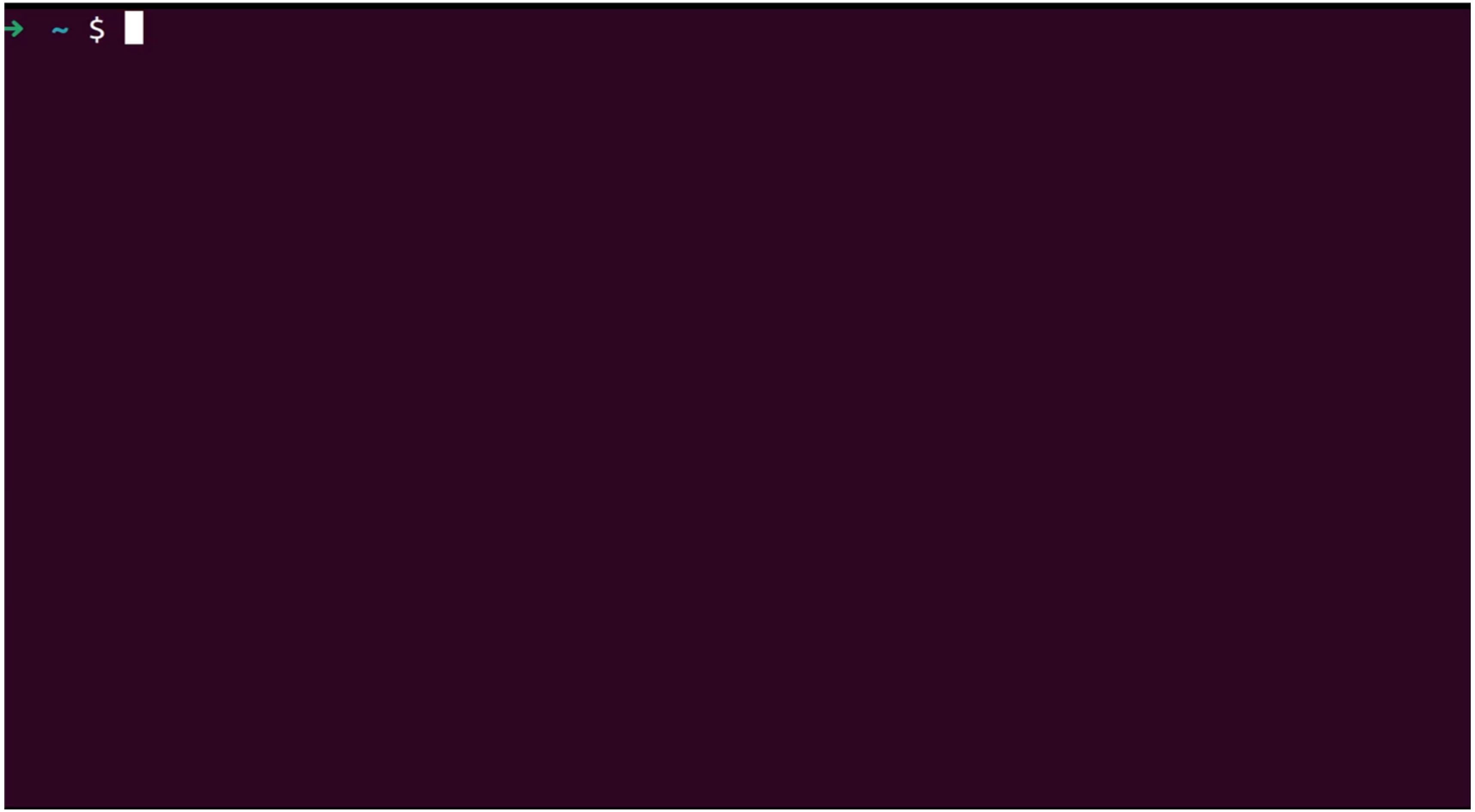
On-demand-fork: A Microsecond Fork for Memory-Intensive and Latency-Sensitive Applications

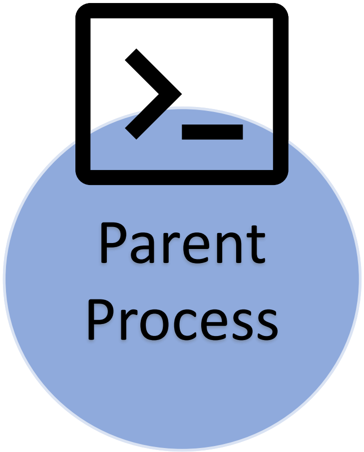
Kaiyang Zhao, Sishuai Gong, Pedro Fonseca

Purdue University



What is process fork?

Fork creates a child process by **duplicating** the calling process.



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Modern uses of fork

Fuzzers

Serverless

Databases

<u>Modern Uses</u>

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(Hundreds of **MBs**)

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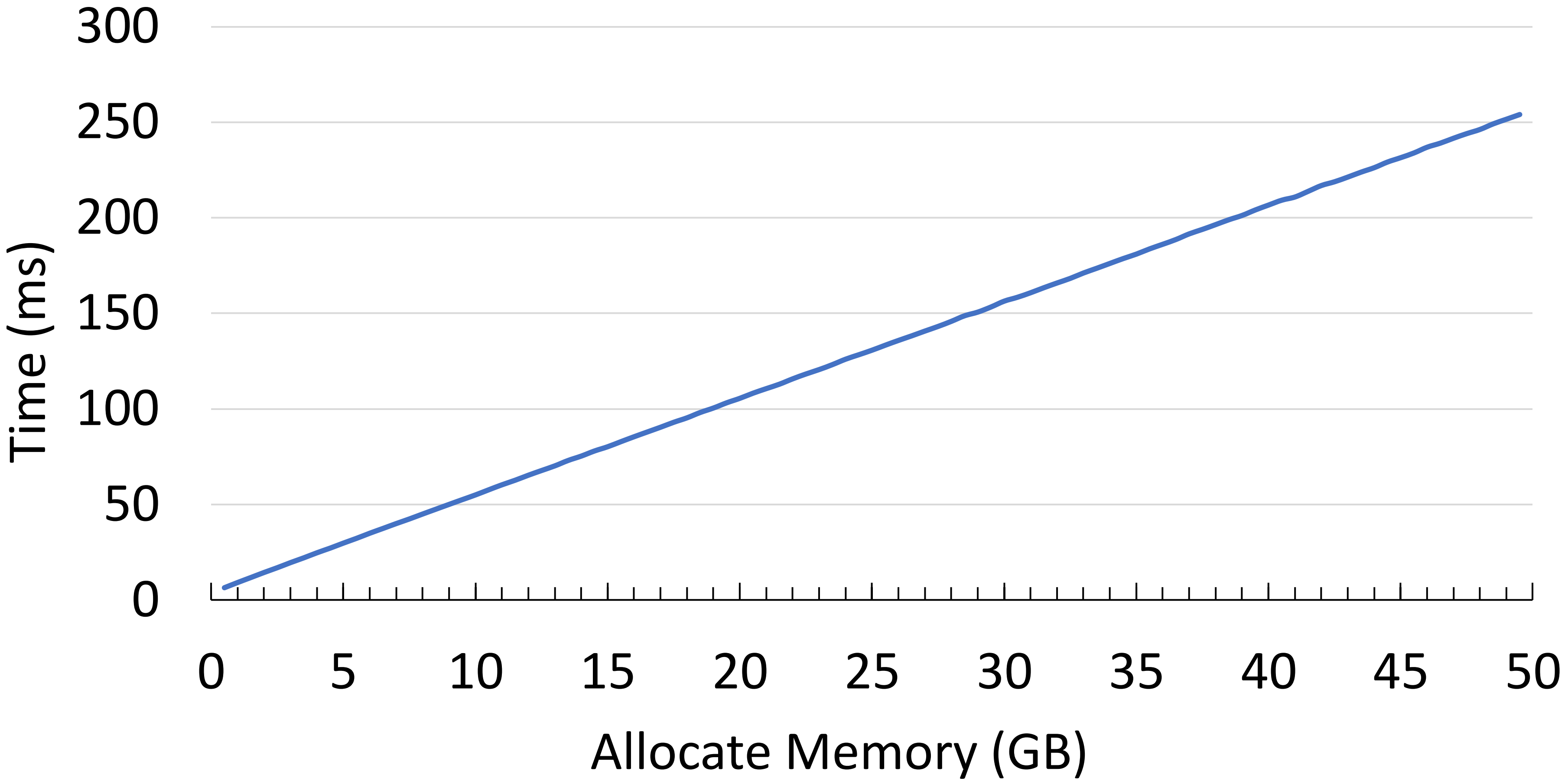
Modern Uses

Fork has a latency problem



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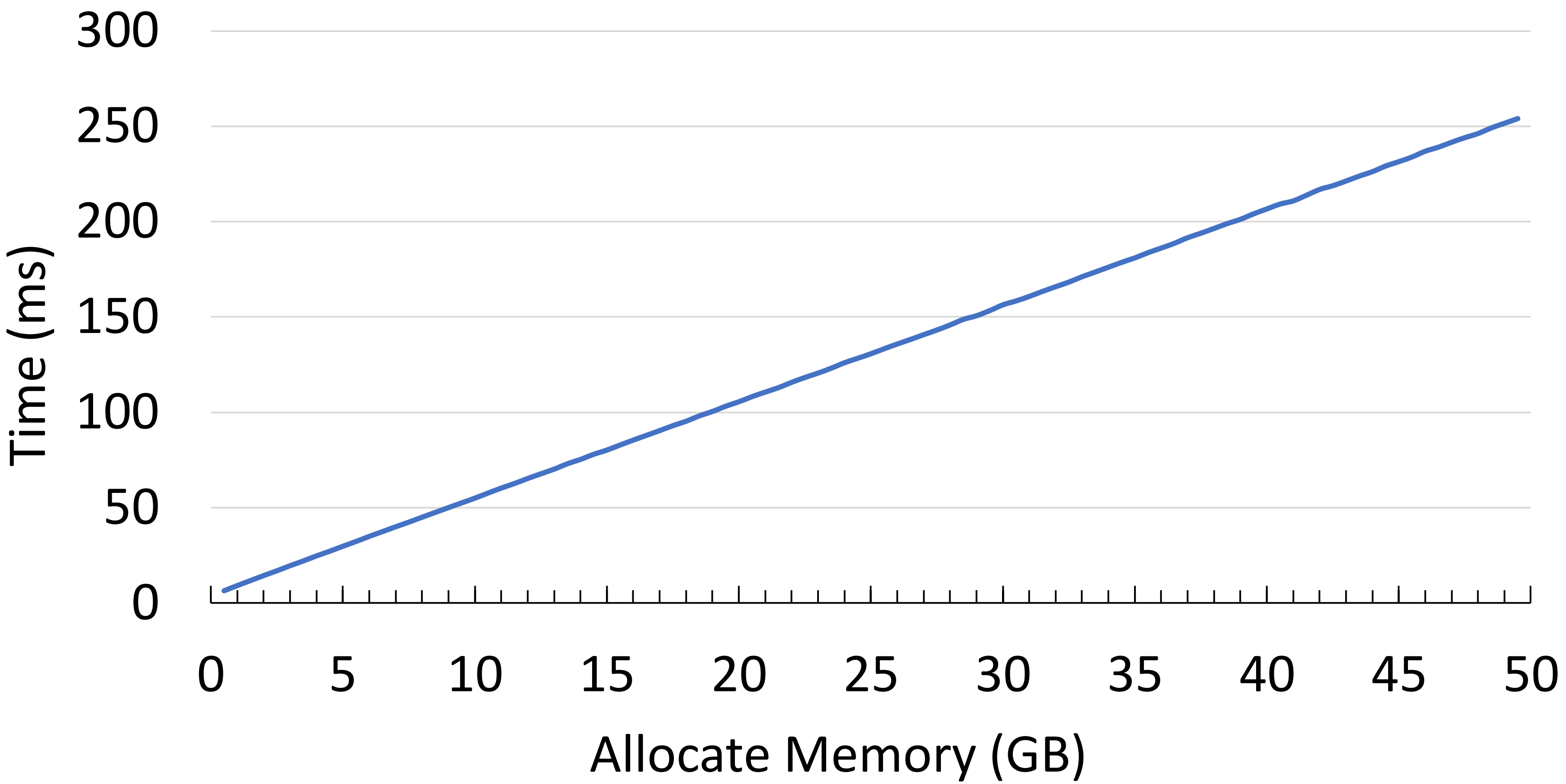

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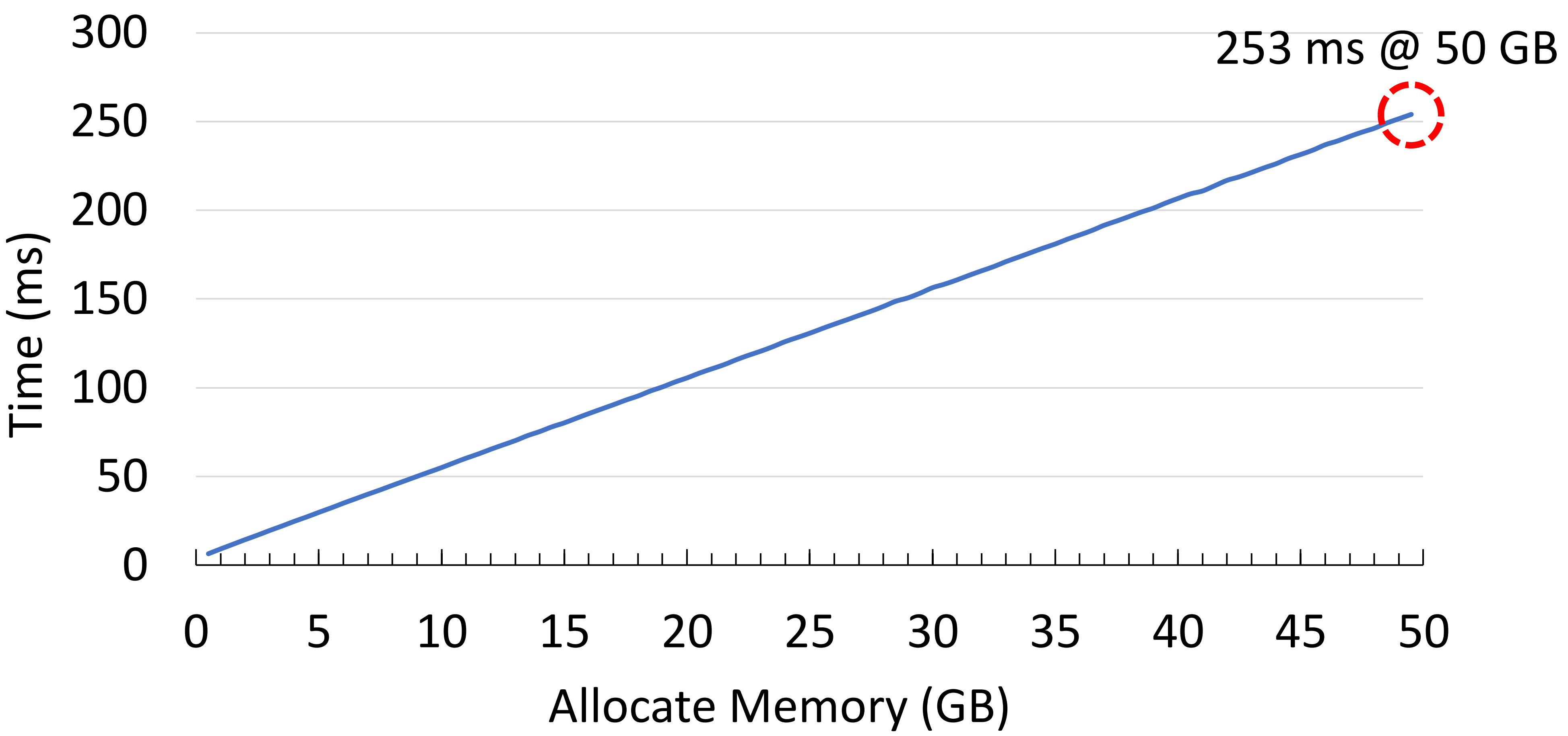

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A slow fork is bad

Code for snapshotting

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Code for snapshotting

handle_request()

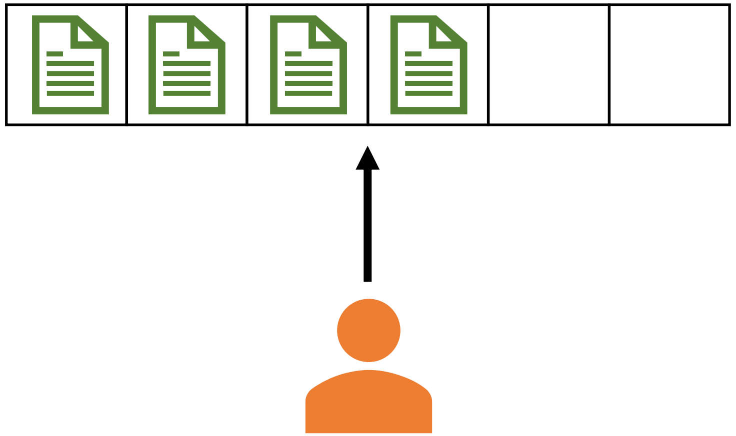
↓

fork()

↓

handle_request()

Requests keep queueing



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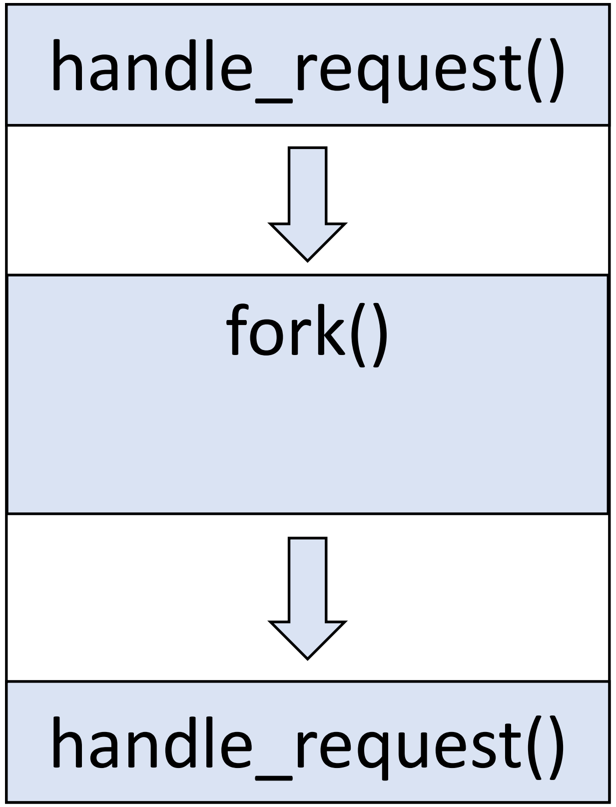

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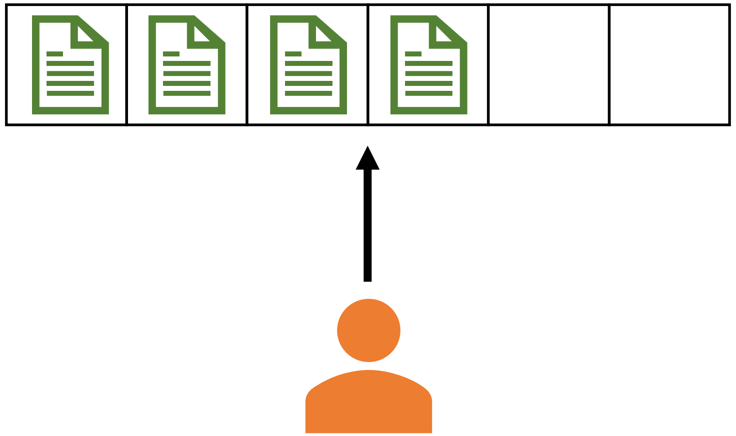

Long latency of fork blocks applications on the critical path

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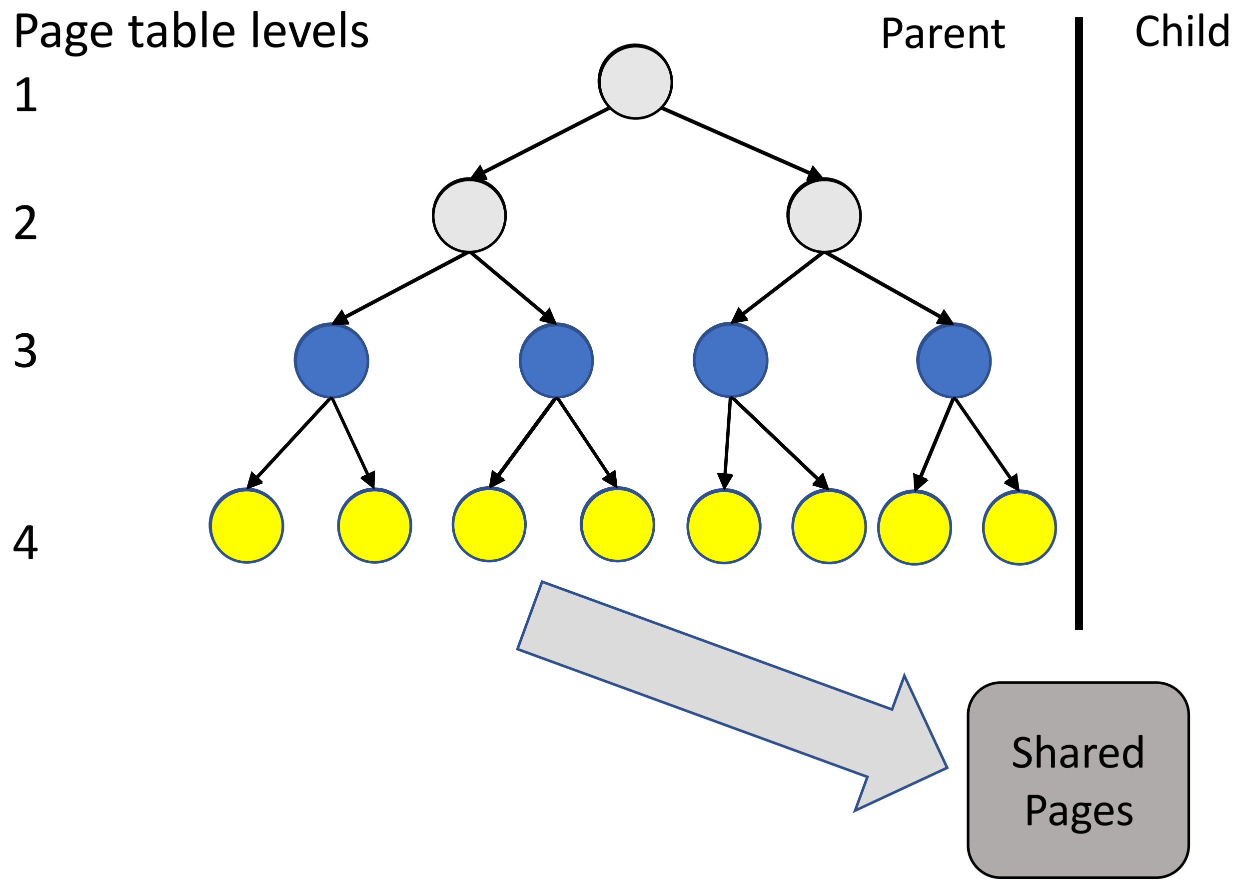
Setting up the whole address space is wasteful

Why is fork **slow** and **inefficient**?

Fork copies page tables



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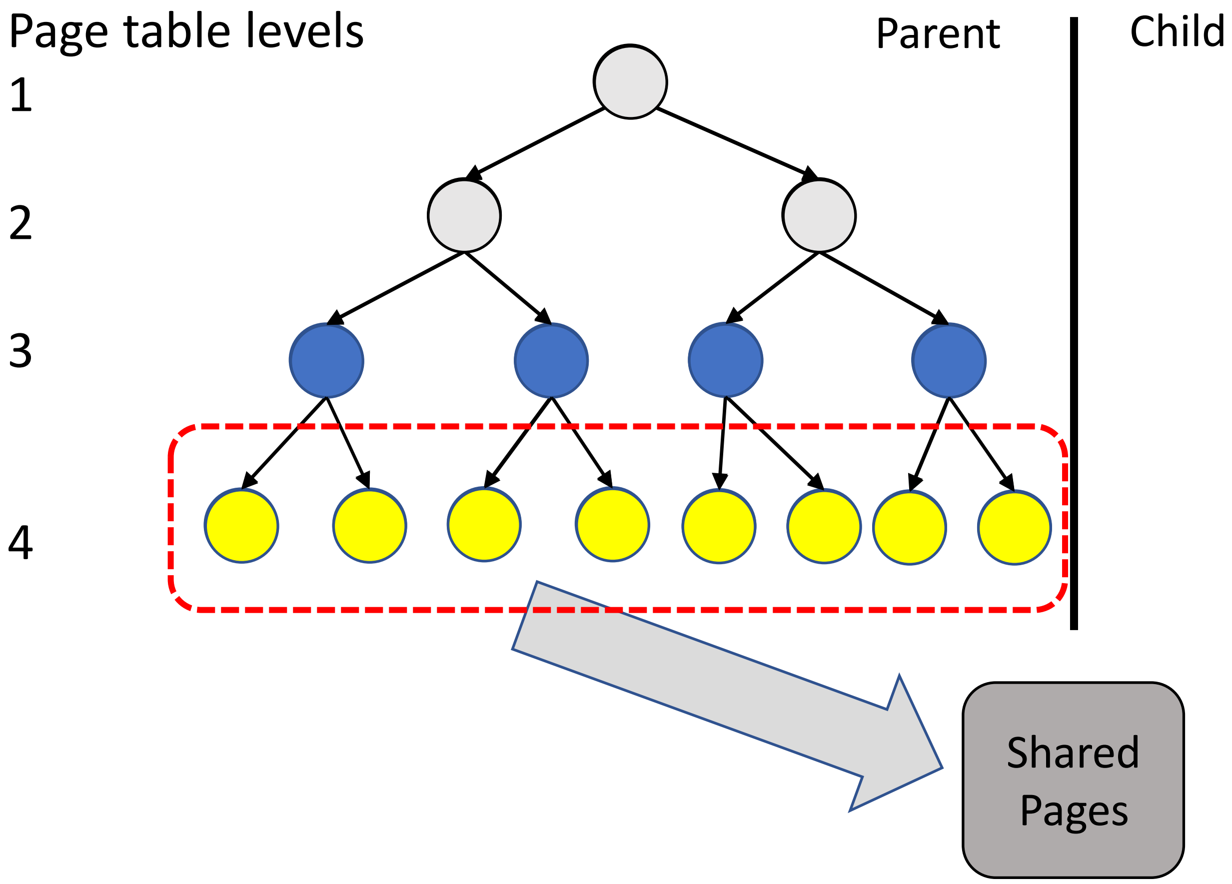

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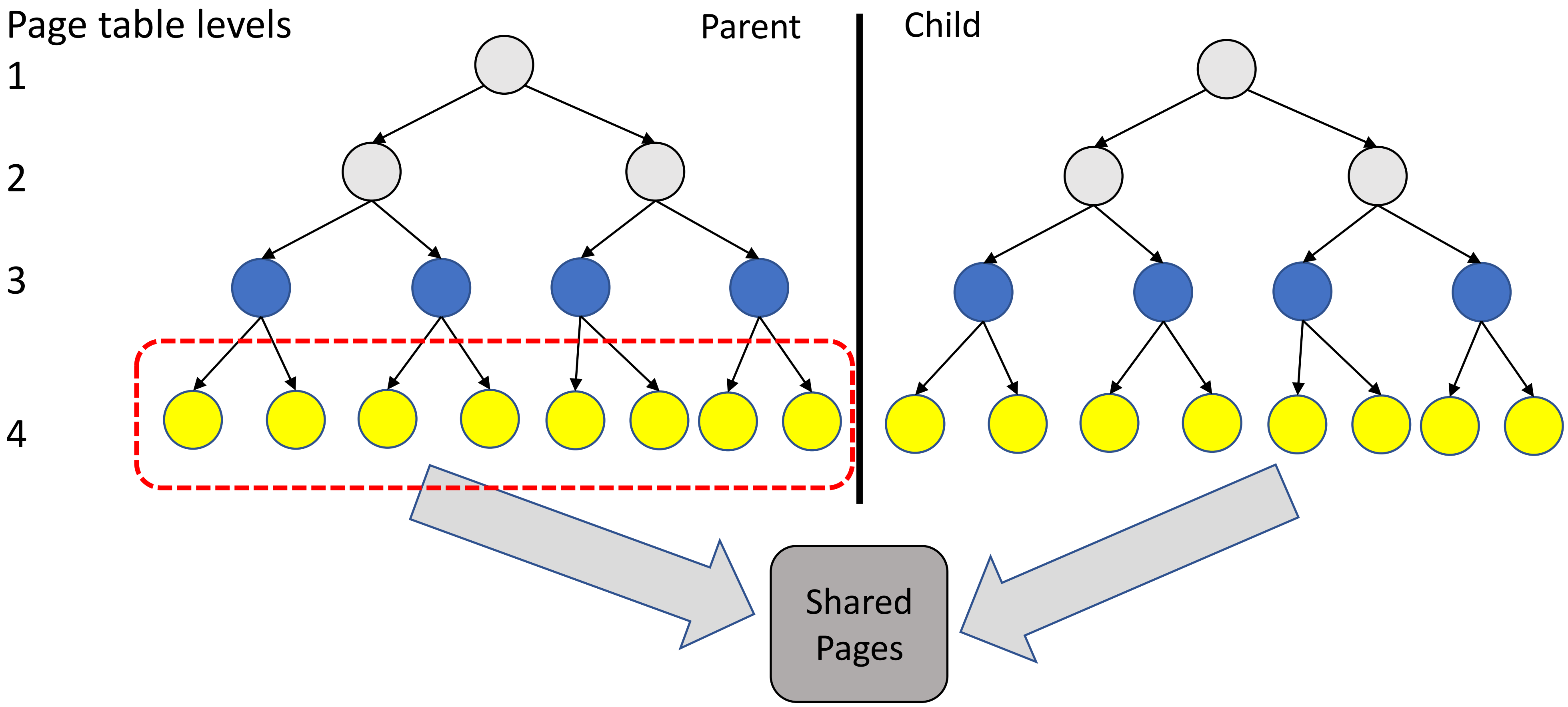

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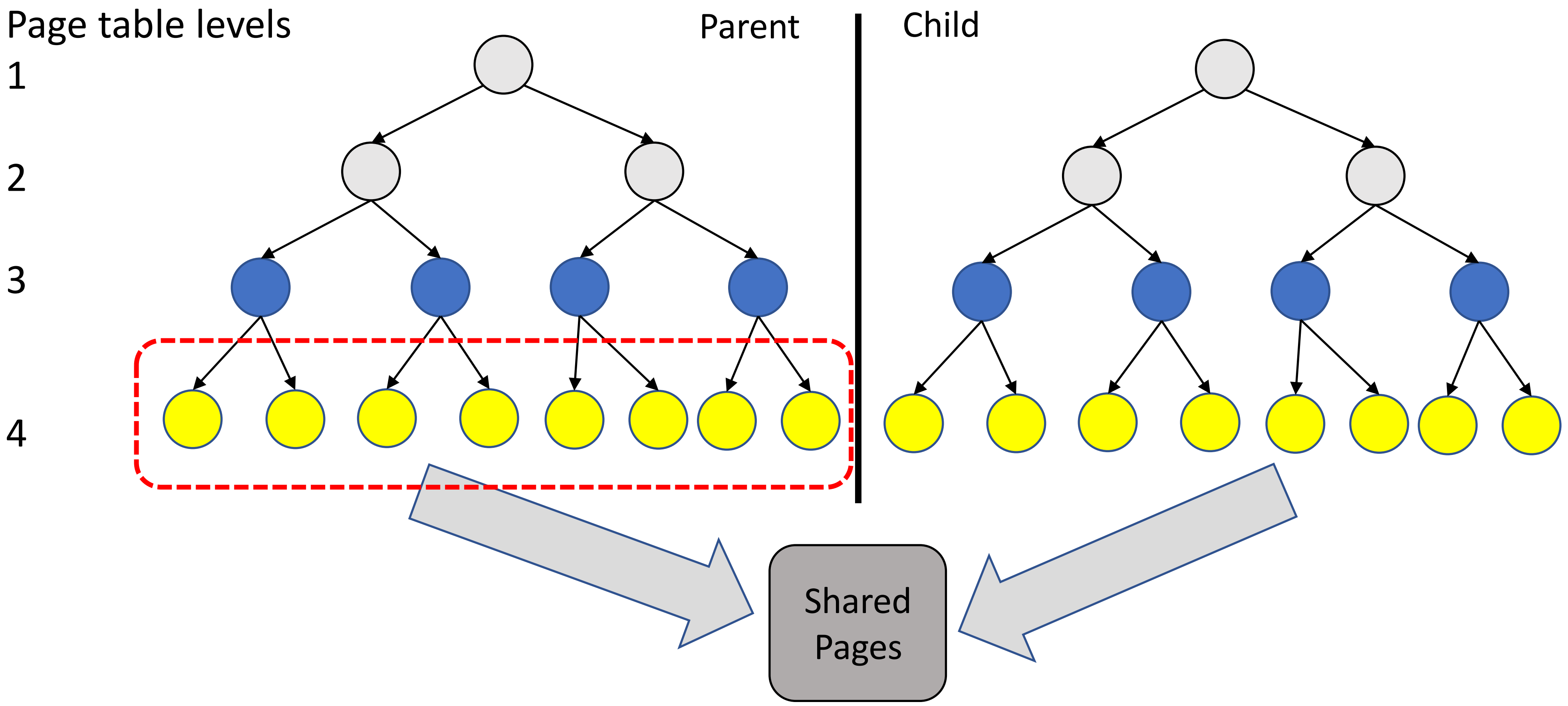
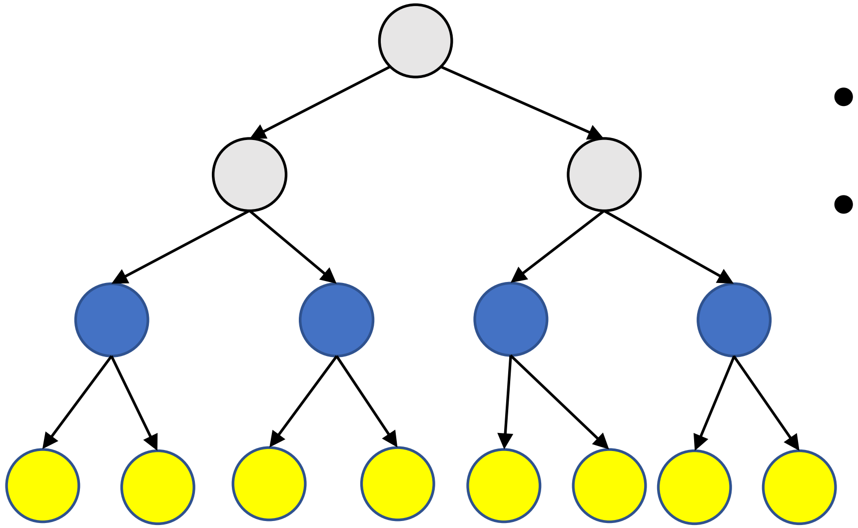


Copying is prohibitively expensive for large applications

Huge pages are not a good solution



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- Lower the latency of fork, but suffer from:

Increased internal fragmentation

Expensive page faults

System-wide latency spike

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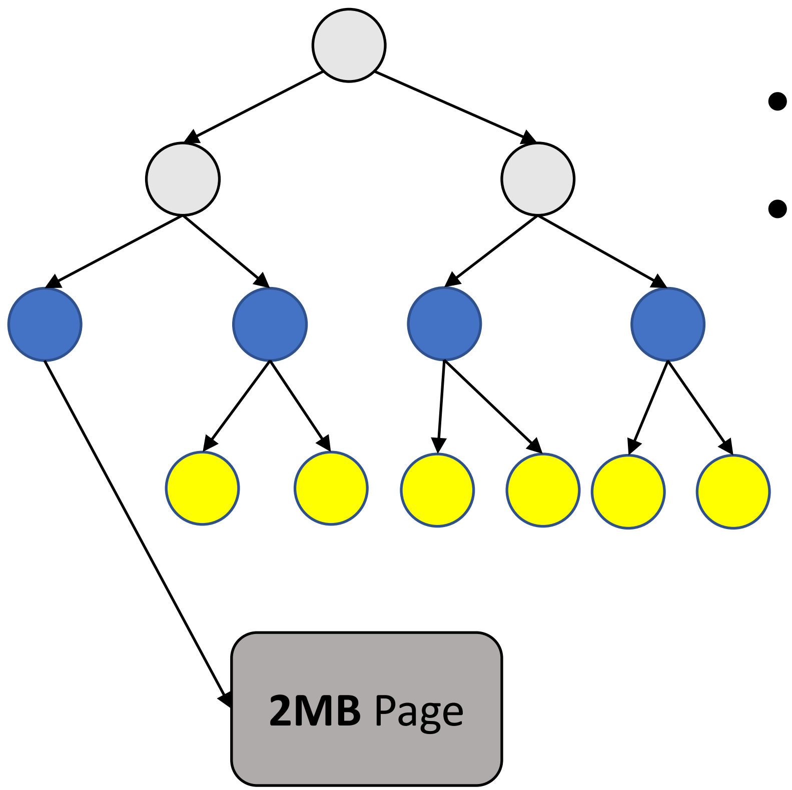

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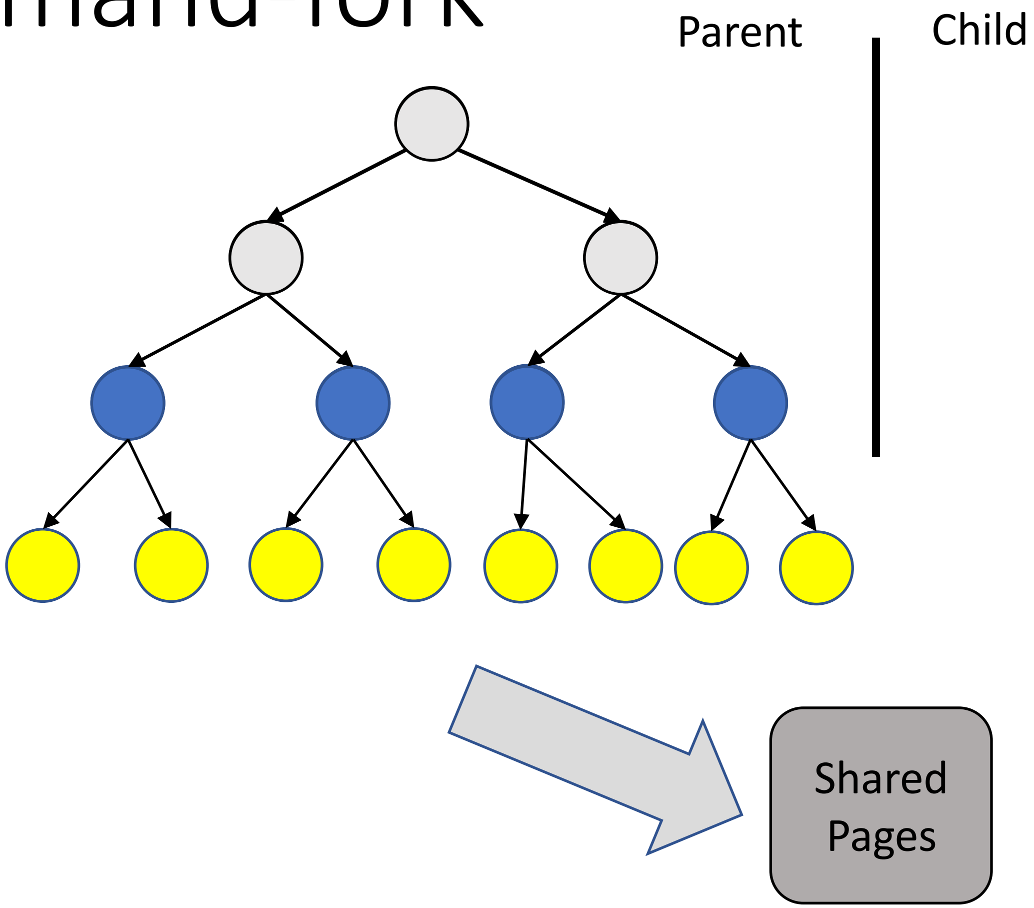

- Shares last-level page tables during fork
- Ensures microsecond-level latency for dozens of GBs of memory
- No issues of huge pages

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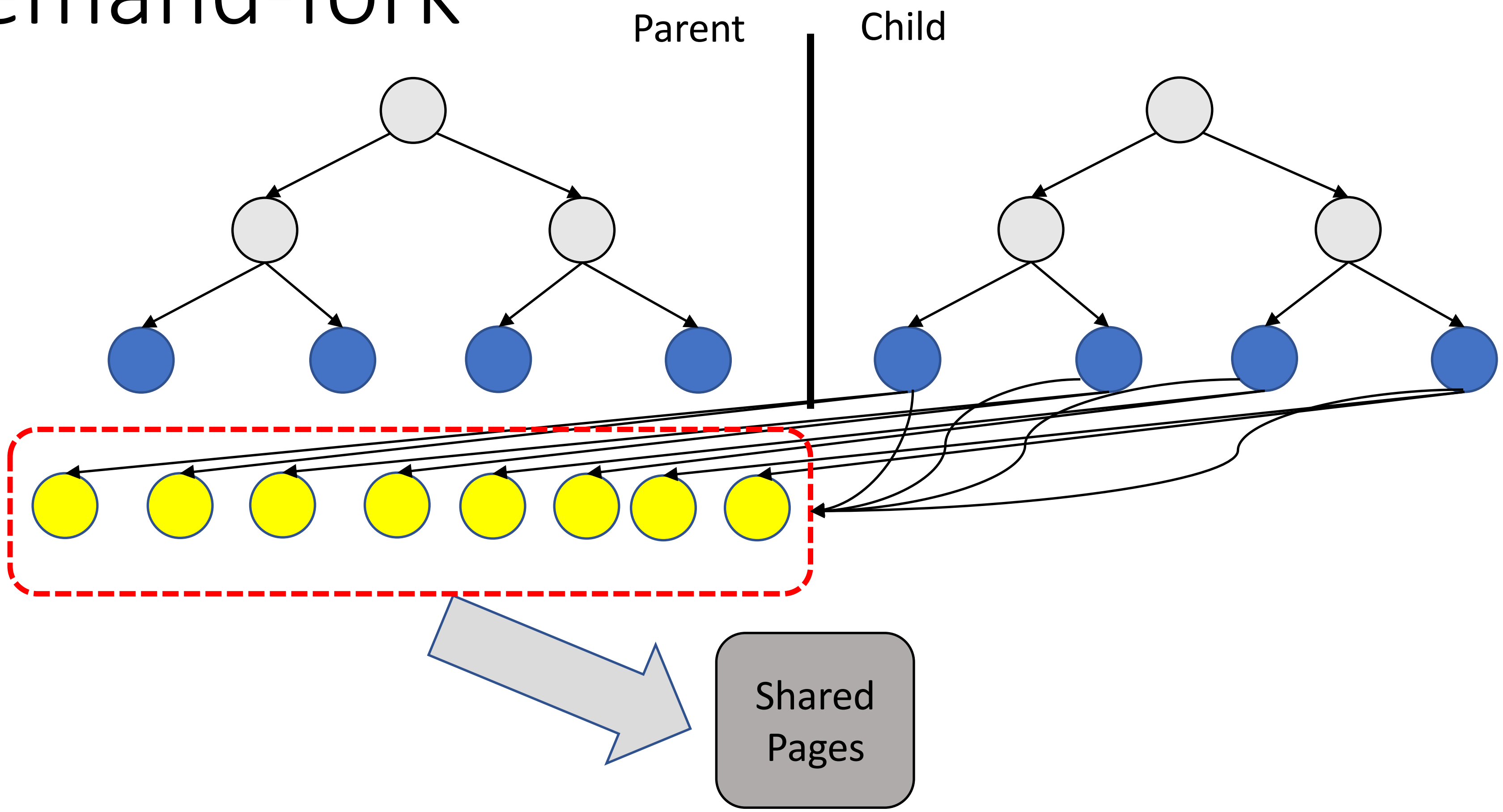

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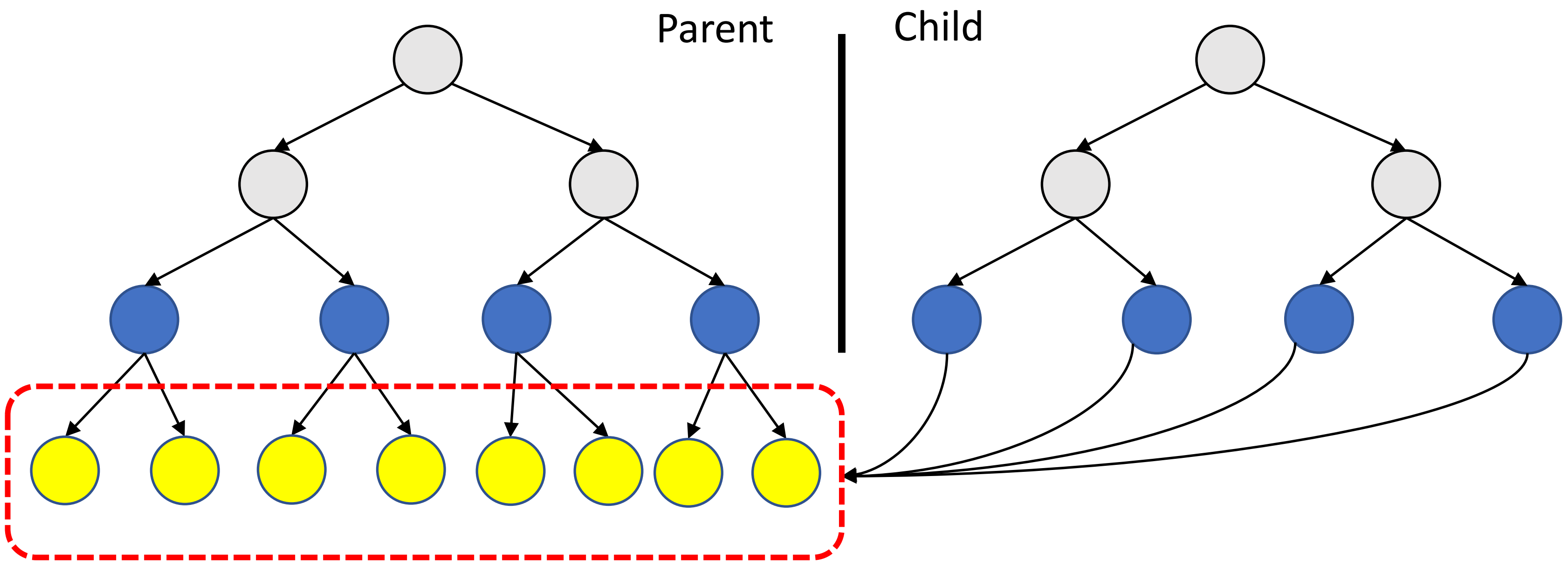

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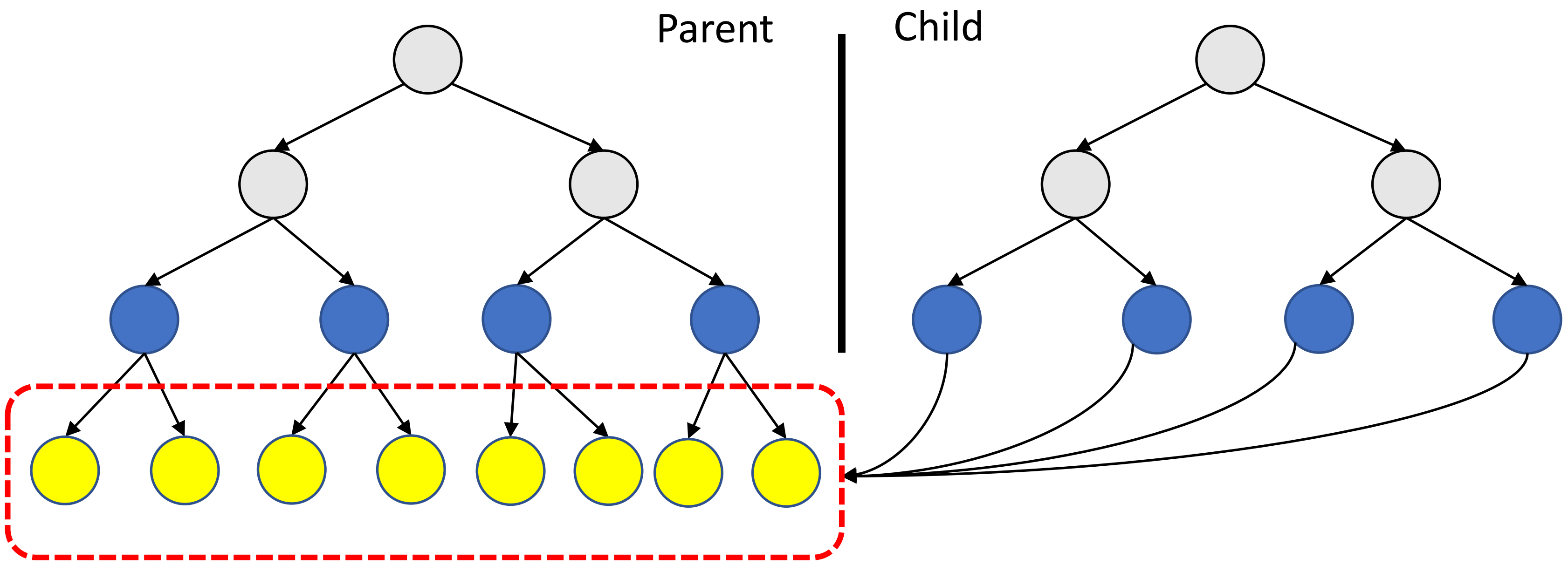

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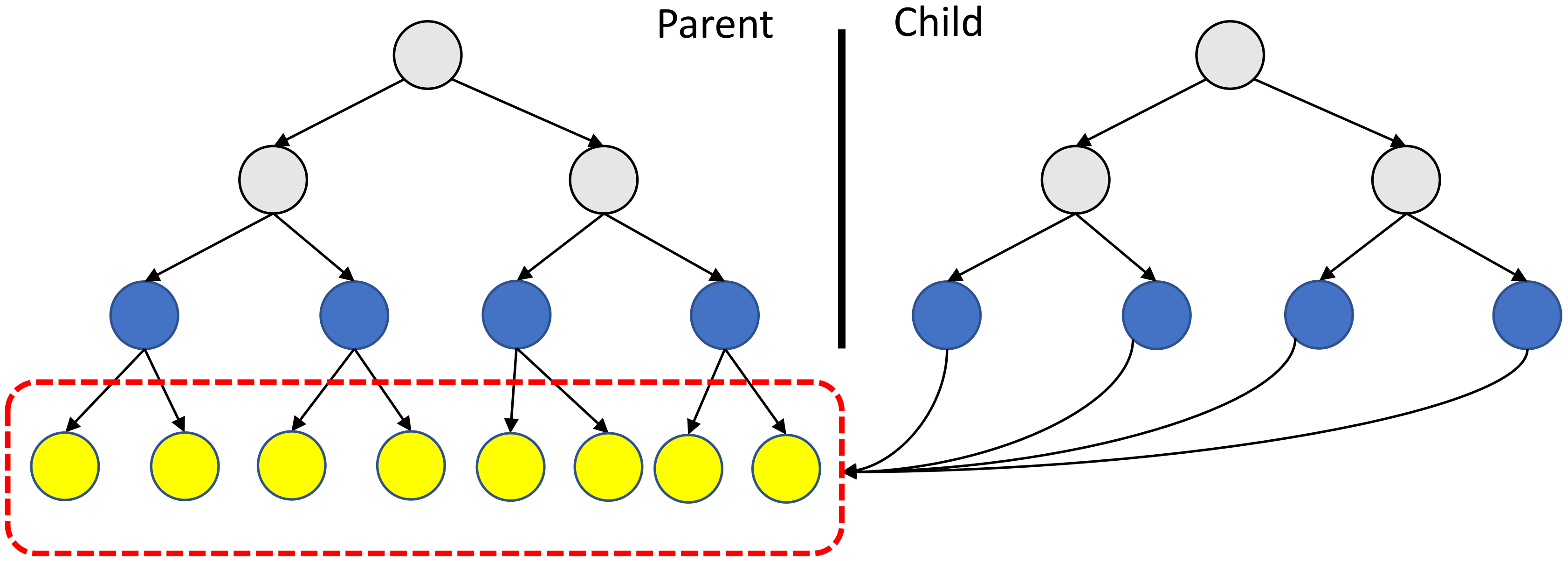

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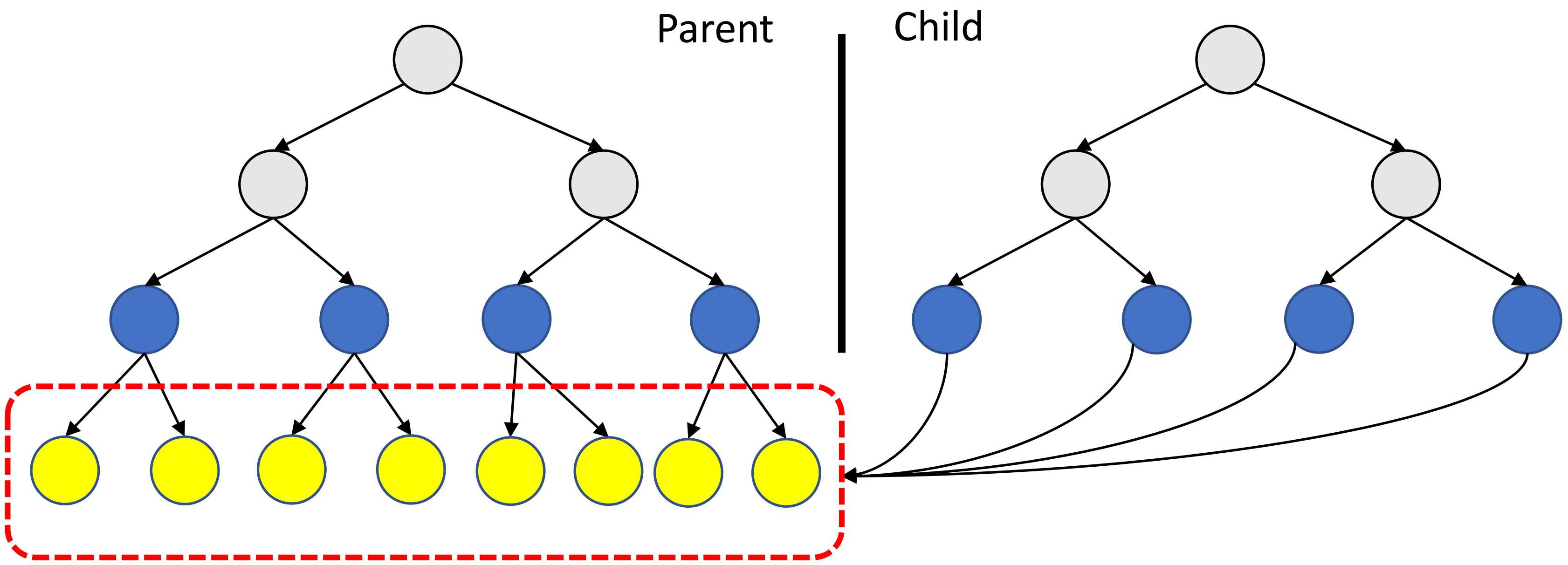
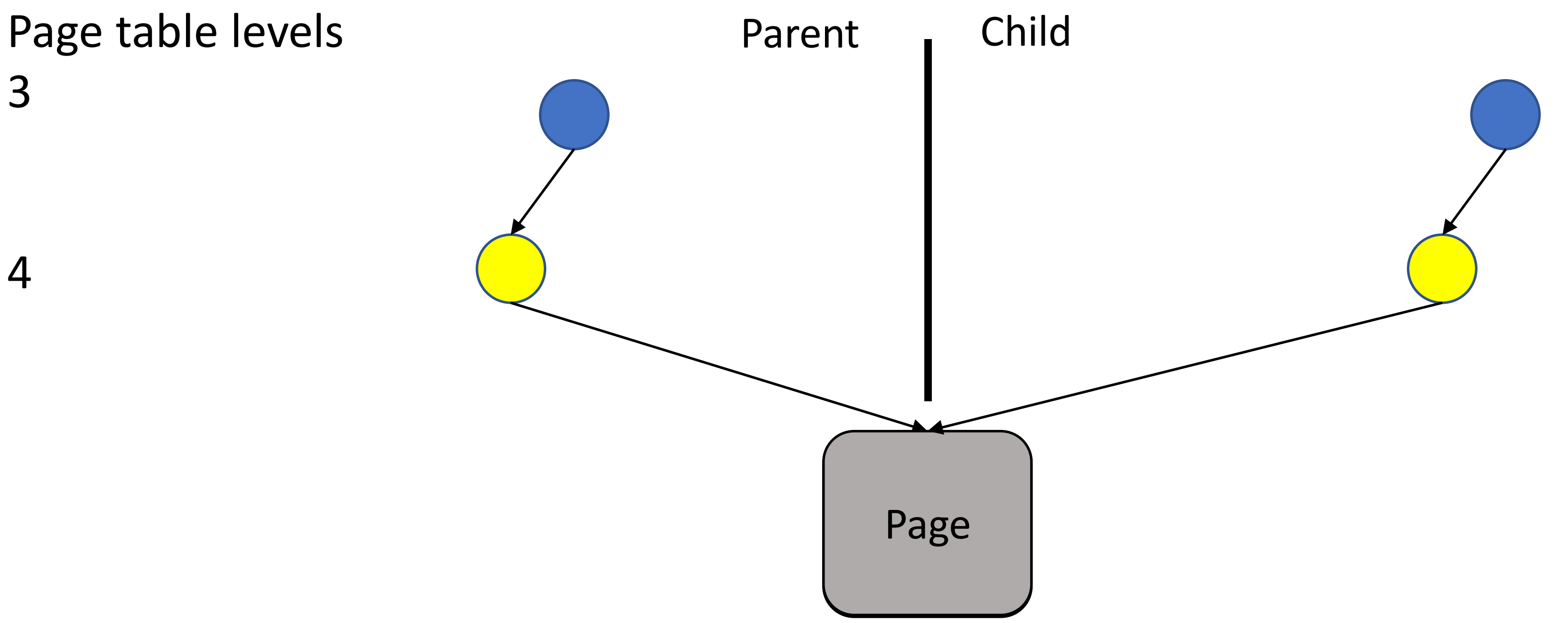


No cost of copying page tables for read access

Preserving copy-on-write semantics



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- Traditional fork disables the write permission in **last-level** page tables
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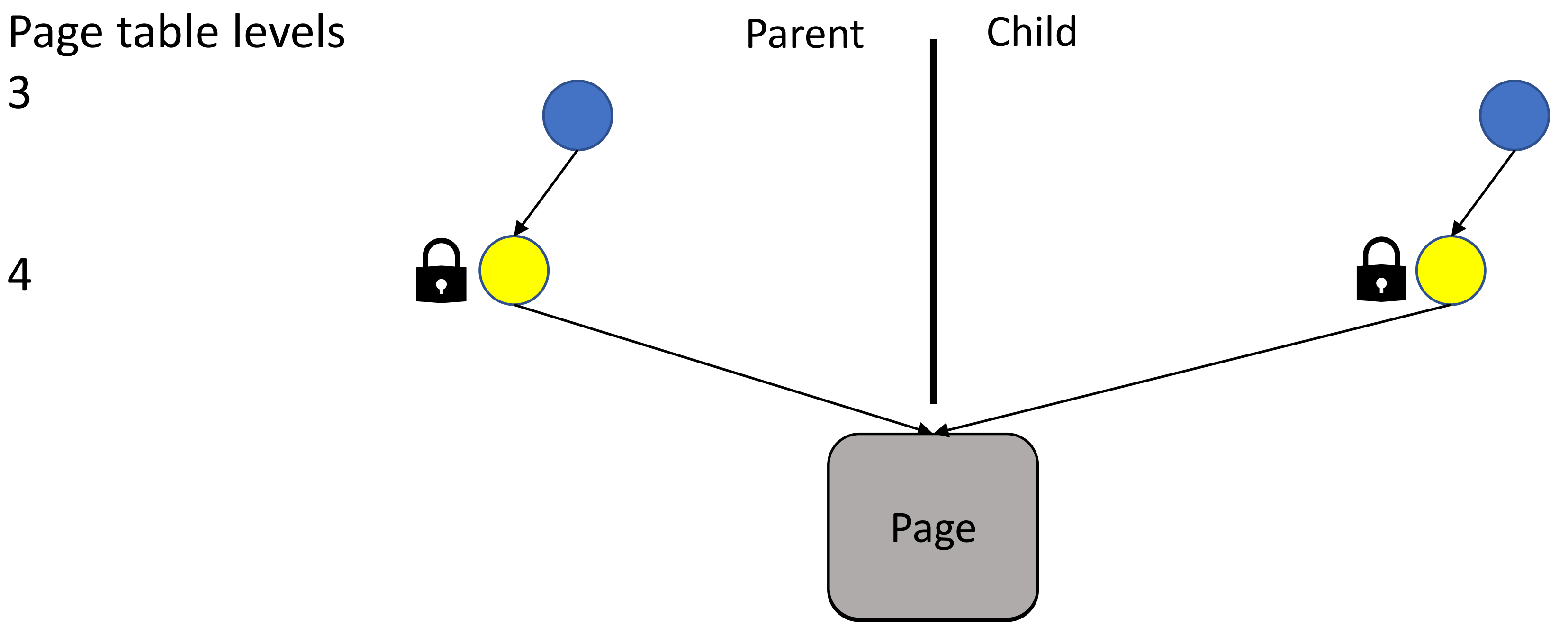

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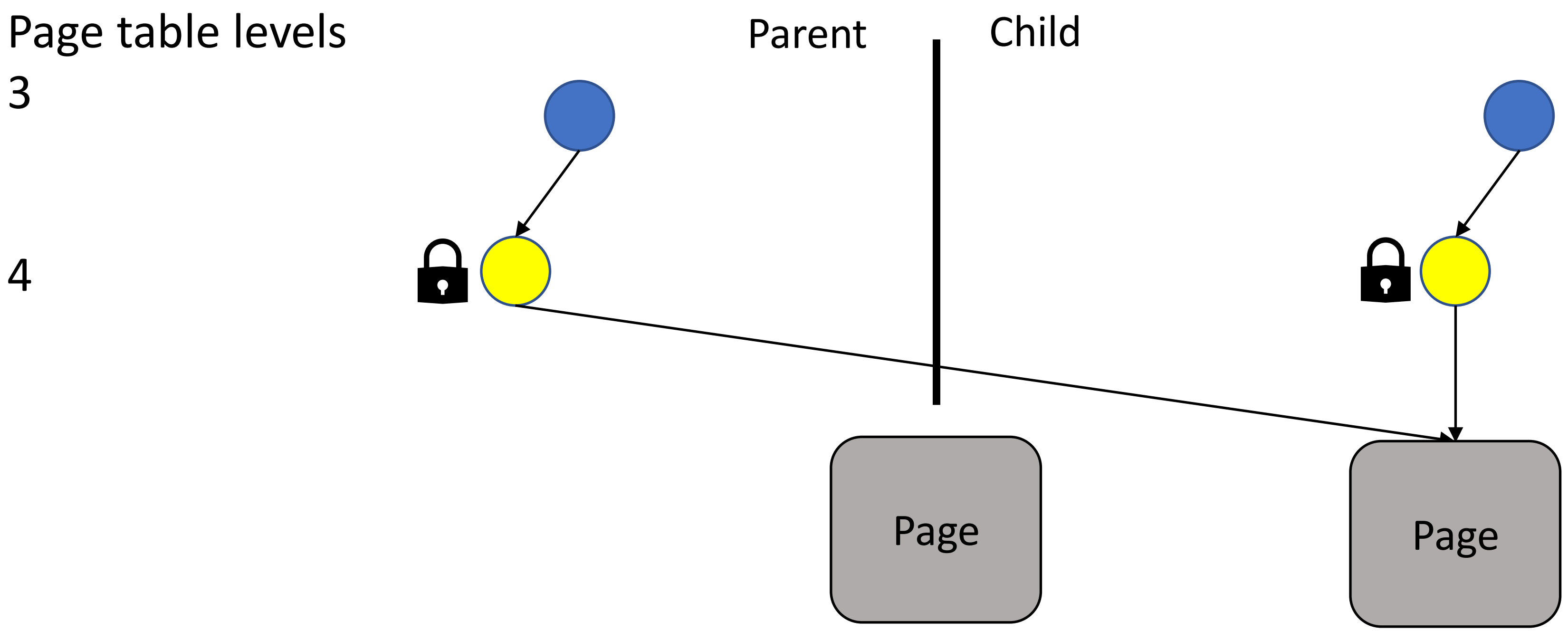

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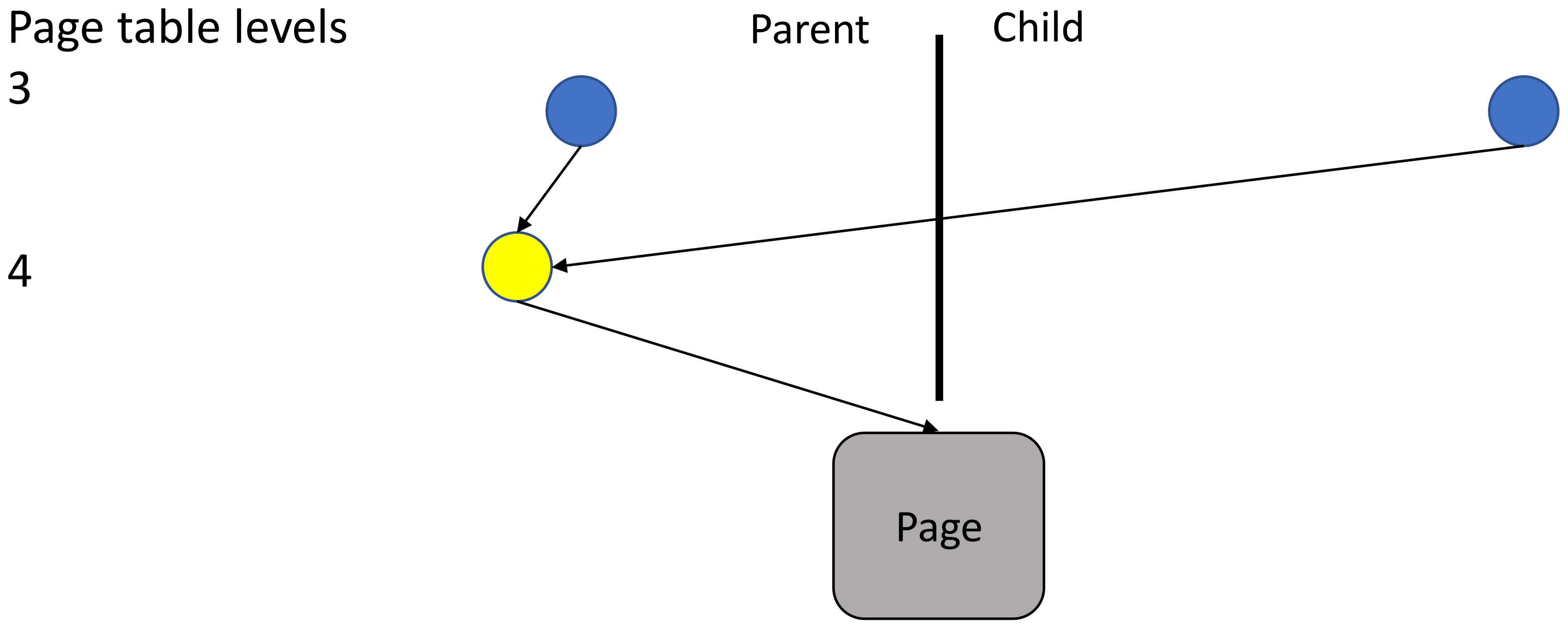

On-demand-fork disables the write permission in **3rd** level tables

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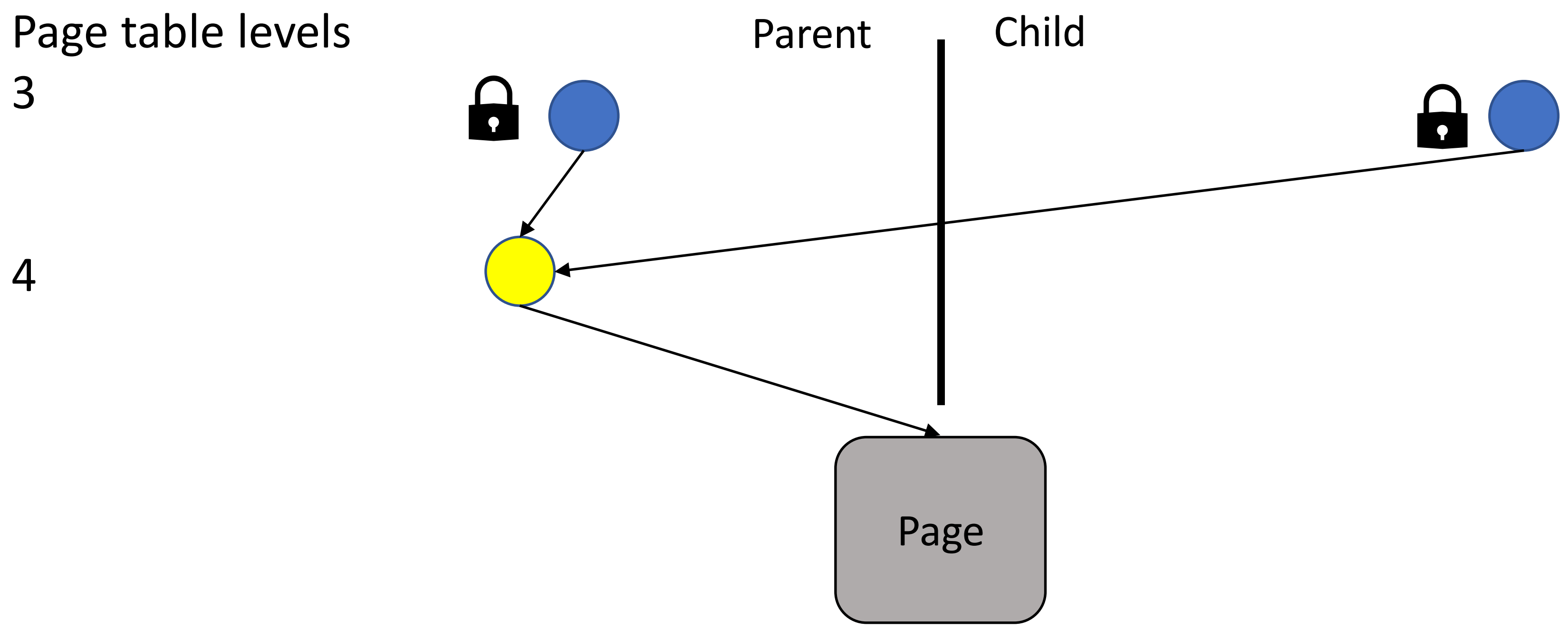

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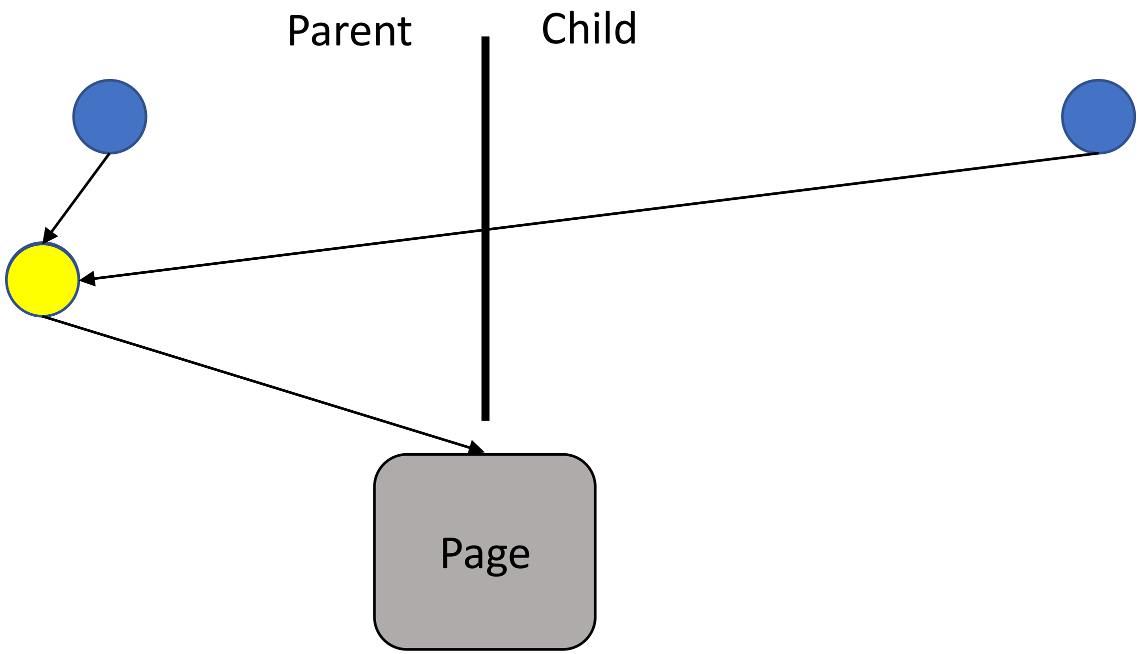
On-demand page table copying



- Page faults for write access only
- Increased cost for only the first write access

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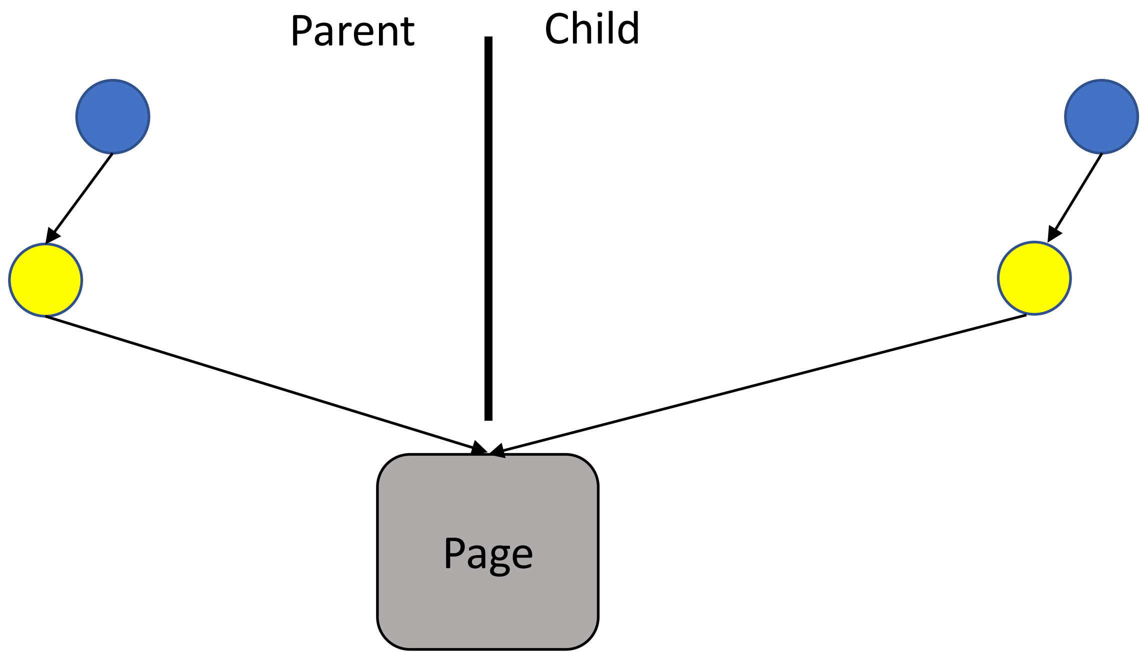

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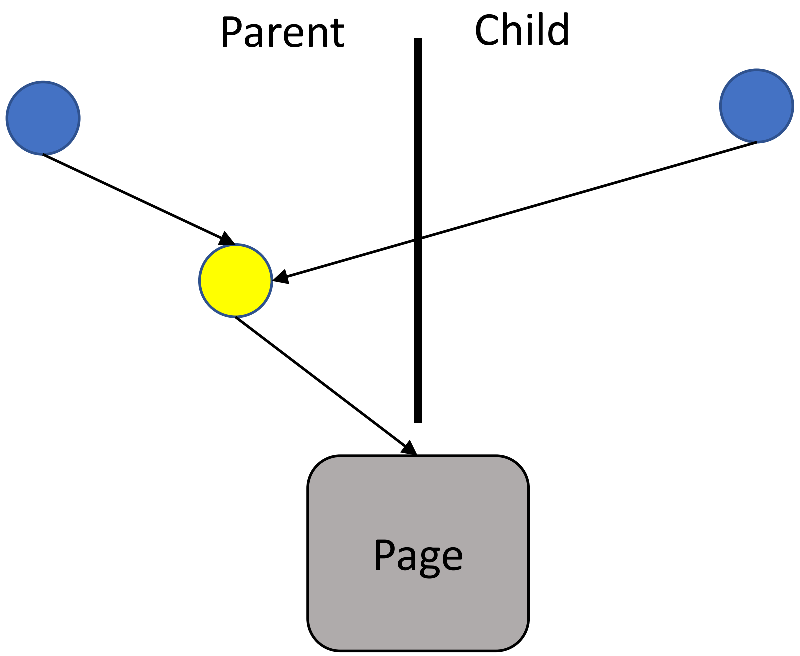
Keeping track of shared tables



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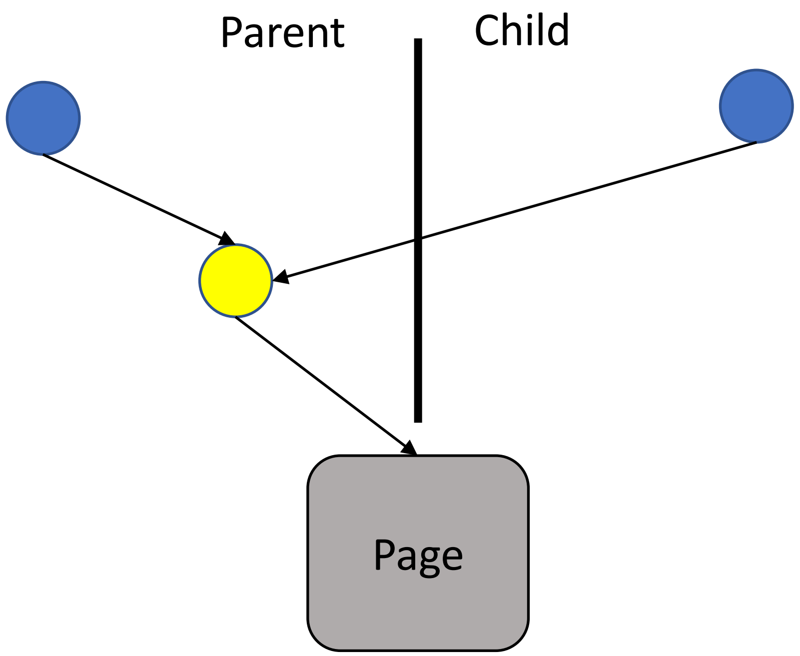

- **Challenge**: Need to know when to free last-level page tables
- **Solution**: reference counts last-level page tables

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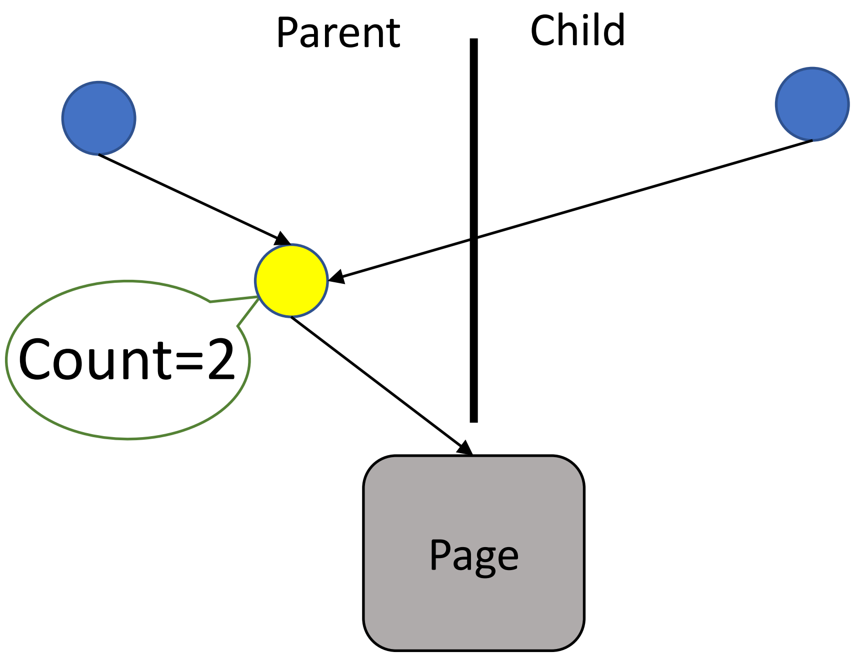

During system call

- Reference counts last-level page tables
- Count equals the number of processes that share the page table

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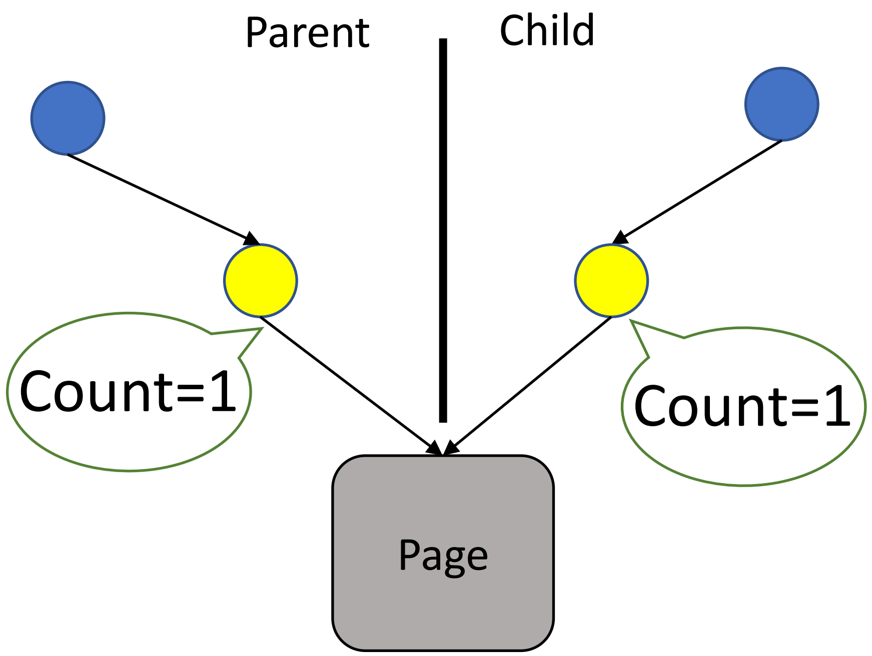

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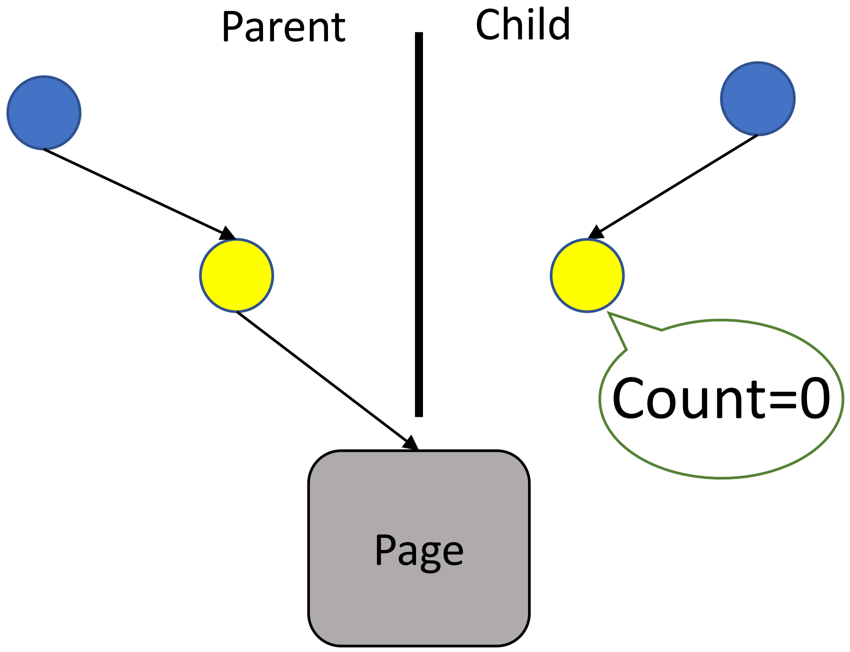
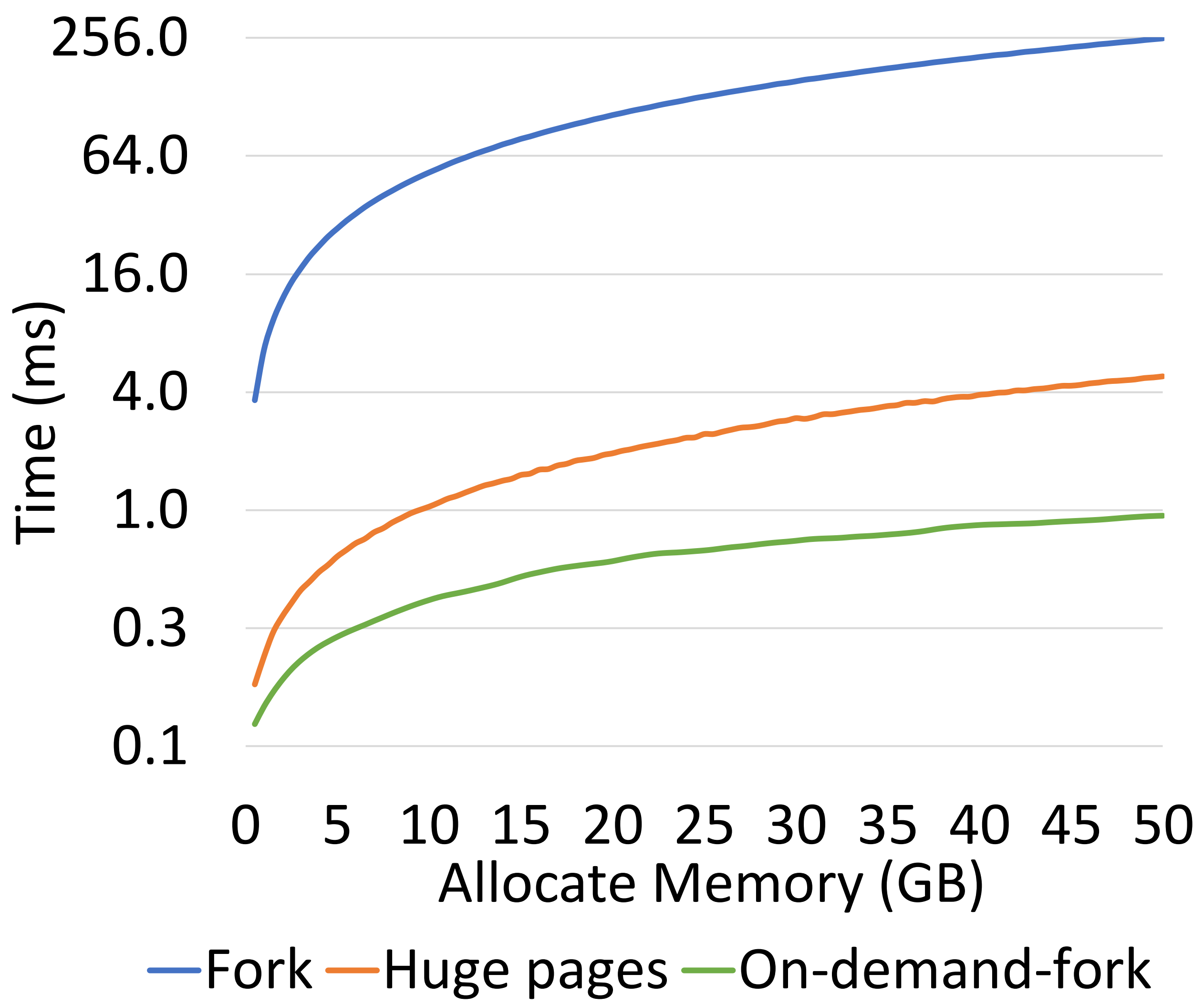


Unmapping

Last-level page tables are freed after count reaches zero

Microbenchmarks: system call latency



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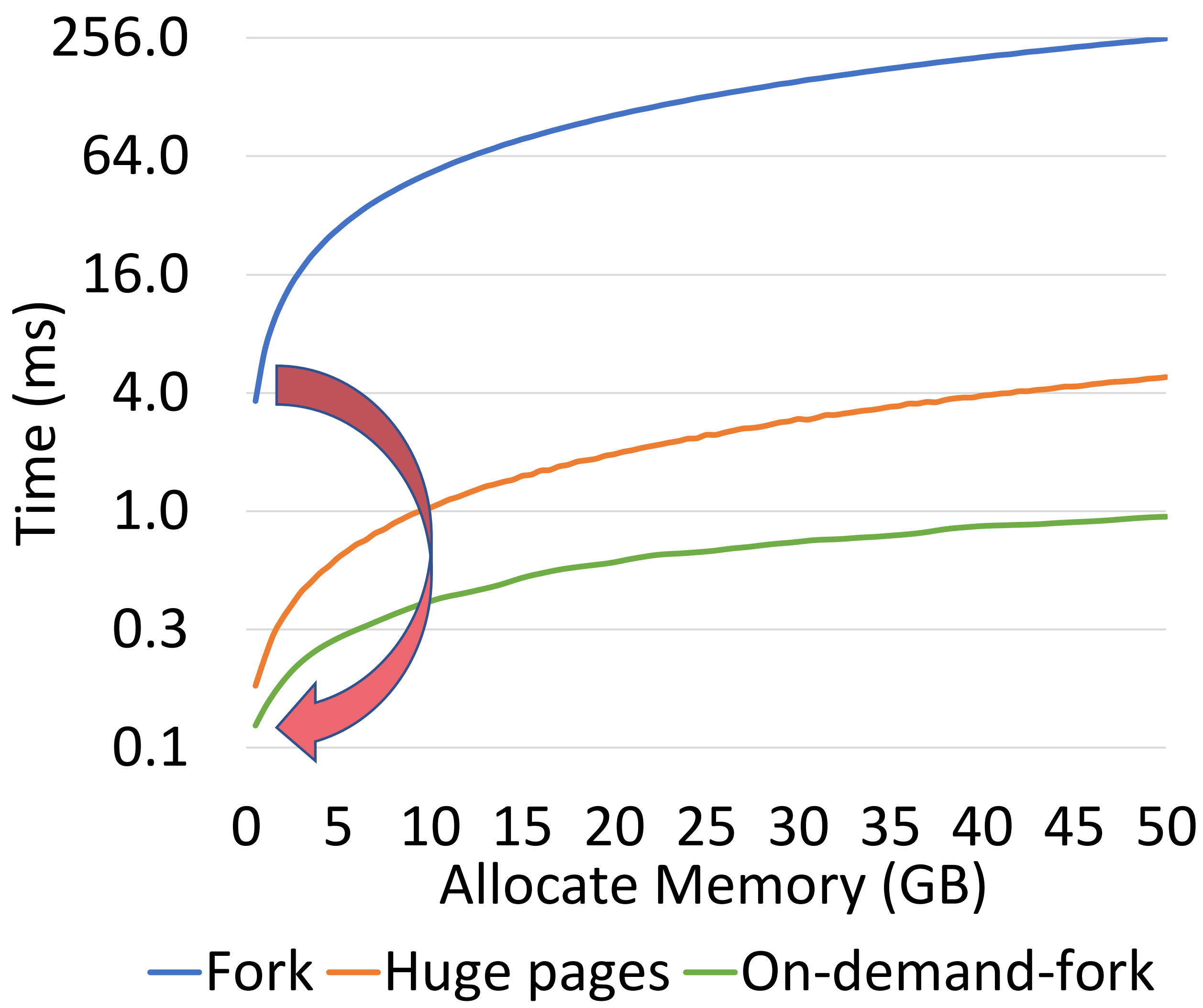

65 times faster at 1GB

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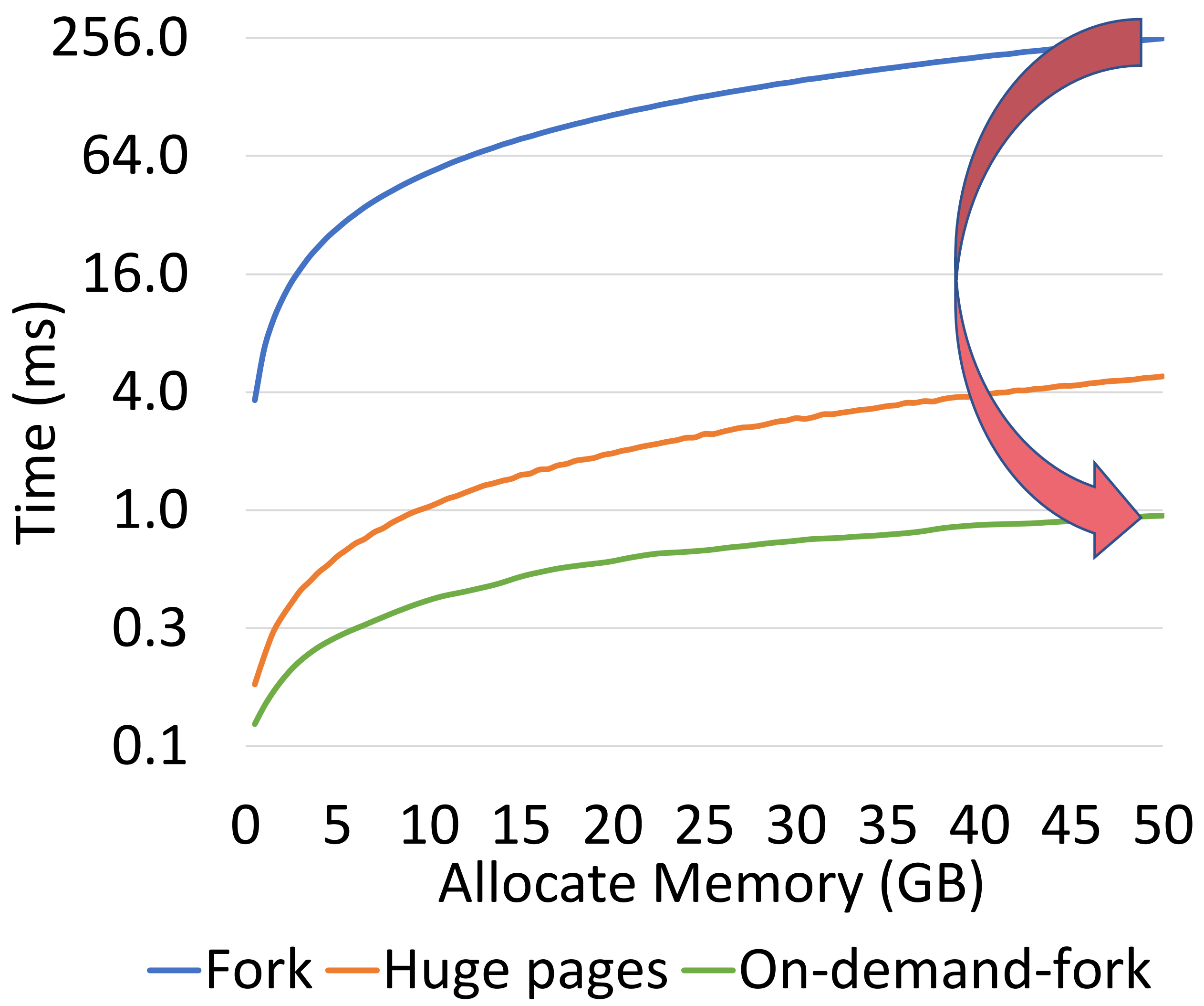

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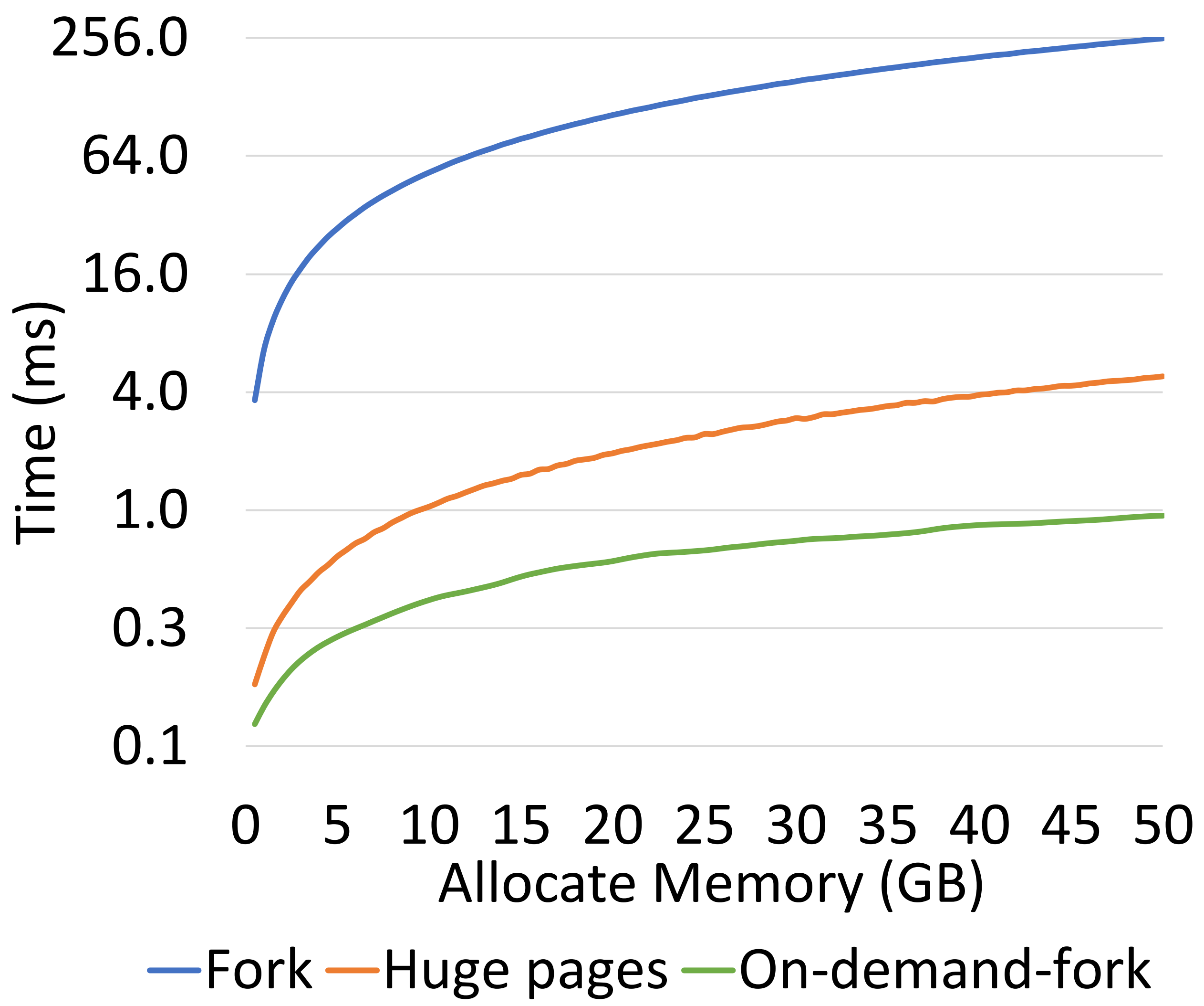

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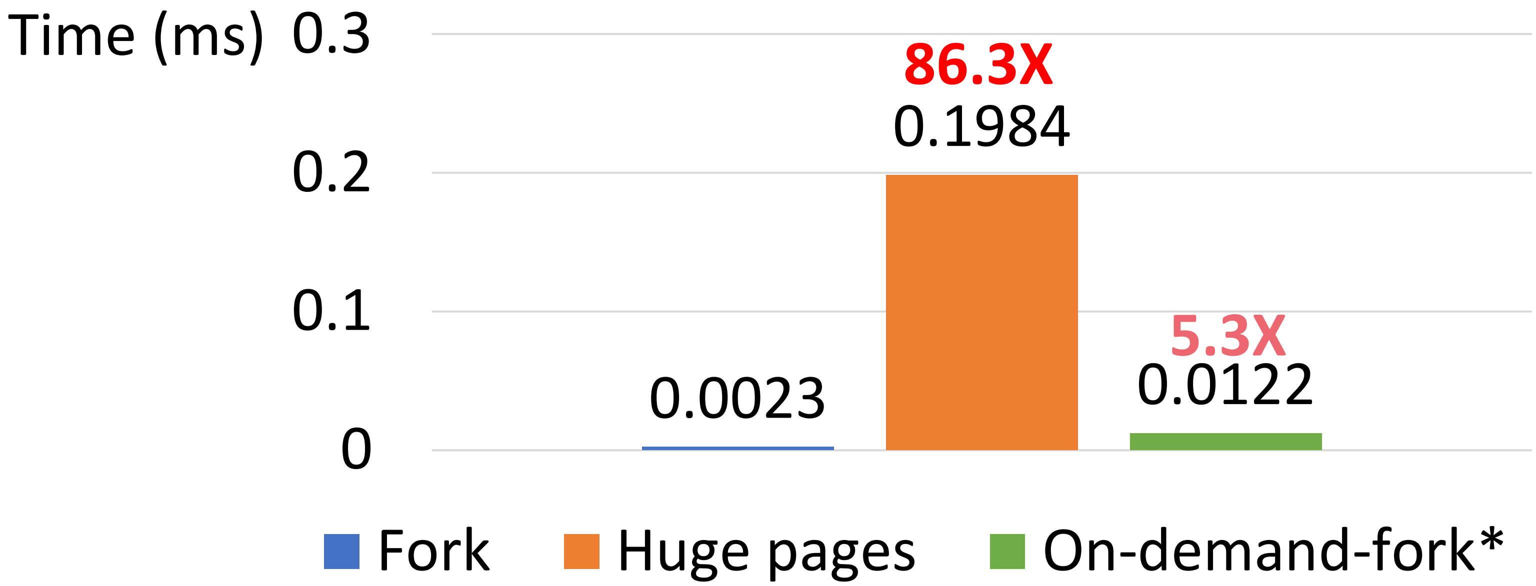
Faster than huge pages

Microbenchmarks: fault handling time



*: worst-case

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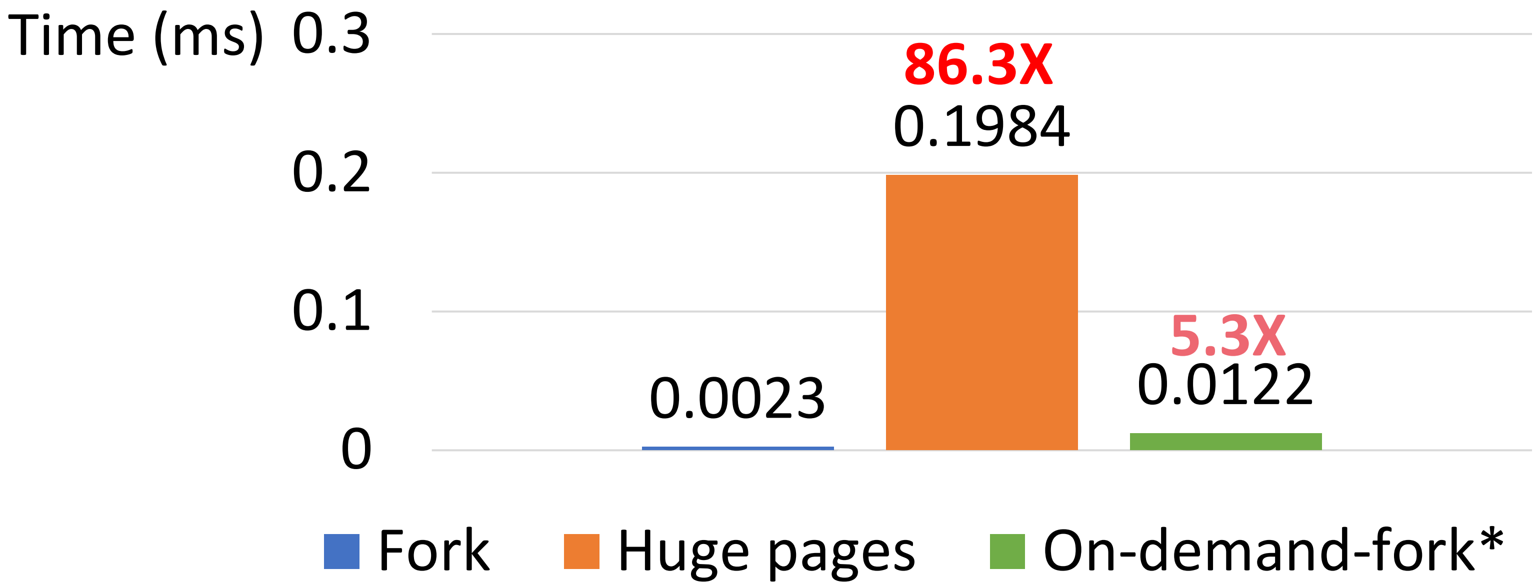

Worst case page fault handling time is reasonable

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The test suite runs each test case in a child process

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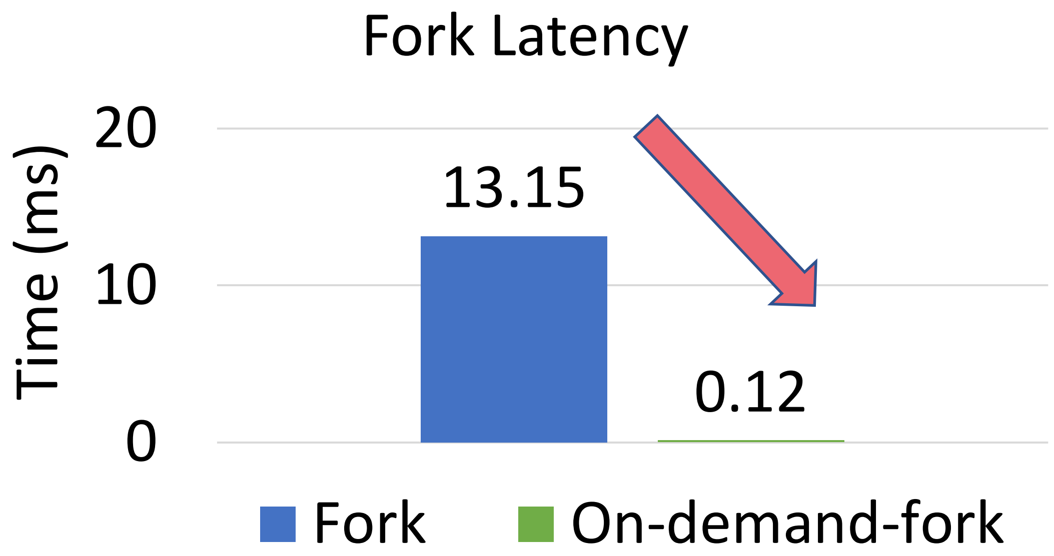

99% lower fork latency

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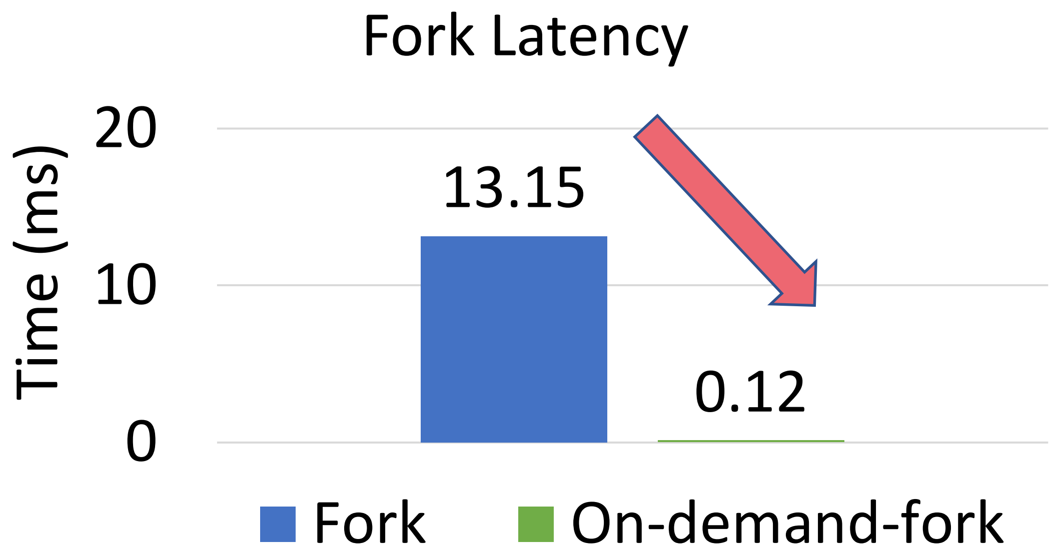

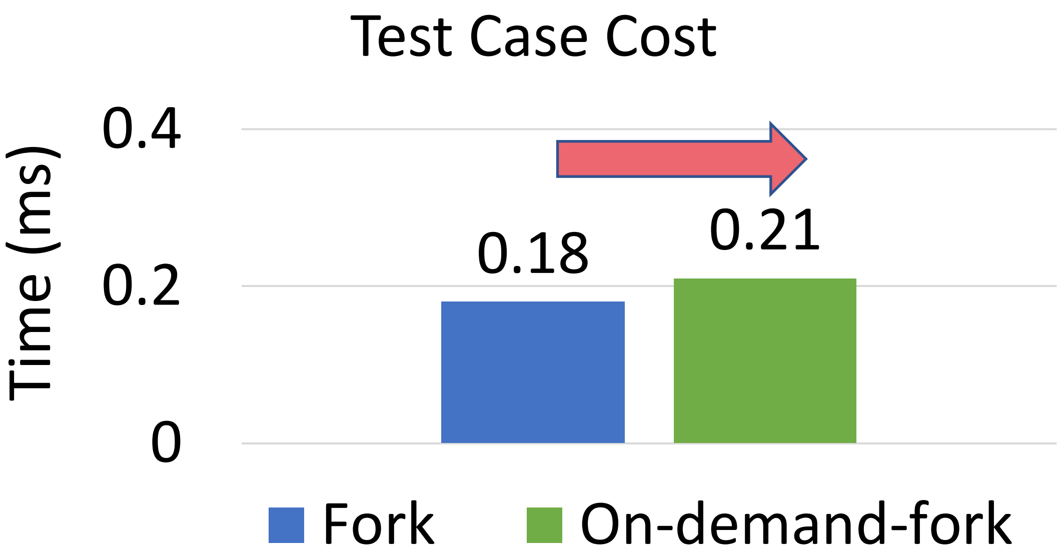

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Similar cost of running a test

Real-world applications: Redis

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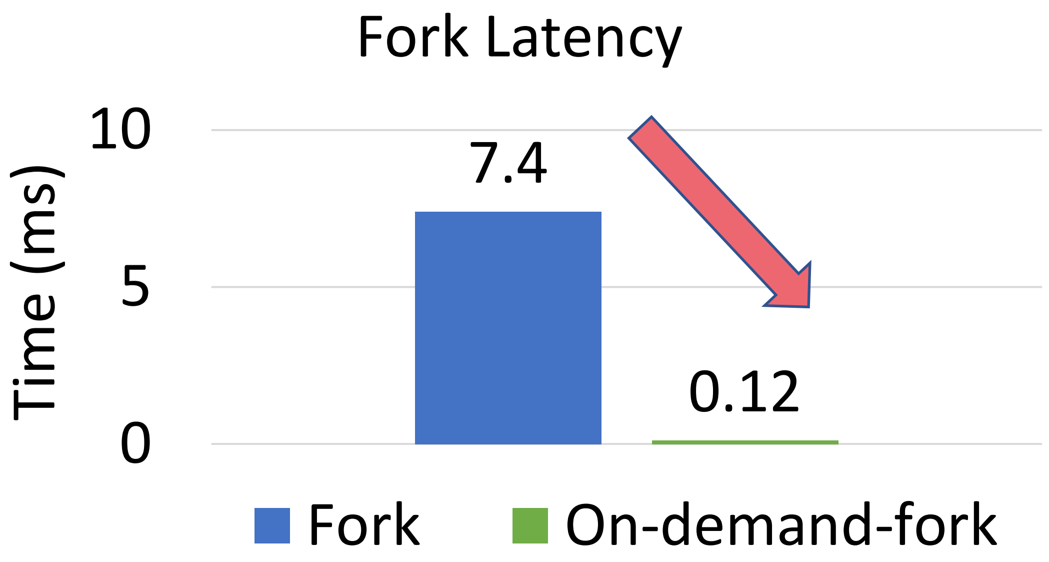

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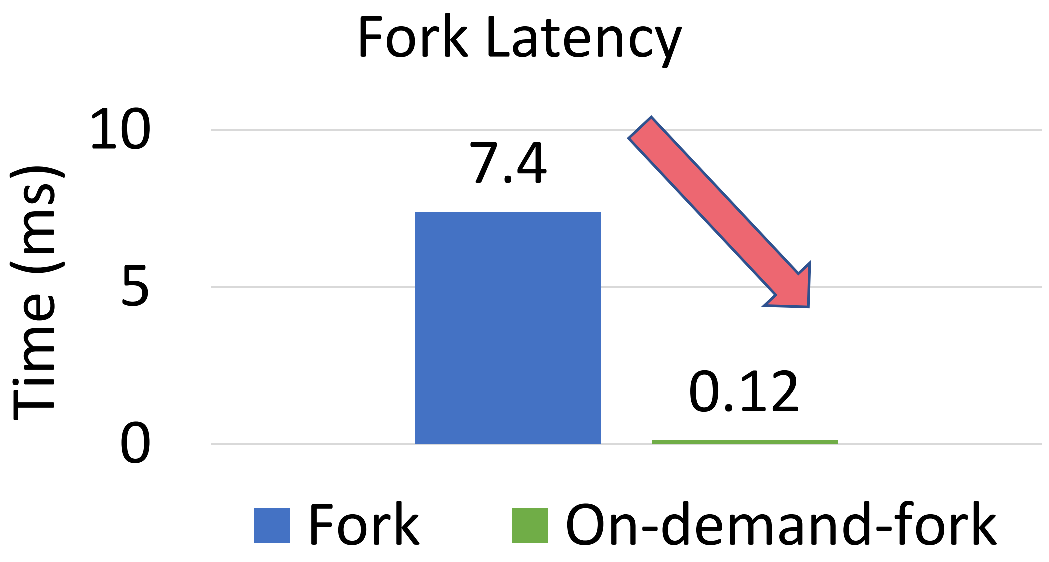
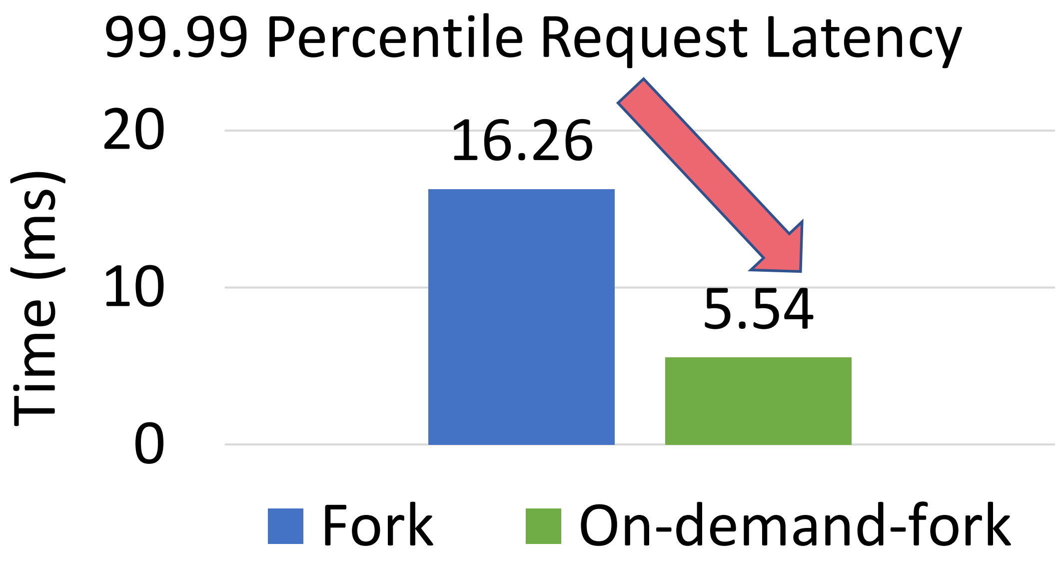
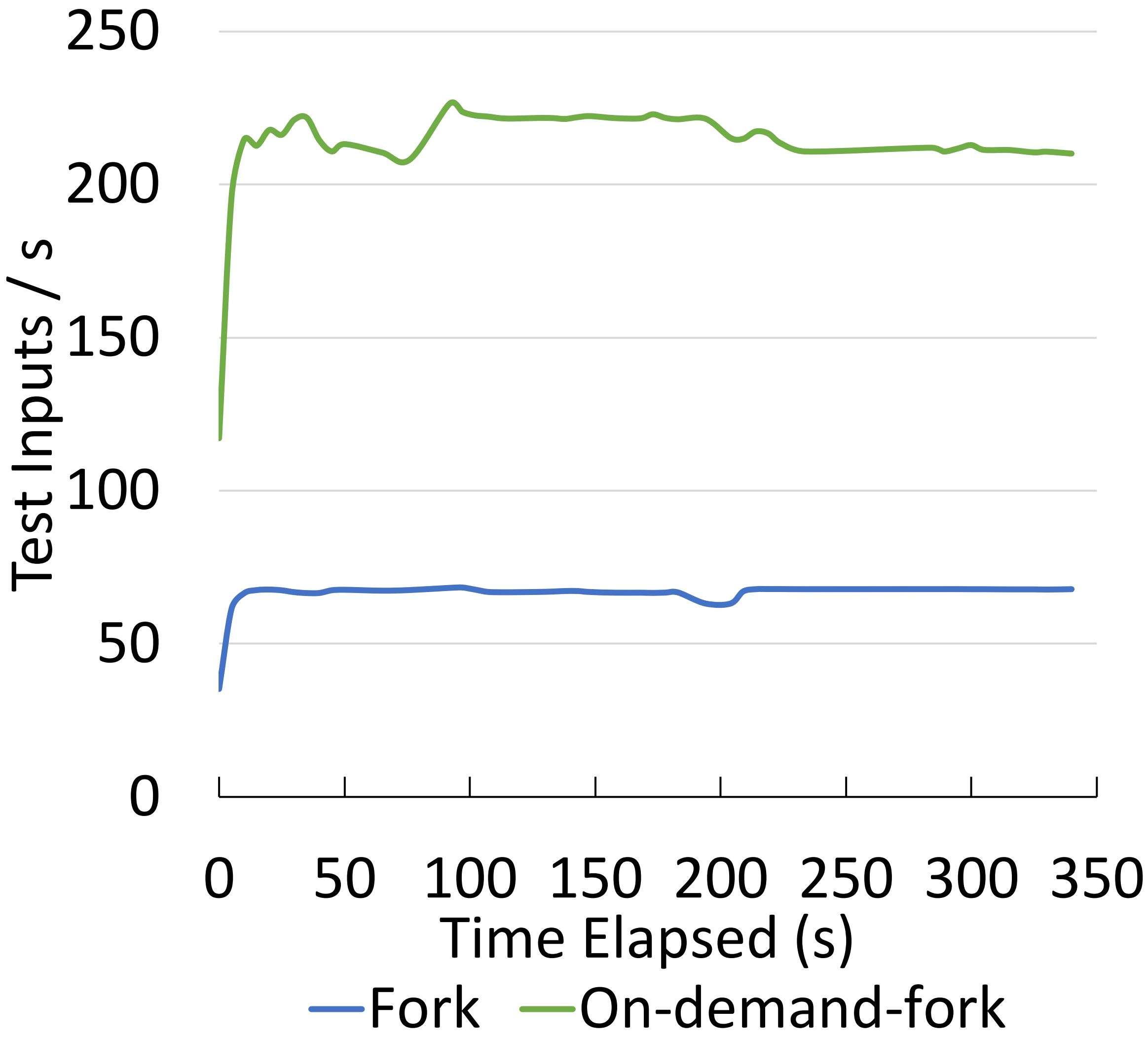




98% lower fork latency

65.95% lower tail request latency

Real-world applications: AFL



AFL instruments the target program to repeatedly fork to take inputs

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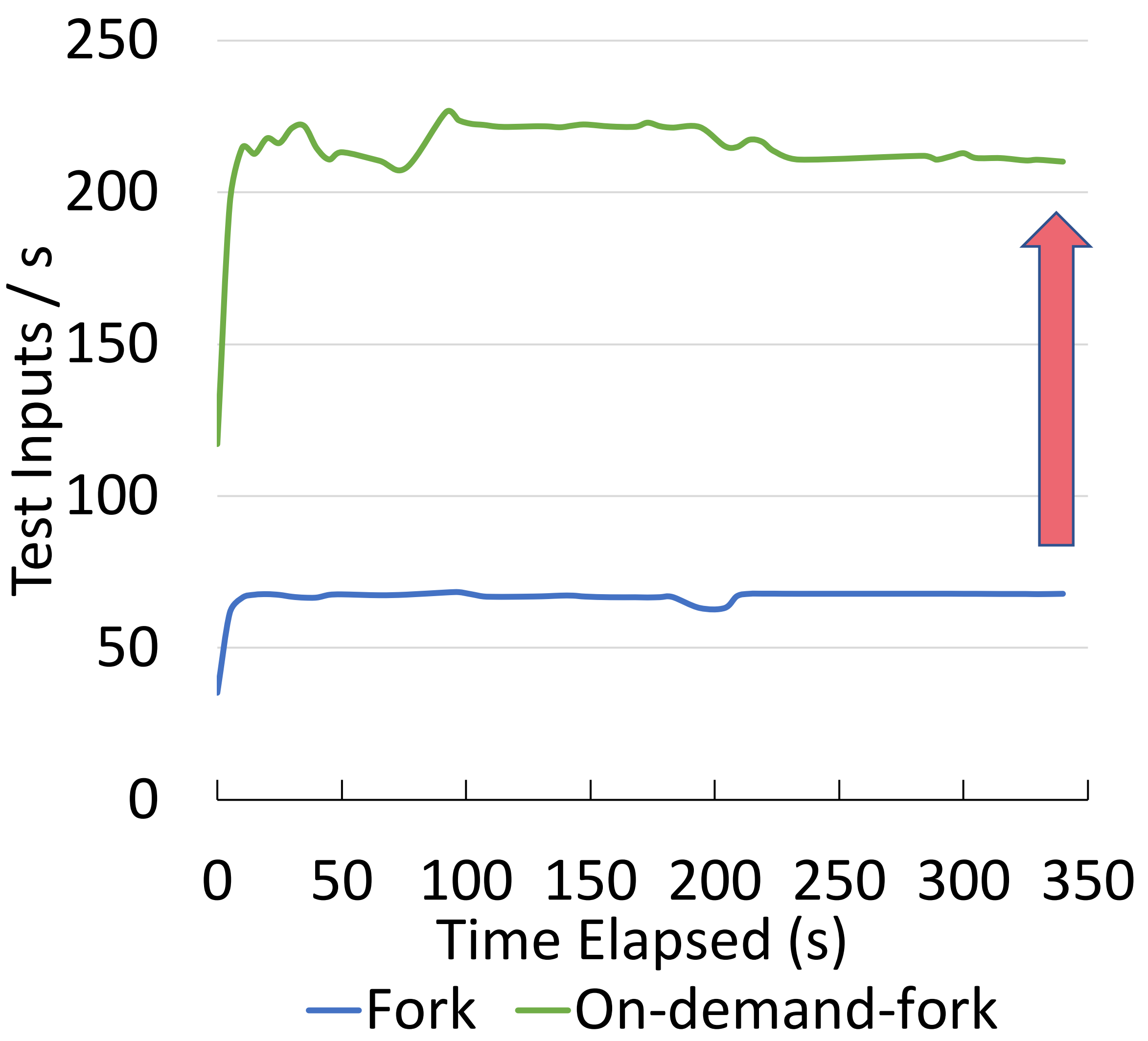

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2.26 times higher fuzzing throughput

Conclusion

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