Memory Management 101: Introduction to Memory Management in Linux

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Jump Trading LLC

Overview

- ❑ Memory and processes
- ❑ Real/Virtual memory and Paging
- ❑ Machine configuration
- ❑ Processes use of memory
- ❑ Overcommit
- ❑ Knobs
- ❑ Processor cache use

Pages and physical page frame numbers

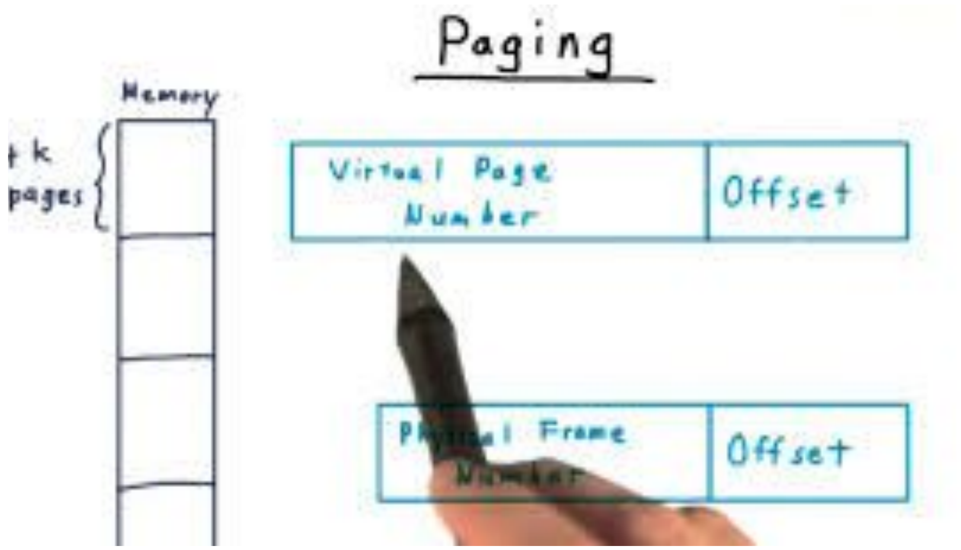
- Division of memory into “pages”
  - 1-N bytes become split at page size boundaries and become
    M = N/page size
    pages
- We refer to memory by the Page Frame Number (PFN) and an offset into the page.

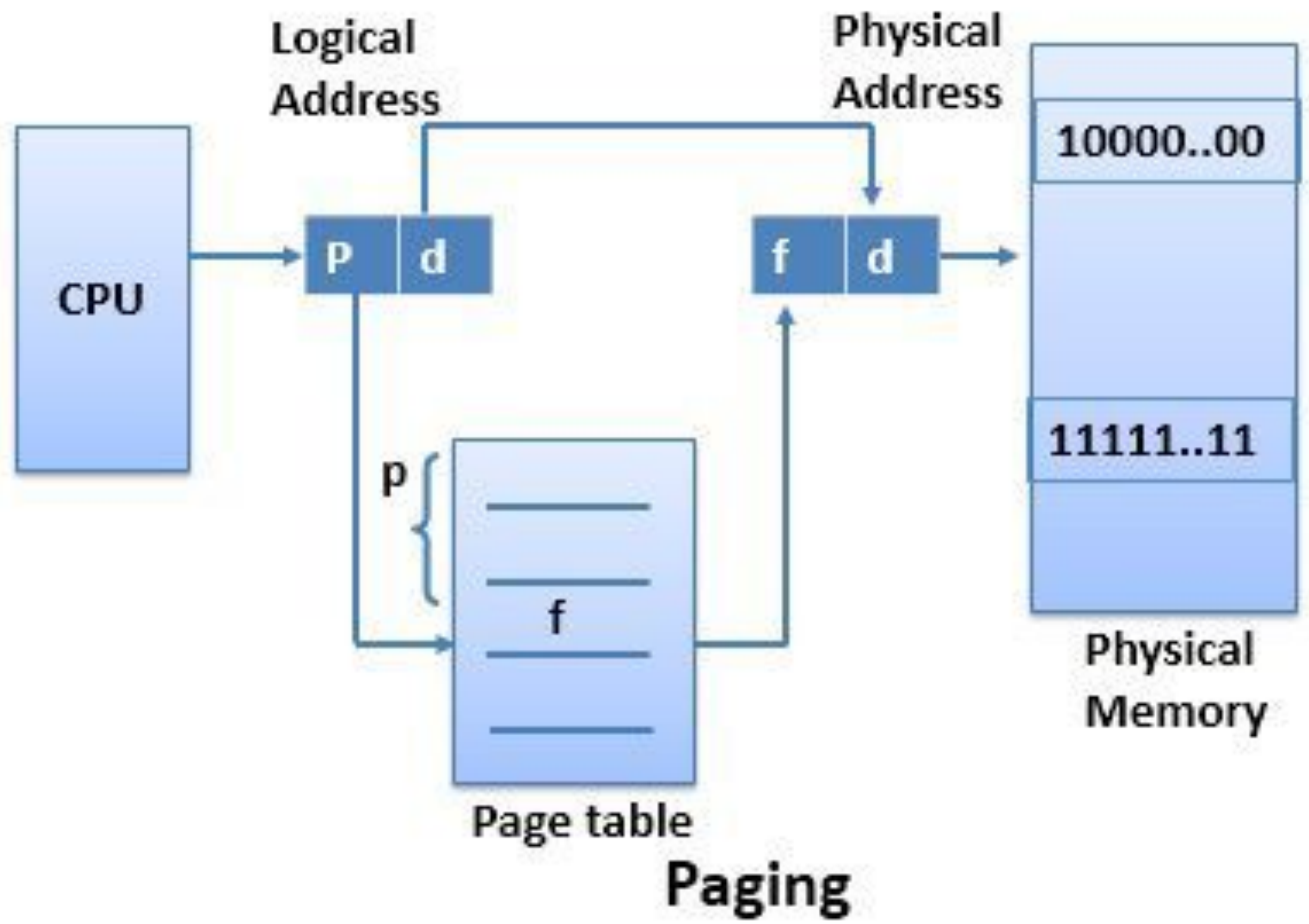
- Common size is 4k (Intel legacy issues)
- MMU creates virtual addresses.

Basics of "paging"

- Processes have virtual memory
- -> PFN
- Page Tables

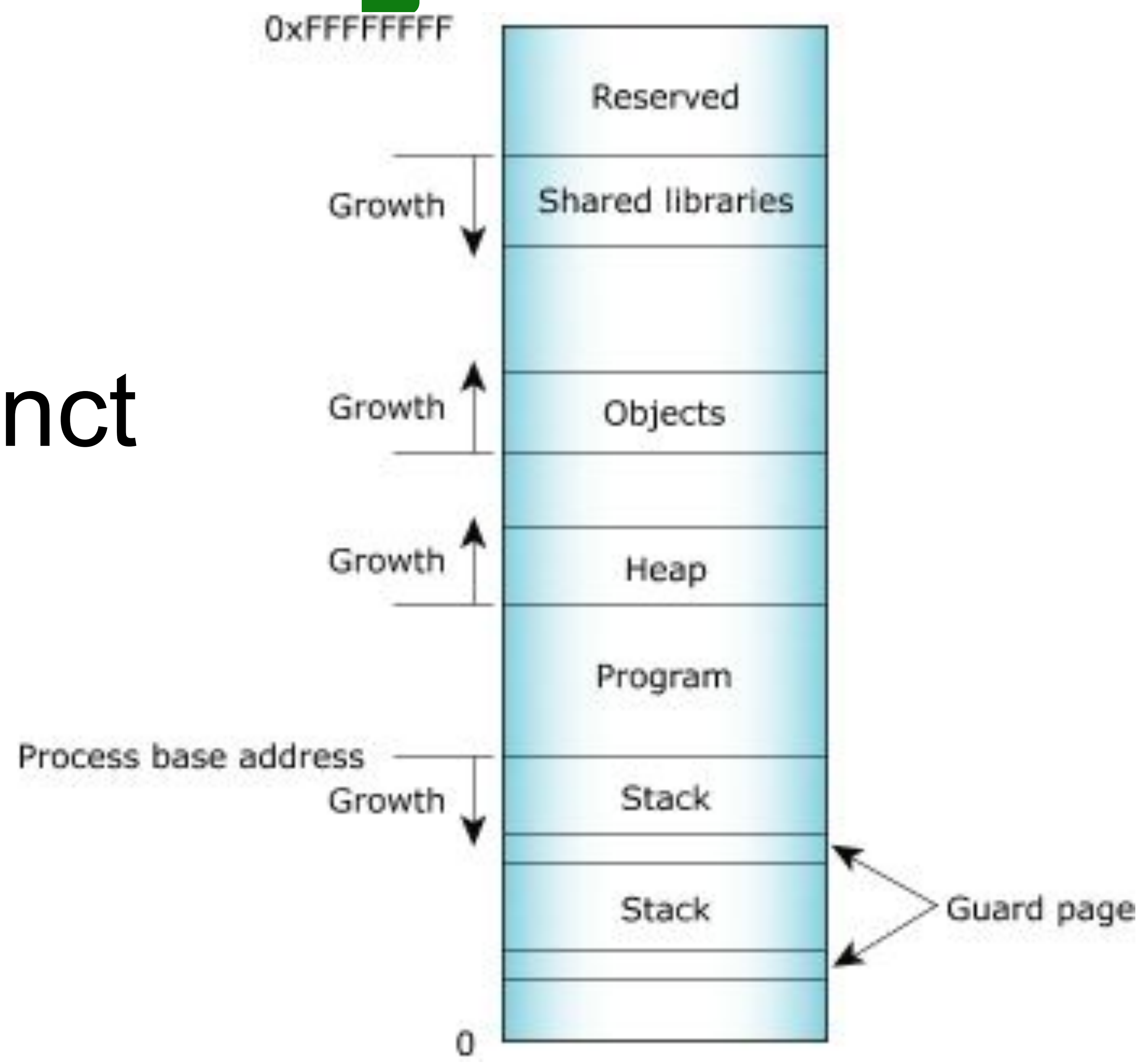
- Faults
  - Major
  - Minor
- Virtual vs physical



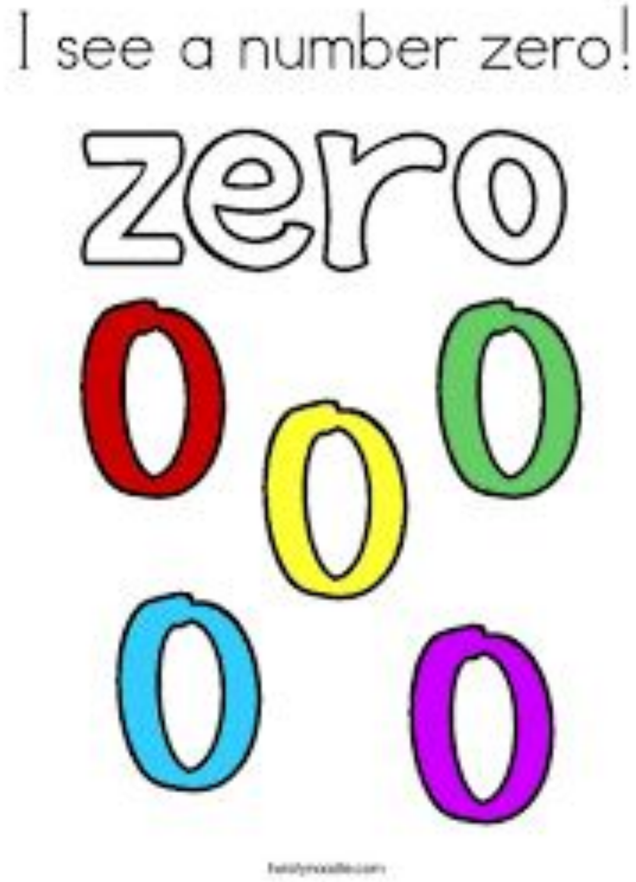


Process Memory

- Virtual memory maps to physical memory
- A view of memory that is distinct for each process.
- Pages shared
- Access control
- Copy on Write



Swap, Zero pages etc.



- Swap page
- Zero page
- Read data behavior
- Write data behavior
- Anonymous vs file backed pages

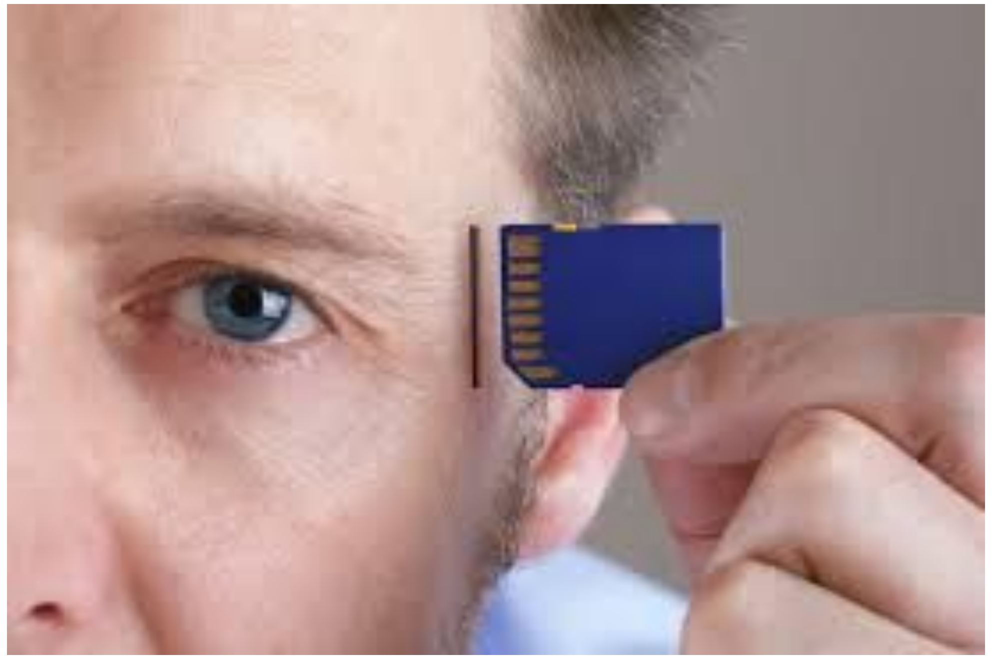
Kernel Basic memory information

/proc/meminfo

/sys/devices/system/ has lots of more detailed information on hardware (processors and memory)

Commands:
numactl --hardware
free, top, dmesg

MemTotal:	31798552 kB
MemFree:	25949124 kB
MemAvailable:	30823580 kB
Buffers:	220988 kB
Cached:	4679188 kB
SwapCached:	0 kB
Active:	2803000 kB
Inactive:	2336992 kB
Active(anon):	240776 kB
Inactive(anon):	6432 kB
Active(file):	2562224 kB
Inactive(file):	2330560 kB
Unevictable:	0 kB
Mlocked:	0 kB
SwapTotal:	2097148 kB
SwapFree:	2097148 kB
Dirty:	48 kB
Writeback:	0 kB



AnonPages:	239716 kB
Mapped:	195596 kB
Shmem:	7396 kB
Slab:	550628 kB
SReclaimable:	443040 kB
SUnreclaim:	107588 kB
KernelStack:	6840 kB
PageTables:	11176 kB

Inspecting a processes use of memory

/proc/<pid>/status
/proc/<pid>/*maps

(there are other files in /proc/<pid>/* with more information about the processes)

Commands:
ps, top

Name:	sshd
VmPeak:	65772 kB
VmSize:	65772 kB
VmLck:	0 kB
VmPin:	0 kB
VmHWM:	6008 kB
VmRSS:	6008 kB
RssAnon:	1216 kB
RssFile:	4792 kB
RssShmem:	0 kB

VmData:	1332 kB
VmStk:	132 kB
VmExe:	492 kB
VmLib:	8076 kB
VmPTE:	168 kB
VmSwap:	0 kB

User limit (ulimit)

- ➢ Max memory size
- ➢ Virtual memory
- ➢ Stack size
- ➢ and lots of other controls.

```
cl@nuc-kabylake:/proc/6713$ ulimit -a
core file size          (blocks, -c) 0
data seg size           (kbytes, -d) unlimited
scheduling priority             (-e) 0
file size               (blocks, -f) unlimited
pending signals                 (-i) 123132
max locked memory       (kbytes, -l) 16384
max memory size         (kbytes, -m) unlimited
open files                      (-n) 1024
pipe size            (512 bytes, -p) 8
POSIX message queues     (bytes, -q) 819200
real-time priority              (-r) 0
stack size              (kbytes, -s) 8192
cpu time               (seconds, -t) unlimited
max user processes              (-u) 123132
virtual memory          (kbytes, -v) unlimited
file locks                      (-x) unlimited
```

Overcommit configuration

Virtual memory use vs physical

overcommit_kbytes
overcommit_memory
- 0 - overcommit. Guess if mem is available.
- 1 - Overcommit. Never say there is no memory
- 2 - Only allocate according to the ratio

overcommit_ratio
- total = swap + physical * ratio

Important VM control knobs

Found in **/proc/sys/vm**
More descriptions of these knobs in Kernel source code. **linux/Documentation/admin-guide**

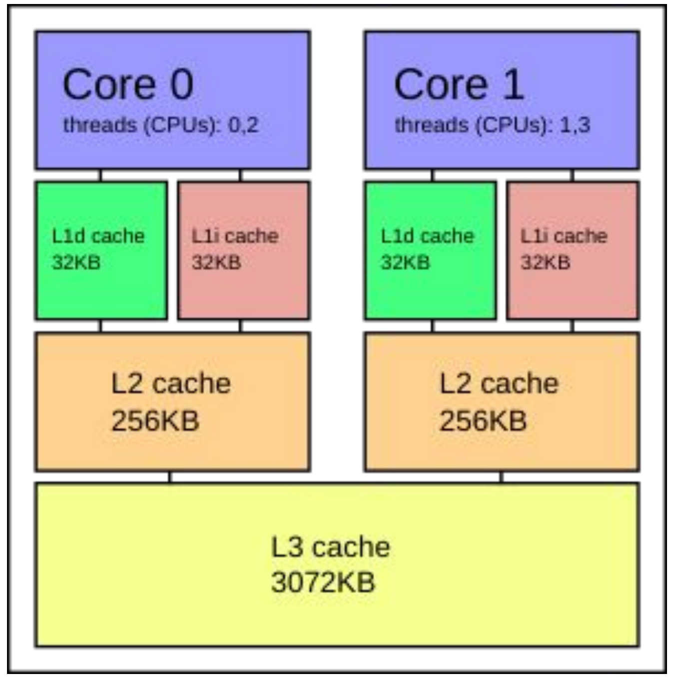
admin_reserve_kbytes **dirty_writeback_centisecs** min_free_kbytes numa_zonelist_order stat_refresh block_dump drop_caches min_slab_ratio oom_dump_tasks swappiness compact_memory extfrag_threshold min_unmapped_ratio oom_kill_allocating_task user_reserve_kbytes compact_unevictable_allowed hugetlb_shm_group mmap_min_addr overcommit_kbytes vfs_cache_pressure **dirty_background_bytes** laptop_mode mmap_rnd_bits overcommit_memory watermark_scale_factor **dirty_background_ratio** legacy_va_layout mmap_rnd_compat_bits overcommit_ratio zone_reclaim_mode dirty_bytes lowmem_reserve_ratio nr_hugepages page-cluster dirty_expire_centisecs max_map_count nr_hugepages_mempolicy panic_on_oom **dirty_ratio** memory_failure_early_kill nr_overcommit_hugepages percpu_pagelist_fraction **dirtytime_expire_seconds** memory_failure_recovery numa_stat stat_interval

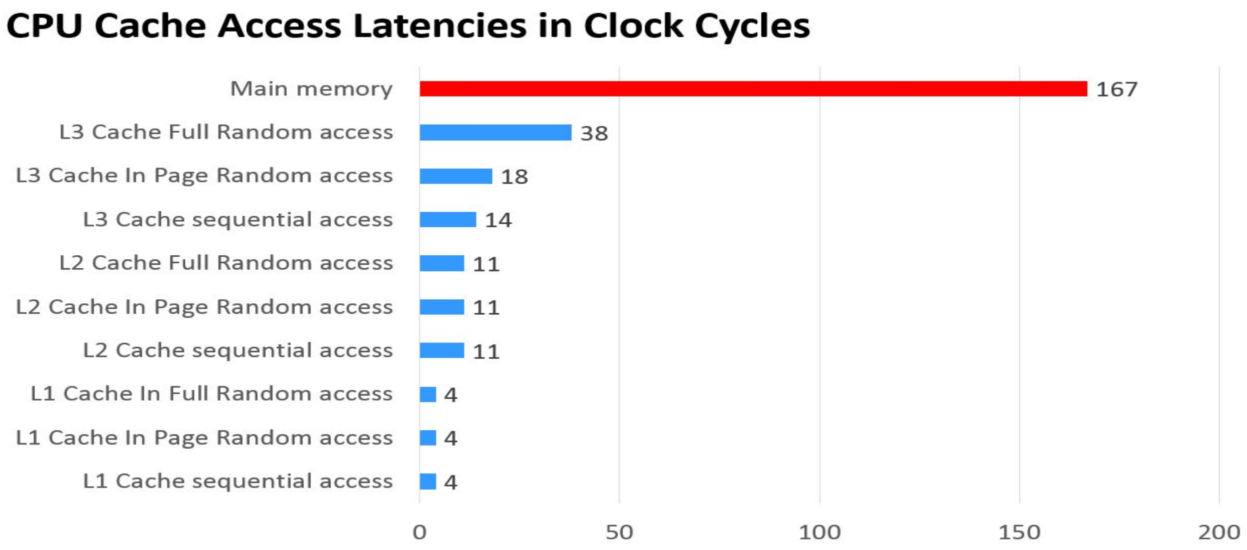
Resources

- Admin Guide online https://www.kernel.org/doc/html/v4.14/admin-guide/index.html
- Kernel.org has wikis and documentation (www.kernel.org)
- manpages (especially for system calls and coding)

"Simple" Memory Access

- ***UMA*** (Uniform Memory Access)
- Any access to memory has the same characteristics (performance and latency)
- The vast major of systems have only UMA.
- But there is always a processor cache hierarchy
  - The CPU is fast, memory is slow
  - Caches exist to avoid accesses to main memory
- ***Alias***ing
- ***Color***ing
- Cache Miss
- Trashing

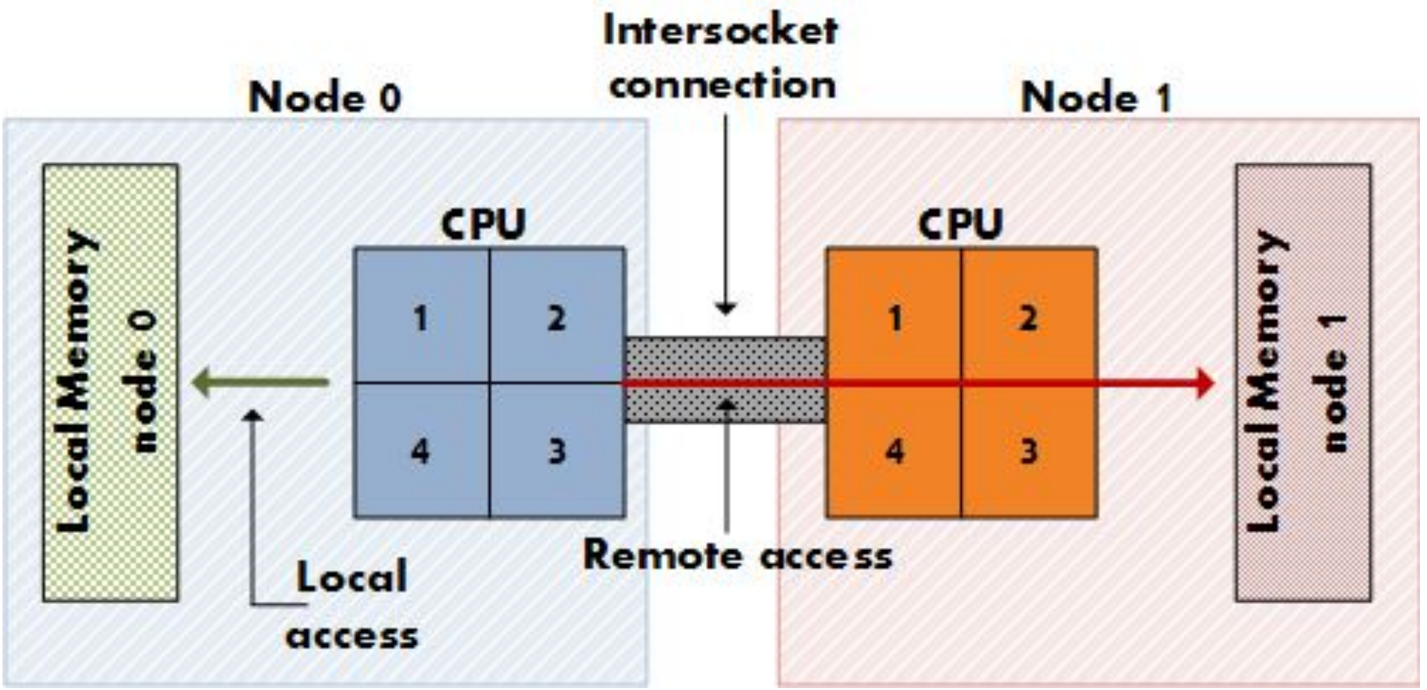


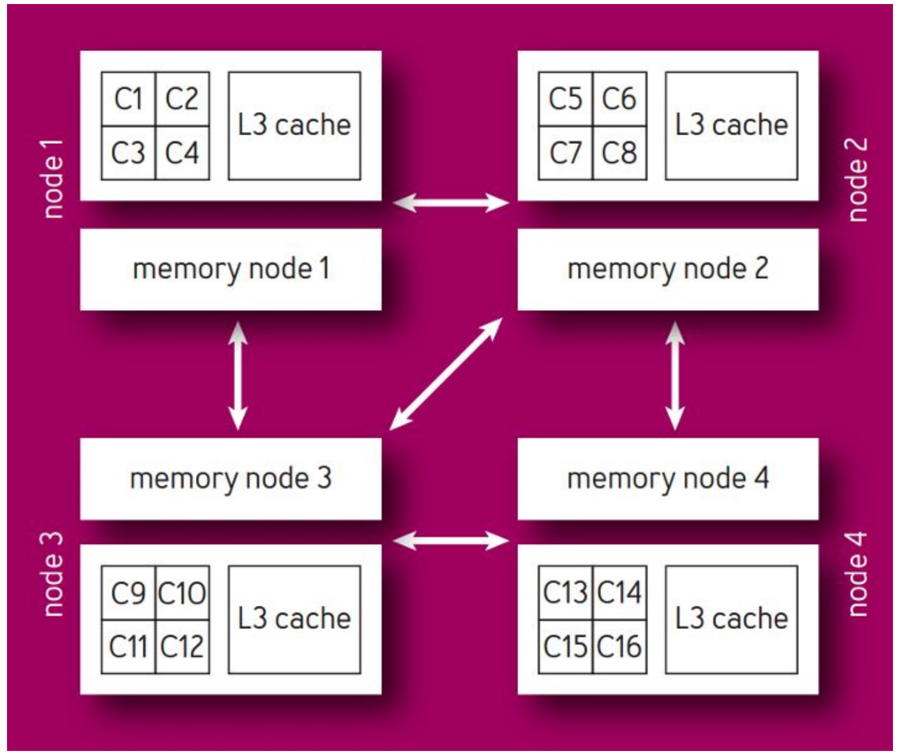


NUMA Memory

- Memory with different access characteristics

- Memory ***Affinities*** depending on where a process was started
- Control ***NUMA*** allocs with memory policies
- System Partitioning using Cpusets and Containers
- Manual memory ***migration***
- Automatic memory migration





Huge Memory

- Typical memory is handled in chunks of base page size (Intel 4k, IBM PowerX 64K, ARM 64K)
- Systems support larger memory chunks of memory called Huge pages (Intel 2M)
- Must be pre configured on boot in order to guarantee that they are available
- Required often for I/O bottlenecks on Intel.
- 4TB requires 1 billion descriptors with 4K pages. Most of this is needed to compensate for architectural problems on Intel. Intel processors have difficulties using modern SSDs and high speed devices without this.
- Large contiguous segments (I/O performance)
- Fragmentation issues
- Uses files on a special file system that must be explicitly requested by mmap operations from special files.

Q & A

An Introduction to Linux memory management. The basics of paging. Understanding basic hardware memory management and the difference between virtual, physical and swap memory. How do determine hardware installed and how to figure out how processes use that memory. How a process uses physical and virtual memory effectively. How to control overcommit and virtual and/or physical memory limits.

Basic knobs in Linux to control memory management. System calls for a process to control its memory usage