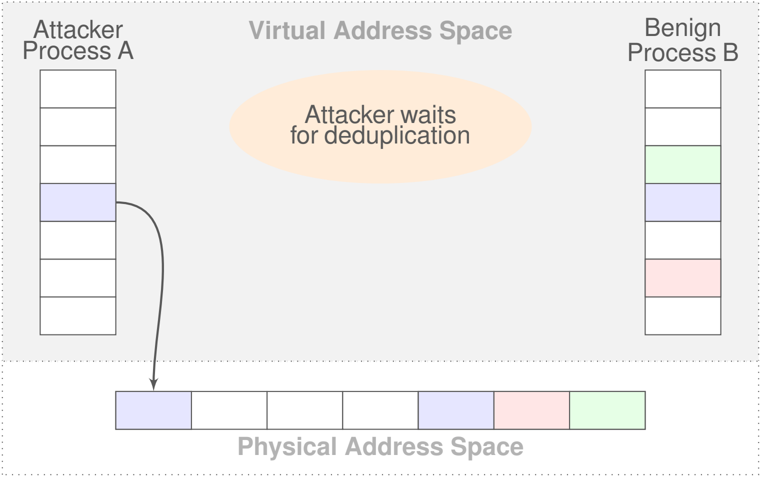

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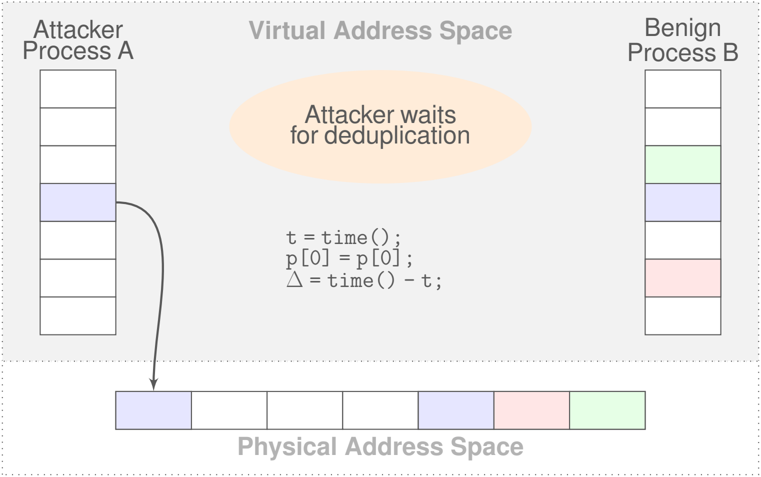

```
t = time();
p[0] = p[0];
△ = time() - t;
```

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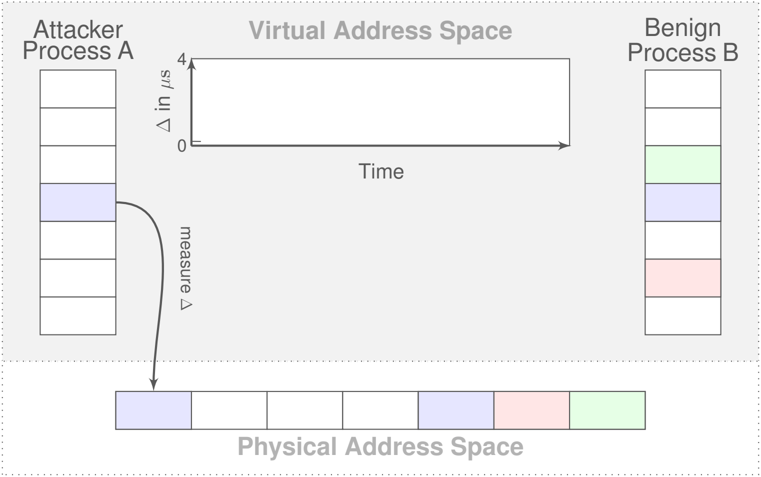

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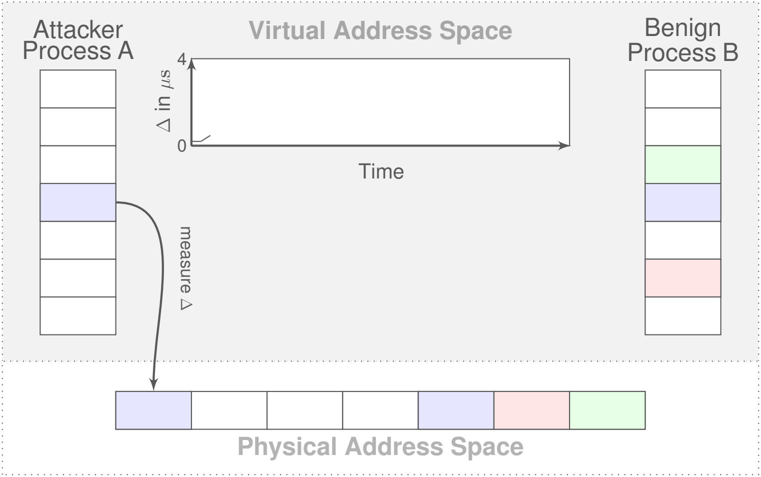

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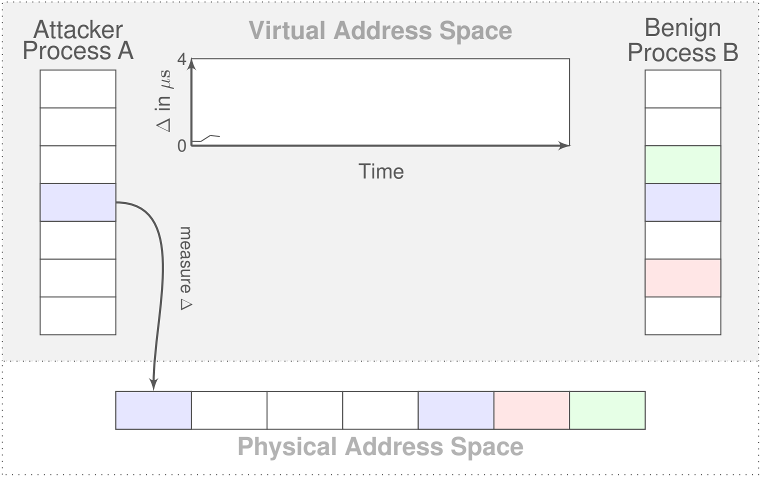

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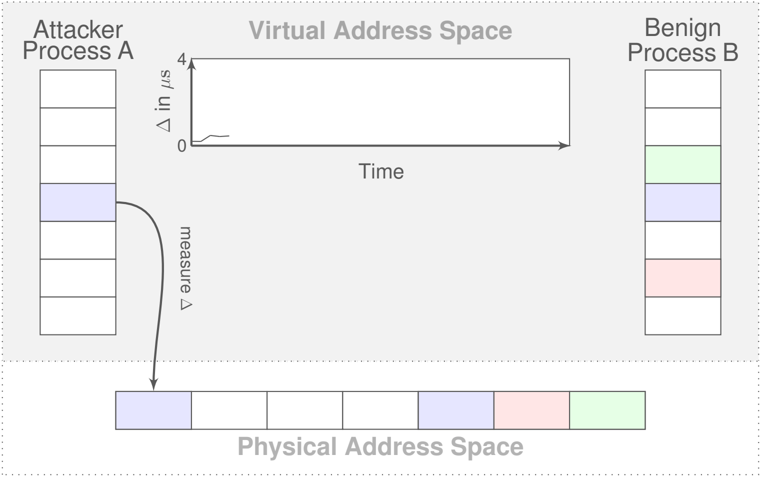

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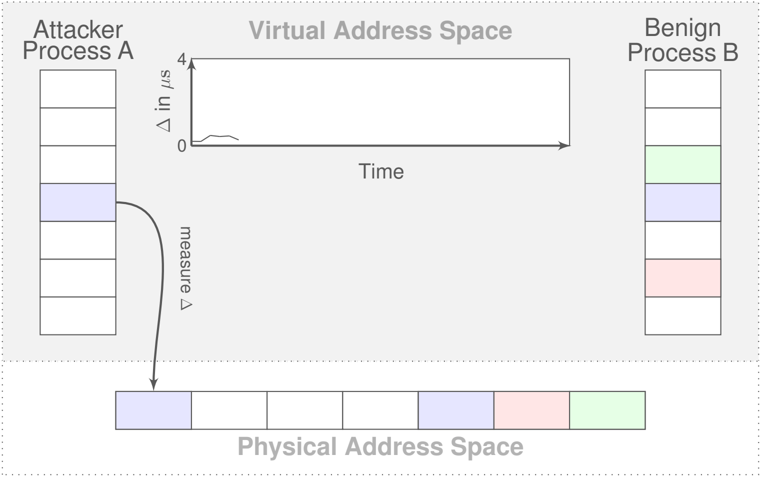

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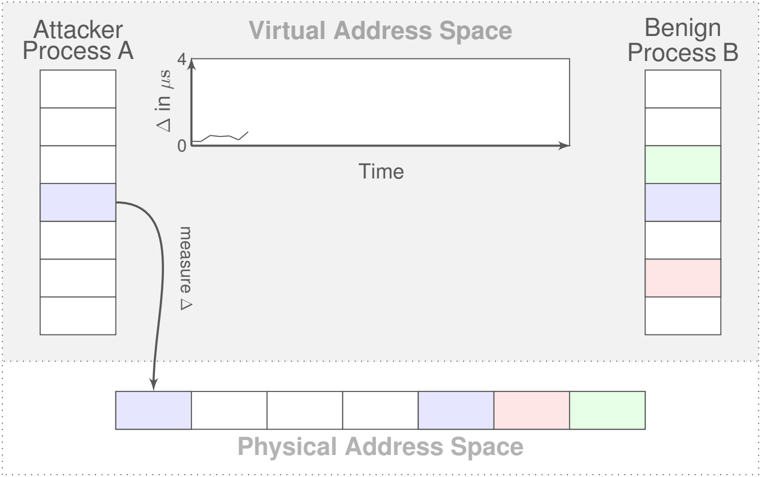

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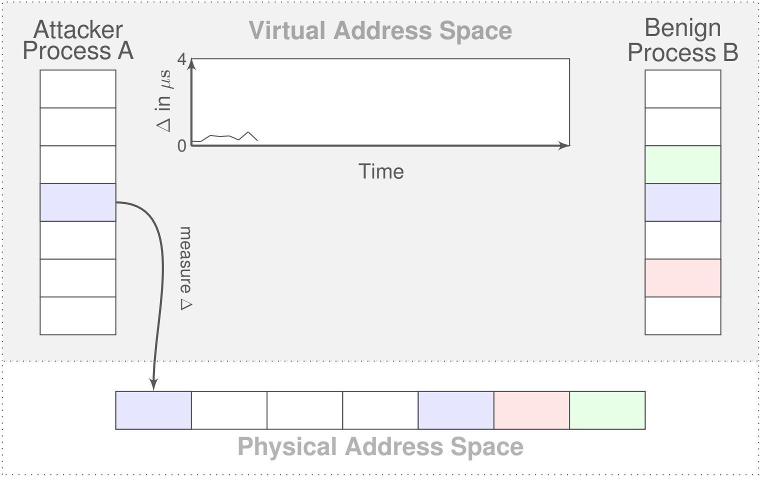

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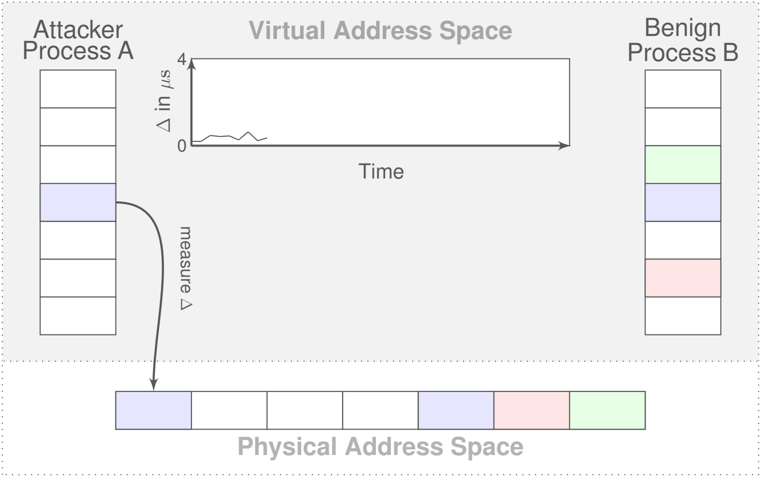

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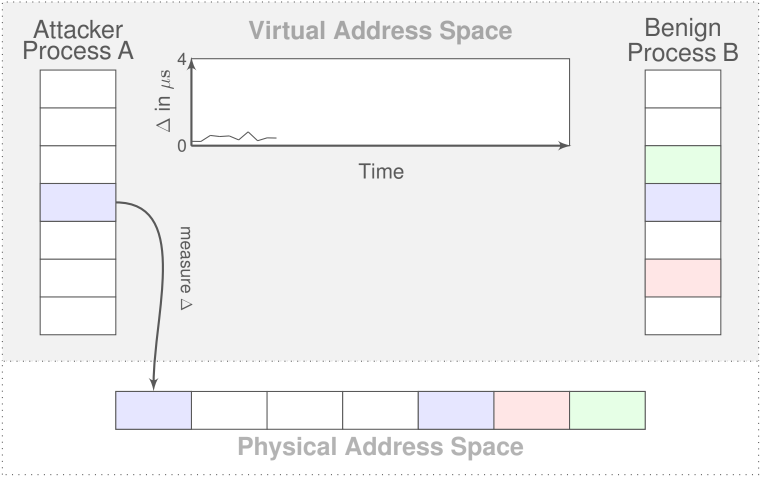

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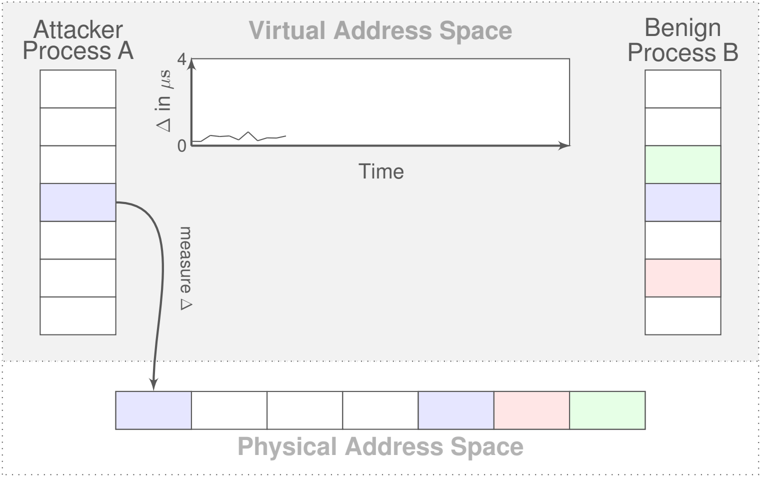

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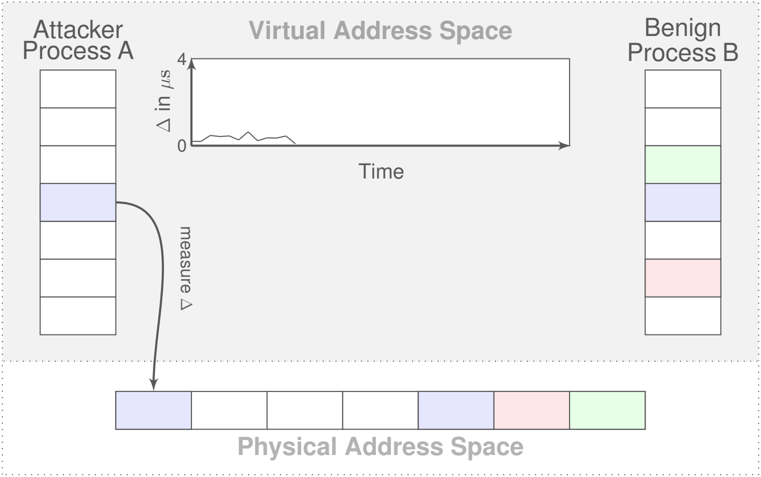

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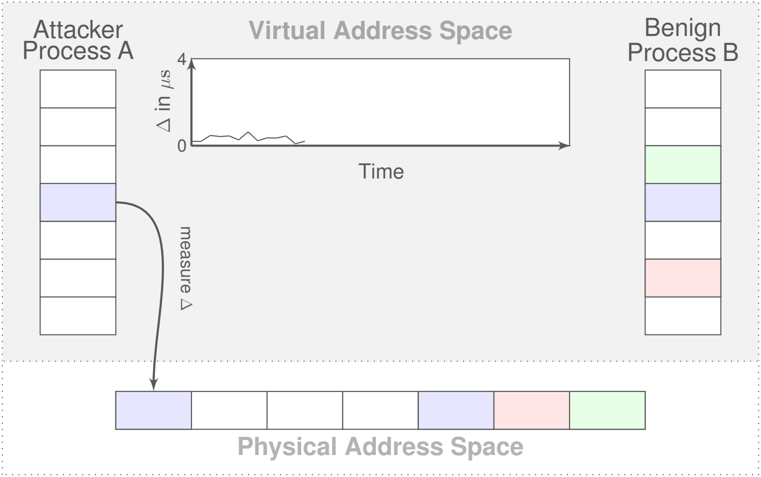

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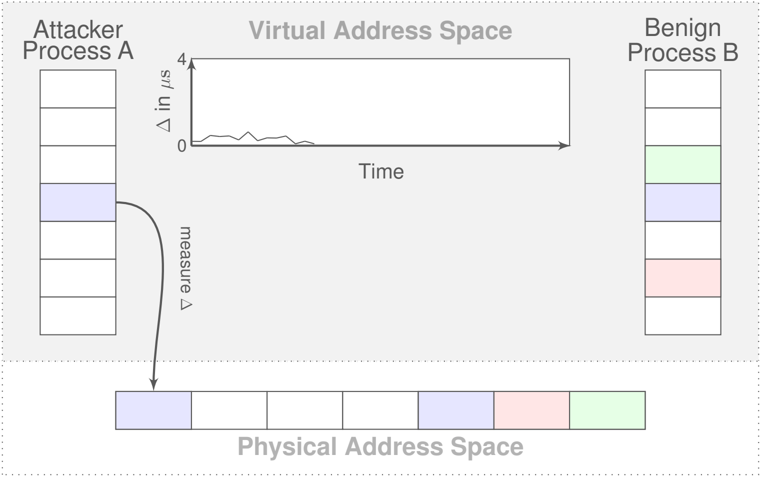

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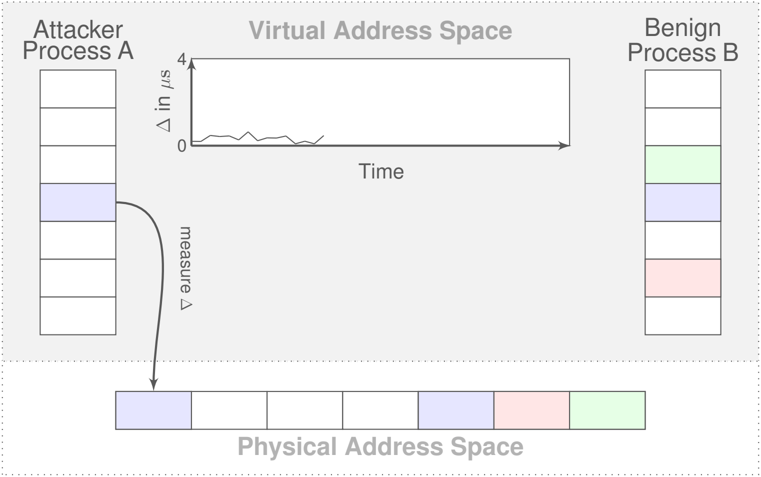

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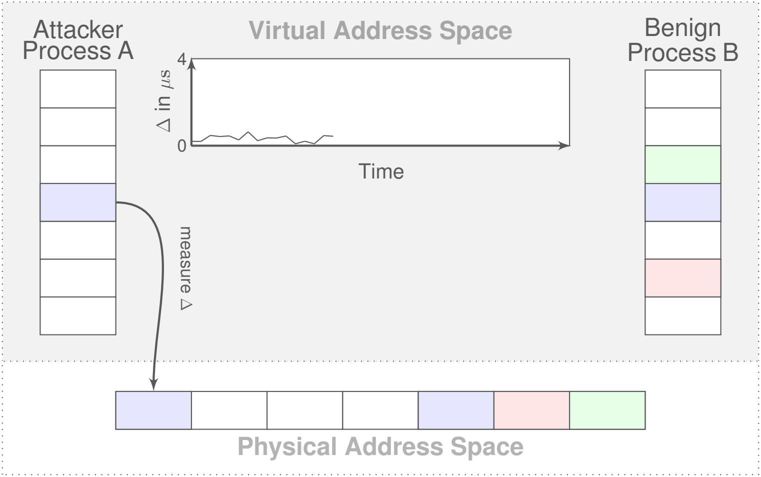

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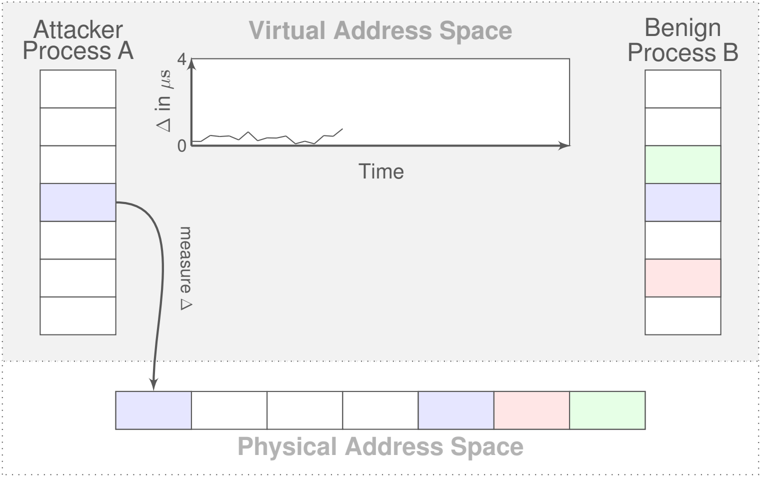

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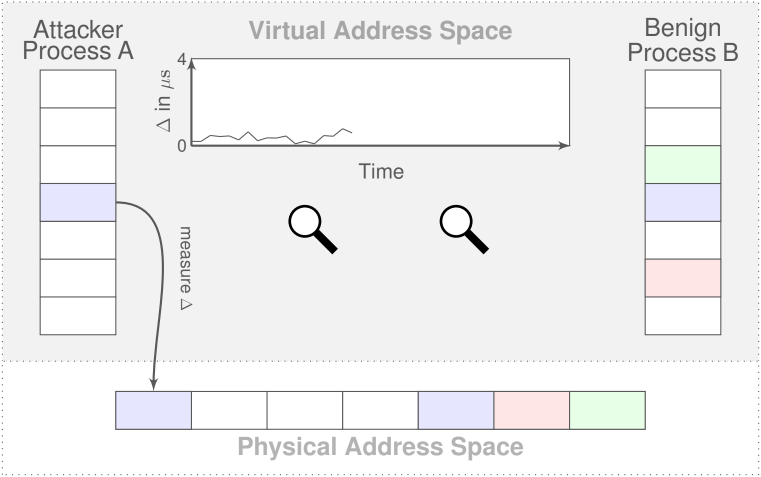

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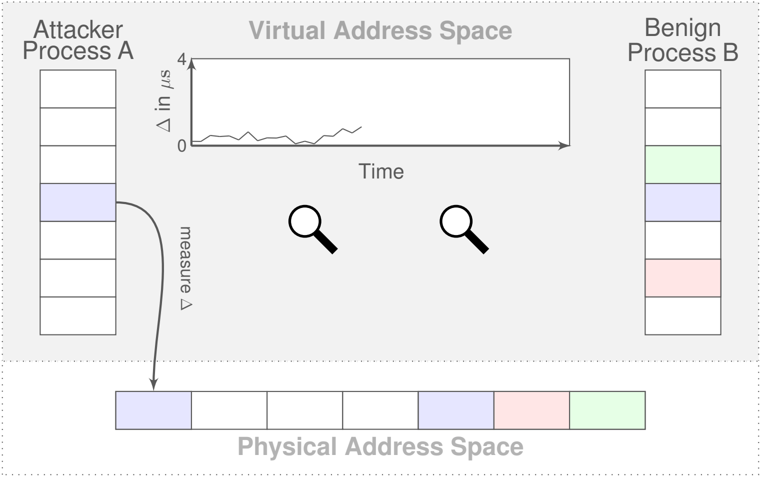

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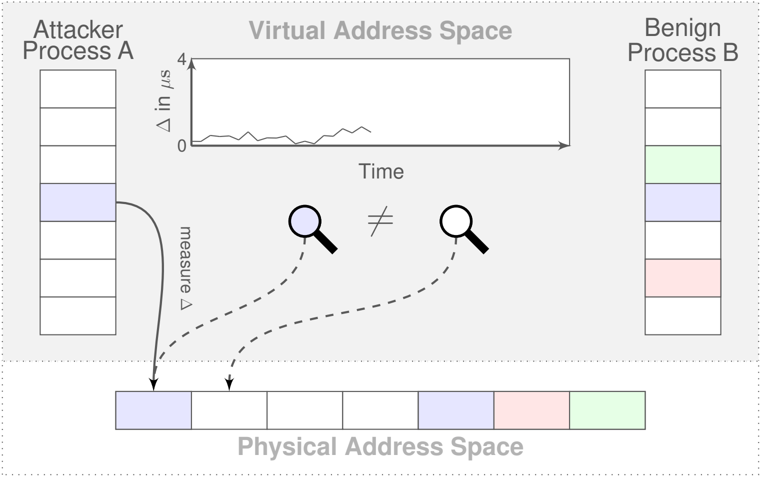

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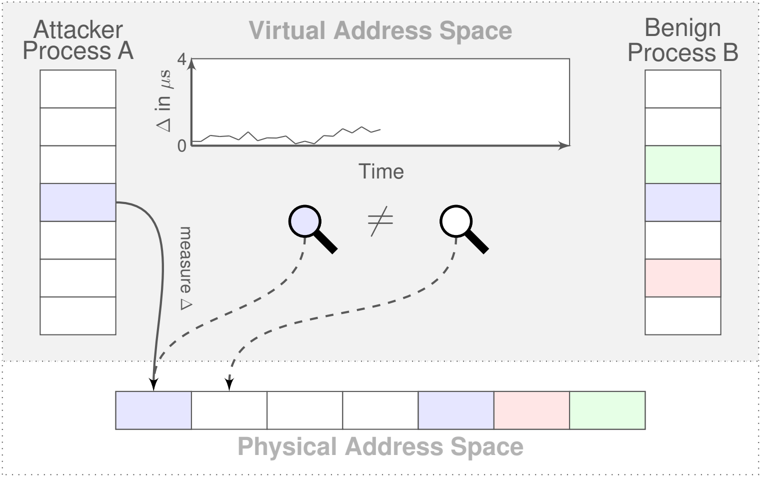

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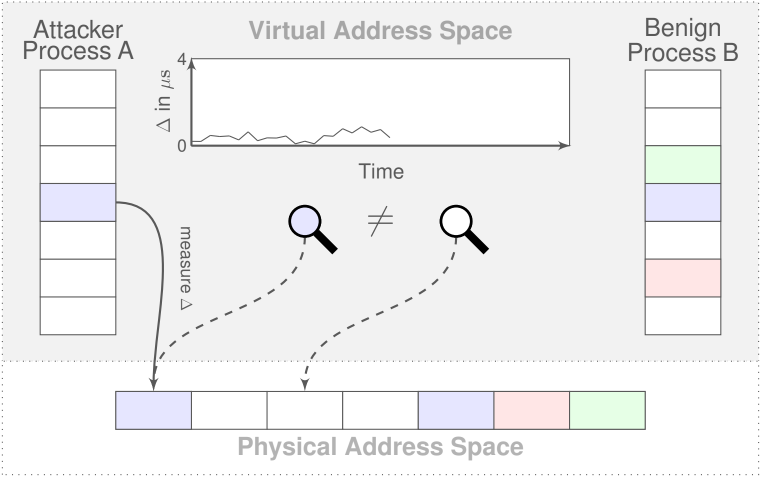

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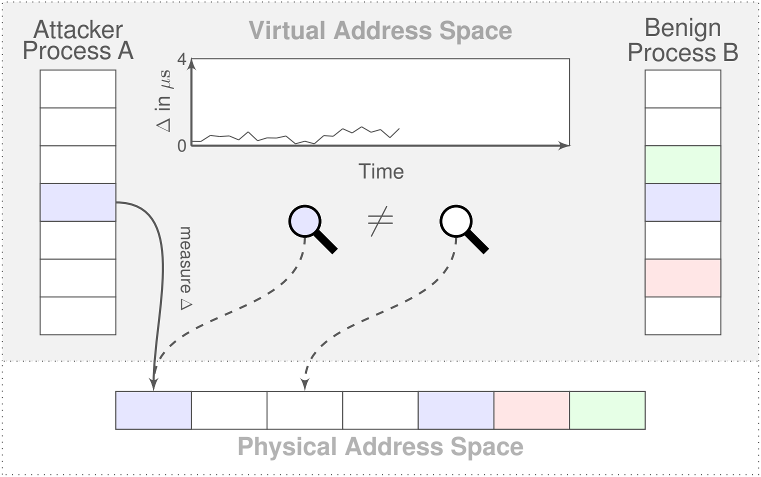

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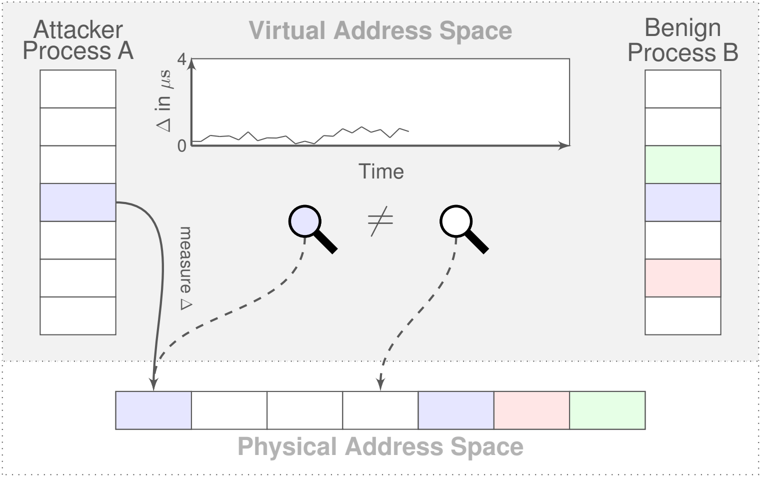

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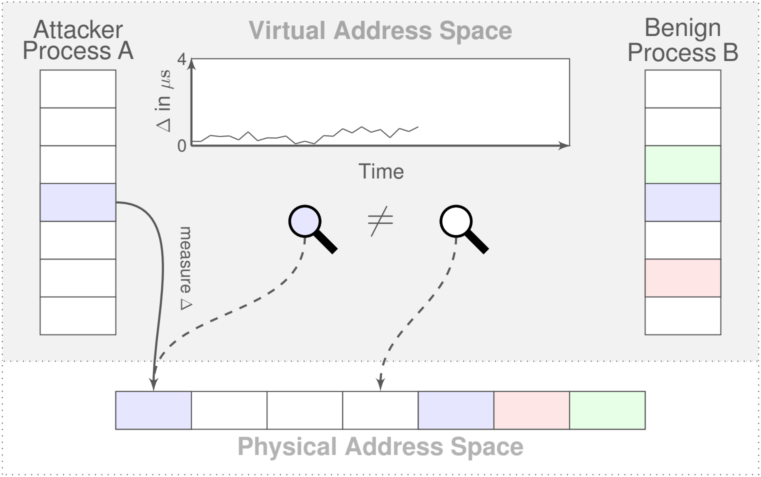

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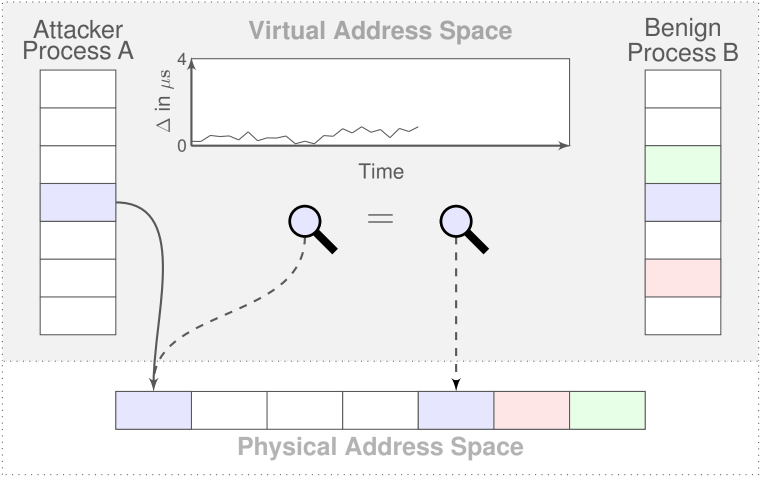

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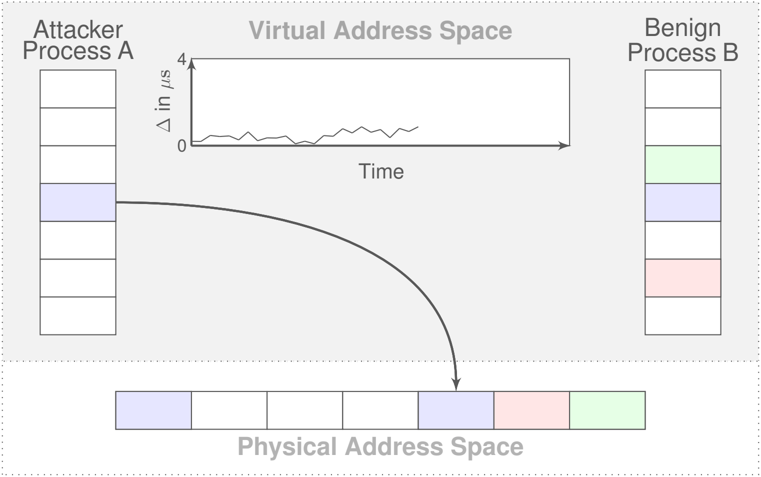

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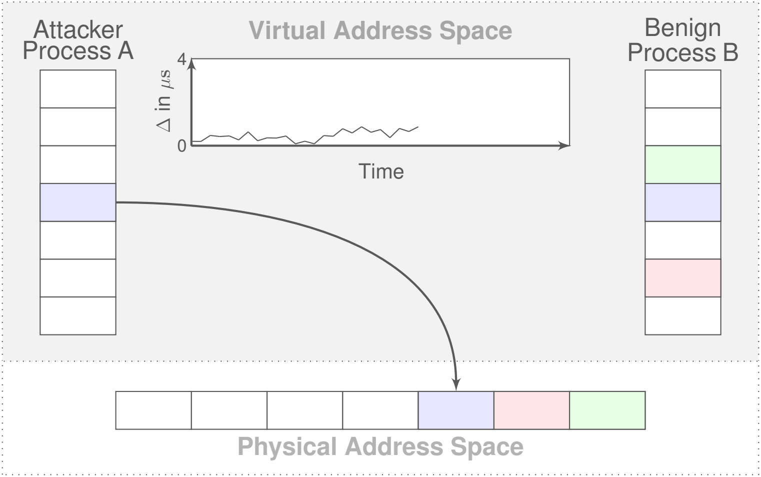

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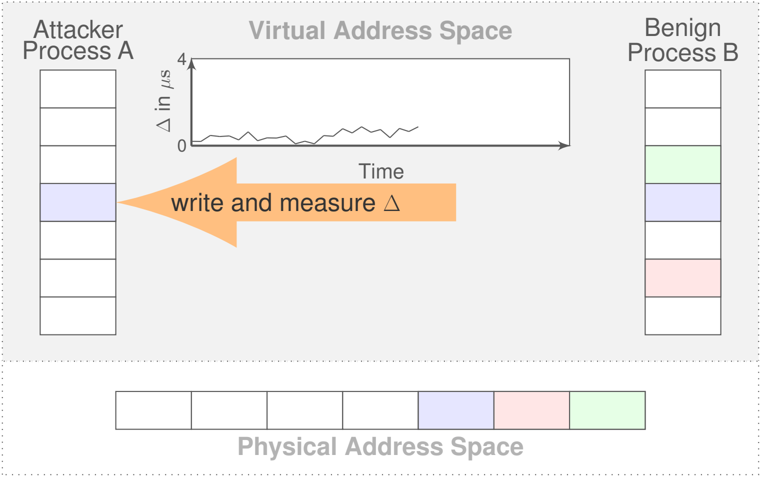

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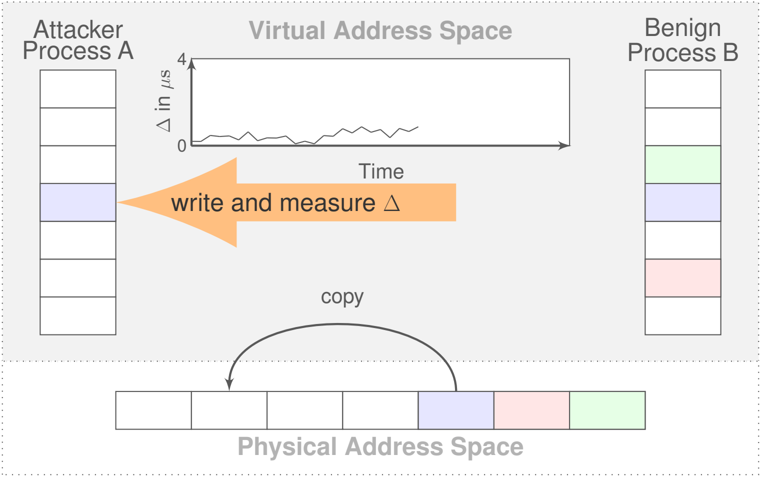

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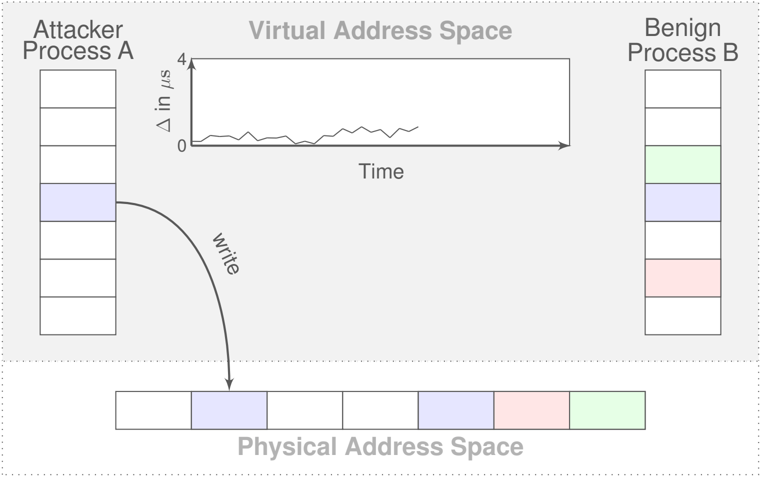

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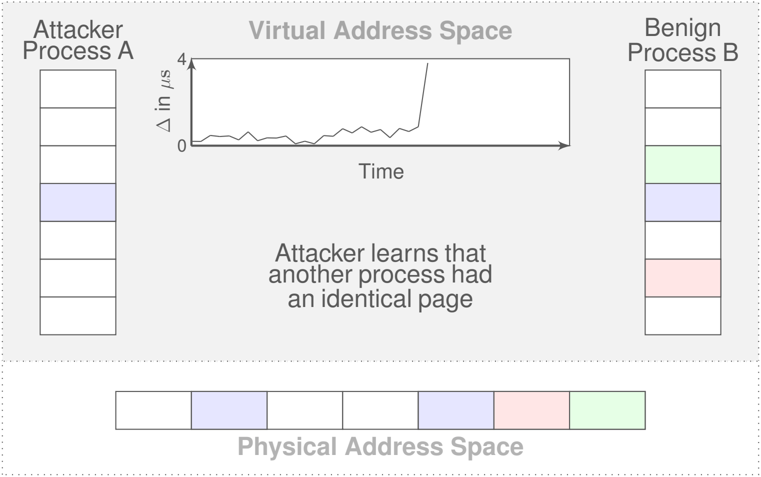

Attacker learns that another process had an identical page

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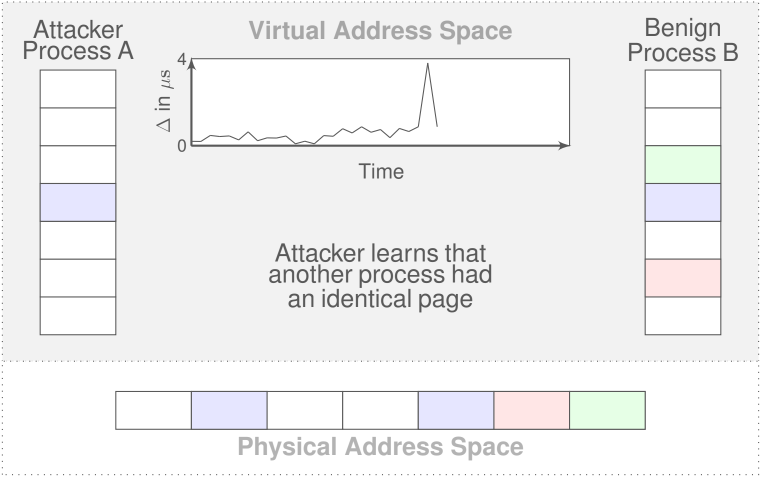

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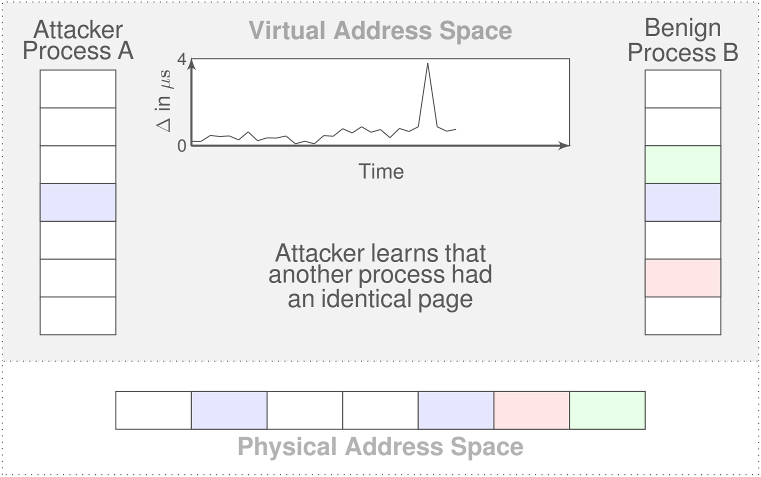
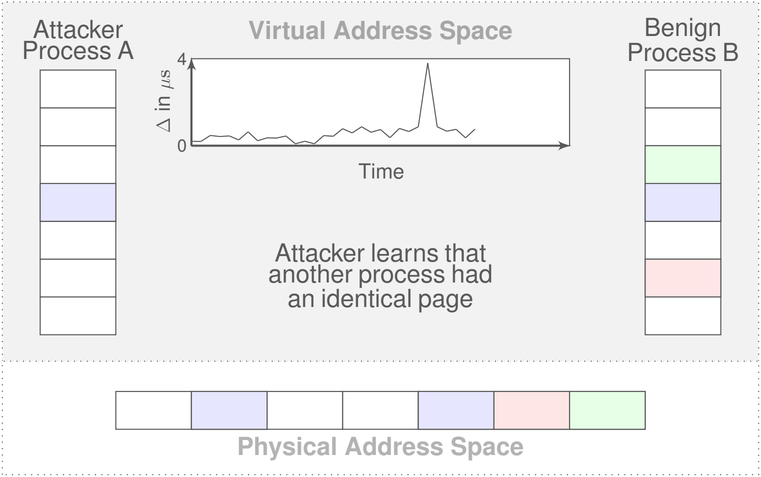


Attacker learns that another process had an identical page

Page Deduplication Attack



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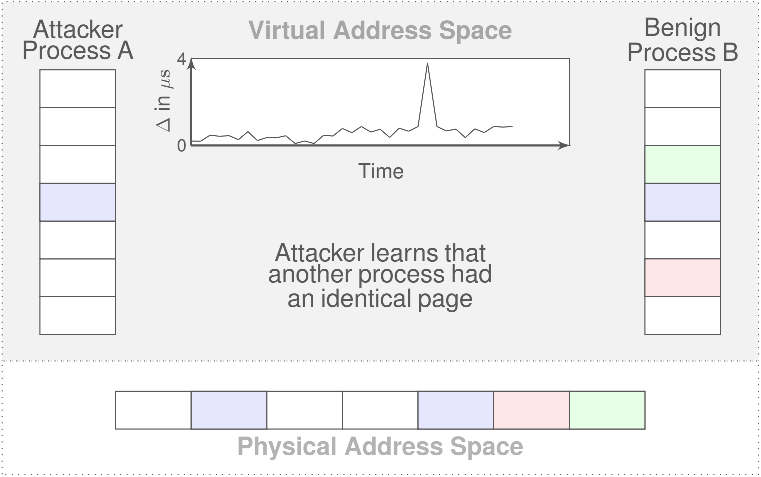

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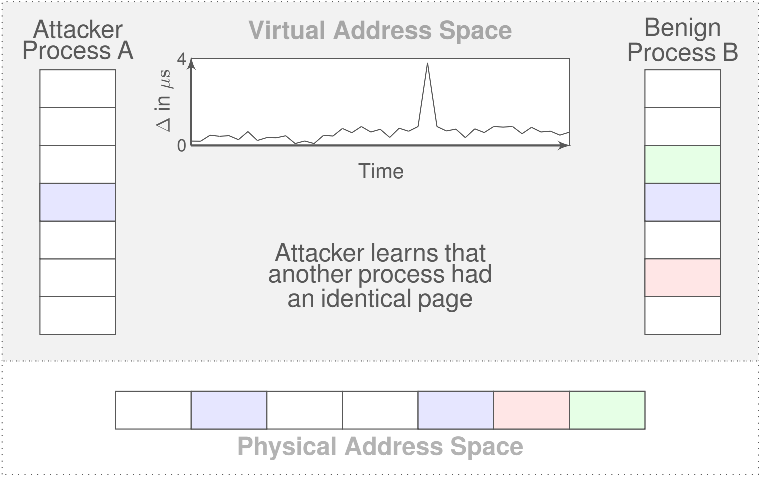
Page Deduplication Attack



Attacker learns that another process had an identical page

What can be attacked?

Existing Attacks:

- Detect binary versions in co-located VMs
- Detect downloaded image in Firefox under certain conditions

→ Attacks on hypervisors

- Native code only

Suzaki et. al. 2011, Owens et. al. 2011, Xiao et. al. 2012, 2013

What can be attacked?

Our Contribution:

- Detect CSS files and images of opened websites
  - Chrome, Firefox and Internet Explorer
- Perform the attack in JavaScript

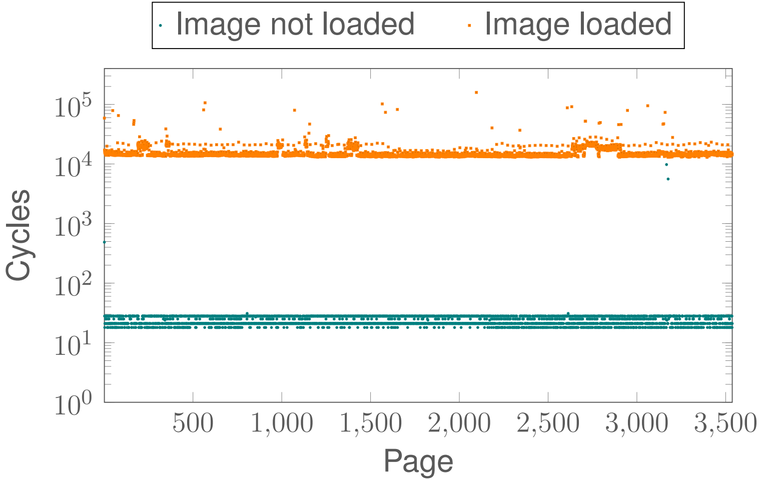
→ Attacks on KVM, Windows 8.1 and Android

Attacking Browsers

- Images and CSS files are page-aligned in memory
- Load them into memory for all websites of interest
- Detect deduplication

→ Malicious ad networks: alternative to tracking pixels?

Detect Image (Native, Cross-VM, KVM)



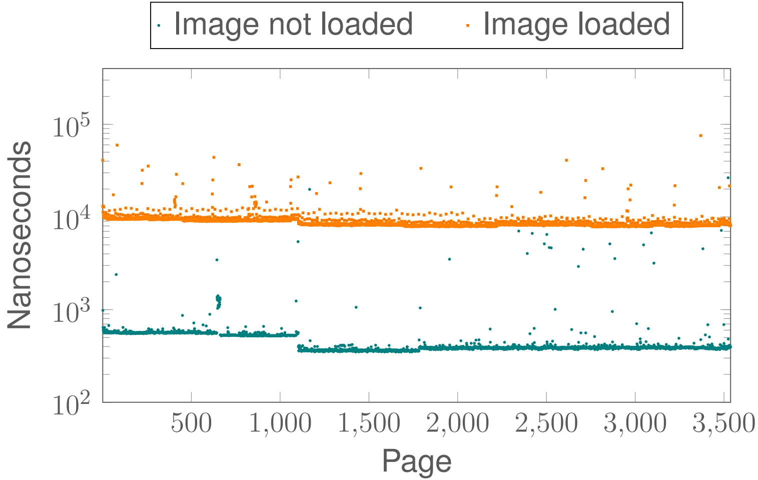
Challenges of JavaScript-based attacks

- No cycle counting (`rdtsc`)
- No access to virtual addresses

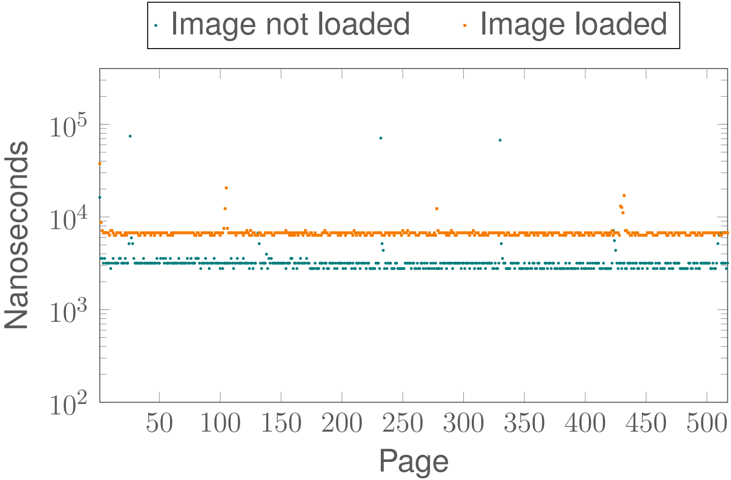
Page Deduplication Attacks in JavaScript

- Only require microsecond accuracy
  - `performance.now()` is accurate enough
  - Can even work with millisecond accuracy
    - Accumulate time difference
    - Only possible with enough image/CSS data
- Large typed arrays are allocated page-aligned

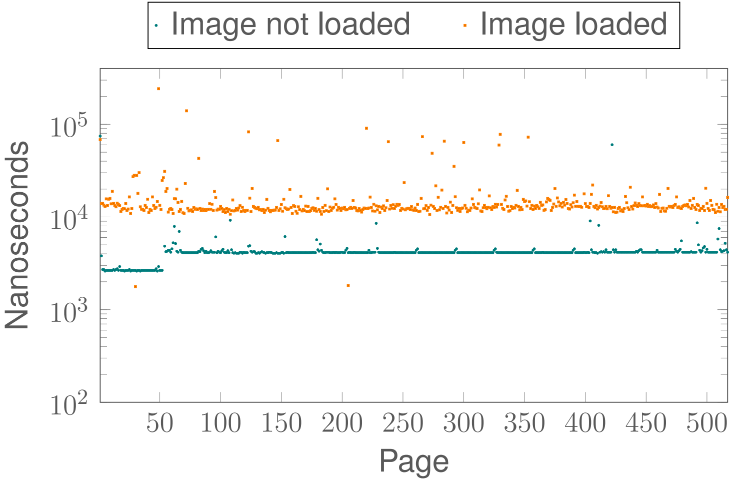
Detect Image (JavaScript, Cross-VM, KVM)



Detect Image (JavaScript, Windows 8.1)



Detect Image (JavaScript, Android 4.4.4)



Detection of Open Websites

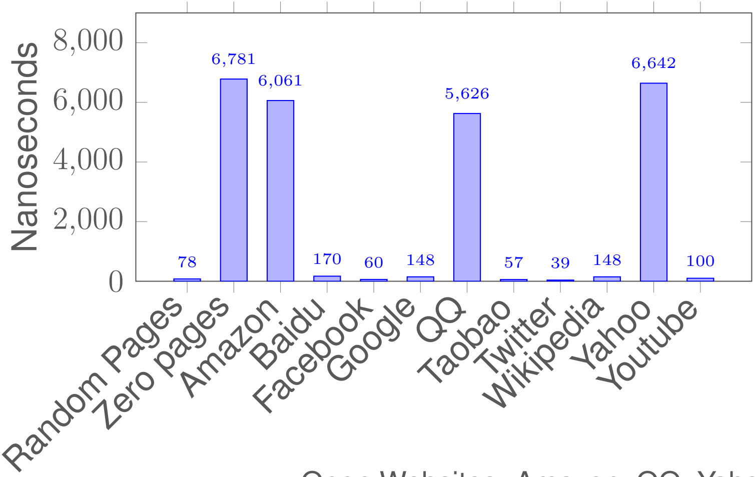
- Attacker chosen set of websites
- Load website images and CSS files into arrays
    - Served image and CSS files depend on: Browser, OS, resolution, etc.

  → Reuse HTTP headers of system under attack
- Reduce noise by measuring write accesses to several pages

Detection of Open Websites

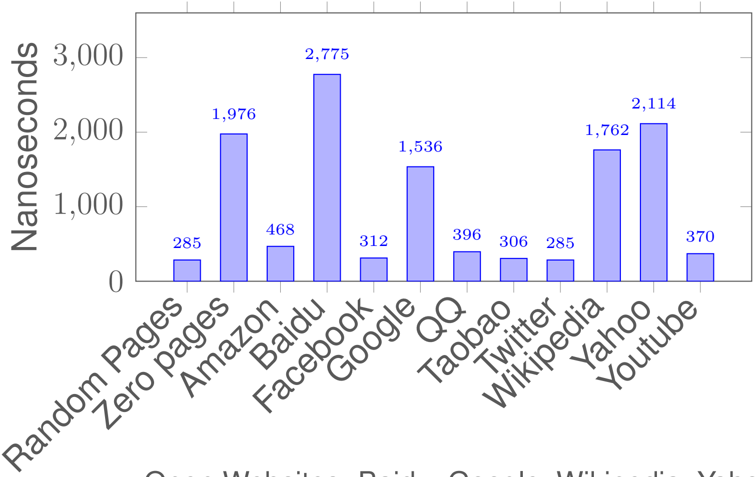
- Compare with:
  - zero pages (always deduplicated)
  - random pages (never deduplicated)
- Top 10 websites:
  Amazon, Baidu, Facebook, Google, QQ, Taobao, Twitter, Wikipedia, Yahoo, Youtube
- Examples for different platforms

Example: JavaScript, Cross-VM, KVM



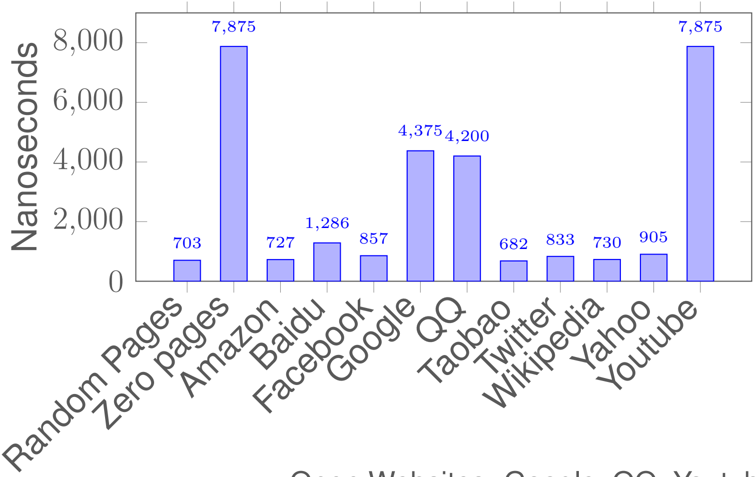
Open Websites: Amazon, QQ, Yahoo

Example: JavaScript, Windows 8.1



Open Websites: Baidu, Google, Wikipedia, Yahoo

Example: JavaScript, Android 4.4.4



Open Websites: Google, QQ, Youtube

Countermeasures

JavaScript:

- Reduce timer accuracy?
- Prevent page-aligned arrays?
- Website diversification?
- Prevent control over full pages
    - Every n-th byte not part of JavaScript array

Countermeasures

JavaScript:

- Reduce timer accuracy?
- Prevent page-aligned arrays?
- Website diversification?
- Prevent control over full pages
    - Every n-th byte not part of JavaScript array

Generic:

- Disable page deduplication (for writable pages)

Conclusion

- Page deduplication not only a problem on IaaS clouds

→ Privacy issue on personal computers and smartphones

- Remote attacks through malicious websites
- Same code for all platforms → large scale attacks
- Disable page deduplication if possible

Practical Memory Deduplication Attacks in Sandboxed JavaScript

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