AIFM: High-Performance, Application-Integrated Far Memory

Zain (Zhenyuan) Ruan[*] Malte Schwarzkopf[†] Marcos K. Aguilera[‡] Adam Belay[*]

[*]MIT CSAIL [†]Brown University [‡]VMware Research

In-Memory Applications

Data Analytics

Web Caching

Database

Graph Processing

Memory Is Inelastic

- Limited by the server physical boundary.

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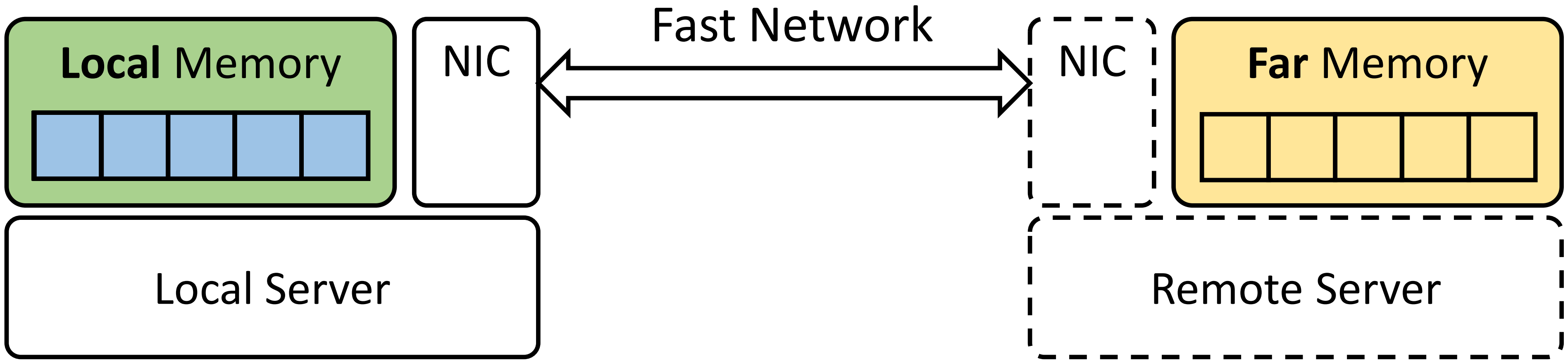
➢ Expensive solution: overprovision memory for peak usage.

Trending Solution: Far Memory

➢Leverage the idle memory of remote servers (with fast network).



Existing Far-Memory Systems Perform Poorly

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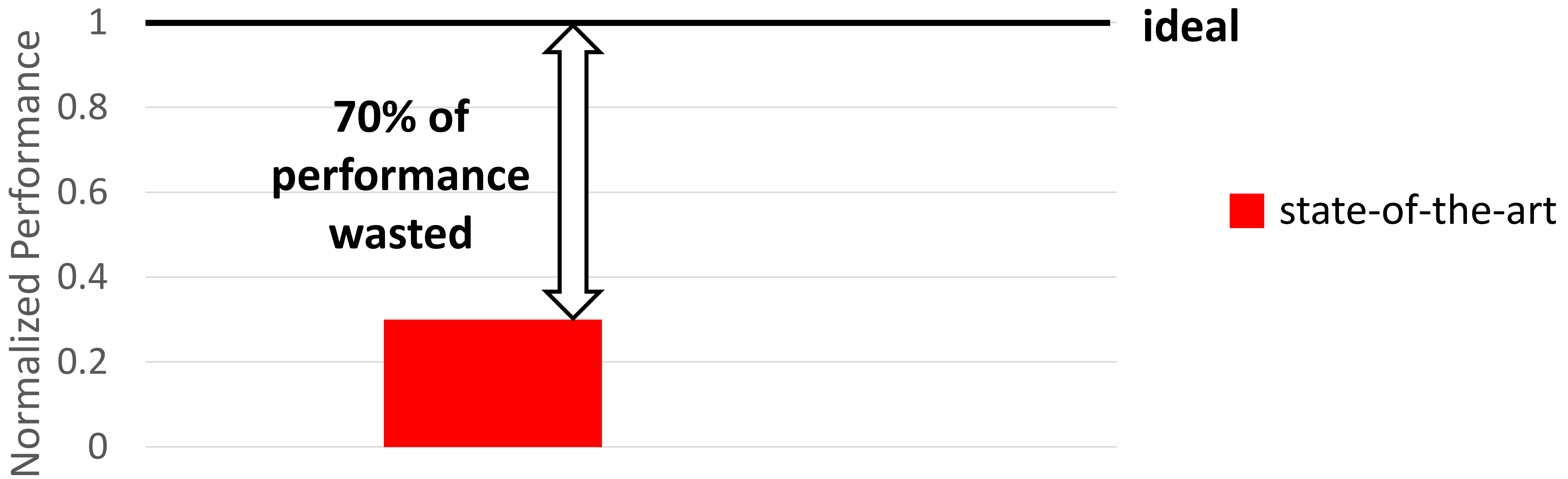

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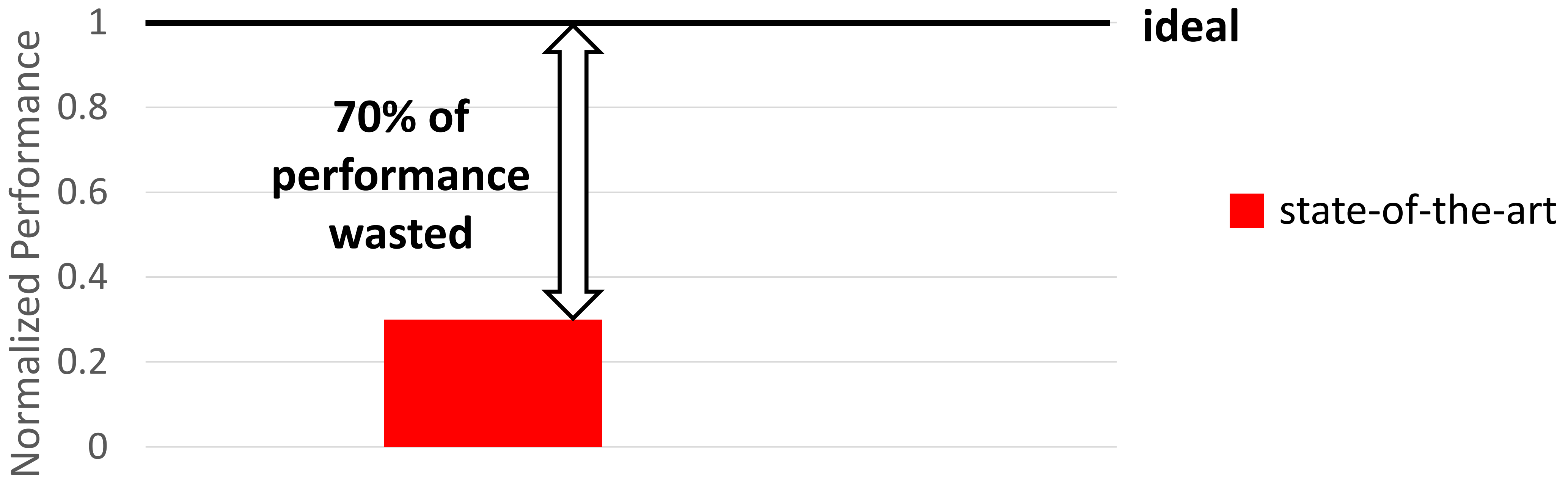

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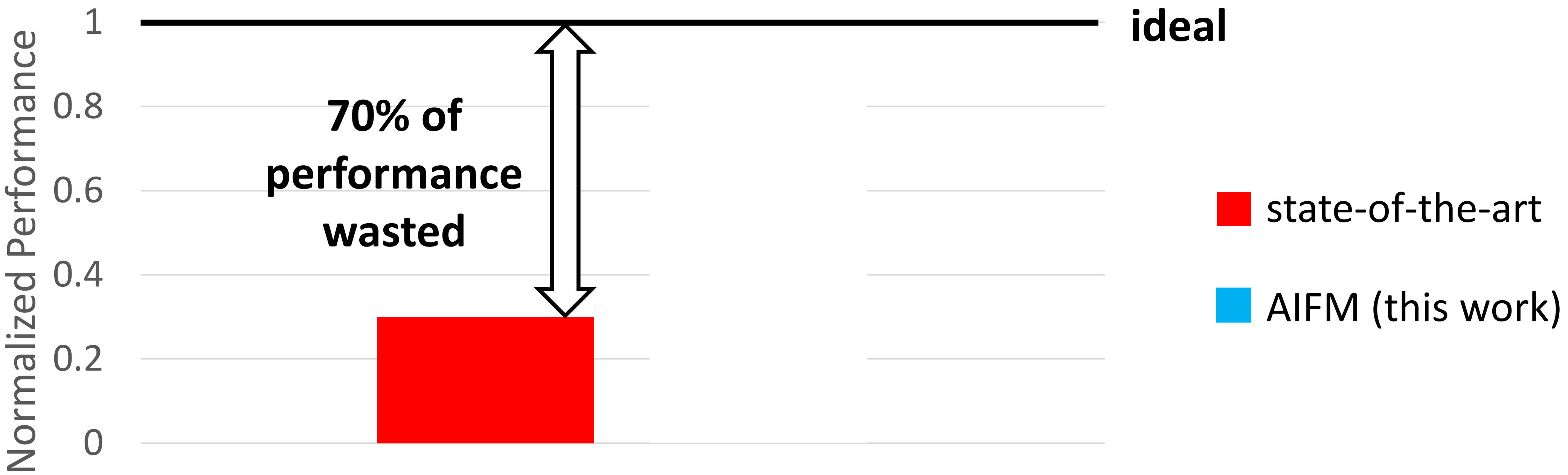

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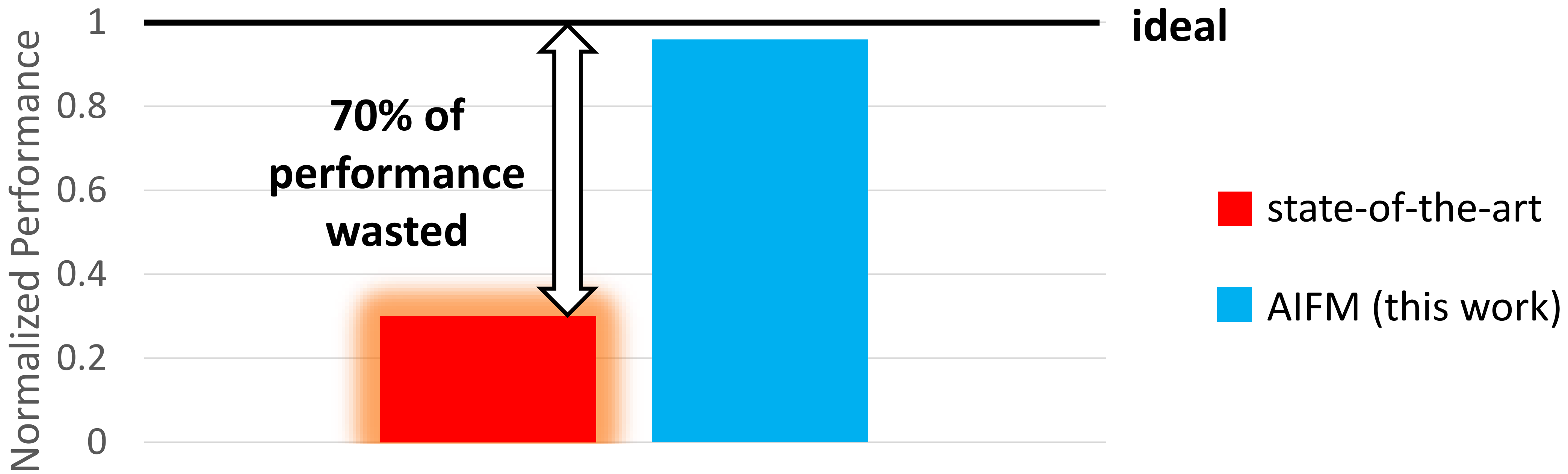
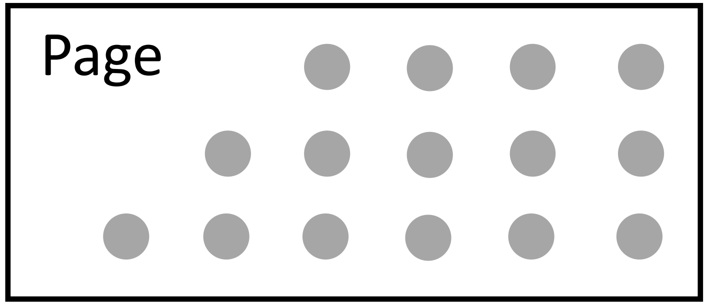


Why Do Existing Systems Waste Performance?

- Problem: based on **OS paging**.
  - Semantic gap.
  - High kernel overheads.

Challenge 1: Semantic Gap

- ➢Page granularity → **R/W amplification.**



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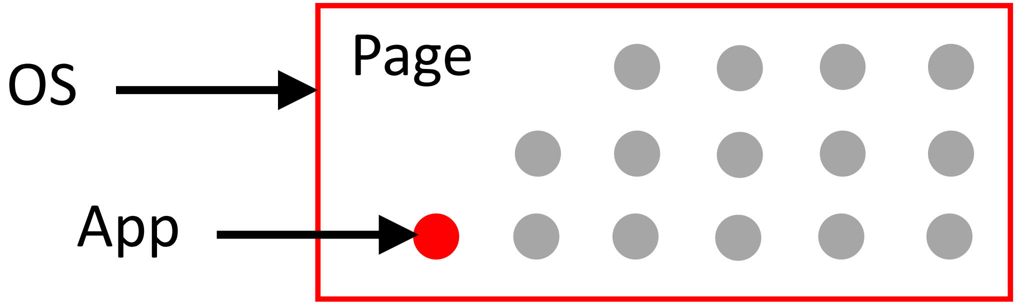

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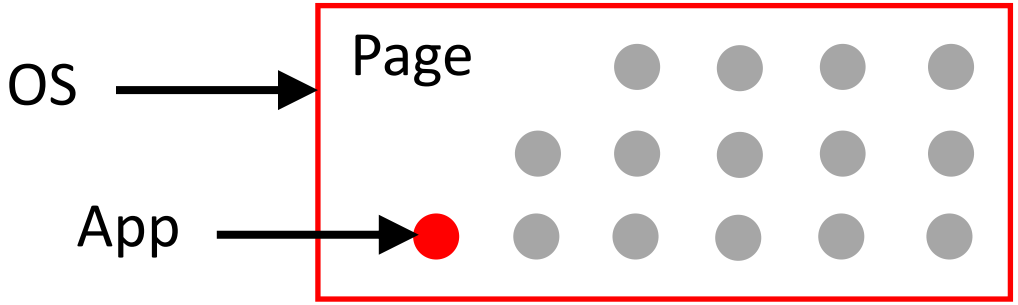

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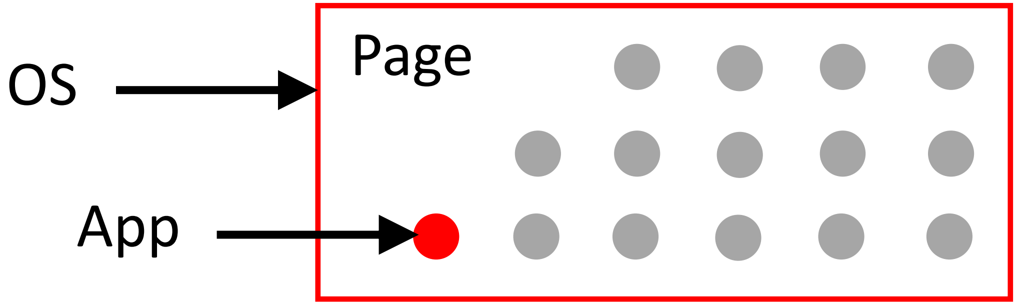

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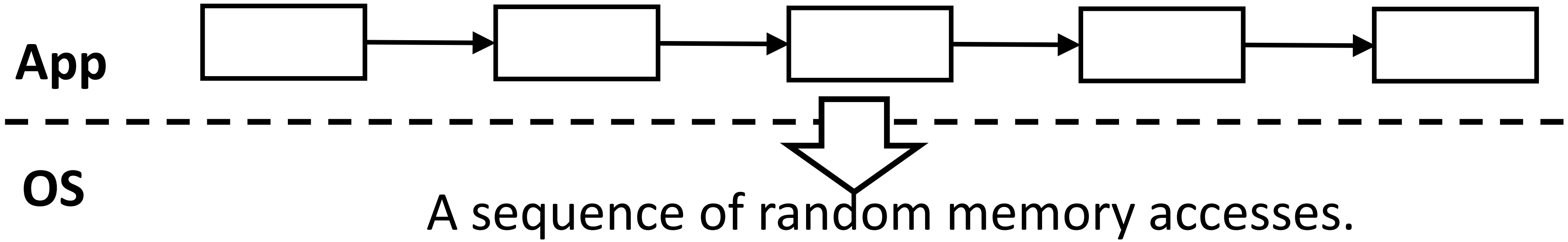

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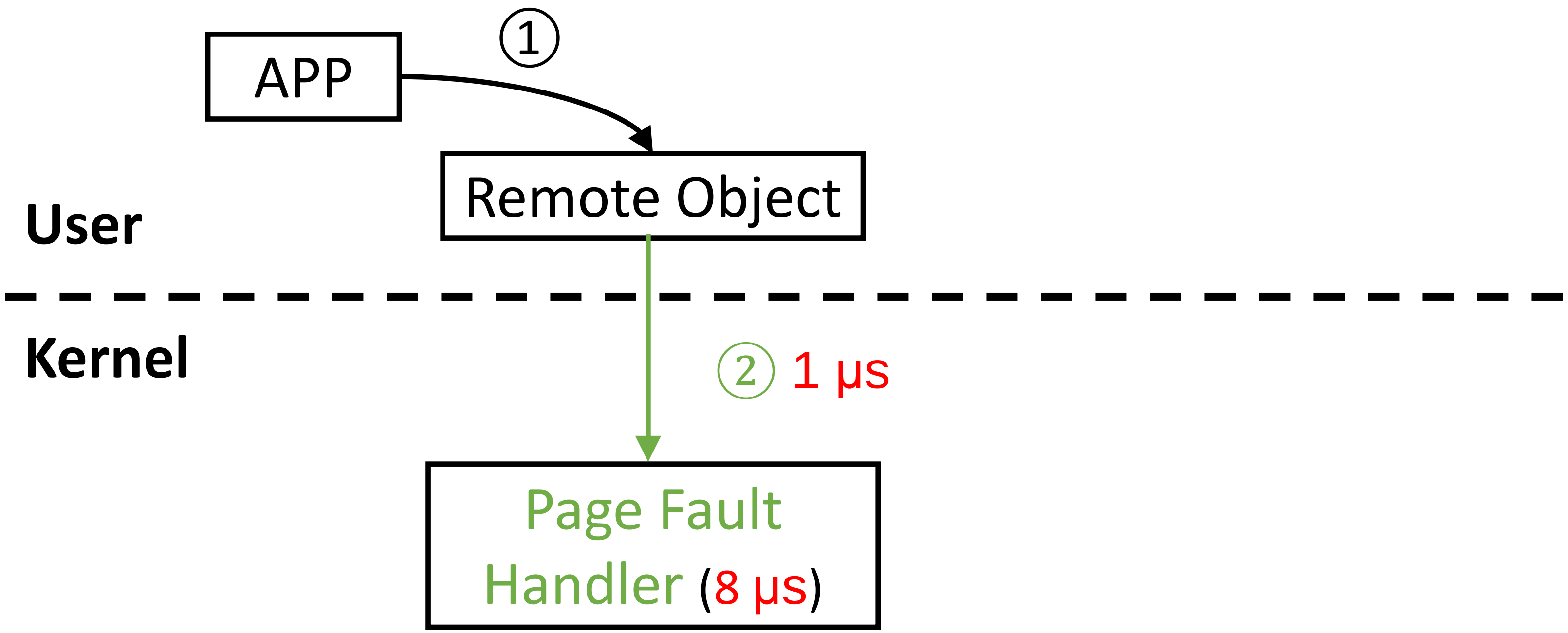

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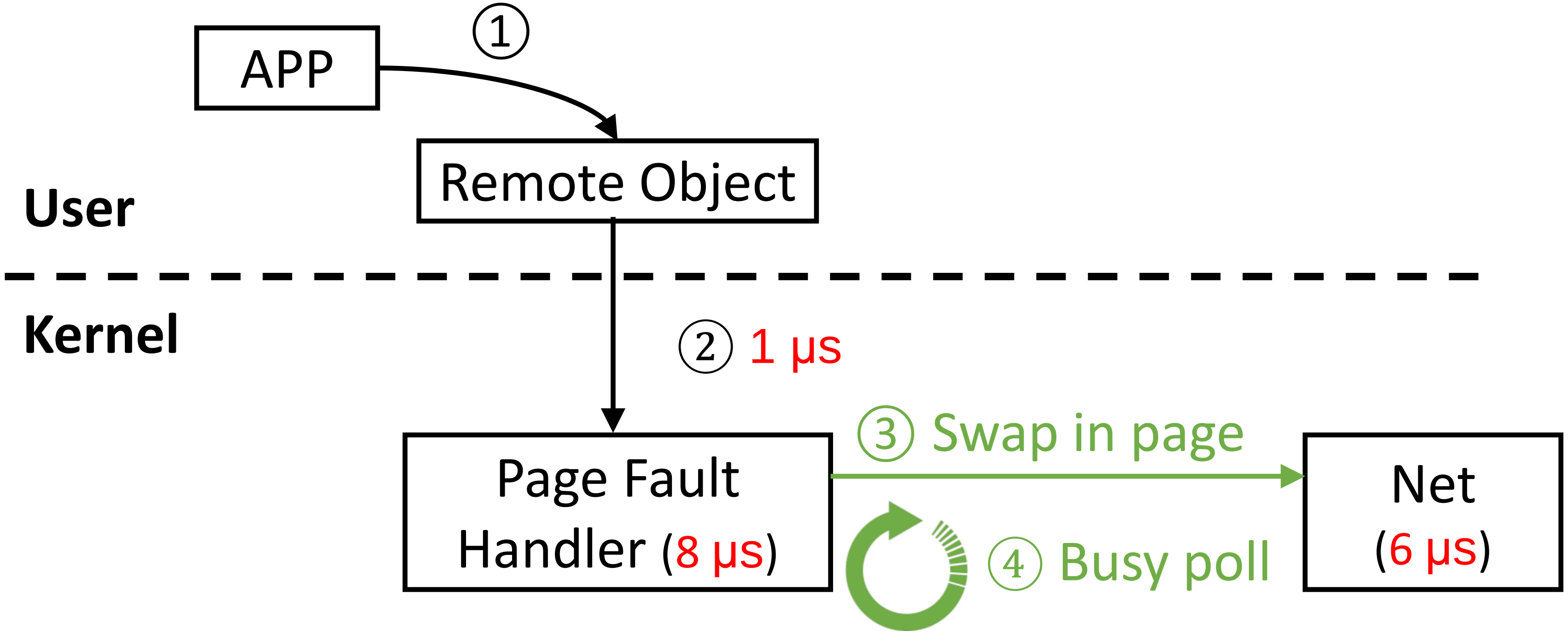
➢ Busy Polling for in-kernel net I/O → **burn CPU cycles**.



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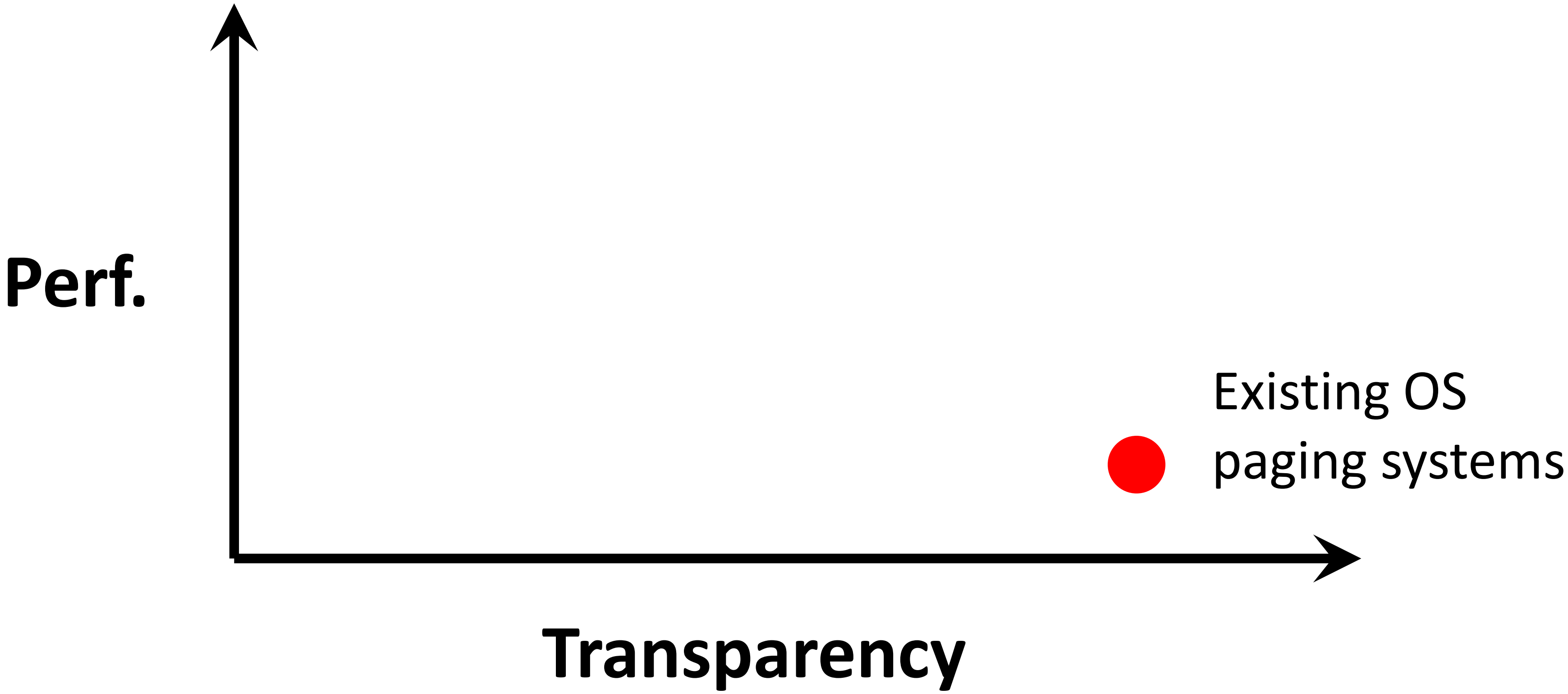

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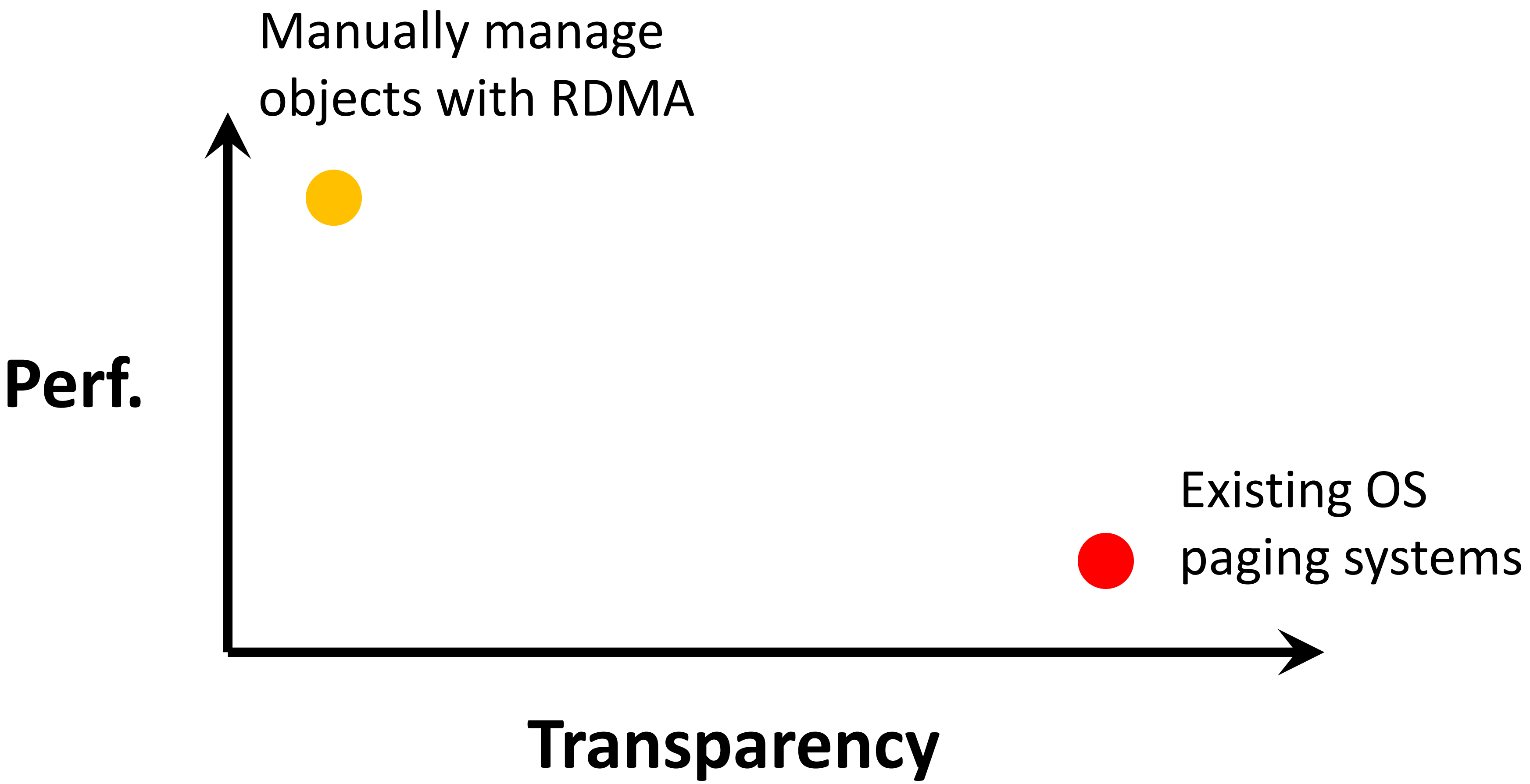

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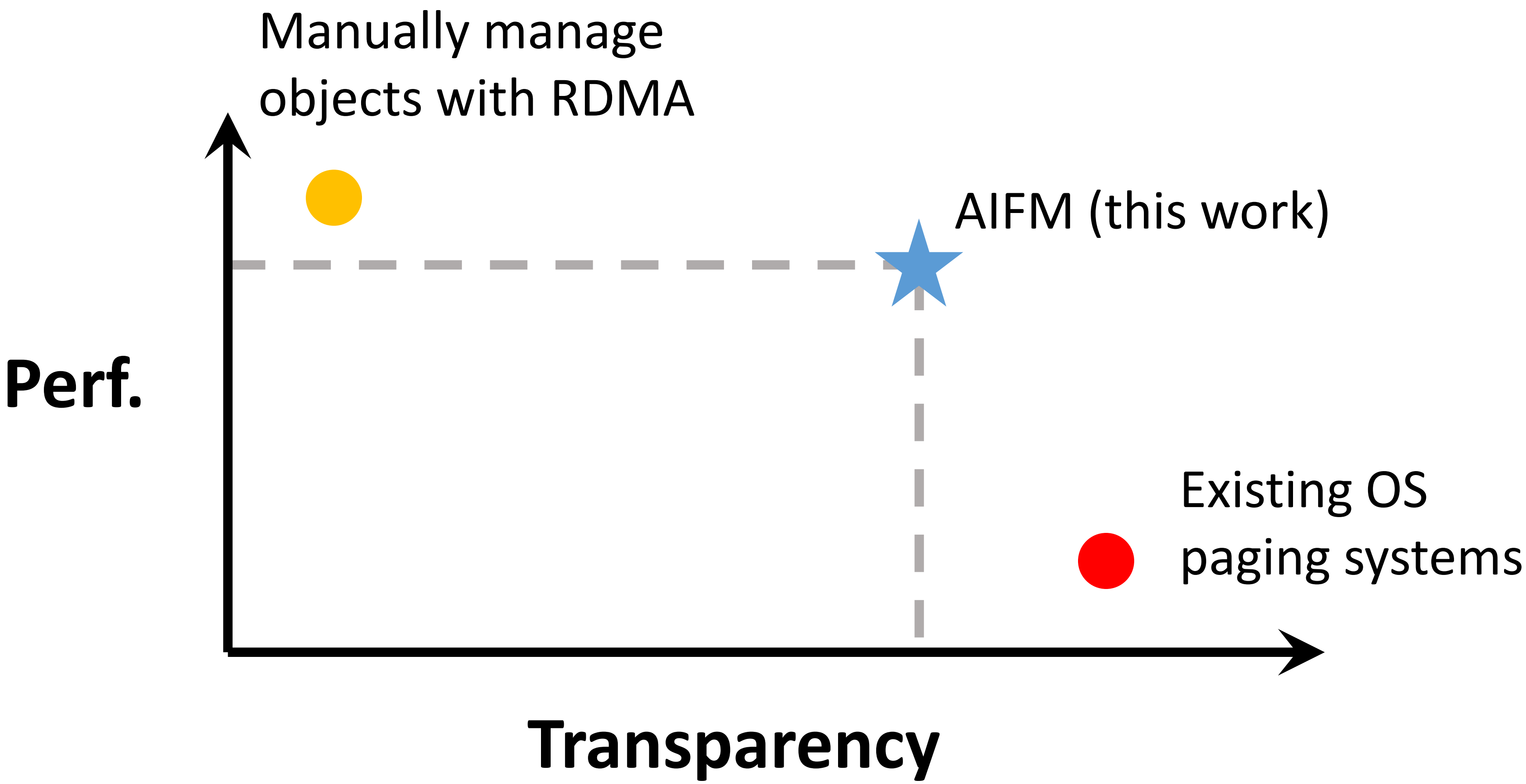

AIFM’s Design Overview

- Key idea: swap memory using a userspace runtime.

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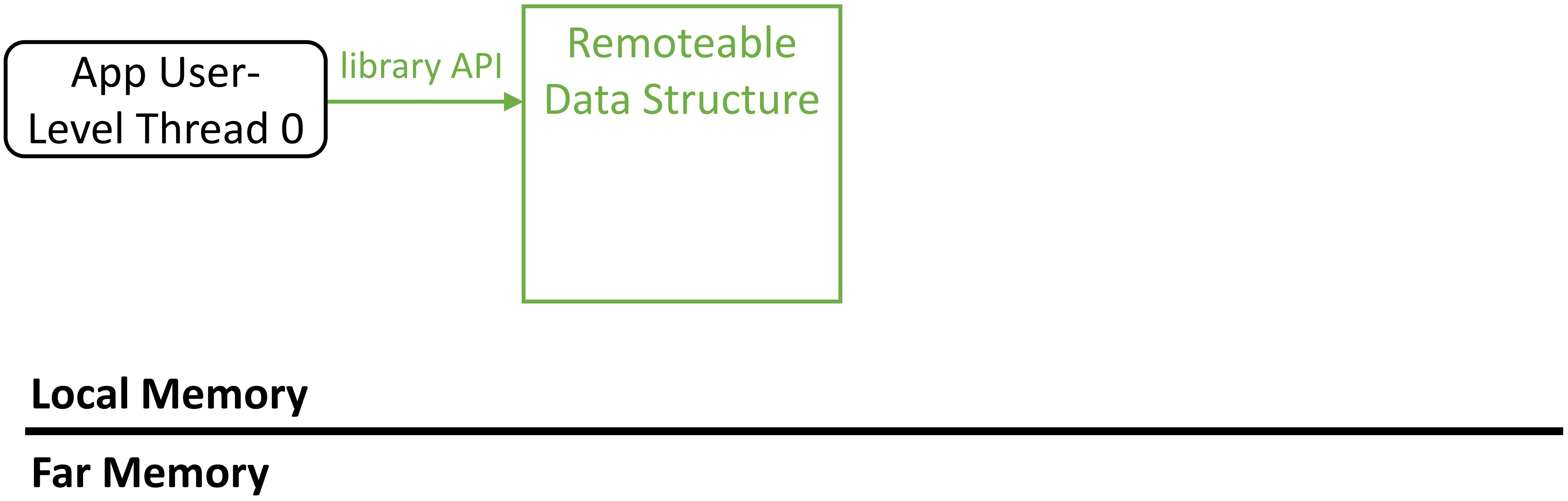
Challenge	Solution
1. Semantic gap (Amplification, Hard to prefetch)	Remoteable Data structure library
2. Kernel overheads (page faults, busy poll for net I/O)	Userspace runtime
3. Impact of Memory Reclamation (pause app threads)	Pauseless evacuator
4. network BW < DRAM BW	Remote Agent

AIFM in Action

1. Remoteable Data Structure Library

➢Solved challenge: semantic gap.



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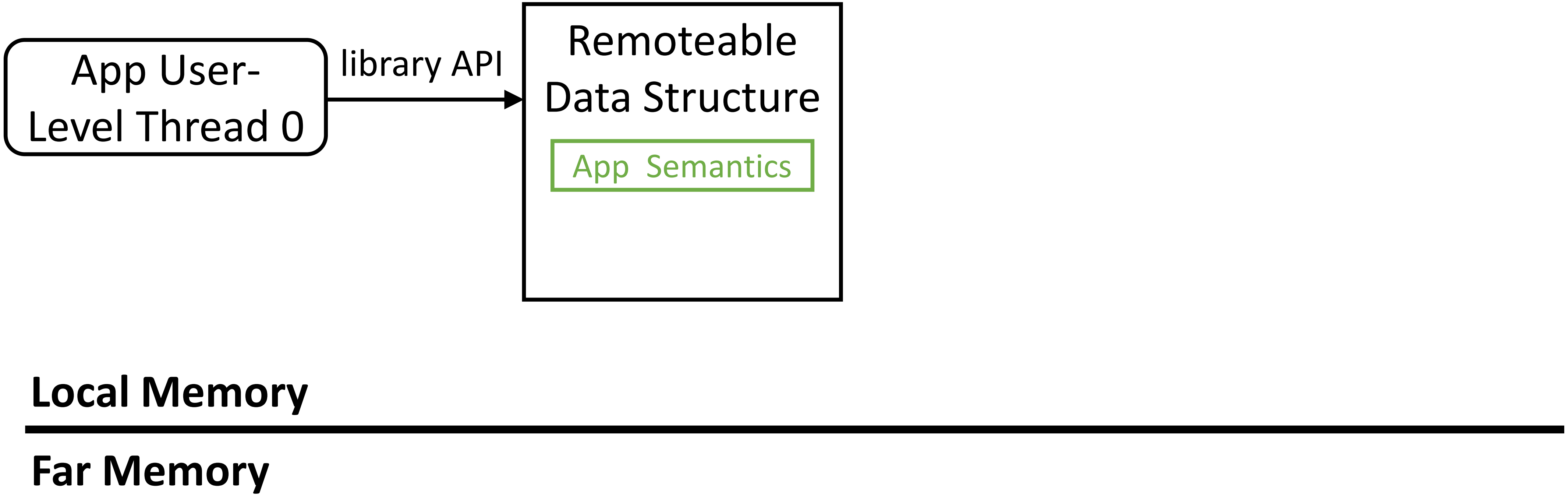

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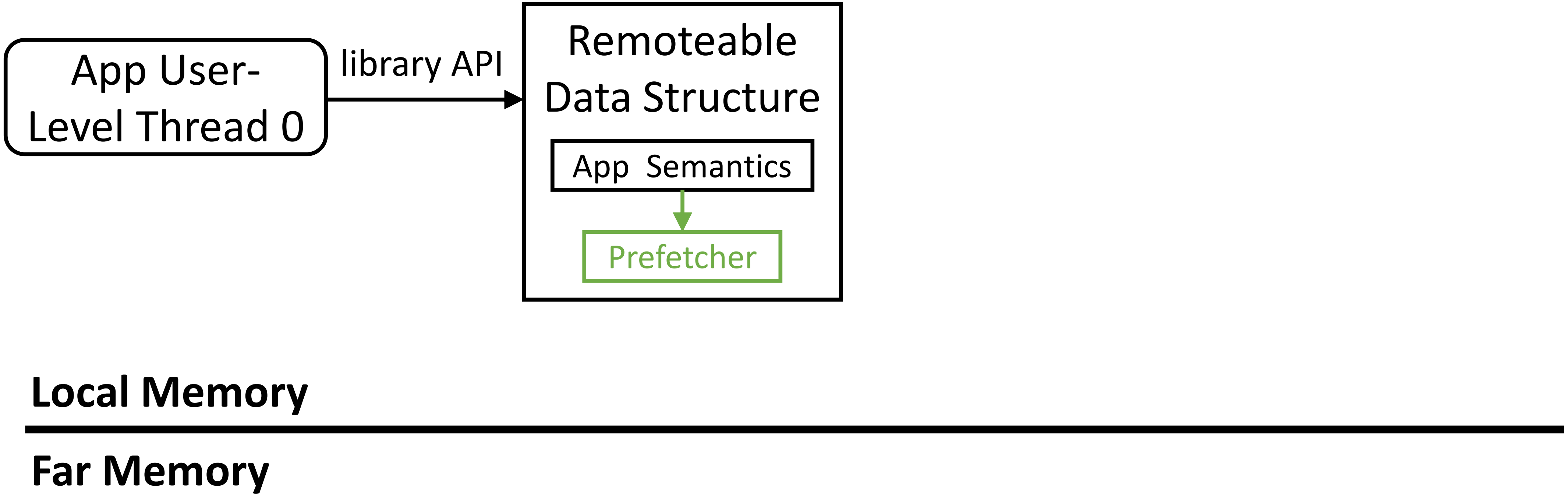

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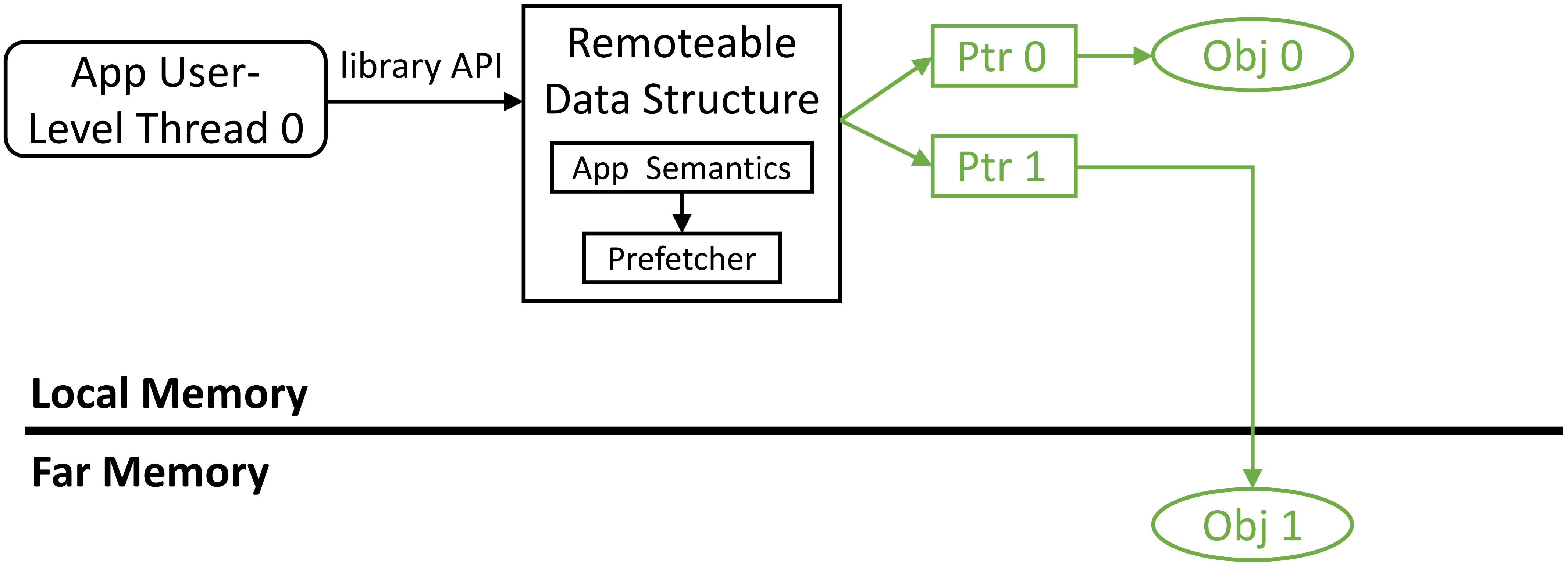

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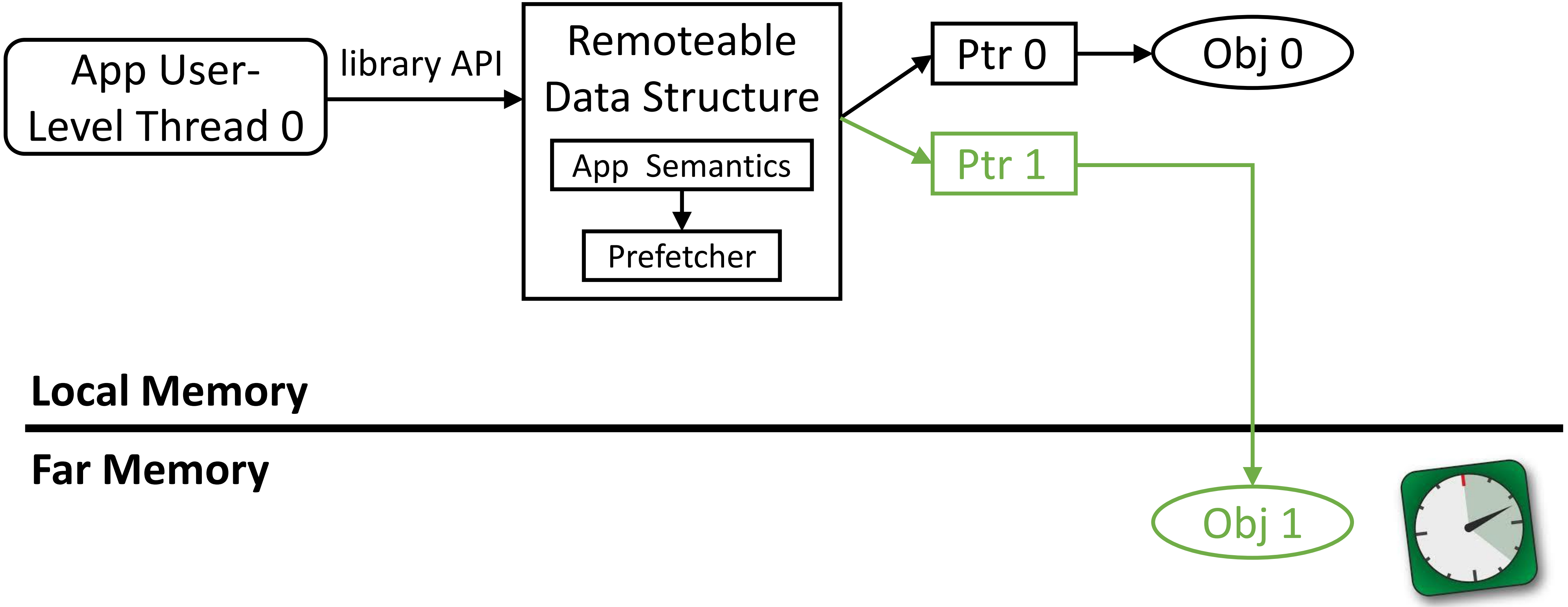

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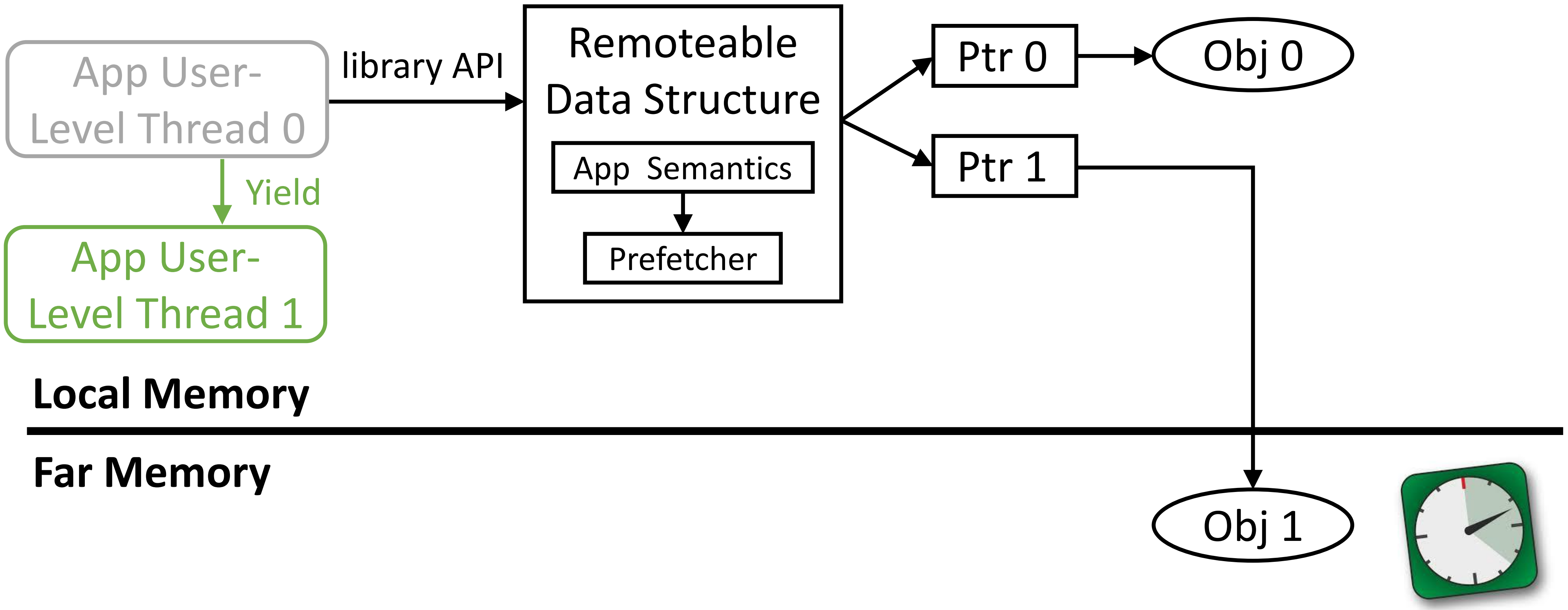

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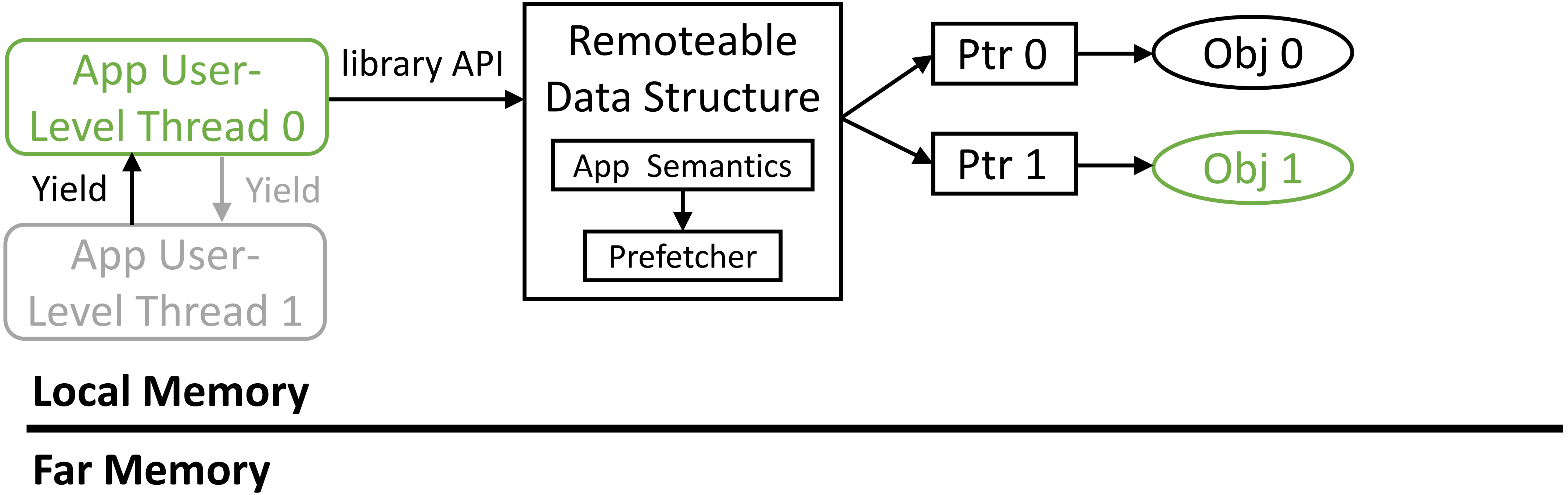

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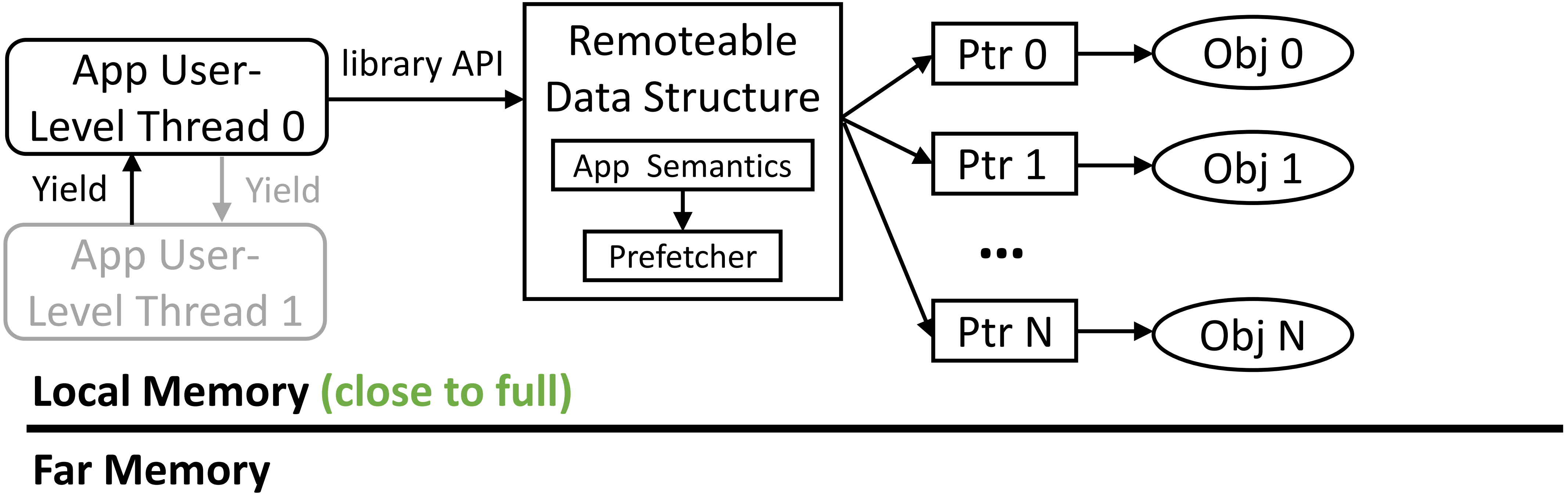

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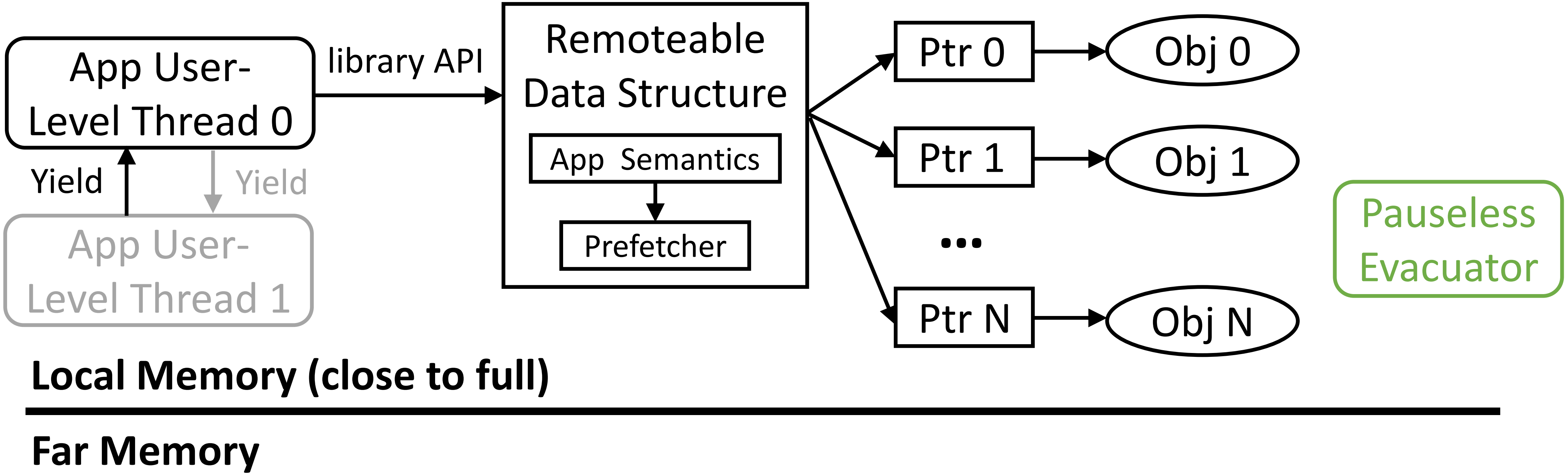

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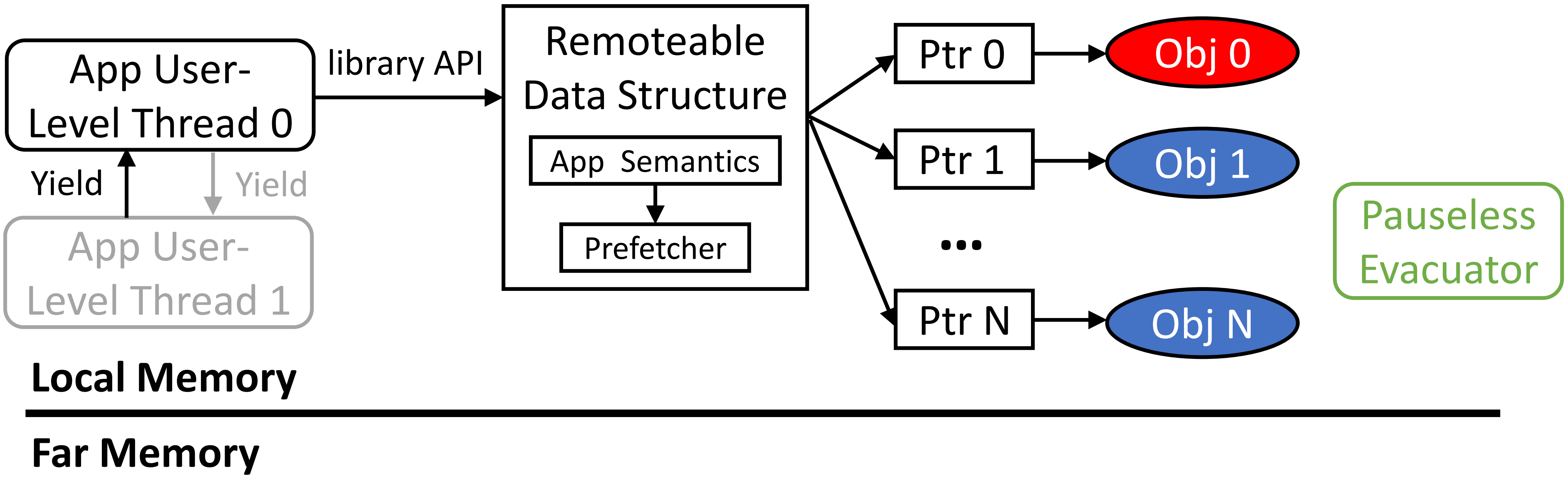

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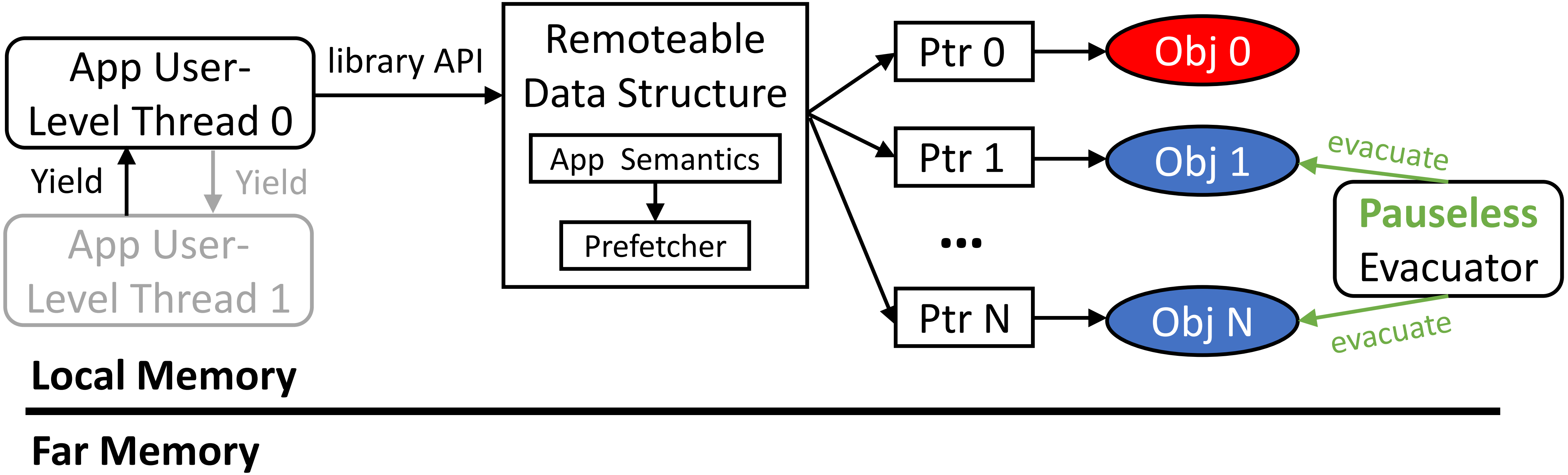

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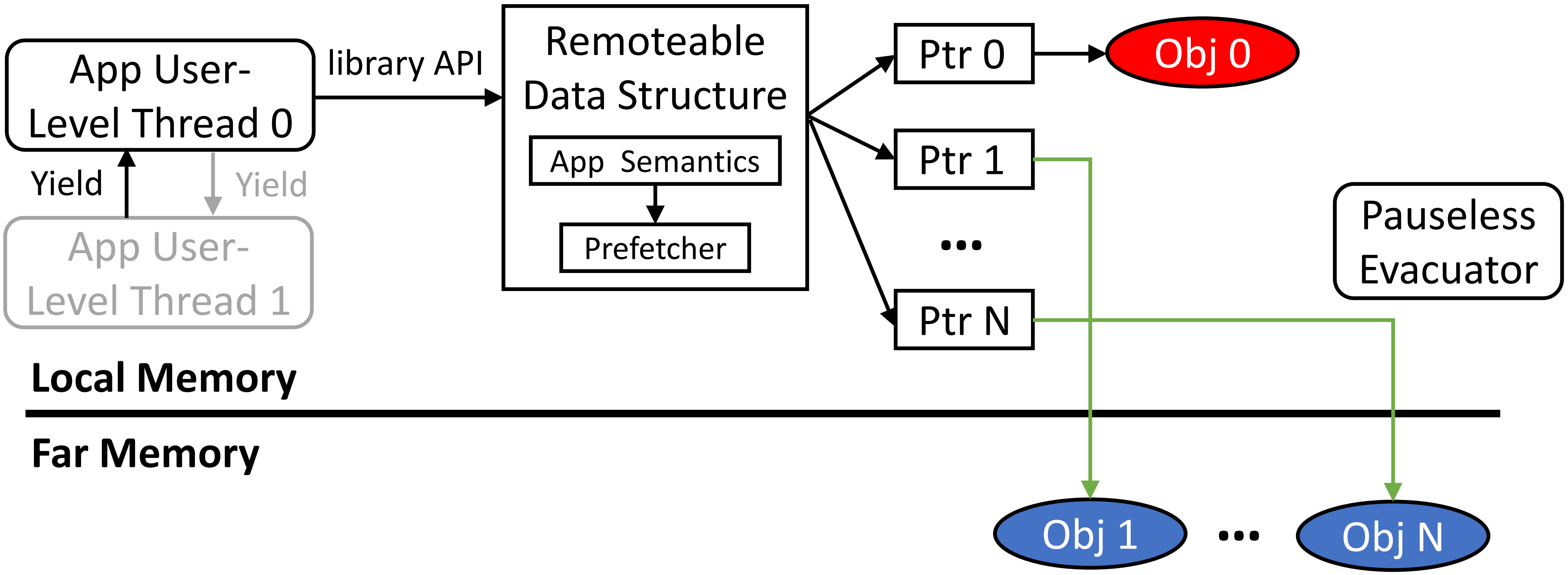

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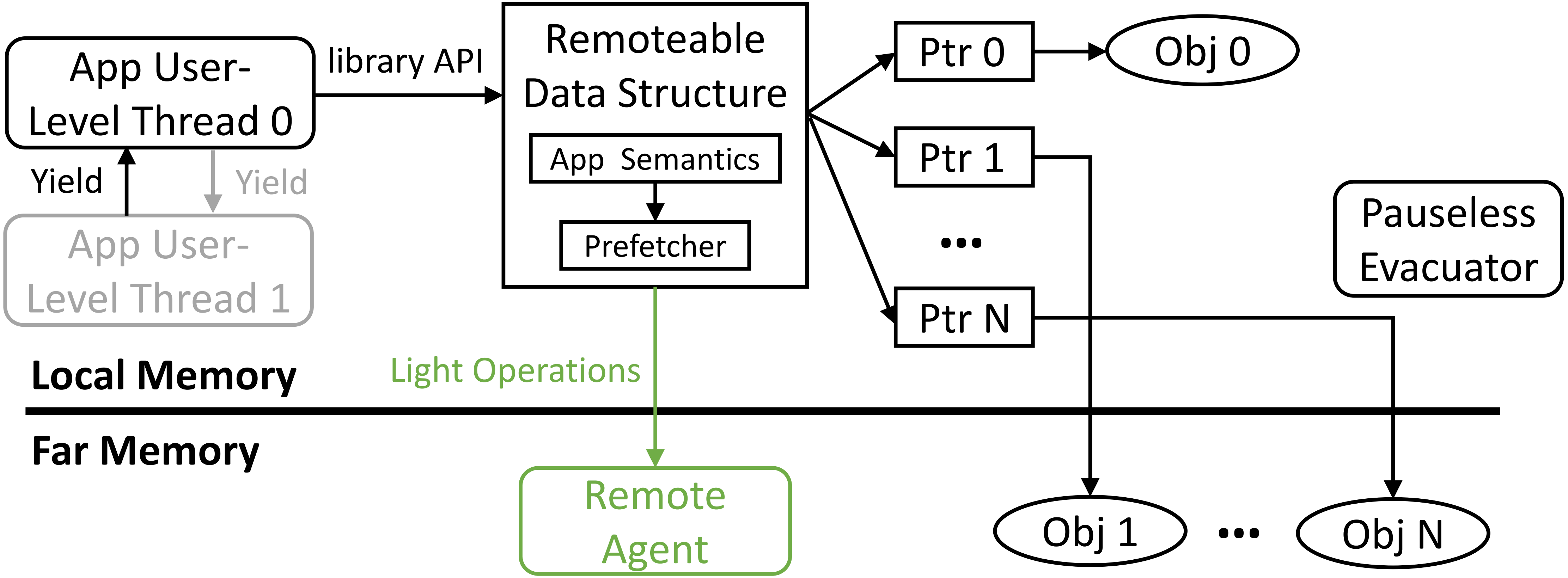

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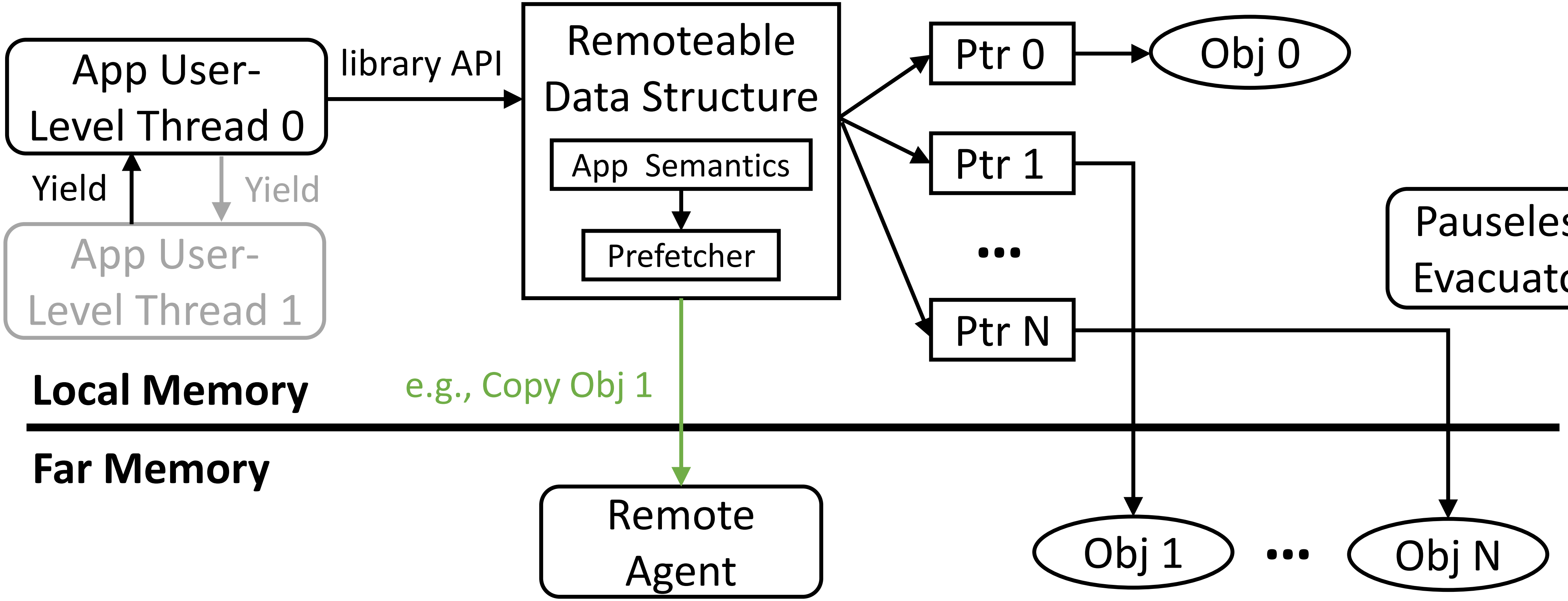

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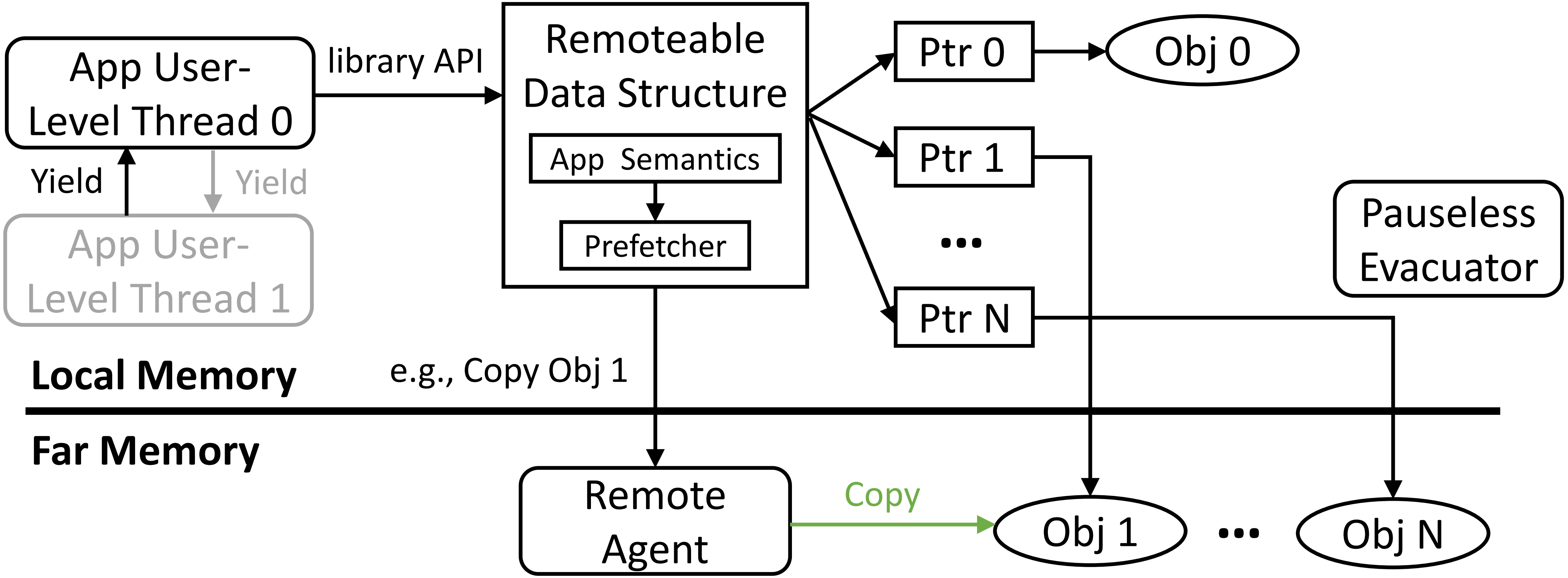

Sample Code

```
std::unordered_map<key_t, int> hashtable;
std::array<LargeData> arr;

LargeData foo(std::list<key_t> &keys_list) {
    int sum = 0;
    for (auto key : keys_list) {

        sum += hashtable.at(key);
    }

    LargeData ret = arr.at(sum);
    return ret;
}
```

Sample Code

```
RemHashTable<key_t, int> hashtable;
RemArray<LargeData> arr;

LargeData foo(RemList<key_t> &keys_list) {
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        DerefScope scope;
        sum += hashtable.at(key, scope);
    }
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Ensure the accessed objects will not be moved by the evacuator.

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LargeData foo(RemList<key_t> &keys_list) {
  int sum = 0;
  for (auto key : keys_list) {                    Prefetch list data.
    DerefScope scope;
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  }
  DerefScope scope;
  LargeData ret = arr.at</*don't cache*/ true>(sum, scope);   Avoid polluting local mem.
  return ret;
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  - Array, List, Hashtable, Vector, Stack, and Queue.

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➢LoC: 6.5K (runtime) + 5.5K (data structures) + 0.8K (Shenango)

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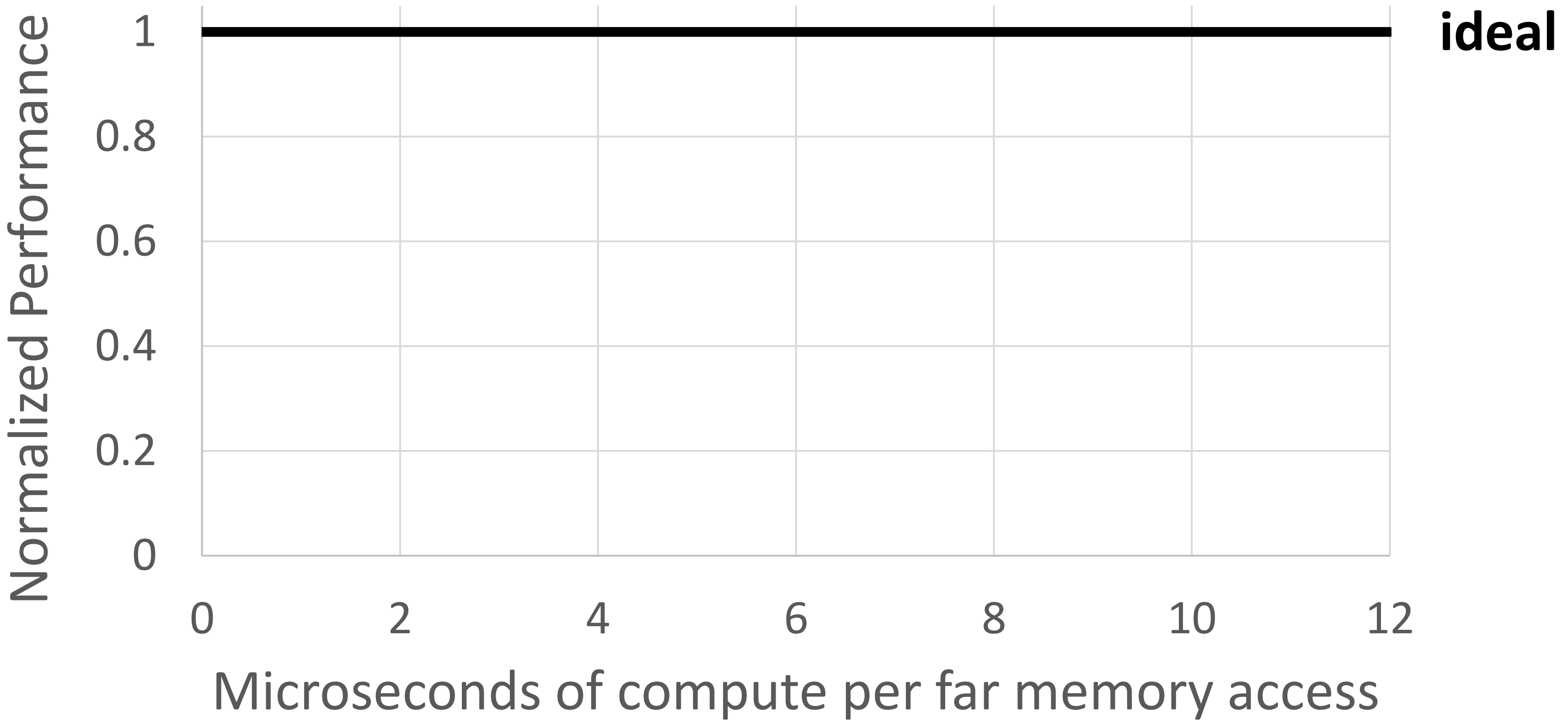
  - … compare to the local-only (ideal) system?
  - ➢ … compare to the state-of-the-art paging system, Fastswap [EuroSys' 20]?

Performance on Different Compute Intensities



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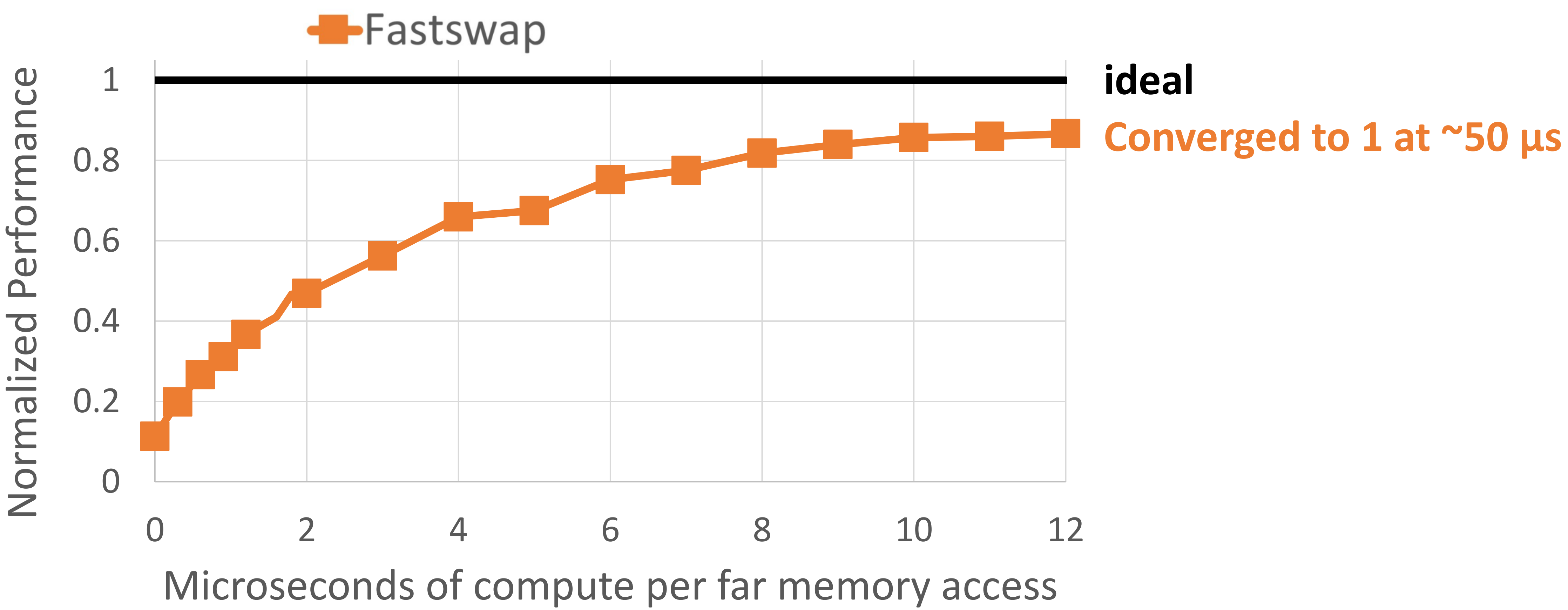

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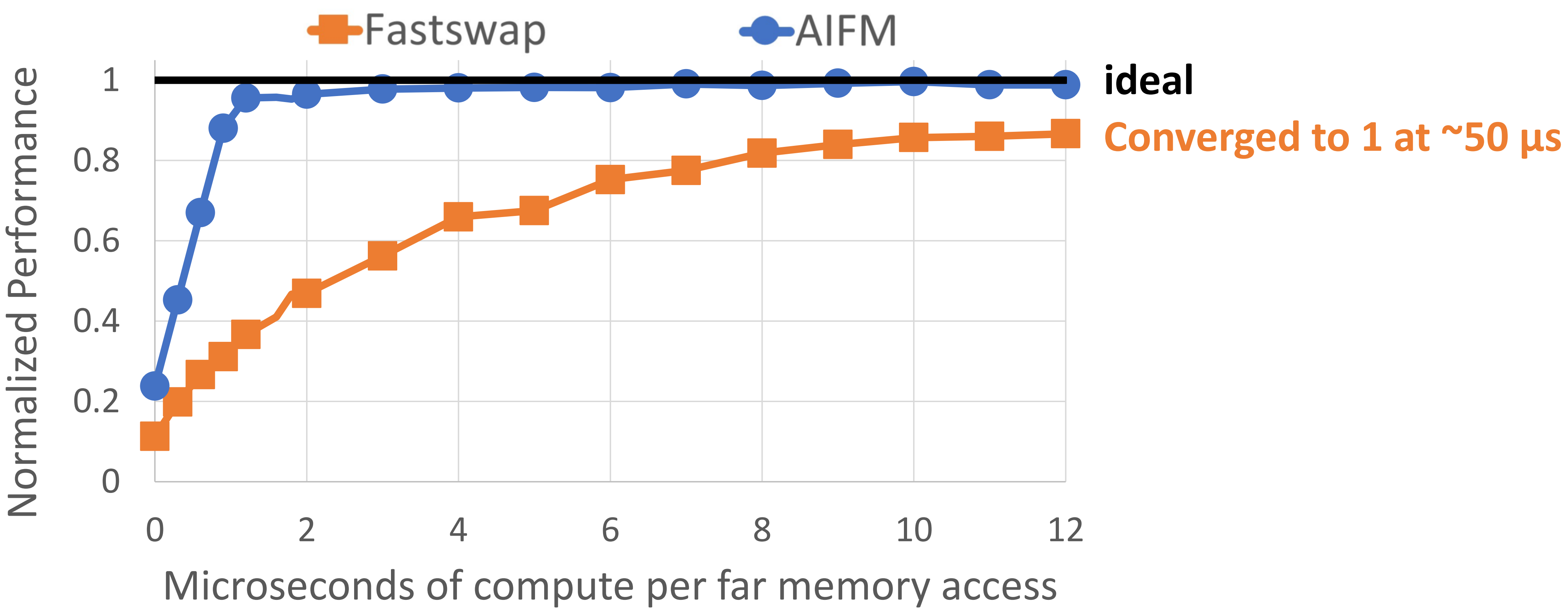

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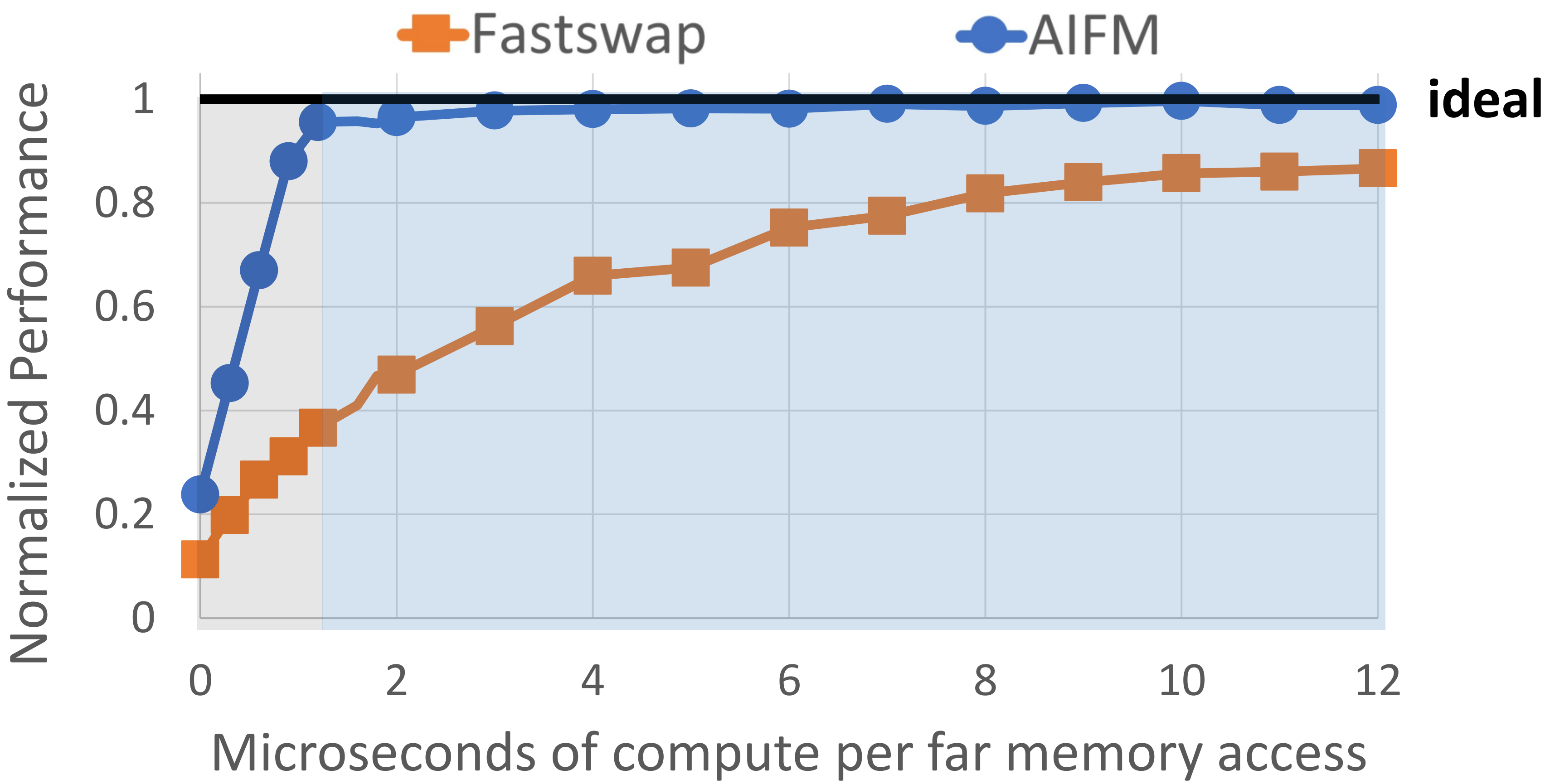

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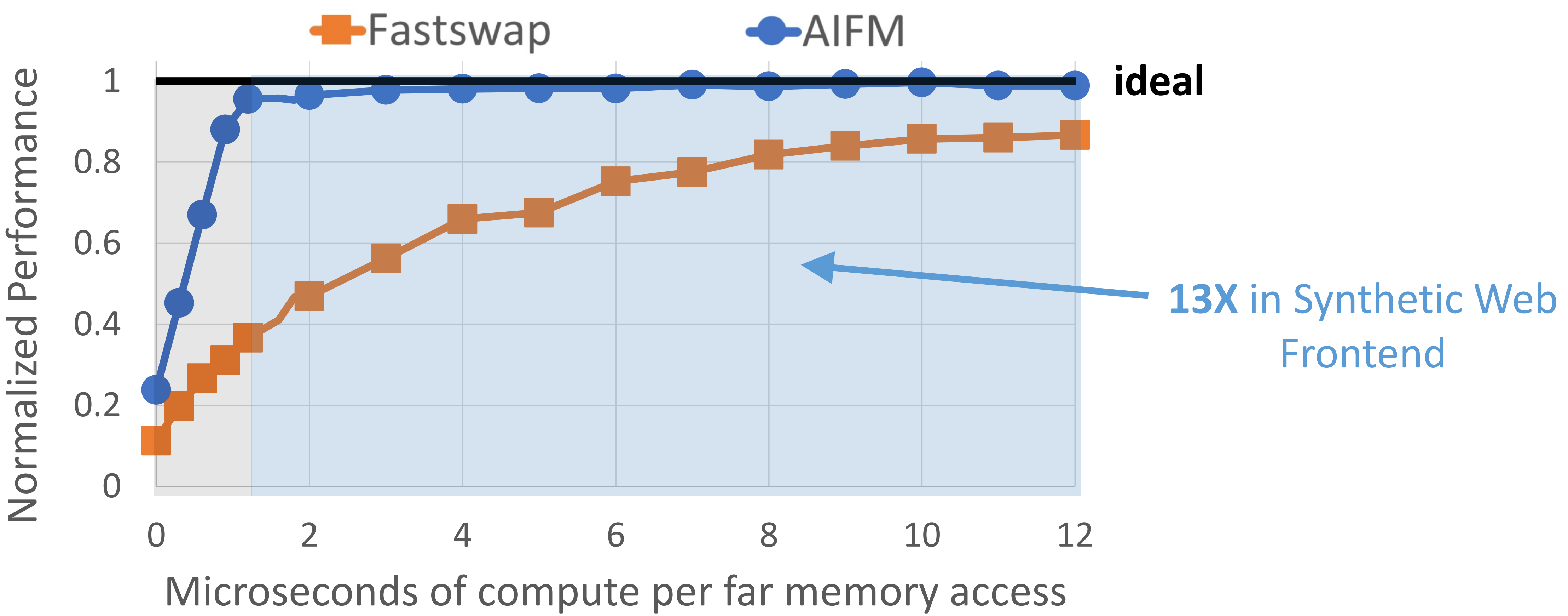

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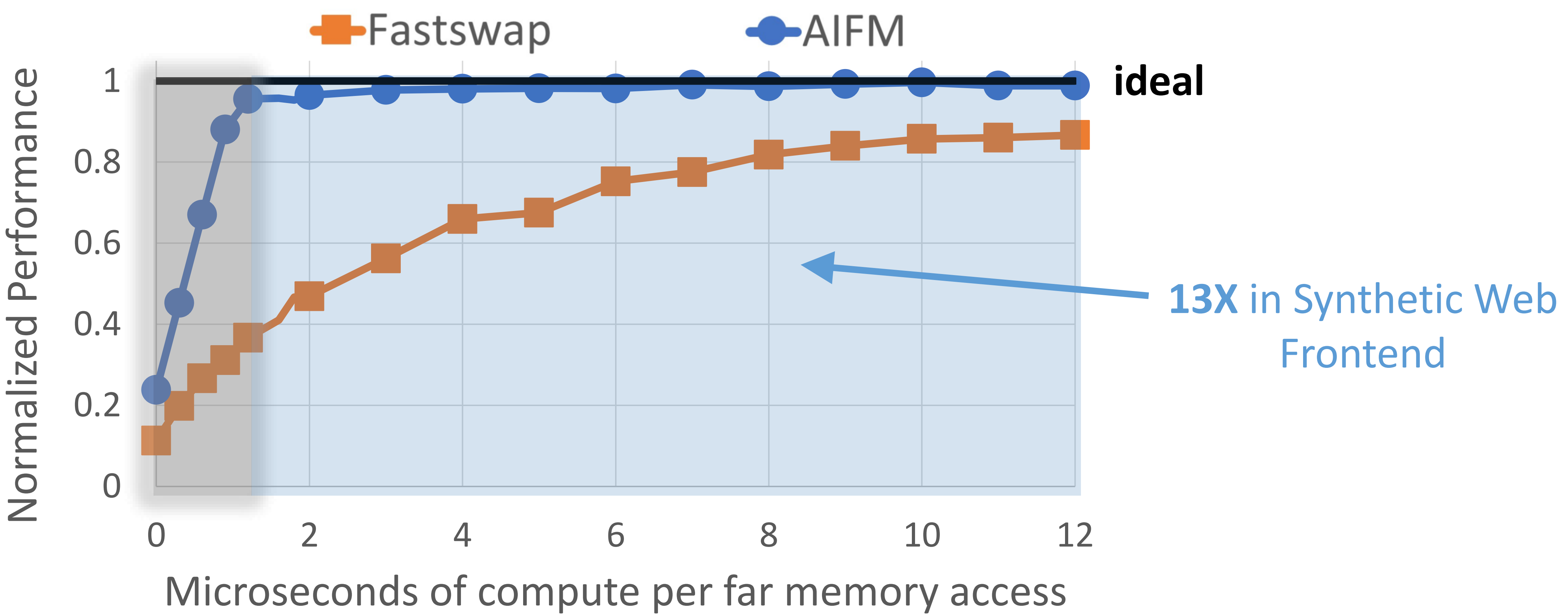

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➢Keep complex operations local and **offload** very light operations.
  - Significantly reduces expensive data transfer over network.

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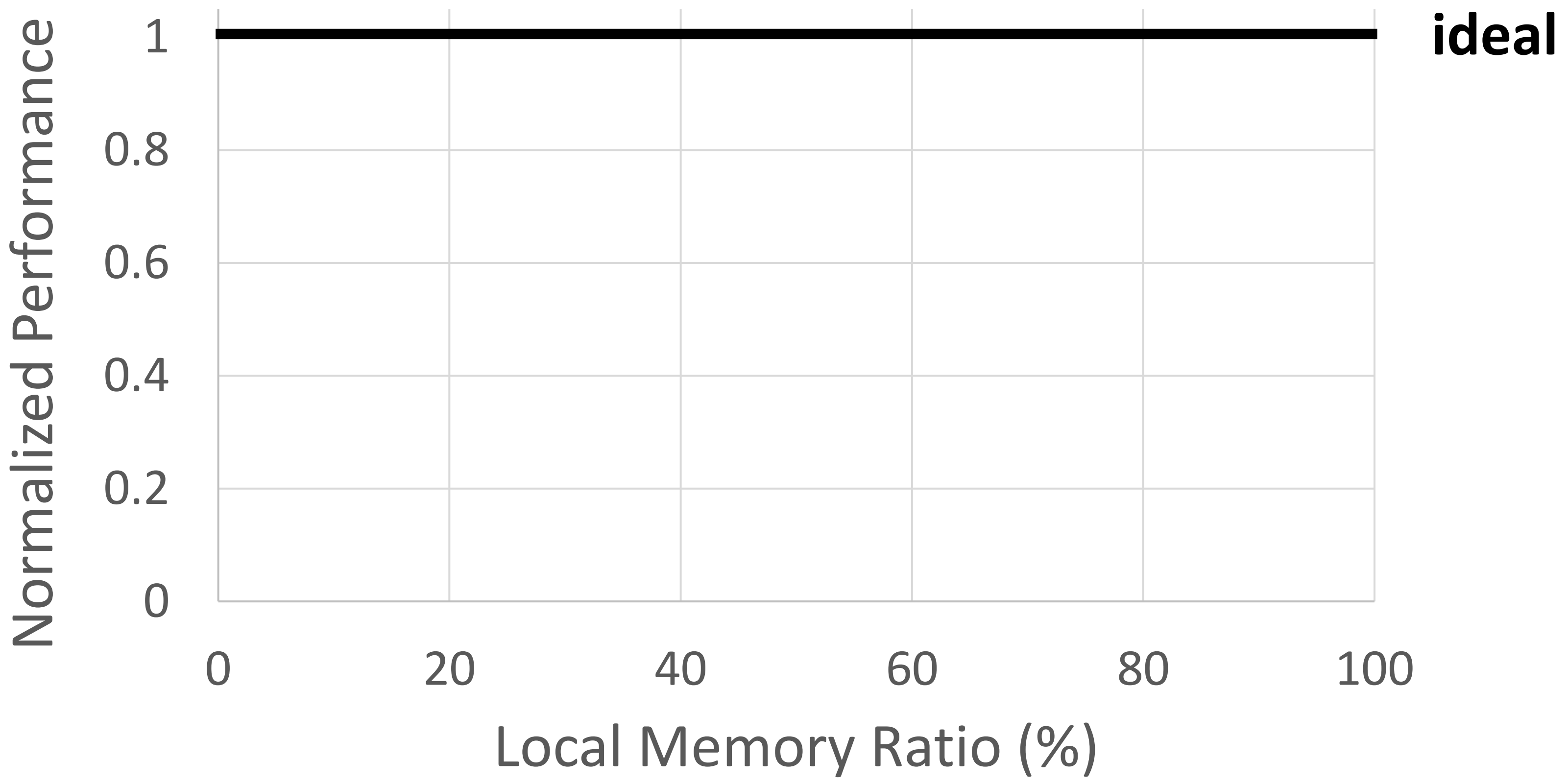

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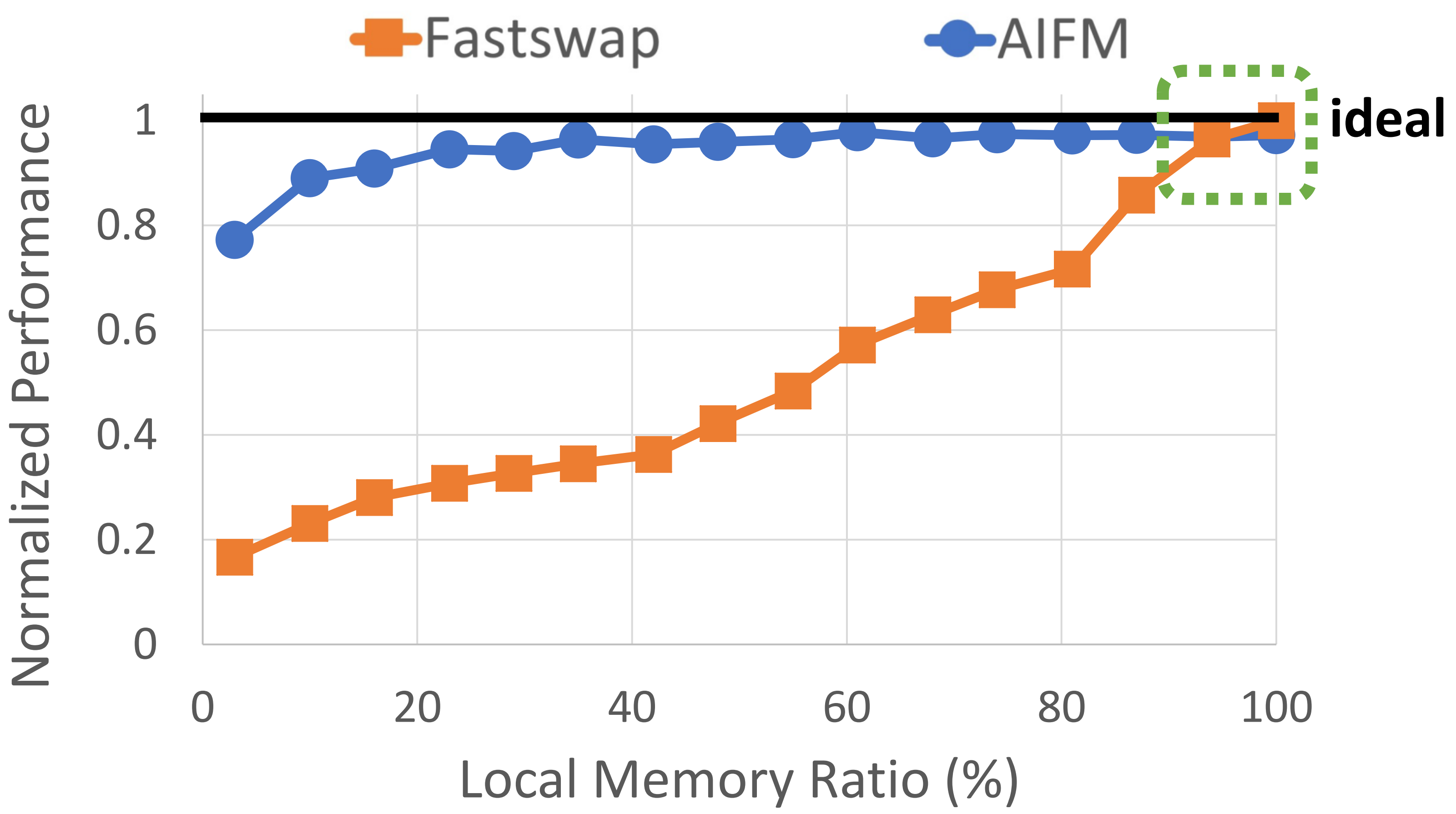

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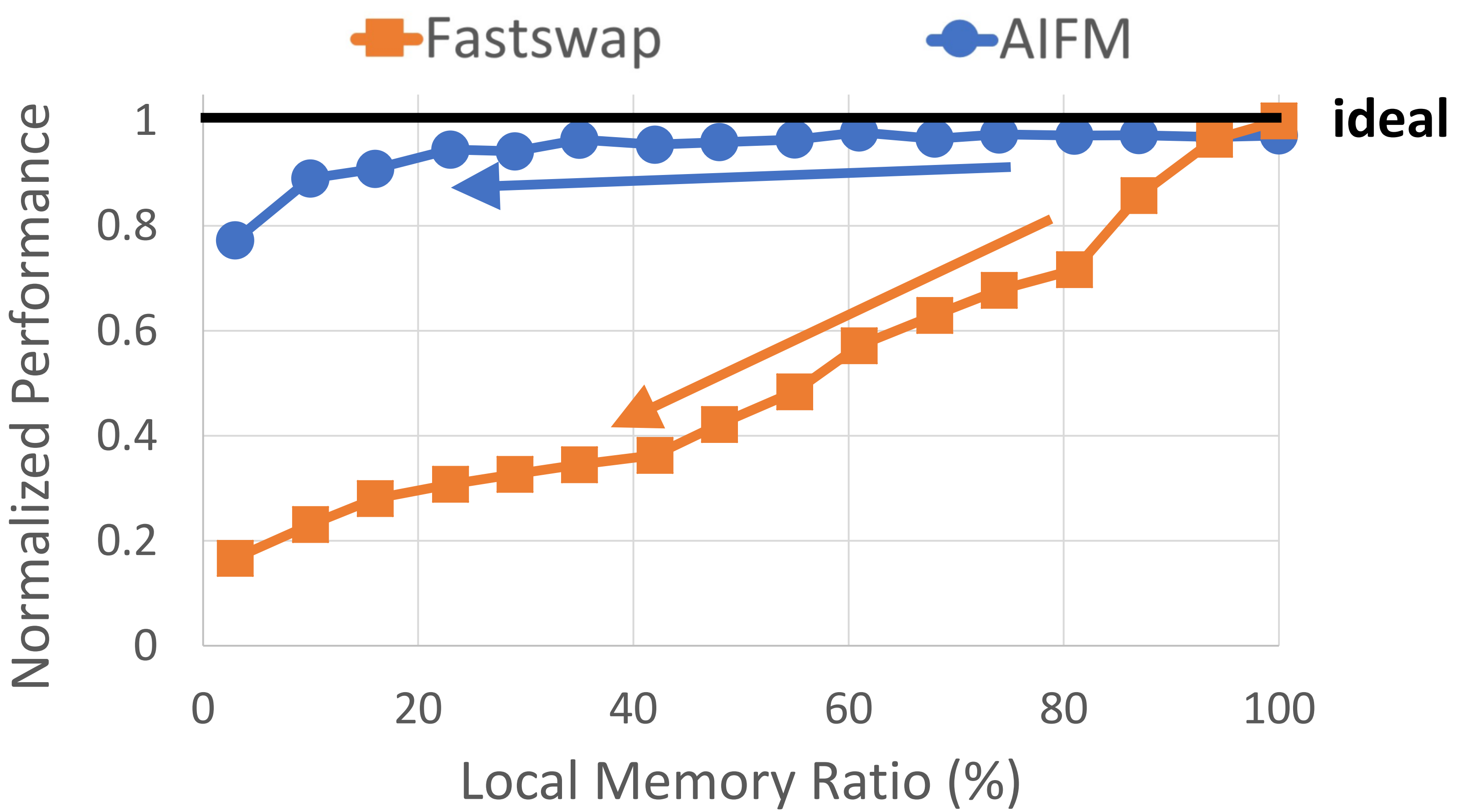

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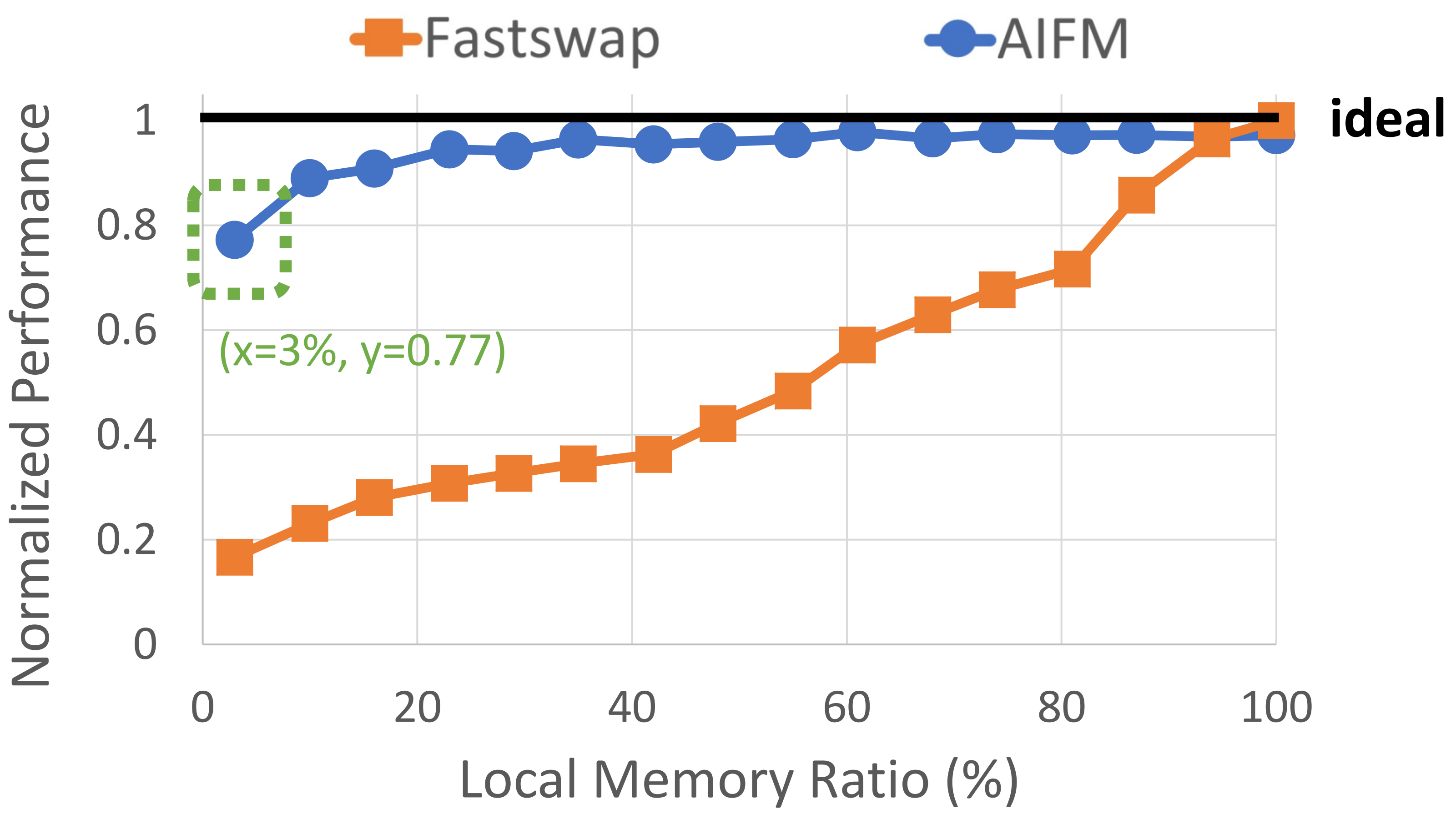

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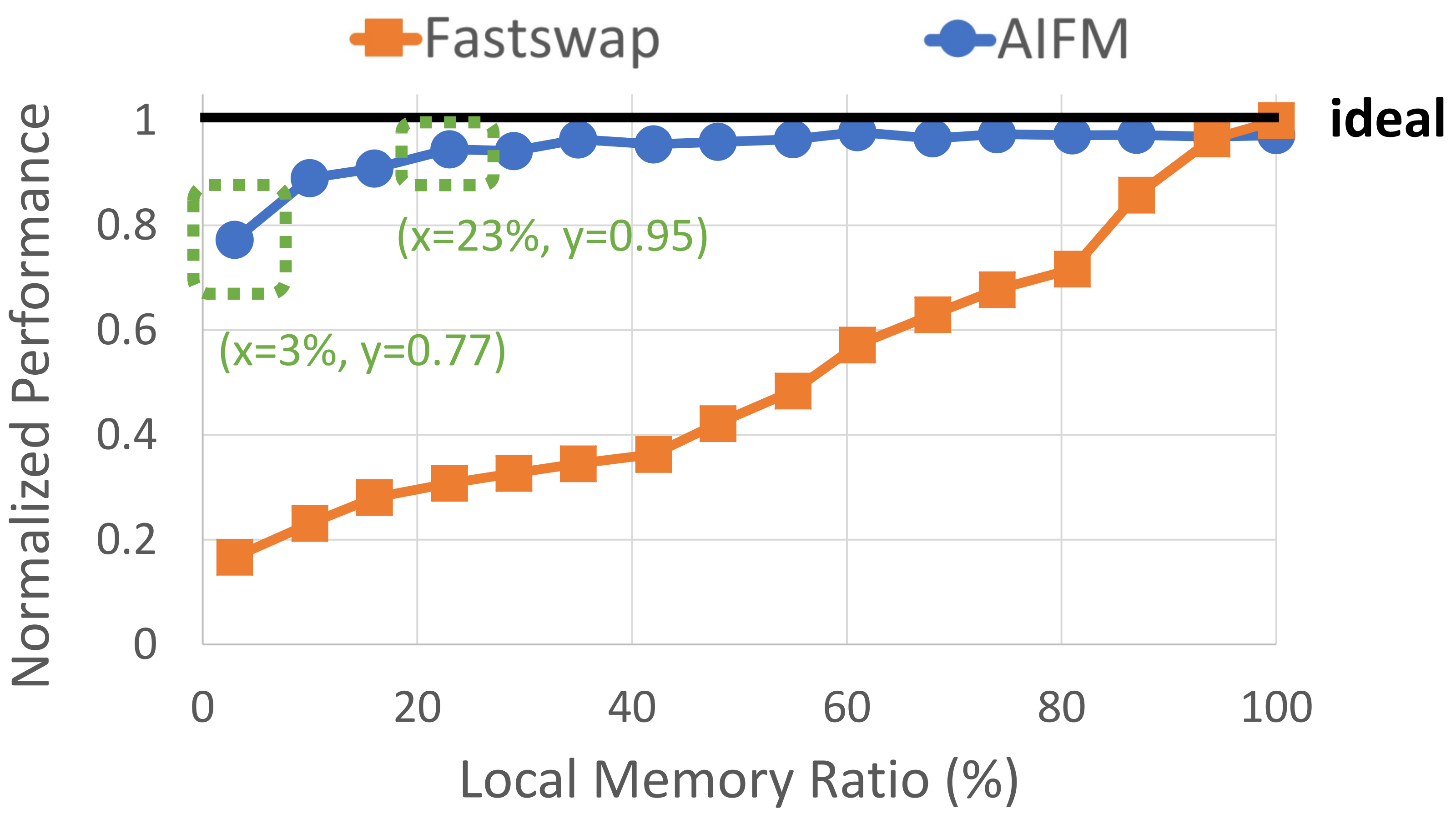

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Other Experiments

- Synthetic web frontend: up to **13X end-to-end** speedup.
- Data structures microbenchmarks: up to **61X** speedup.
- Design Drill-Down.

Read our paper for details.

Related Work

- OS-paging systems.
  - Fastswap [EuroSys’ 20], Leap [ATC’ 20]
- Distributed shared memory.
  - Treadmarks [IEEE Computer’ 96]
- Garbage collection (GC).

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  - Data Structure Library: captures application semantics.
  - Userspace Runtime: efficiently manages objects and memory.
- Achieves 13X end-to-end speedup over Fastswap.

➢ Code released at https://github.com/AIFM-sys/AIFM

Please send your questions to us

zainruan@csail.mit.edu