CHERI-picking: Leveraging capability hardware for prefetching

Shaurya Patel, Sid Agrawal, Alexandra (Sasha) Fedorova, Margo Seltzer
University of British Columbia

Memory management in the datacenter

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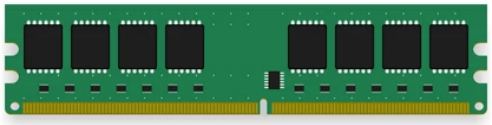

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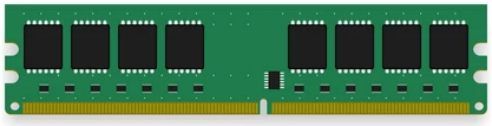

DRAM chips **cost**
30% of a datacenter

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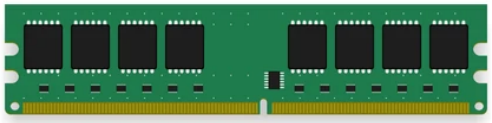

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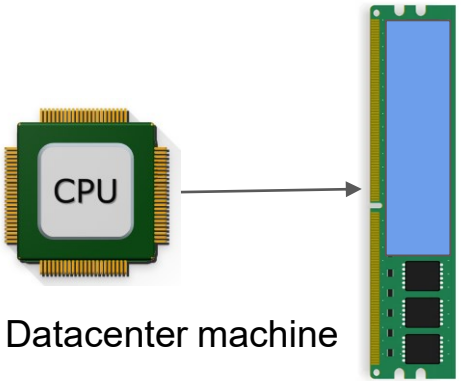
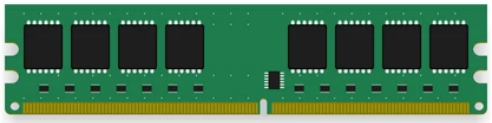


Datacenter machine

Memory management in the datacenter



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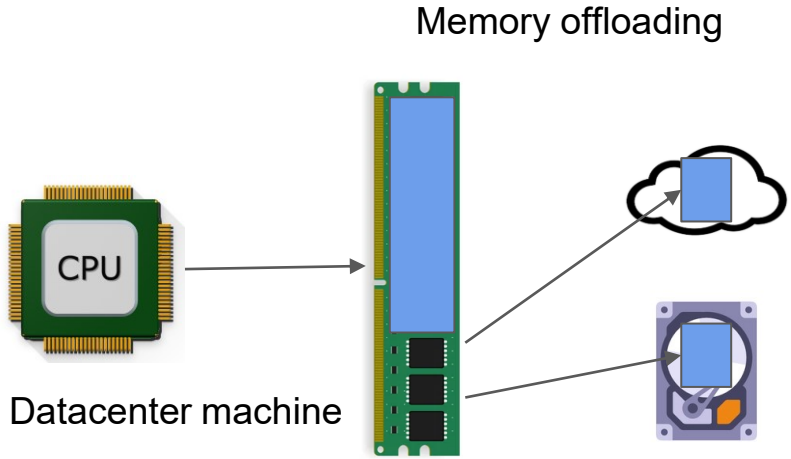

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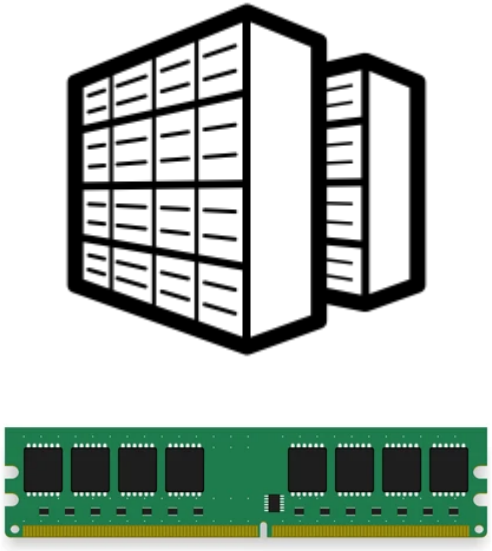

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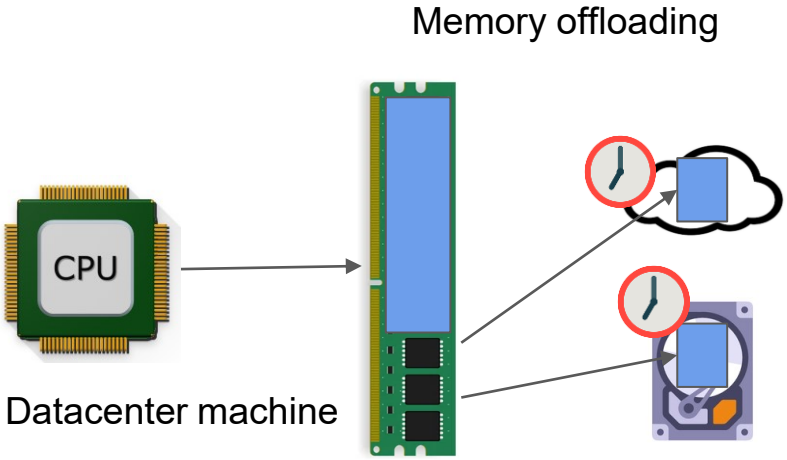
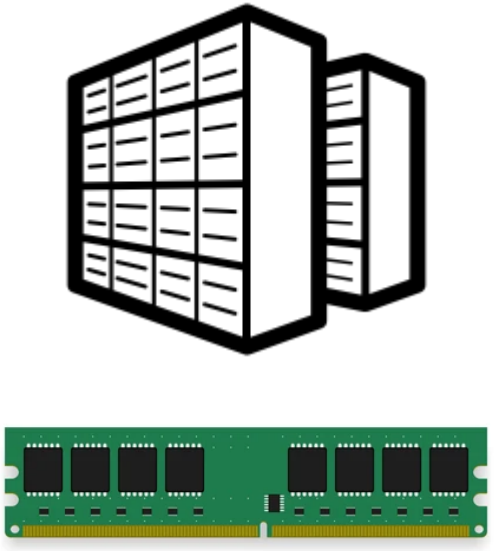
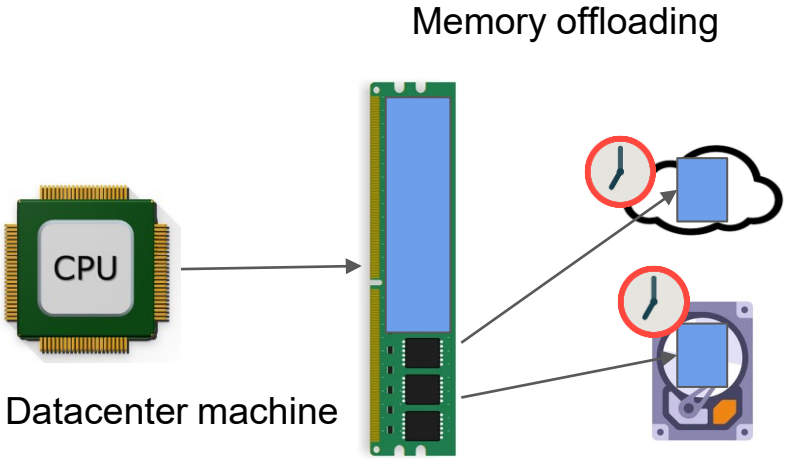


Access to these devices is **slower than DRAM**

Memory management in the datacenter





Prefetching memory pages is an **effective** way to minimize overhead

Problem with current kernel prefetchers

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Sequential patterns:

```
for( i = 0; i < 1000; i++) {
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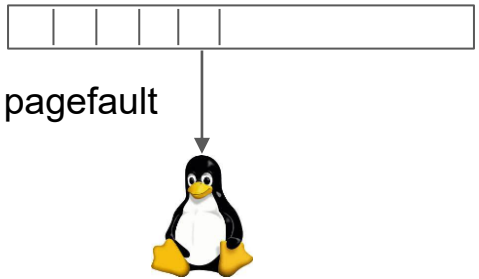

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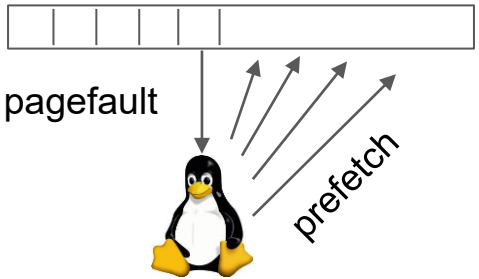

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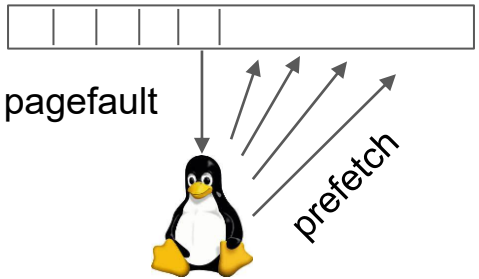

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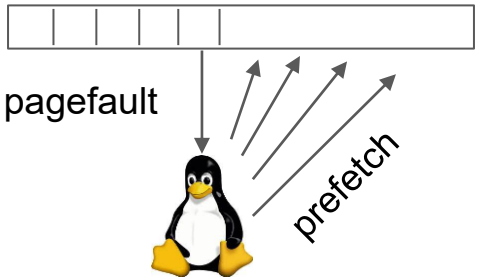

Current kernel prefetchers are **good with sequential** accesses that show regular access patterns

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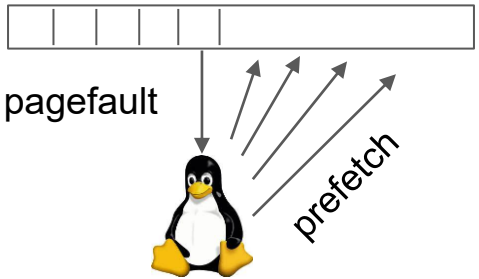

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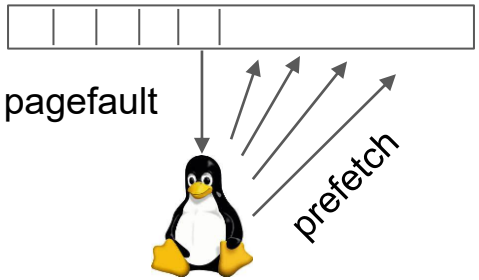


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User u = session.getUser();
Account a = u.getAccount();
Balance b = a.getBalance();
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```
while(!curr) {
        curr = curr->next
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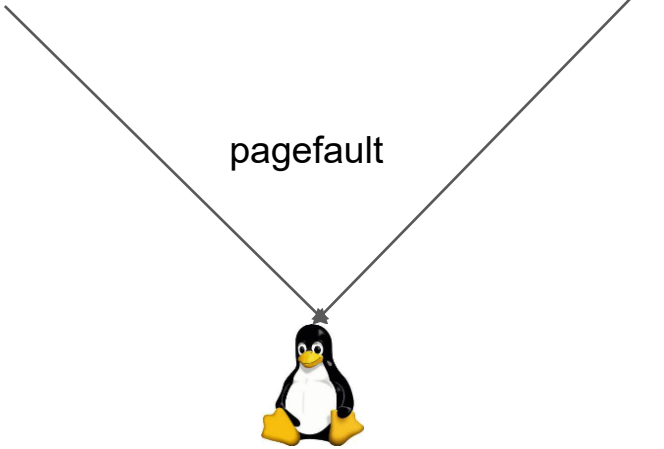

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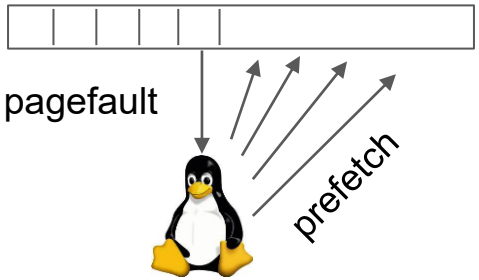


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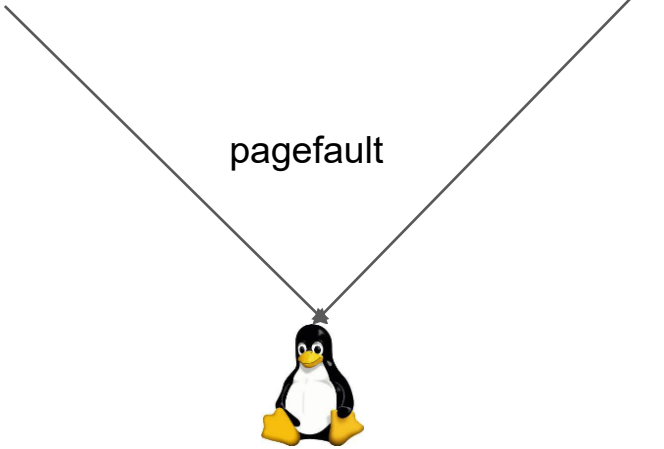

Current kernel prefetchers are **ineffective for irregular patterns** such as reference or pointer based patterns

Do pointer-based patterns even exist?

- What percentage of pointer accesses cause page faults?
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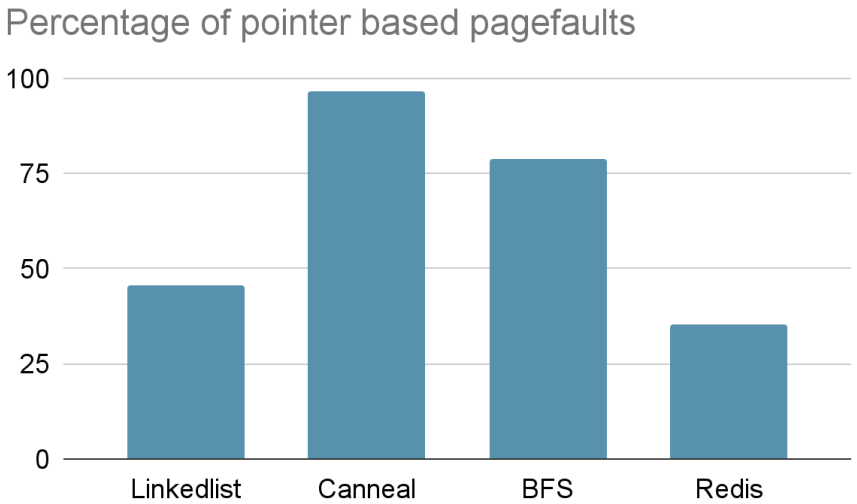

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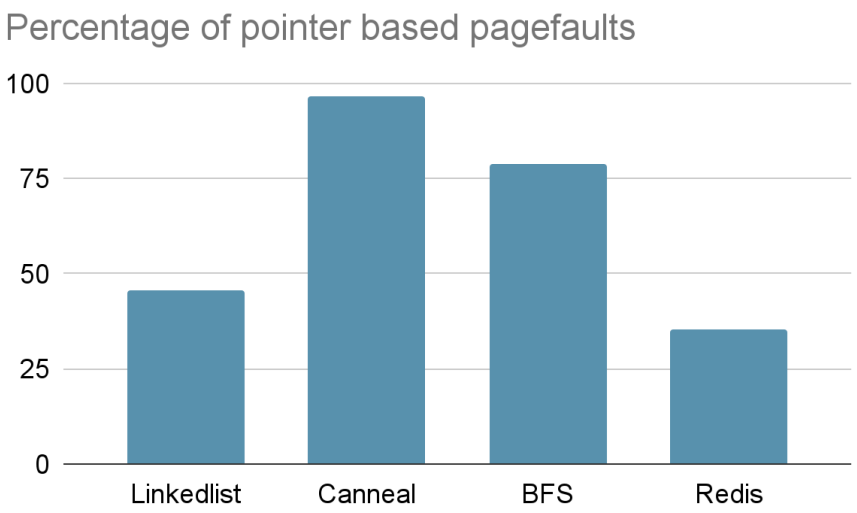

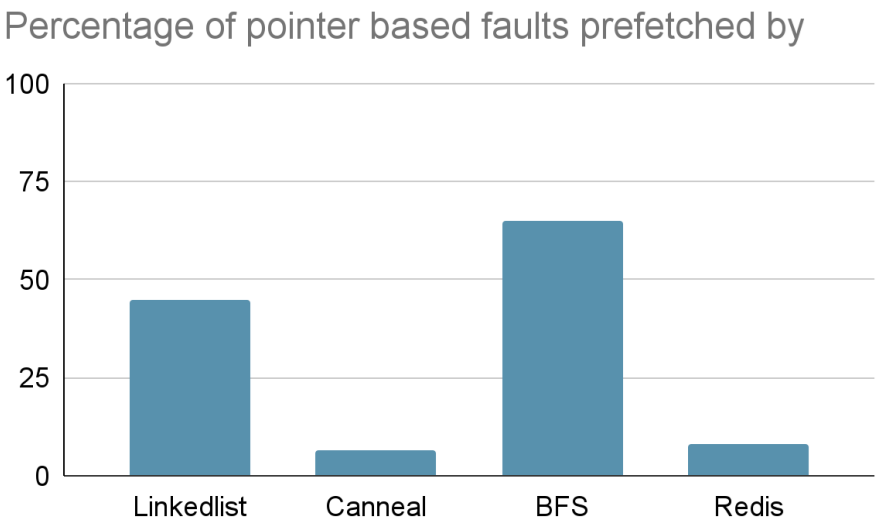

CHERI-picking

Coverage: The percentage of page faults that were satisfied by previously prefetched pages.

Approach	Application agnostic	Coverage
Strided kernel prefetcher		
Application specific approaches [1][2]		
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[1] Canvas: Isolated and Adaptive Swapping for Multi-Applications on Remote Memory. Wang et. al. NSDI 2023
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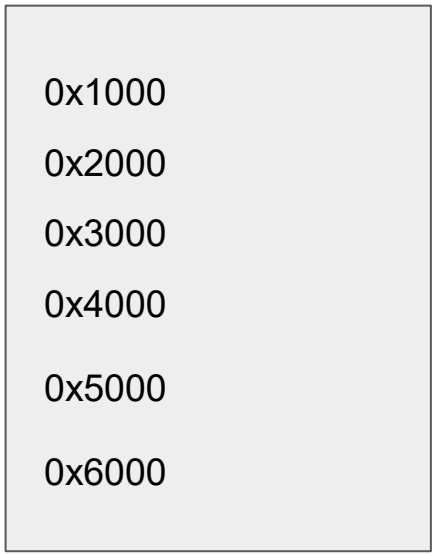

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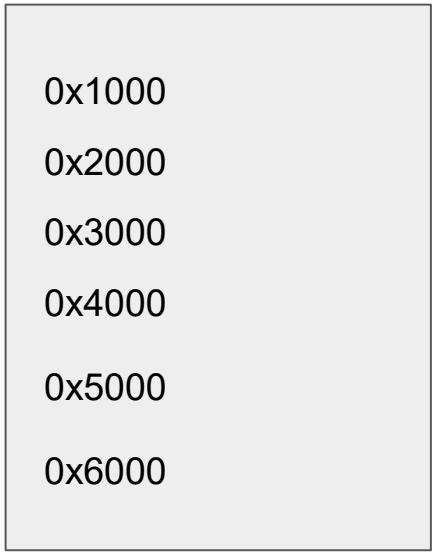
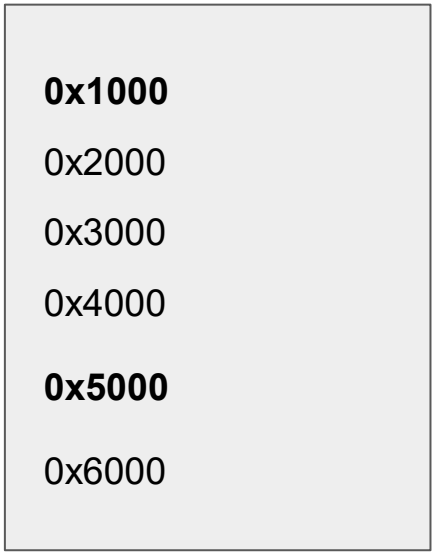


With CHERI



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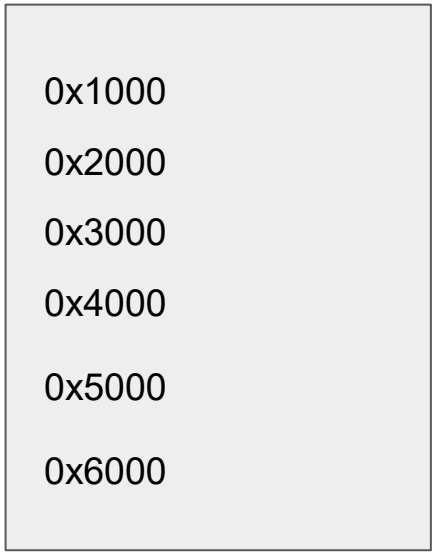

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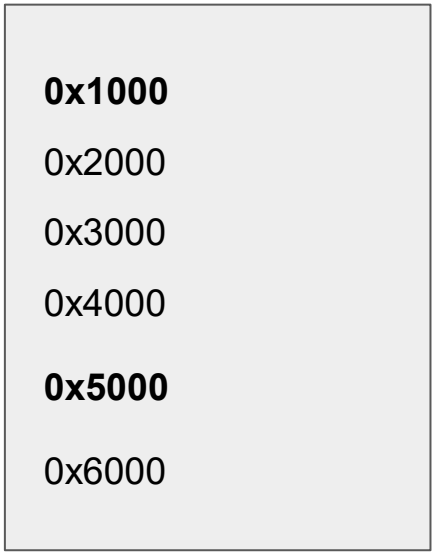

Tag bits
100010

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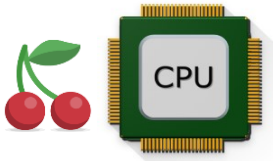
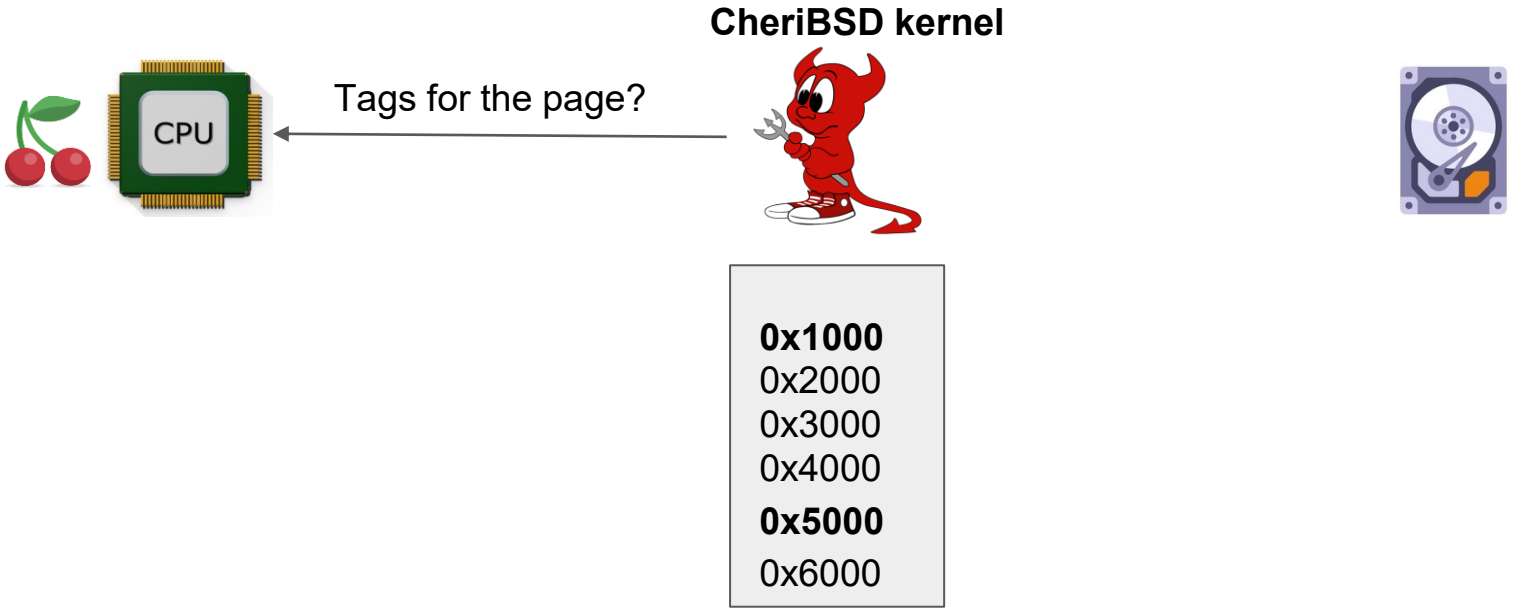
CHERI and swap



CheriBSD kernel

0x1000
0x2000
0x3000
0x4000
0x5000
0x6000

CHERI and swap



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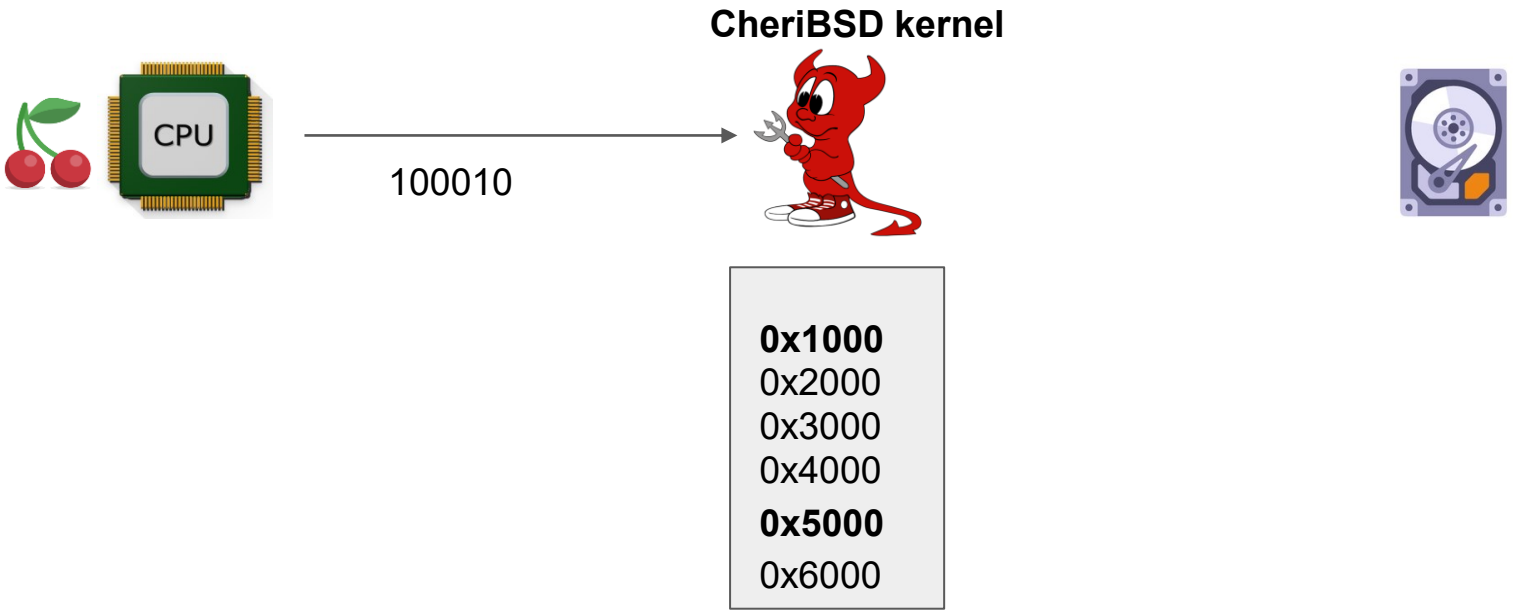
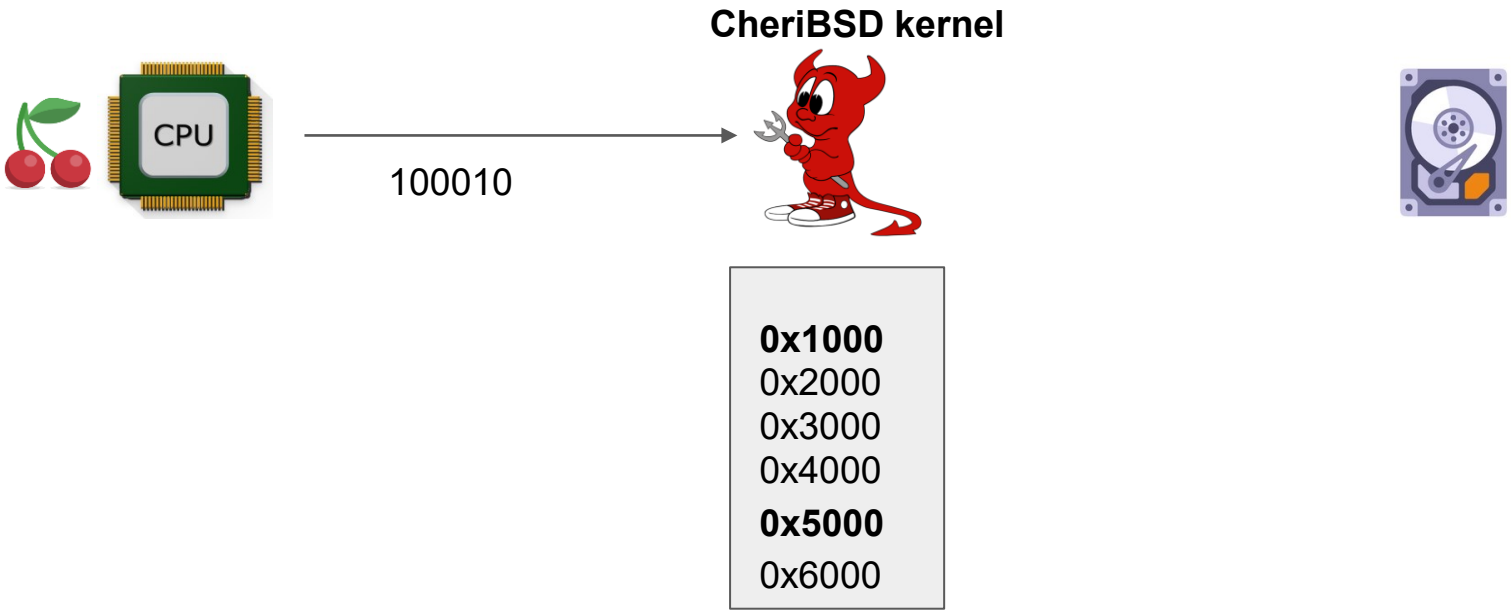


CHERI and swap

Internal tag bitmap



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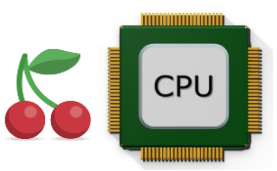

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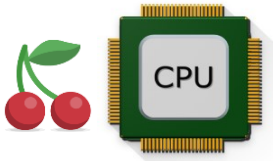

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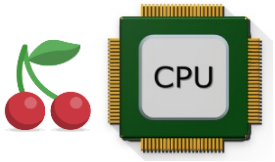

CheriBSD kernel

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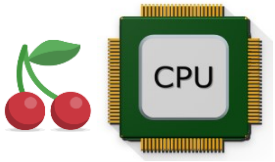

Internal tag bitmap

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CheriBSD kernel

Move page to swap

CHERI and swap

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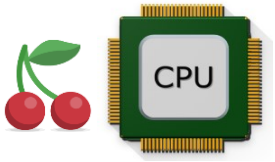

CheriBSD kernel

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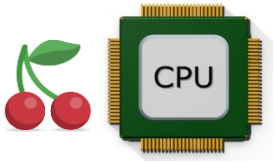

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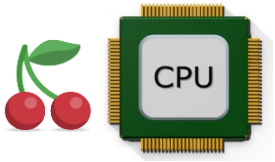

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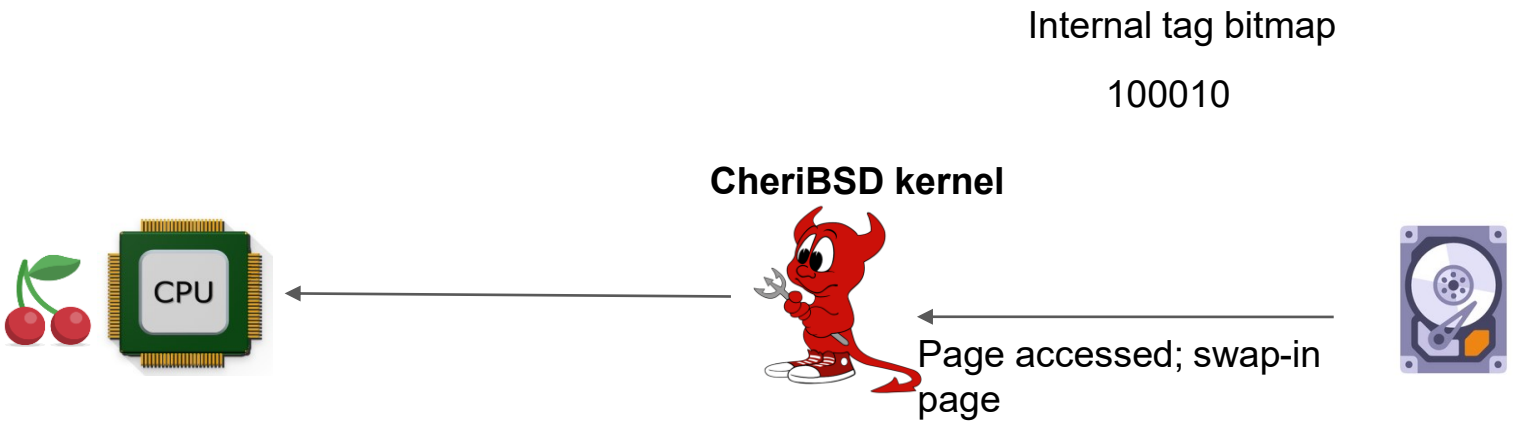
CheriBSD kernel

Page accessed; swap-in page

CHERI and swap



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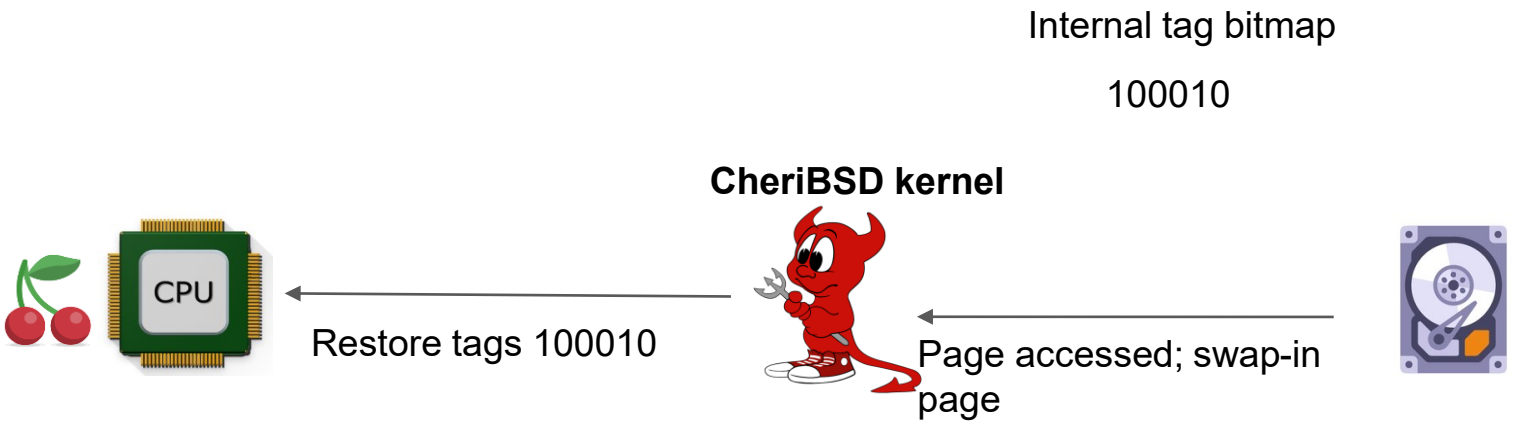

CHERI-picking overview and design

- CHERI-picking leverages CHERI to make prefetching decisions.
- CHERI treats all pointers as capabilities, that allows the OS to identify pointers in an application agnostic manner.

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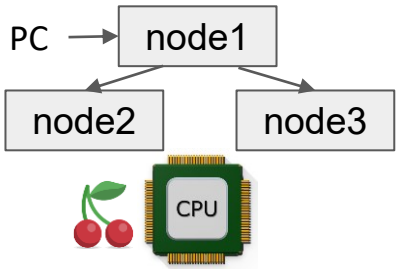

CheriBSD kernel

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Node 2	Mapped
Node 3	Swap

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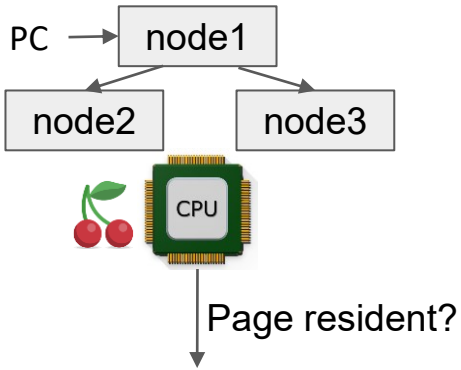

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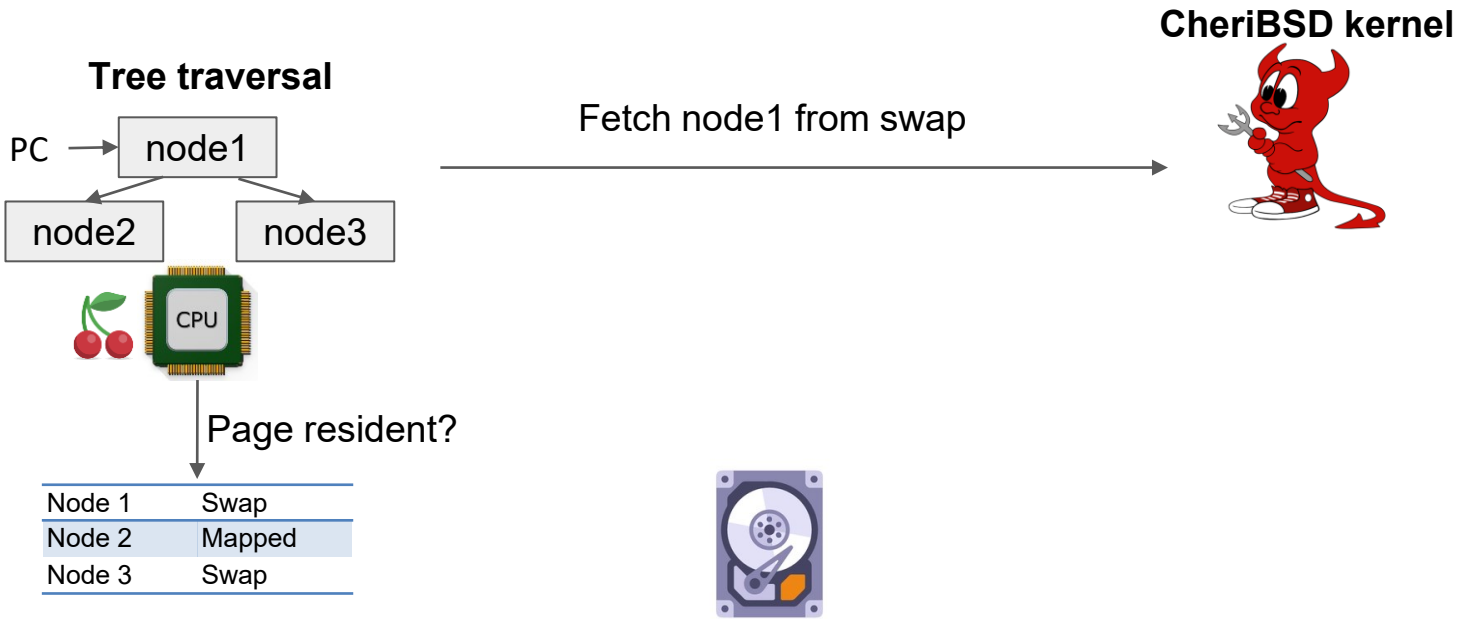

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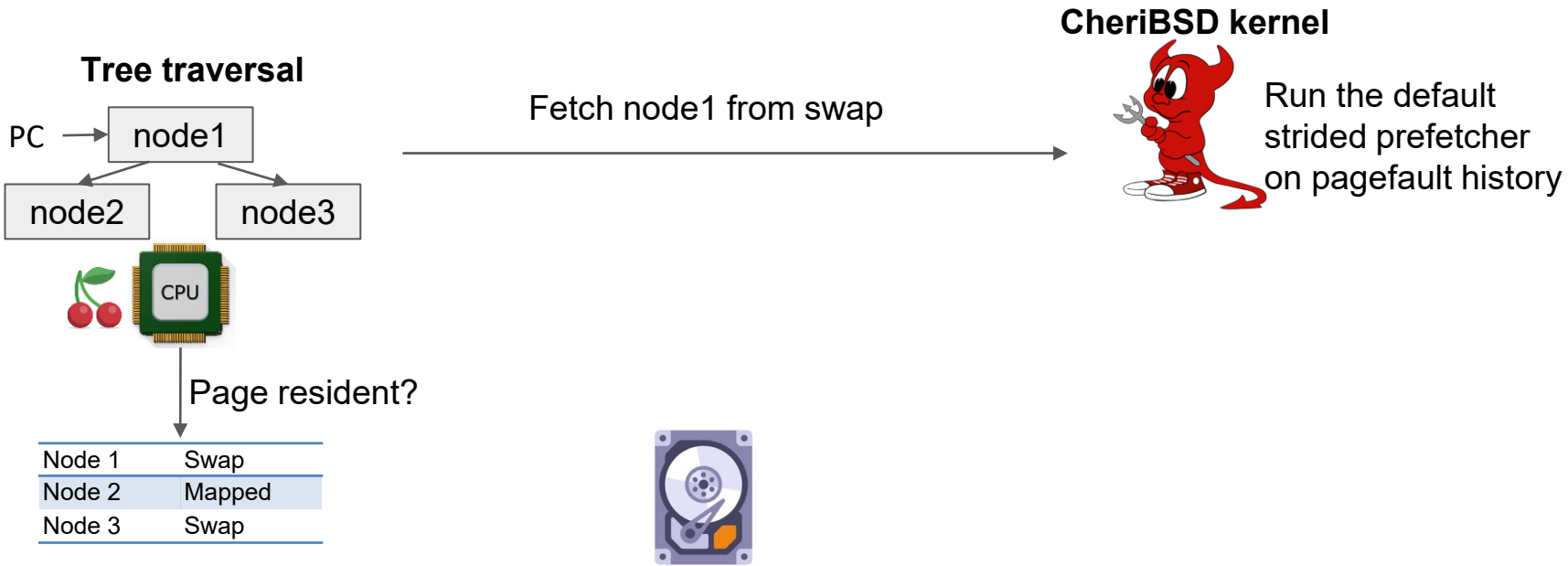

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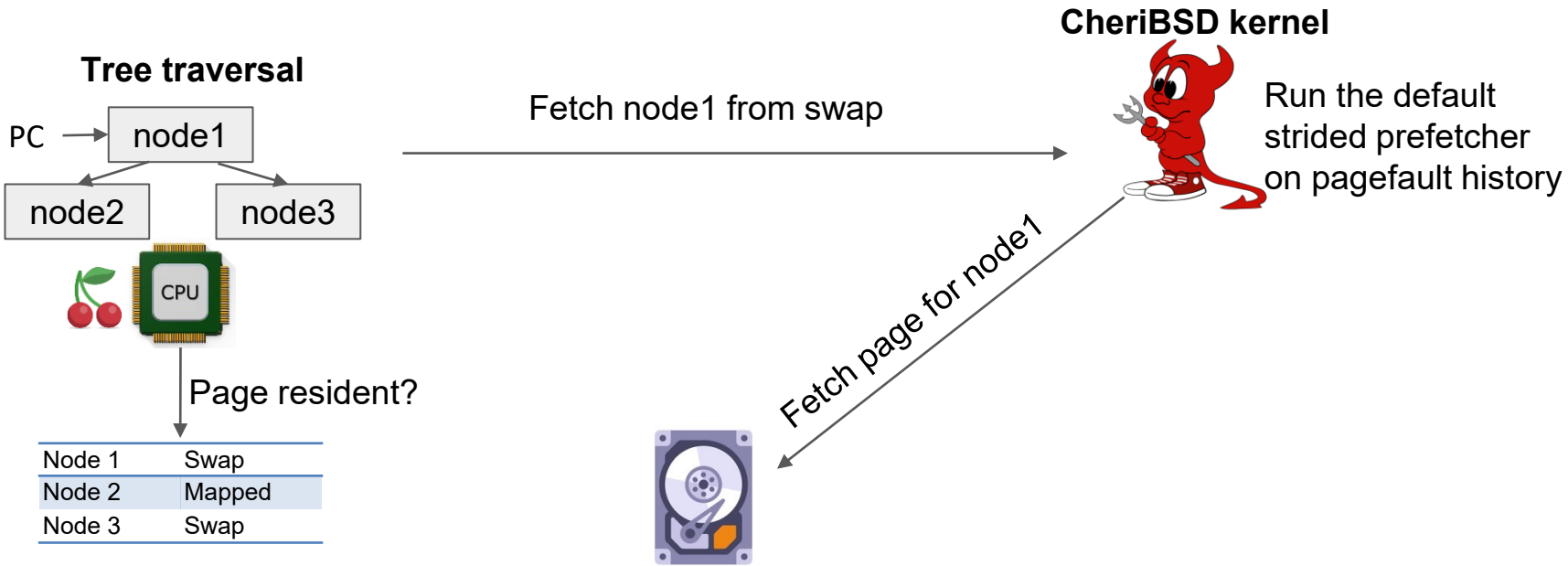

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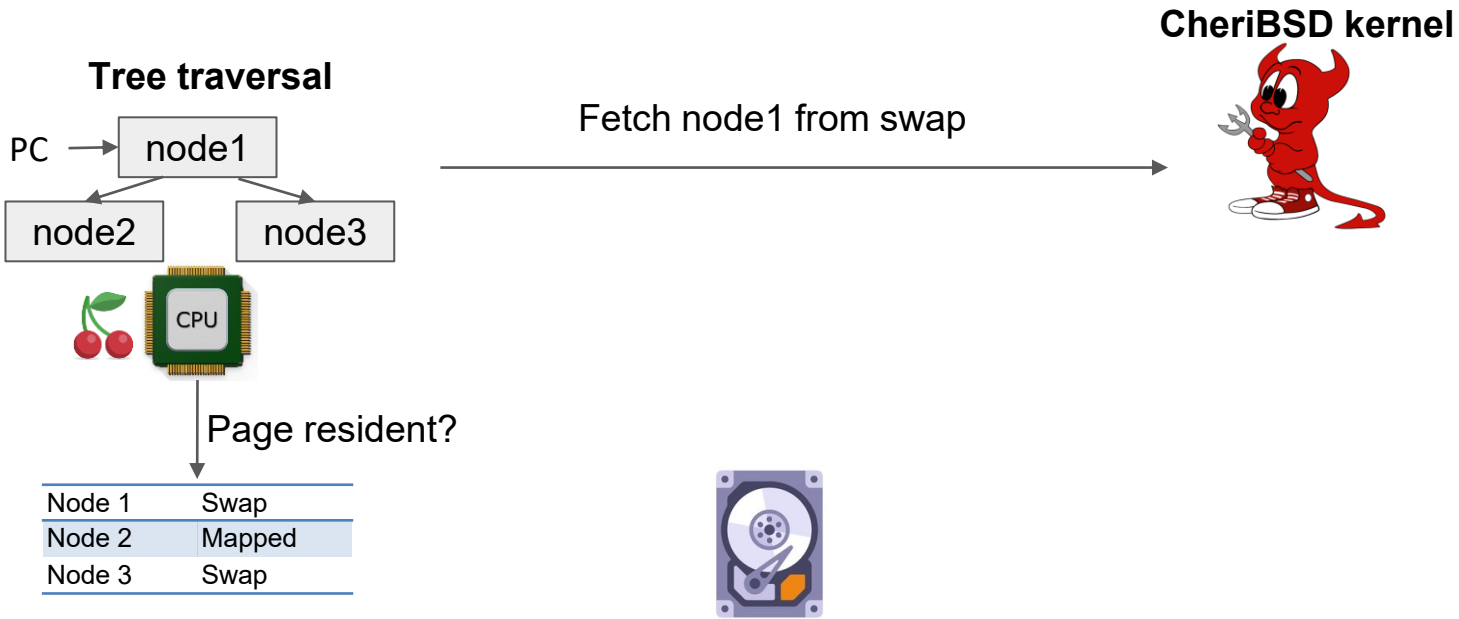

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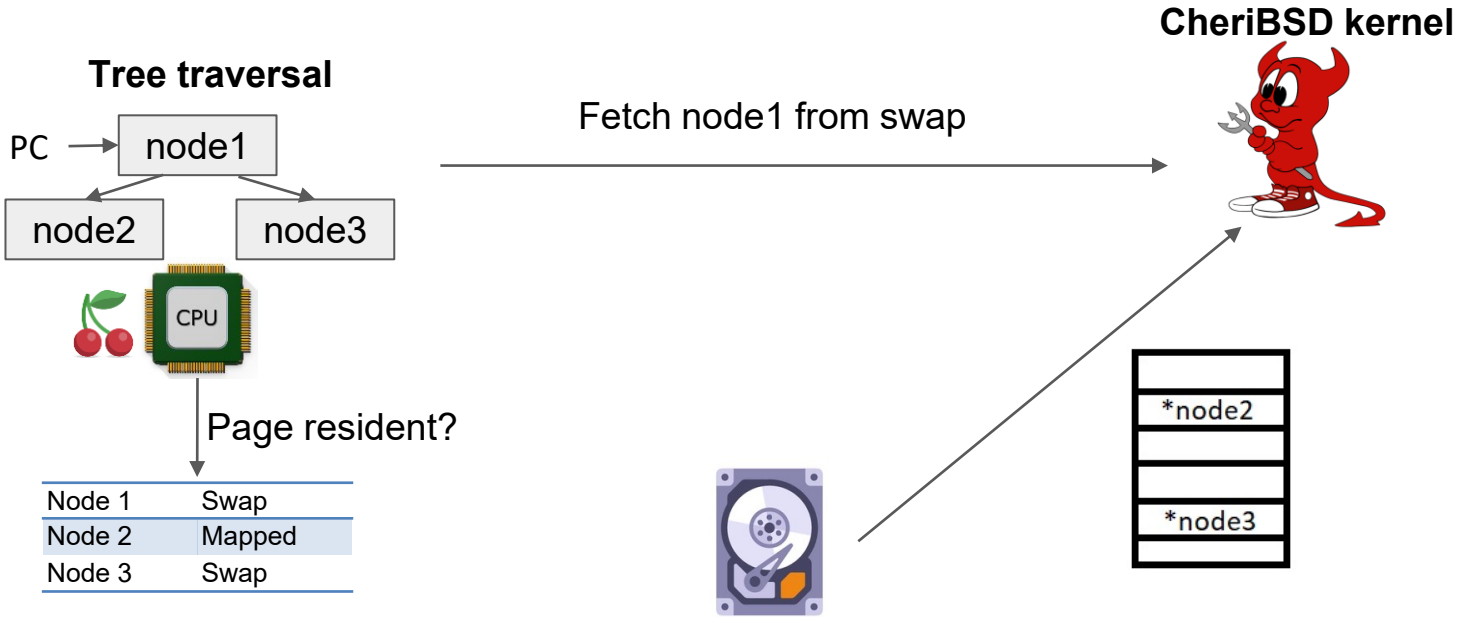

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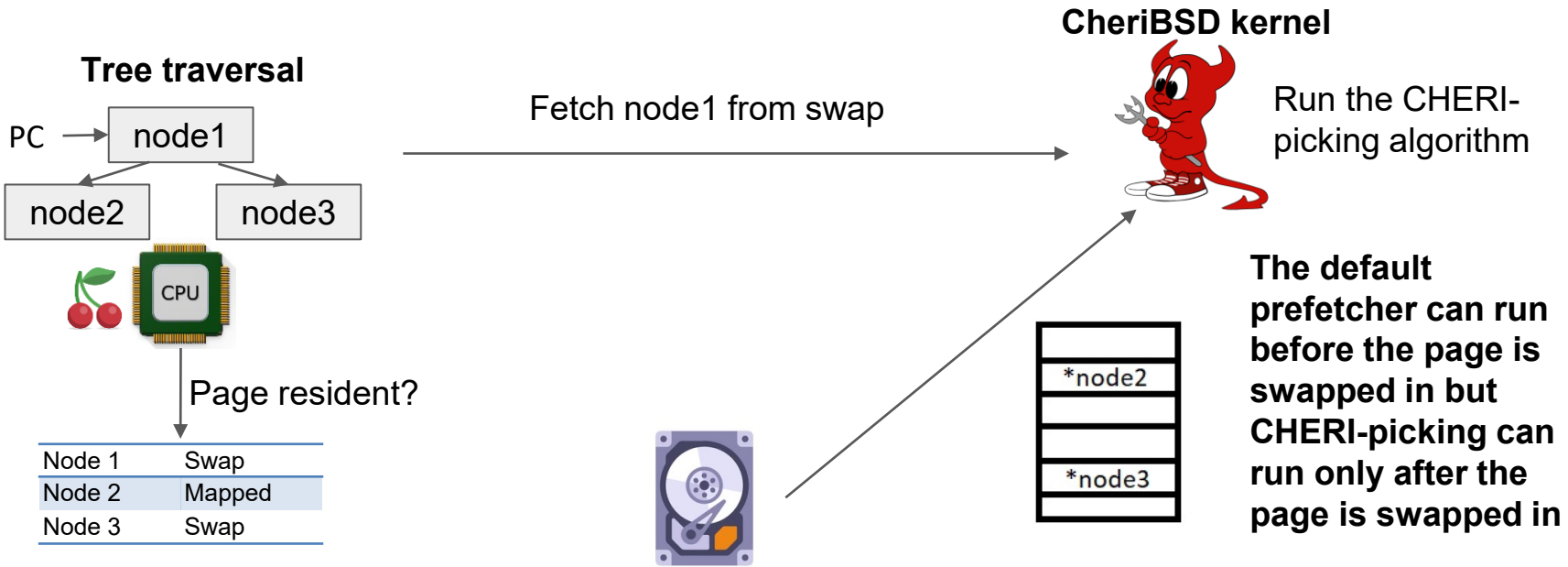

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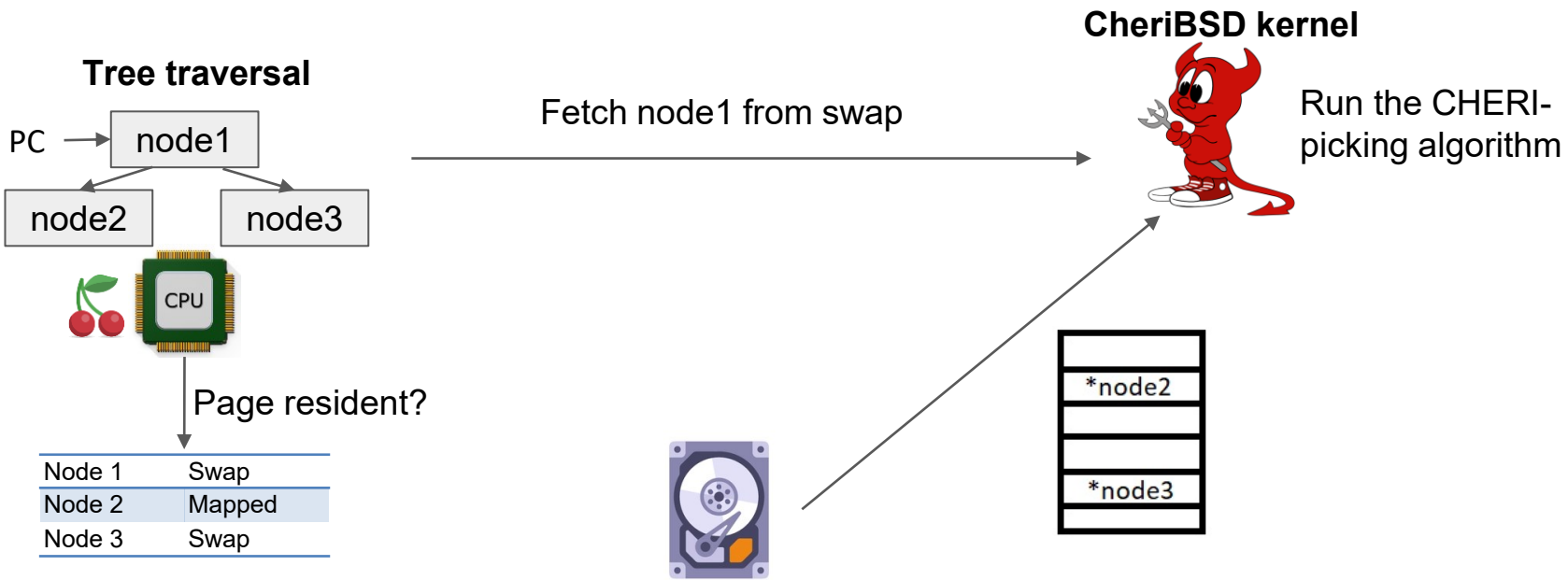

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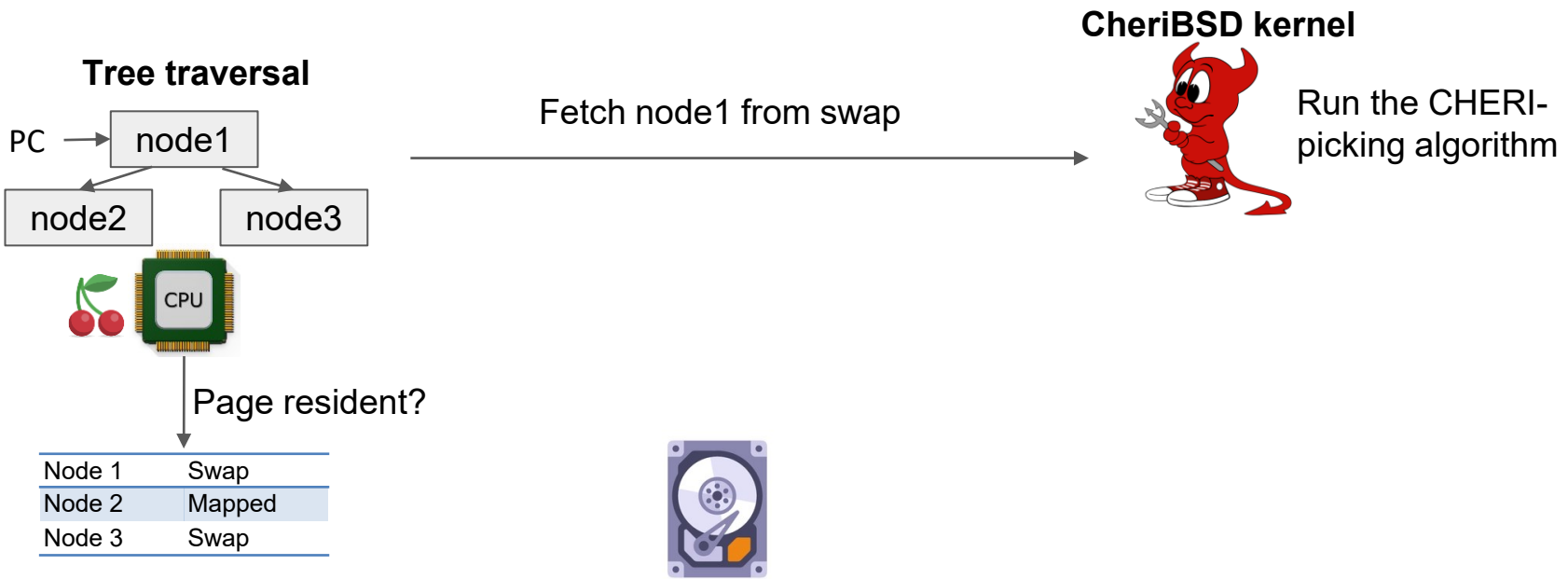

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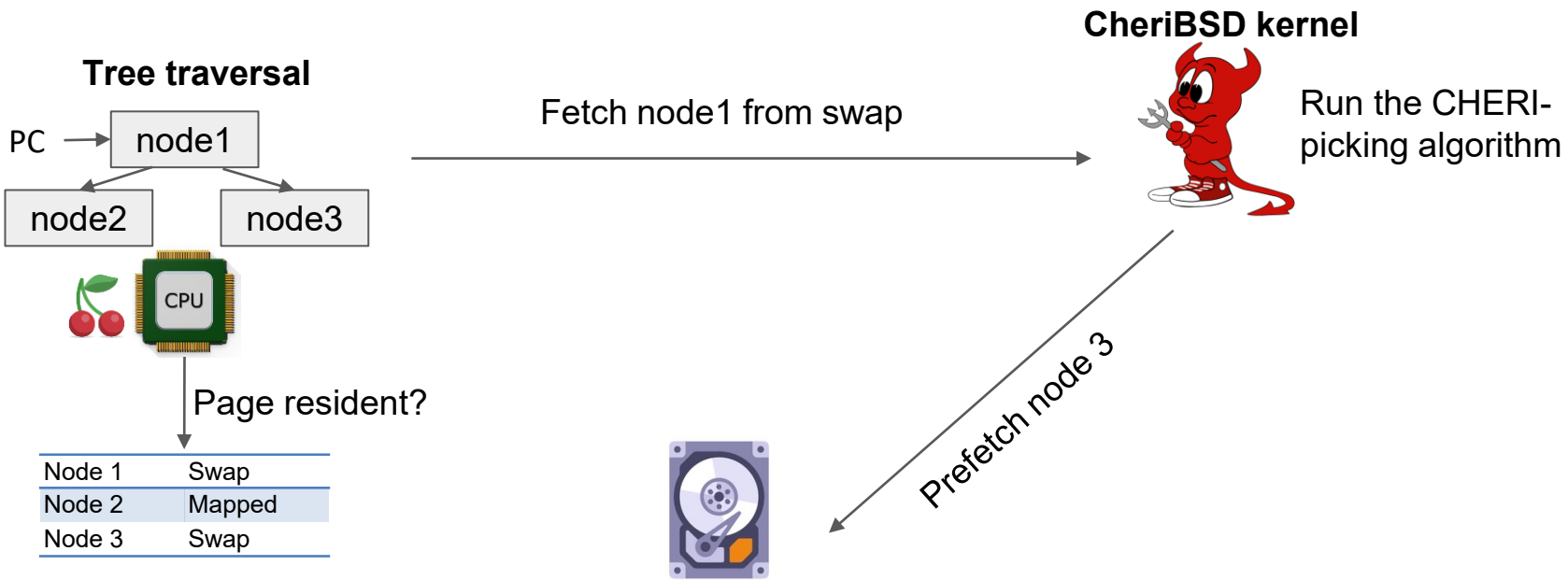

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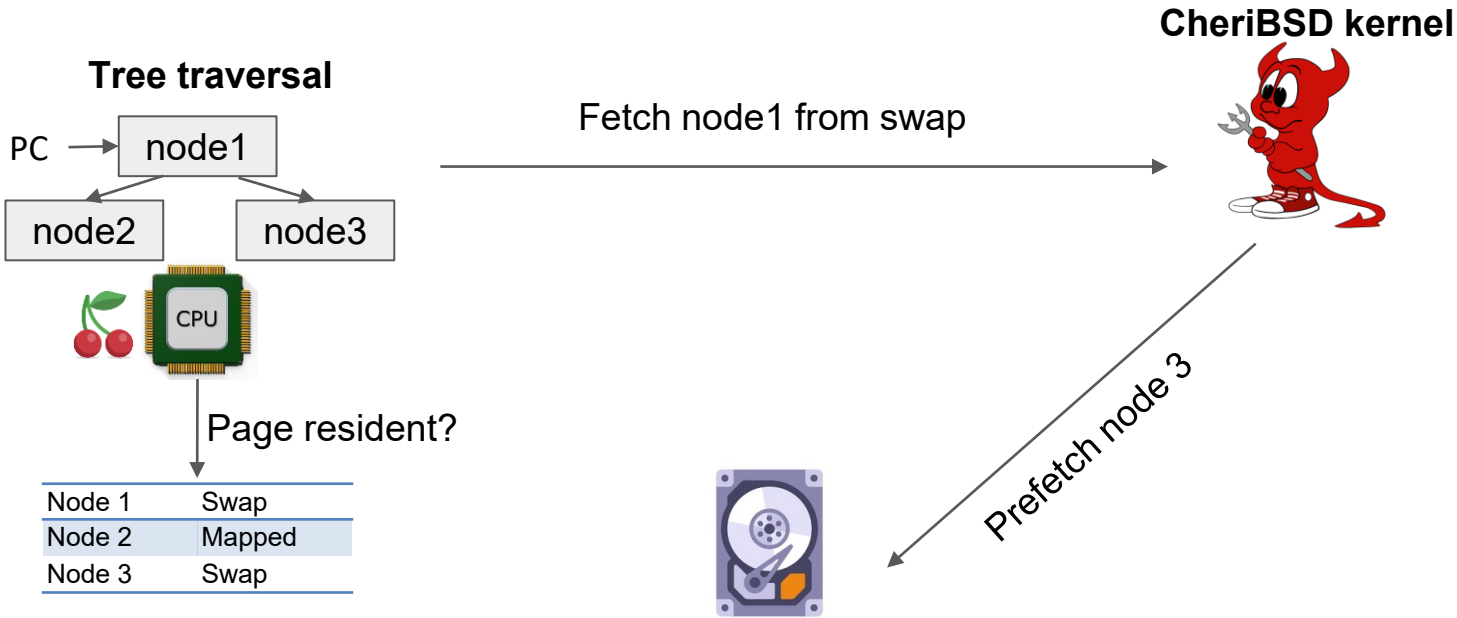

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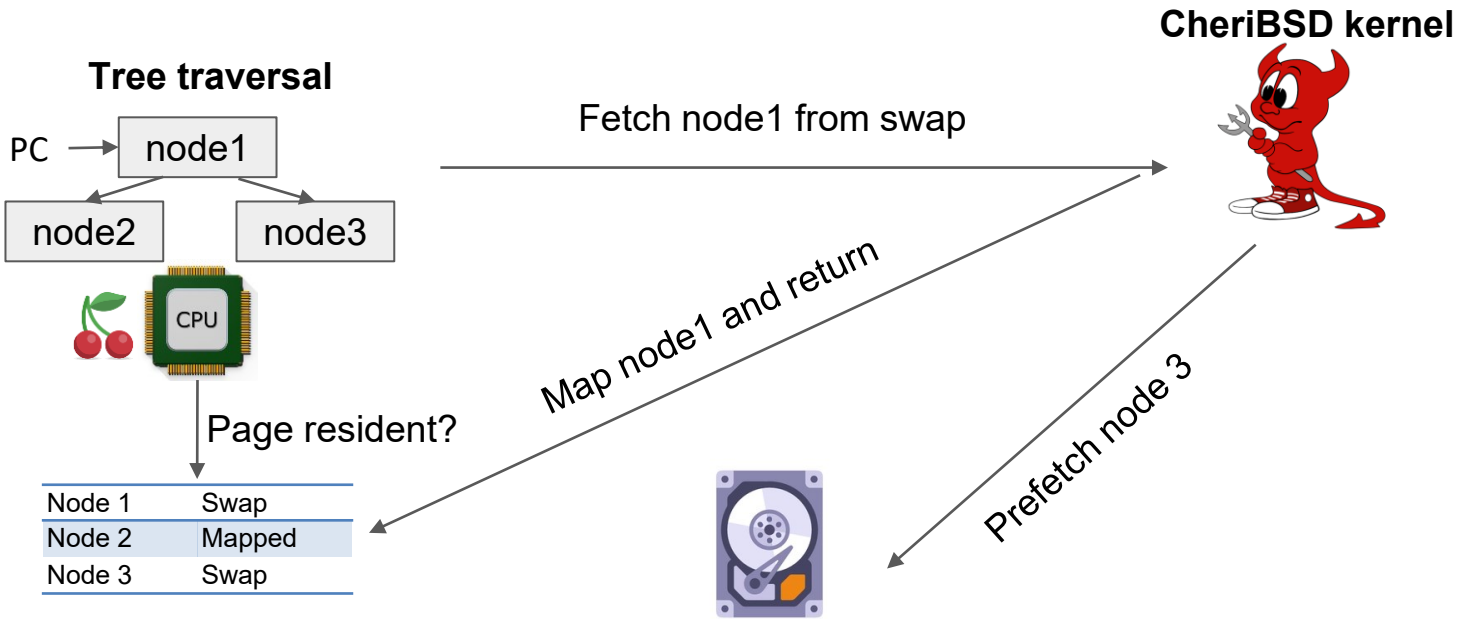


Evaluation

We implemented CHERI-picking in the **CheriBSD kernel version 22.12**

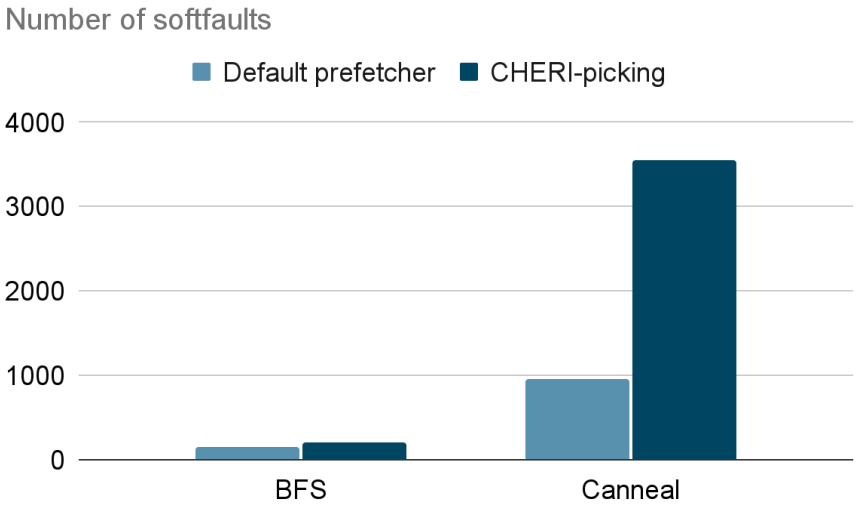
We run evaluations on an **ARM Morello CHERI-capable processor** that contains 4 cores running at 2.4GHz. We limit memory so that the working set size of applications is twice that of the available memory, inducing memory pressure.

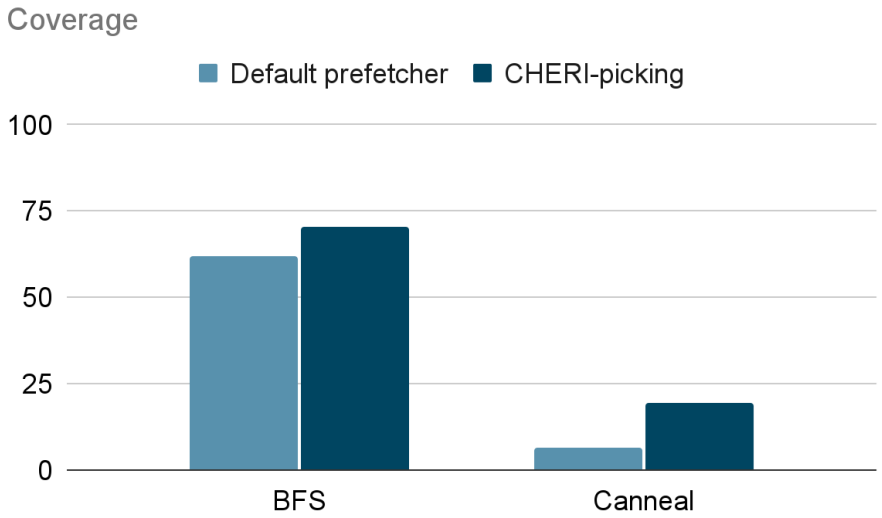
Metrics:

Soft faults: These page faults occur when a page is already in memory, but not mapped into an application's address space; **indicating the prefetcher's prediction capacity.**

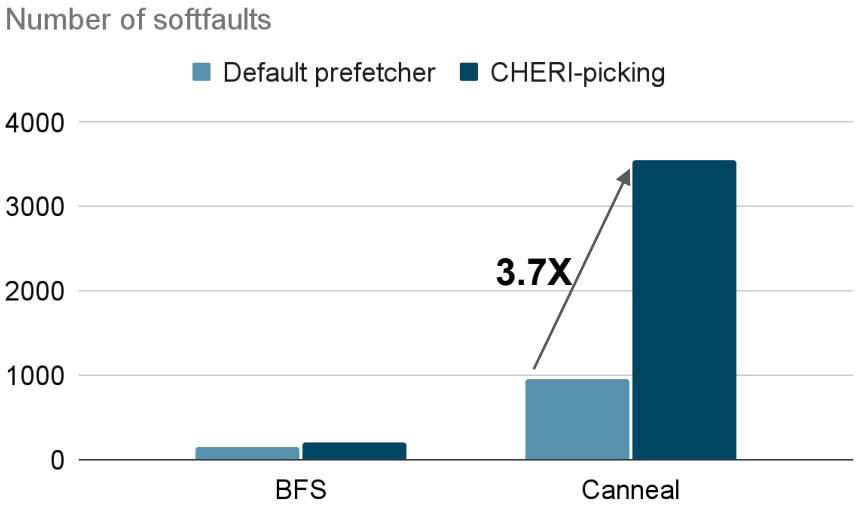
Coverage: The **percentage of page faults that were satisfied** by previously prefetched pages.

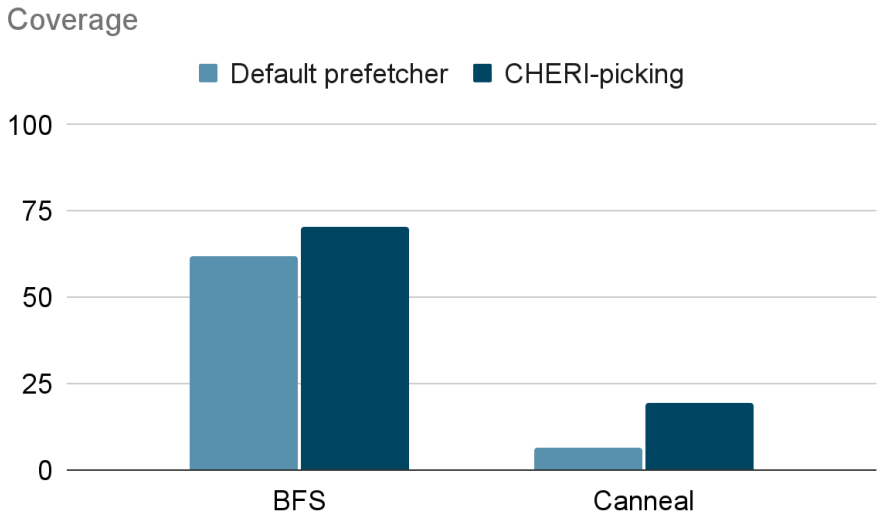
Evaluation


Number of softfaults
Default prefetcher
CHERI-picking
4000
3000
2000
1000
0
BFS
Canneal


Coverage
Default prefetcher
CHERI-picking
100
75
50
25
0
BFS
Canneal

Evaluation


Number of softfaults
Default prefetcher
CHERI-picking
4000
3000
2000
1000
0
3.7X
BFS
Canneal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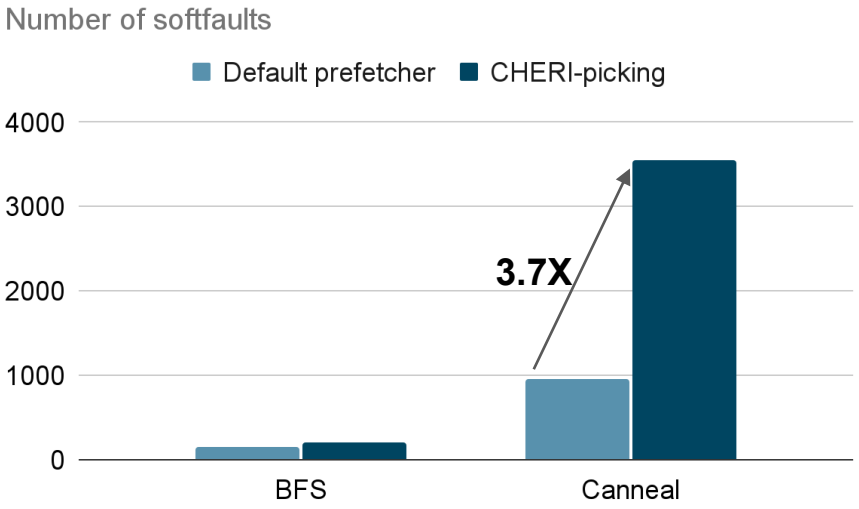
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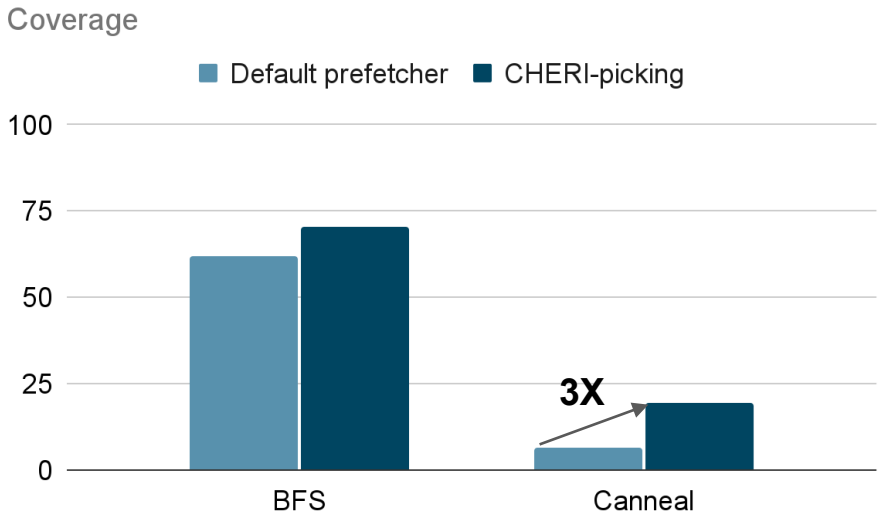
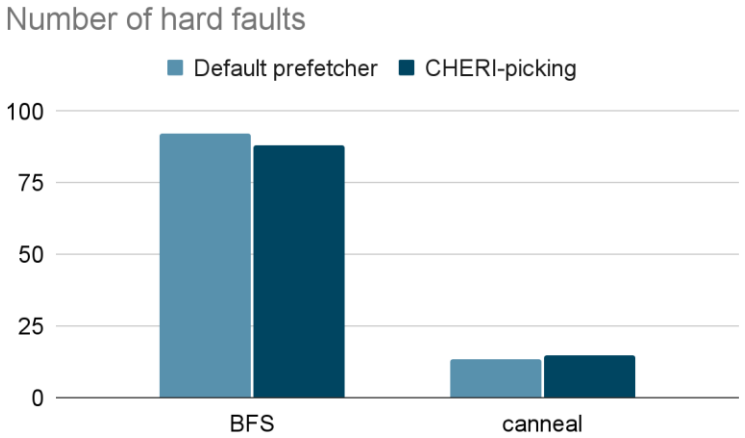

Coverage
Default prefetcher
CHERI-picking
100
75
50
25
0
3X
BFS
Canneal

Challenges

- **The CHERI-picking algorithm is naive** and has low accuracy. Major faults are mandatory pagefaults for pages not present in memory.
- **The overhead of running the CHERI-picking algorithm is high** which limits end to end performance improvement.



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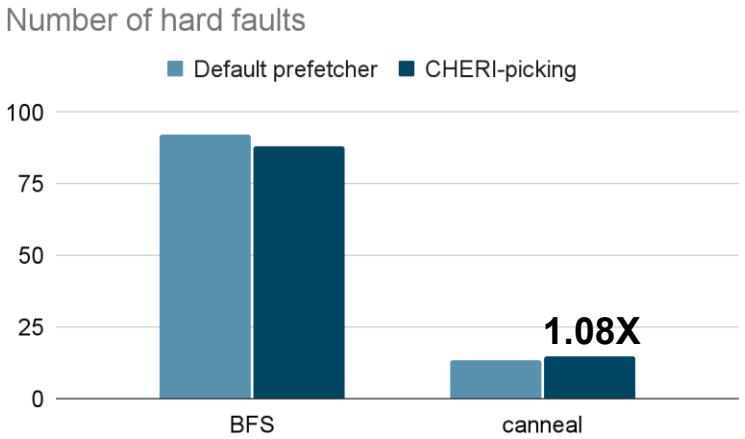

Summary

We develop an analyzer and show that applications experience **non-trivial amount of pointer-based pagefaults**.

We introduce CHERI-picking an **application agnostic kernel pointer prefetcher**.

We find that CHERI-picking **improves prefetching coverage by 3X.**

We plan to optimize the CHERI-picking algorithm and improve end to end performance in the future.