Linux
Plumbers
Conference 2022

>> Dublin, Ireland / September 12-14, 2022

Memory Tiering

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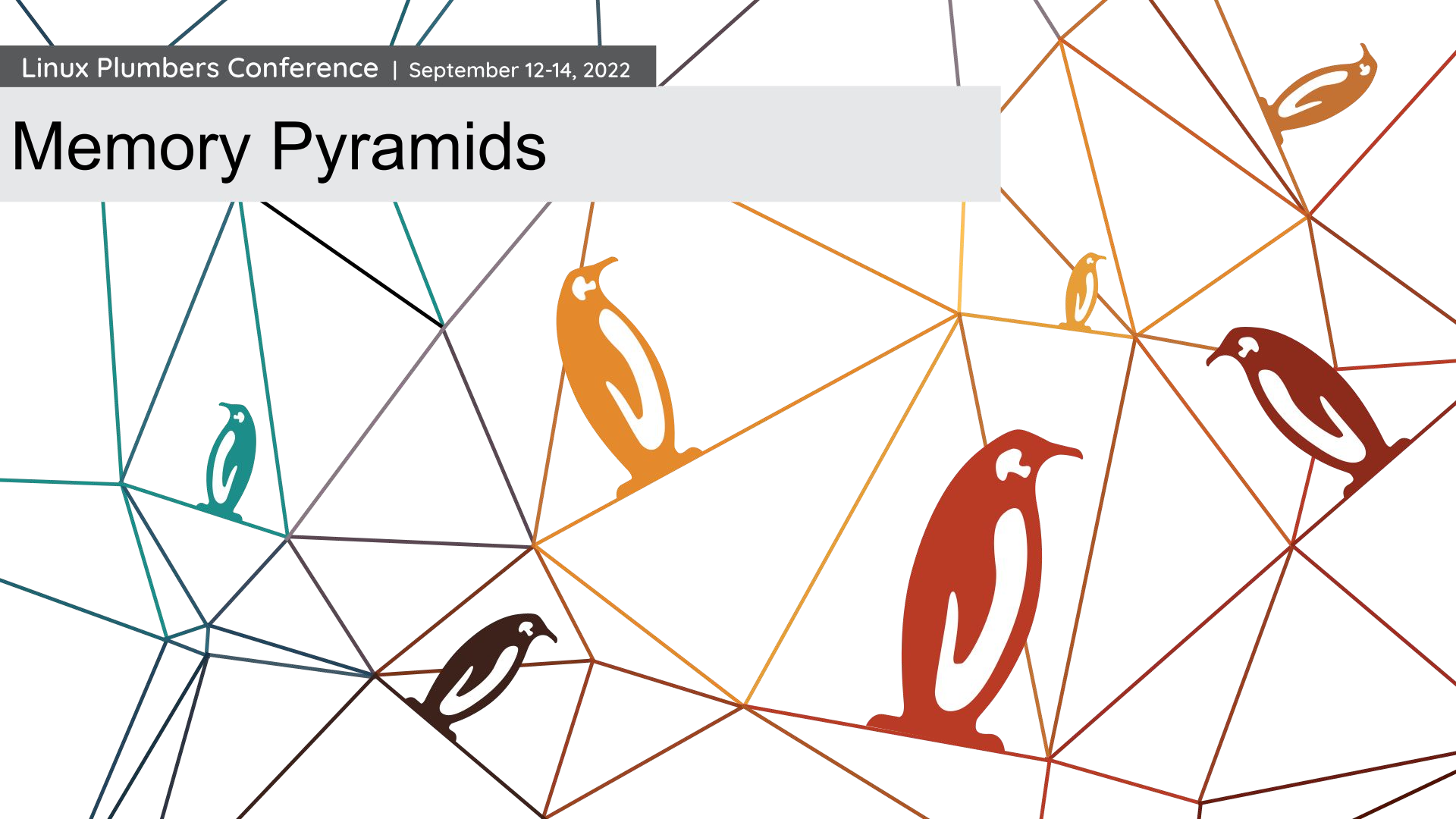
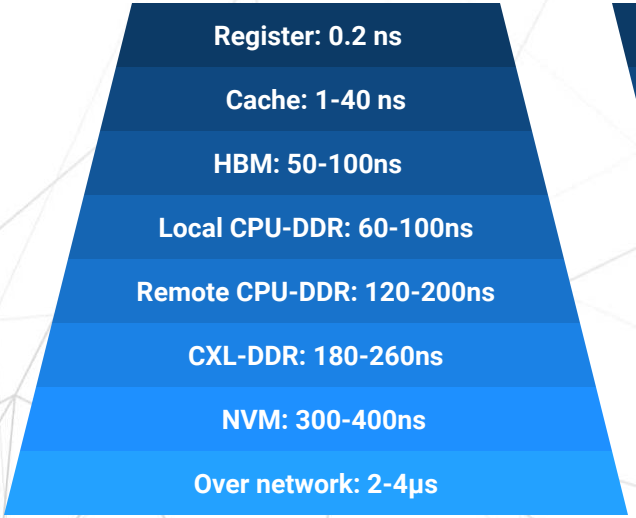
Agenda

- Memory Pyramids
- NUMA Again
- Memory Tiering
- Discussion

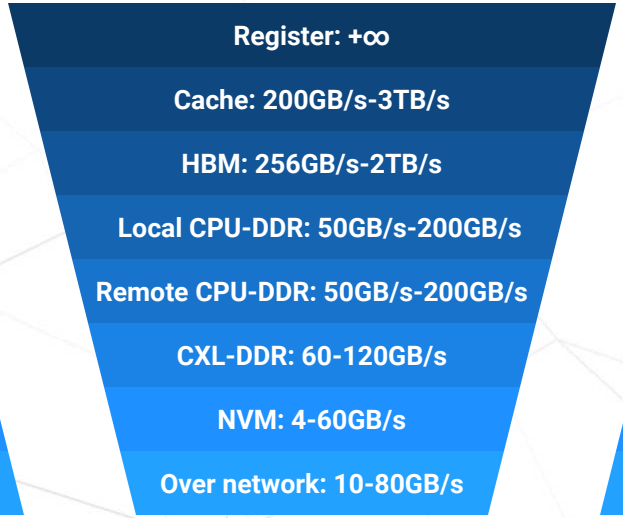
Memory Pyramids



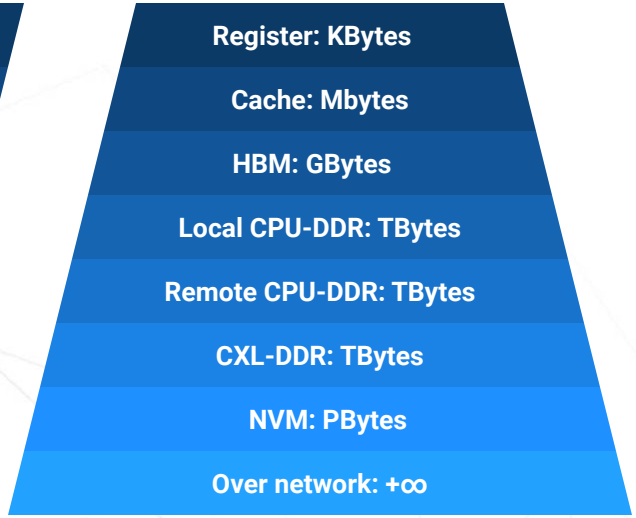
Memory Pyramids



Latency



Bandwidth



Capacity

Capacity / Speed / TCO

Capacity growth faster than memory performance

Physics⇒Capacity++⇒Power++

Memory large chunk of TCO

(Power: 15W / DIMM ⇒ ~120W to 240W & upfront cost)

Capacity & Bandwidth

CPU core counts keep growing

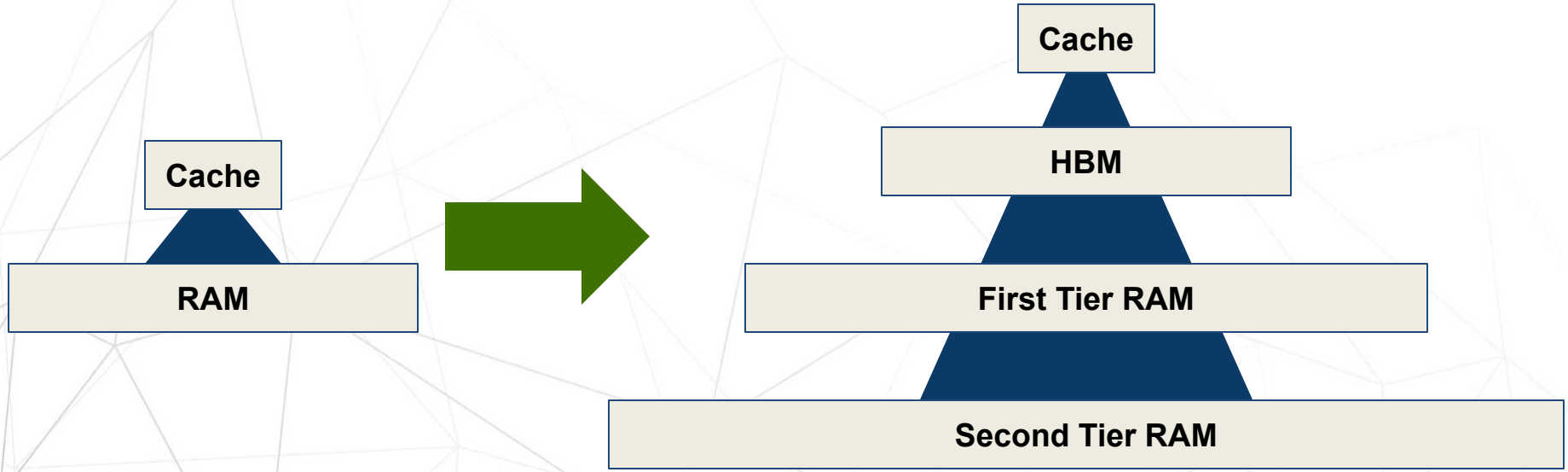
⇒Bandwidth per cores barely improve

⇒Capacity per cores improve slower than needs

Density improvement coming to an end

Memory Tiering

Going toward deeper hierarchy



Performance

Same goal: keep improving compute performance

⇒Hot data must be in the fastest memory

Through hardware == Like cache

Through software == Memory placement

Tenet

- Application can not access all its memory at the same time (not enough CPUs)
- Some data structure in an application are access more often than others
- Which data is access more often can change over application lifetime
- Some applications have predictable access pattern
- Others applications have random access pattern
- Some applications can categorize its data into buckets:
  - From most frequently accessed to least frequently accessed

Explicit vs Implicit

Explicit placement:

- Application place its data to most appropriate memory

Implicit placement:

- Kernel/Daemon place application memory

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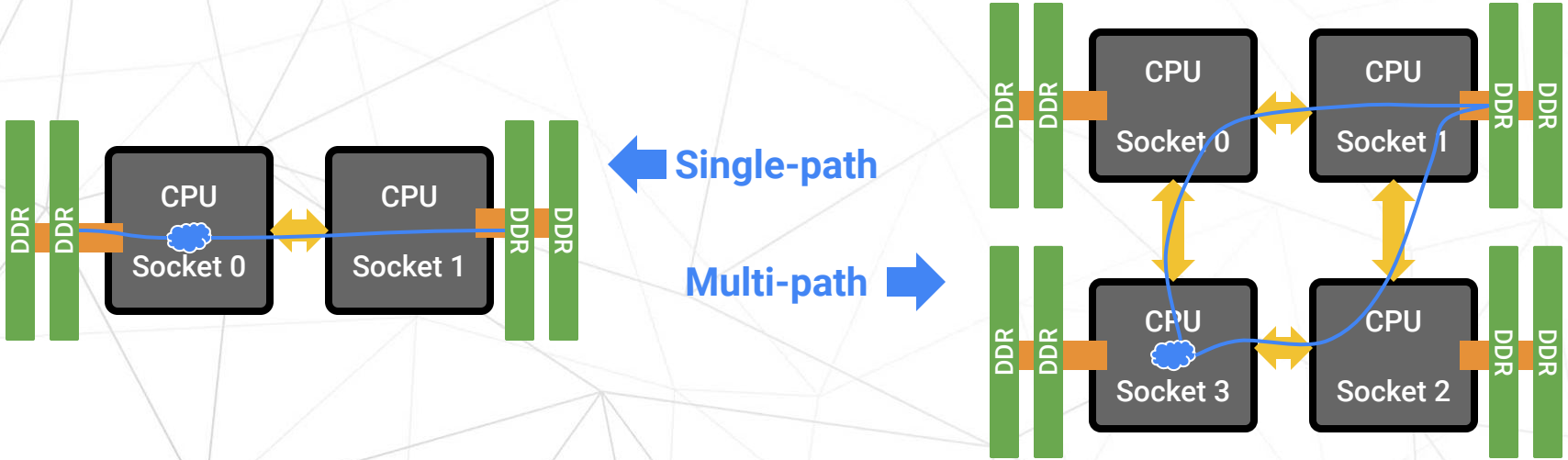
NUMA Again

NUMA Again

Asymmetric bandwidth & latency⇒NUMA again

But even worse NUMA overlay on memory tiering



NUMA lessons

Few application are NUMA aware

- Large application often are
- Smaller application can be through library *(memory allocation)*

⇒Mechanism like autoNUMA

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Memory Tiering

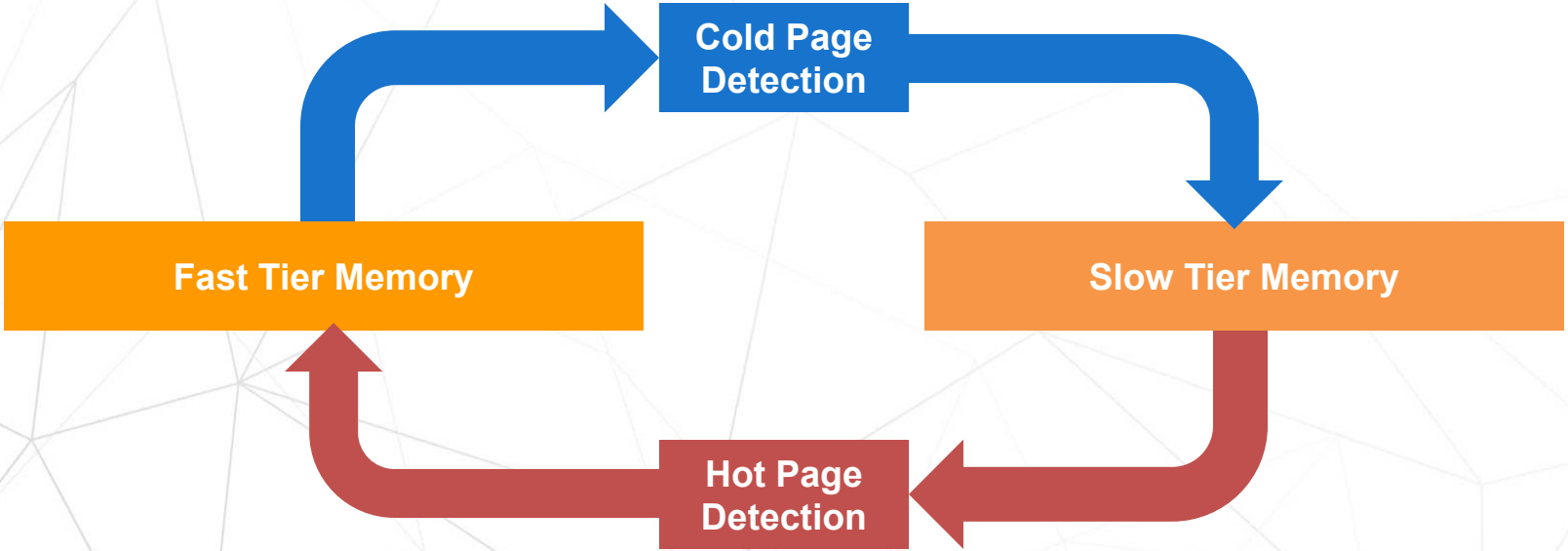
Definitions

Cold Page: a page that was not access in last N ms

Hot Page: access more than K times in last L ms

Threshold (N,K,L) can vary over time

Overall Flow



Measuring Success

What metric can we use to measure success ?

% of memory access to fastest memory for a thread

⇒More access to fast memory→Better perf

Not a silver bullet

Applications with background activity dominating memory access

Kernel Components

Cold Pages detection

Hot Pages detection

Page Migration

Policy & Management

Discussion

Cold Page Detection

- LRU, MGLRU
  - Good candidates⇒migrate before reclaim
- Access Bit
  - Clear Access Bit⇒No access over N ms
- DAMON

DAMON

DAMON == Data MONitor access

Is DAMON good enough ?

- Better to have cold page monitoring != hot page
- Cold page do not need region
- Region can hide cold pages

Hot Page Detection

Hot Page
⇒ Many access over short periods of time
⇒ Software monitoring need high frequency sampling
⇒ Large overhead to do software sampling

We want hardware for hot page detection

- Heatmap
- N most recently used address

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Page Migration

Existing kernel API good enough ?

- move_pages()
- migrate_pages()

Do we want a more asynchronous API ?

Something like io_uring but for memory ?

- Memory Migration
- Memory reclaim
- Virtual Address Space manipulation

Policy & Management

Policy & Management:

- In kernel ? Like LRU
  - One solution fits all ?
- In userspace ?
  - Different strategy per application groups

memcg point toward userspace being a better places

Configuration

How do we want to configure memory tiers ?

- sysfs API
- Disconnect from NUMA distance

Can help bridge kernel & userspace management

See RFC: Memory Tiering Kernel Interfaces (v4)