OpenSolaris and NUMA Architectures

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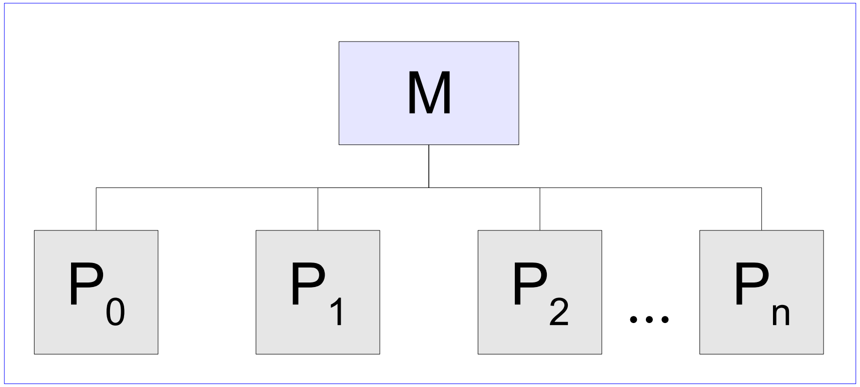
Overview

- Where did NUMA come from ?
- Access latencies
- Topology representation
- Optimizing for NUMA
- Topology discovery
- A peek at the implementation
- Where NUMA is going

Where did NUMA come from ?

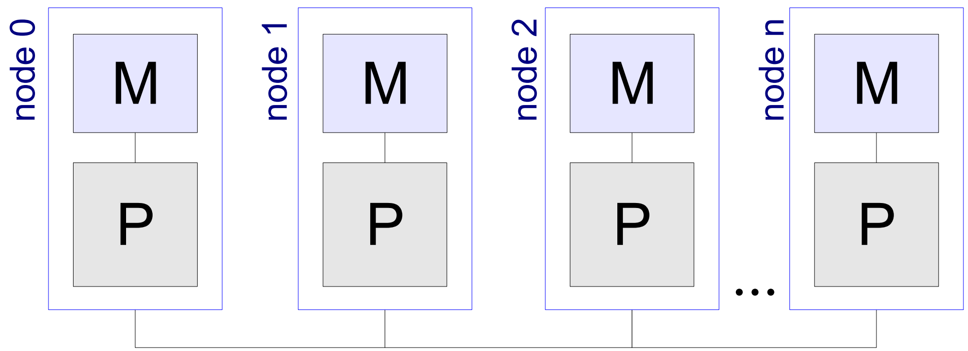
- Symmetric Multiprocessing (SMP)
  - processors connected to memory through a single bus
  - shared memory, single address space
  - Uniform Memory Access (UMA)



  - traditional programming paradigm
  - model doesn't scale as processors are added

Where did NUMA come from ?

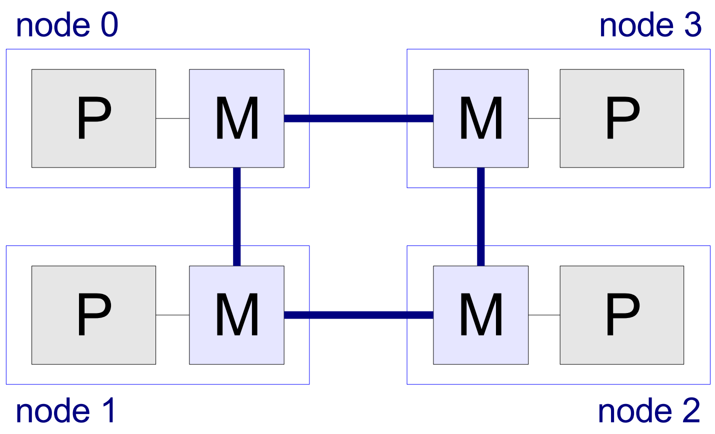
- Clusters
  - each node has it's own memory
  - network connected
  - multiple address spaces



  - scalable
  - network programming paradigm
  - replication (software, data, ..)

Where did NUMA come from ?

- Non-Uniform Memory Access
  - nodes composed of processors with *local* memory
  - can access *remote* memory through the *interconnect*
  - *local* access faster than *remote* (non-uniform)
  - shared memory, single address space



  - more scalable than SMPs
  - traditional programming paradigm

Where did NUMA come from ?

- Non-Uniform Memory Access
  - it's actually "*cache coherent*" NUMA, or *ccNUMA*
  - hardware cache coherence
  - Distributed Shared Memory (DSM)
    - cache coherency algorithm and implementation varies from model to model and between manufacturers
    - affects performance

NUMA and OpenSolaris

- Memory Placement Optimization (MPO)
  - framework to provide better performance through *locality awareness*
  - implemented through
    - Common framework support
      - usr/src/uts/common/sys/lgrp*.h
      - usr/src/uts/common/os/lgrp*.c
    - Platform specific support
      - usr/src/uts/{i86pc,sun4}/os/lgrpplat.c
  - interfaces for observability and control
    - APIs
    - Tools

Access Latencies

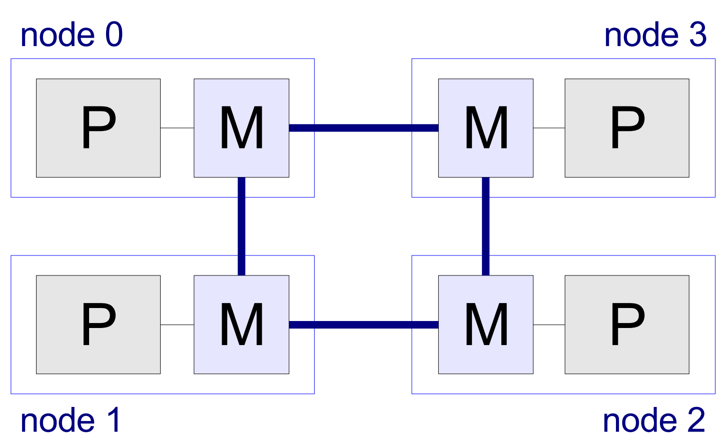
- Local x Remote
  - NUMA factor = Local Access / Remote Access
  - varies between machines/vendors/manufacturers
- Locality awareness
  - keep threads close to where their data/device is
  - avoid remote accesses
  - take advantage of cache warmth
- Conflicting objectives
  - load balance across nodes
  - minimize data migration

Topology Representation

- Locality groups (*lgroups)*
  - represent sets of resources close to each other
  - each lgroup has at least one processor and possibly some memory and/or devices
  - hierarchical: different levels of locality
    - leaf lgroups
    - intermediate lgroups
    - root lgroup
  - forms a *latency topology*

Topology Representation

- Leaf lgroups
  - contain resources at the lowest level of latency
  - only local accesses
  - Example: 4 node, ring topology



Topology Representation

- Leaf lgroups
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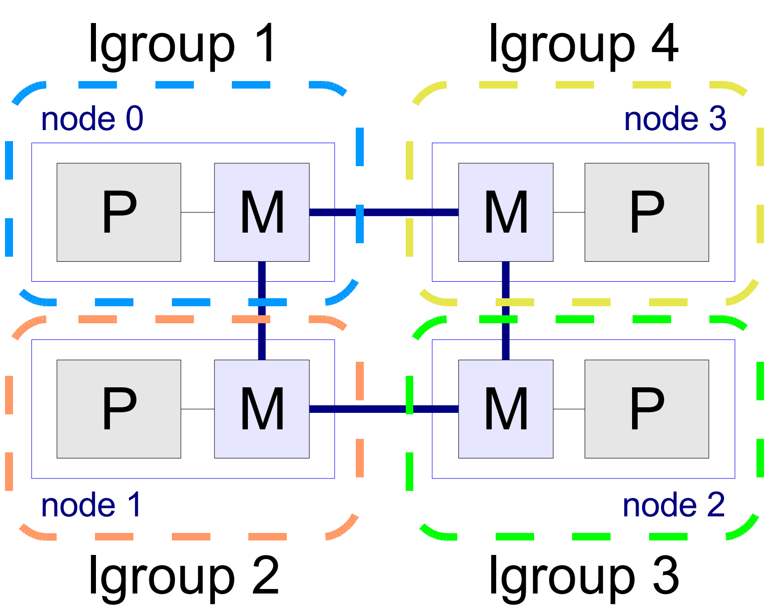

lgroup topology:

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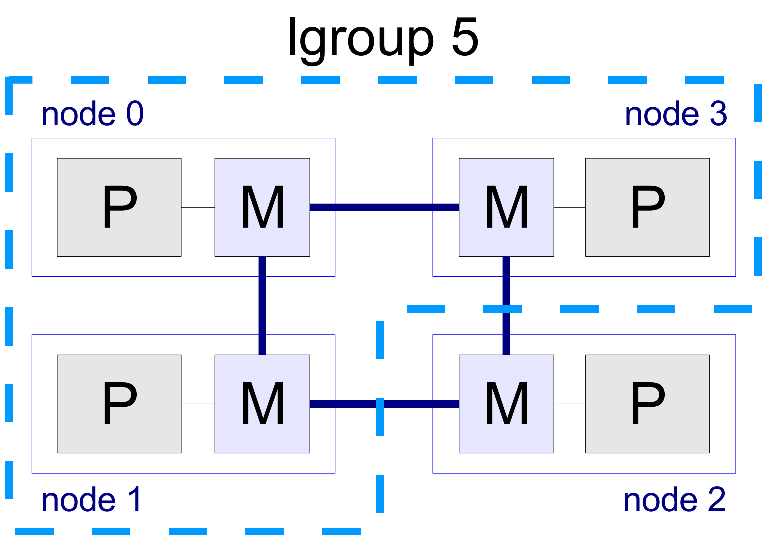
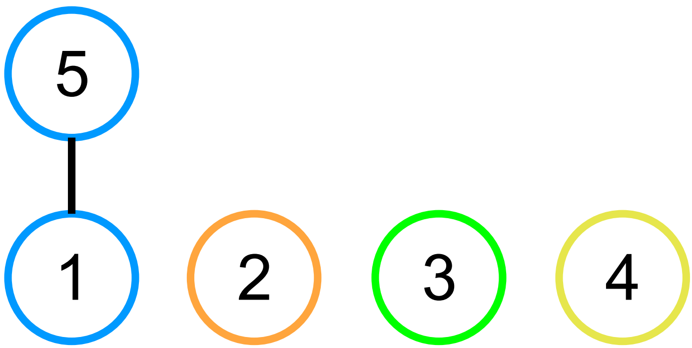
Topology Representation

- Intermediate lgroups
  - contain CPU and memory resources with one hop
  - lgroup 5 contains lgroups 1, 2 and 4

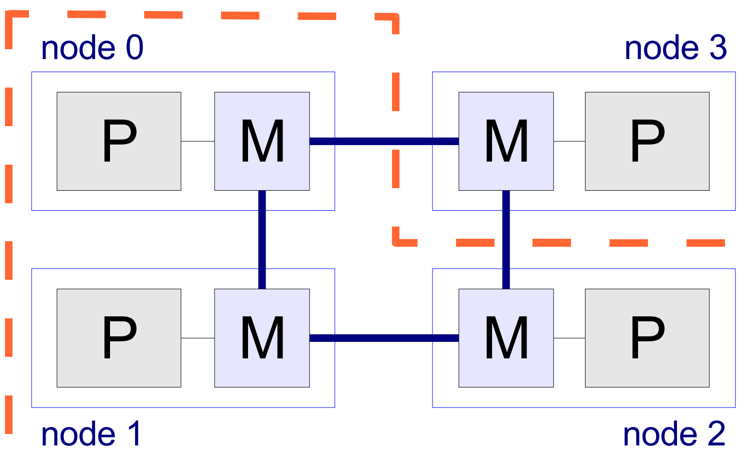


lgroup topology:



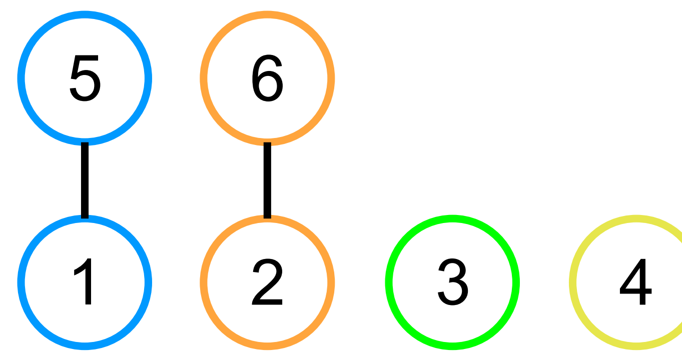
Topology Representation

- Intermediate lgroups
  - contain CPU and memory resources with one hop
  - lgroup 6 contains lgroups 1, 2 and 3



lgroup 6

lgroup topology:



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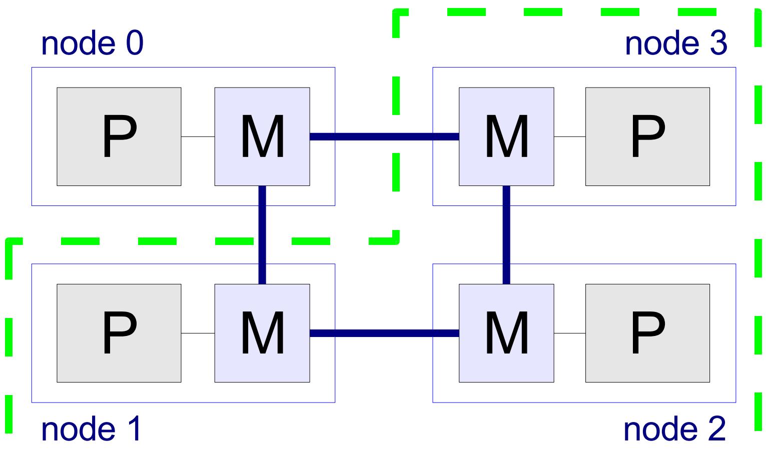
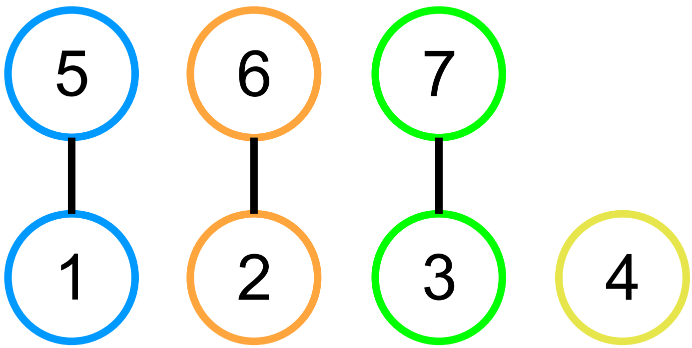
Topology Representation

- Intermediate lgroups
  - contain CPU and memory resources with one hop
  - lgroup 7 contains lgroups 2, 3 and 4



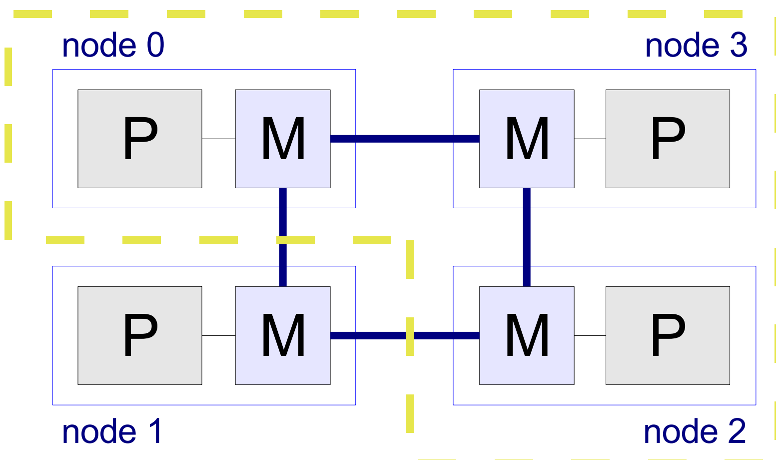
lgroup 7

lgroup topology:



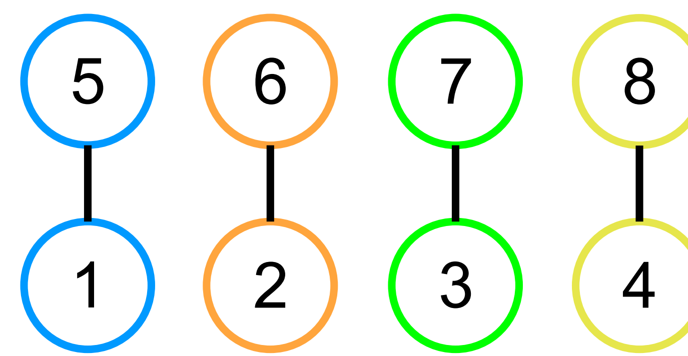
Topology Representation

- Intermediate lgroups
  - contain CPU and memory resources with one hop
  - lgroup 8 contains lgroups 1, 3 and 4



lgroup 8

lgroup topology:



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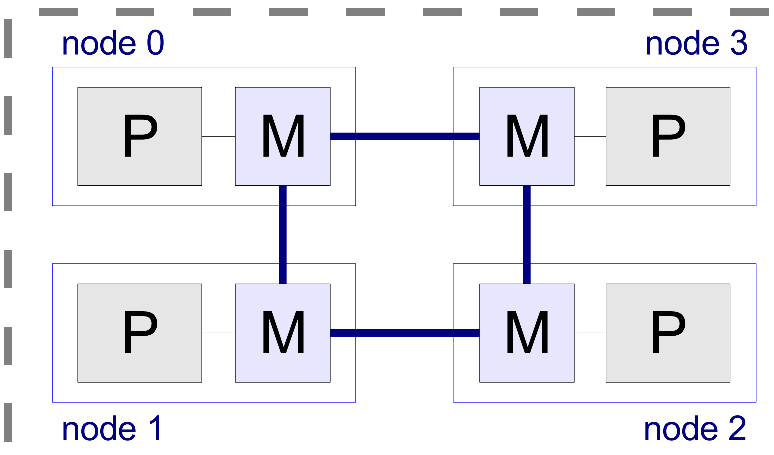
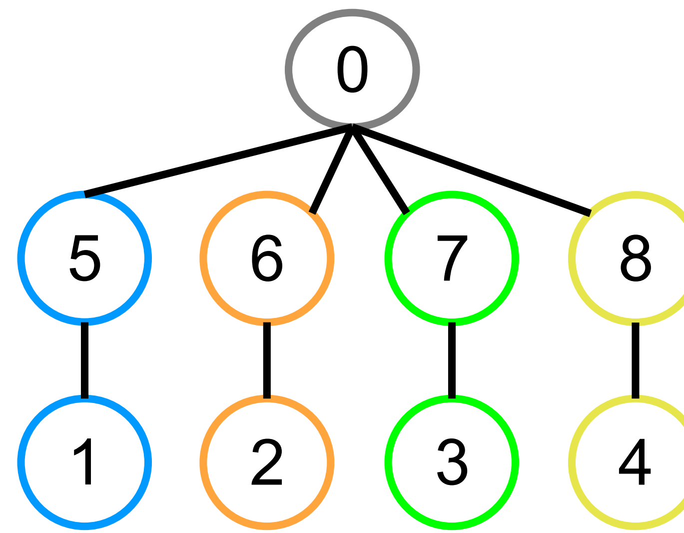
Topology Representation

- Root lgroup
  - contain all the lgroups in the system
  - highest level of latency
  - always lgroup 0



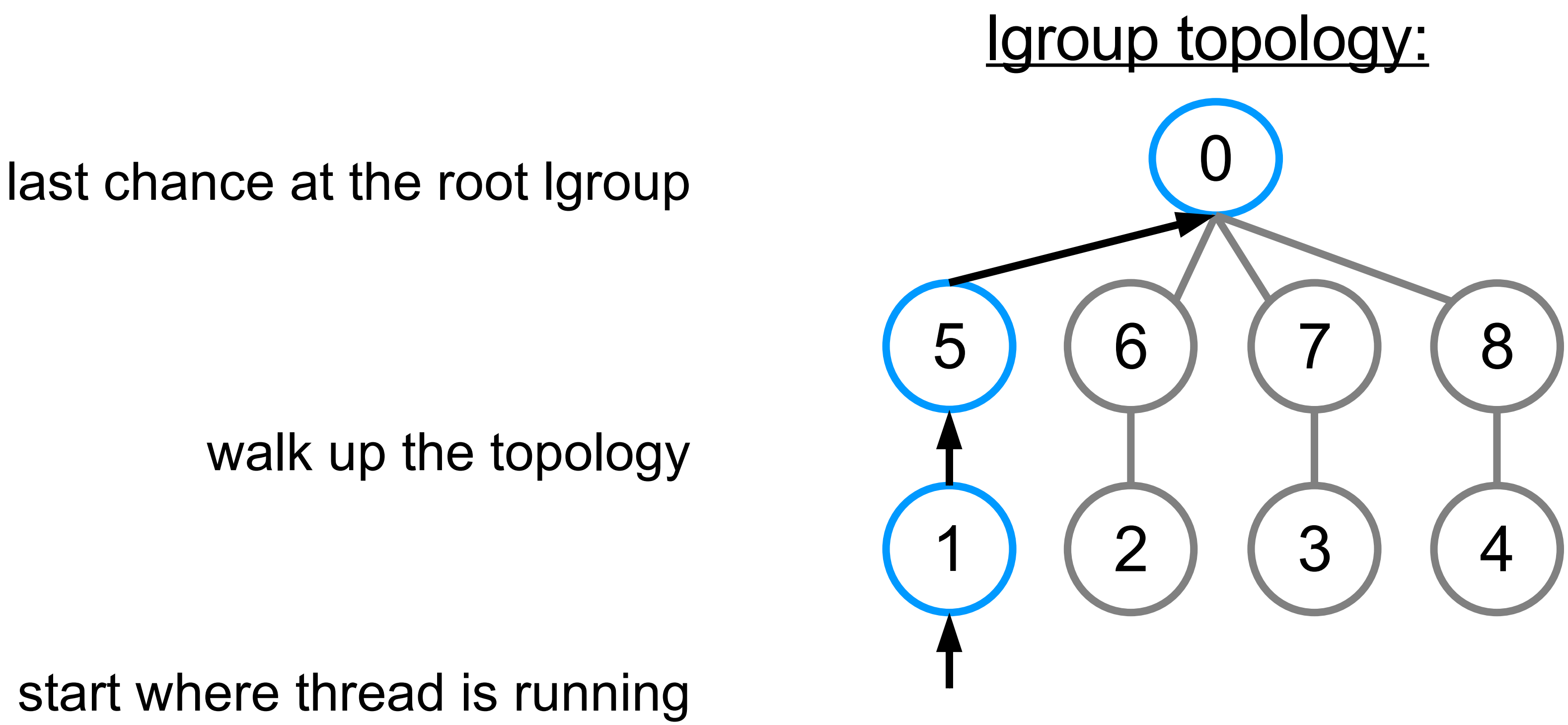
lgroup 0 (root)

lgroup topology:



Topology Representation

- Latency topology
  - used by the scheduler and VM subsystems
  - look for resources closer to the processor where the thread is running



Optimizing for NUMA

- Scheduler
  - threads are associated with a *home lgroup* upon creation
  - scheduler always tries to dispatch thread to a processor at the home lgroup
  - load balancing across CPUs nearby
  - use latency topology to dispatch to/steal from

Optimizing for NUMA

- VM
  - allocation policies:
    - first touch
      - allocate from the faulting thread's home lgroup
      - default for private memory
    - random
      - randomly across leaf lgroups
      - default for shared memory

Optimizing for NUMA

- liblgrp(3LGRP)
  - allows the developer to traverse the topology
  - discover the contents of an lgroup
  - change a thread's affinity for an lgroup
    - affinity != home lgroup
- meminfo(2)
- madvise(2)
- madv.so.1(1)
  - LD_PRELOAD = $LD_PRELOAD:madv.so.1
  - MADV= { normal, random, sequential, access_lwp, access_many, access_default }

Optimizing for NUMA

- lgrpinfo(1)
  - display information about the lgroup hierarchy
- plgrp(1)
  - observe and affect home lgroup and thread affinities
- pmadvise(1)
  - apply advices about memory to a process

Optimizing for NUMA

- lgrpinfo(1)
  - UMA machine

```
# lgrpinfo -Ta
0
|   CPUs: 0 1
|   Memory: installed 1015M, allocated 762M, free 253M
|   Lgroup resources: 0 (CPU); 0 (memory)
|   Load: 0.0493

Lgroup latencies:

-----
  | 0
-----
0 | 0
-----
```

Optimizing for NUMA

- lgrpinfo(1)
  - 2 node NUMA

```
# lgrpinfo -Ta
0
|-- 1
|    CPU: 0
|    Memory: installed 2.0G, allocated 168M, free 1.8G
|    Load: 0.951
|    Latency: 59
`-- 2
     CPU: 1
     Memory: installed 1.9G, allocated 265M, free 1.7G
     Load:    0
     Latency: 59

Lgroup latencies:

------------
  | 0  1  2
------------
0 | 96 96 96
1 | 96 59 96
2 | 96 96 59
------------
```

Optimizing for NUMA

- lgrpinfo(1)
  - 8 node NUMA (lgroup latencies matrix)

```
------------------------------------------------------------------------------------------------------
   |   0   1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24
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 5 | 147 147 147 112 112  79 147 112 147 147 147 147 147 147 147 147 147 147 112 147 147 147 147 147 147
 6 | 147 147 147 112 112 147  79 147 112 147 147 147 147 147 147 147 147 147 147 147 112 147 147 147 147
 7 | 147 147 112 147 147 112 147  79 112 147 147 147 147 147 147 147 147 147 147 147 147 147 112 147 147
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23 | 185 185 147 147 147 147 147 147 147 185 185 185 185 185 185 185 147 185 147 185 147 185 147 147 147
24 | 185 185 147 147 147 147 147 147 112 185 185 185 185 185 185 185 147 185 147 185 147 185 147 147 112
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```

Topology discovery

- How does the system finds out about latencies and topology?
  - probe memory
  - probe PCI space registers (AMD Opteron)
  - ACPI 3.0
    - Static Resource Affinity Table (SRAT)
    - System Locality Information Table (SLIT)
    - default as of Solaris Nevada build 88
    - some gotchas ;)

A peek at the implementation

- UML Diagrams
  - MPO related routines
  - flow and brief description
  - based on snv65
  - work in progress
  - http://blogs.sun.com/rv/resource/browser/browser.html

A peek at the implementation

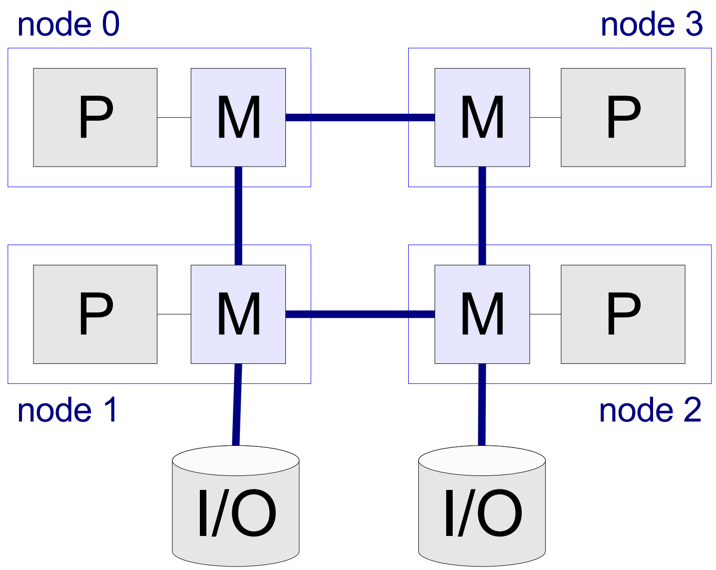
- Home lgroup
  - choosing a thread's home lgroup
    - lgrp_choose()
  - changing a thread's home lgroup
    - lgrp_move_thread()
- Scheduler
  - core routines under
    - usr/src/disp/disp.c

A peek at the implementation

- VM
  - how do we find an lgroup to allocate from ?
    - lgrp_mem_choose()
  - when allocating pages:
    - page_get_freelist()
    - page_get_cachelist()

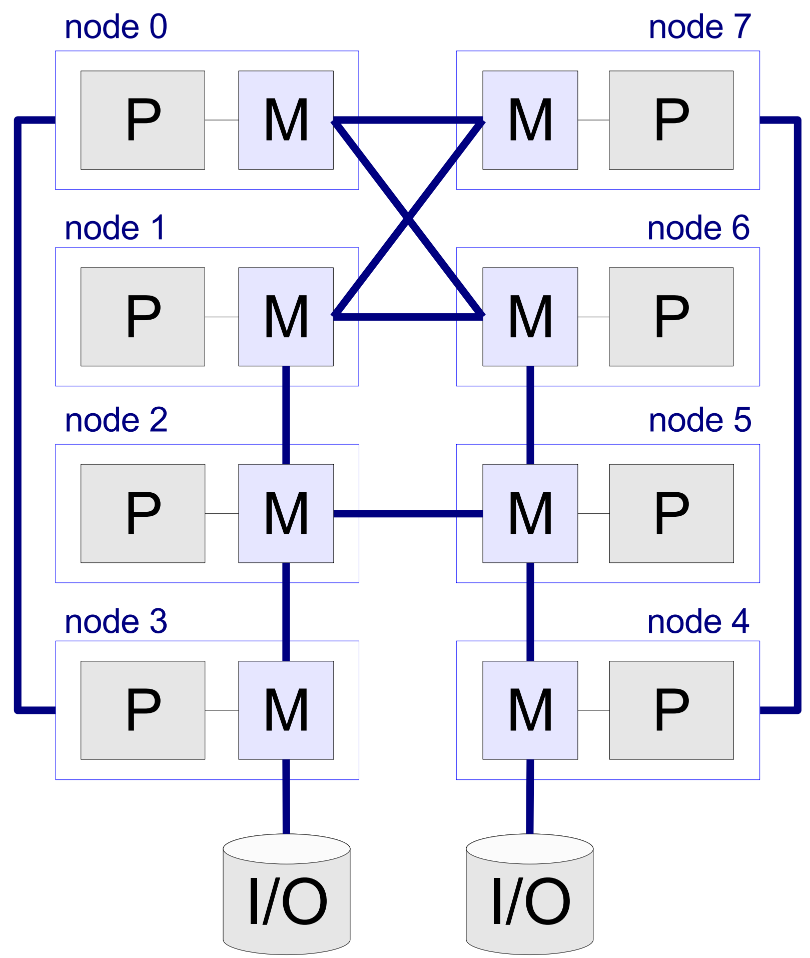
Where NUMA is going

- Virtualization
  - host is not NUMA aware
    - no optimizations
  - host is NUMA aware
    - exports NUMA characteristics to the guest OS
    - doesn't export, does everything by itself
- I/O locality
  - machines with NUMA I/O
  - where to place threads ?
    - app, kernel, driver
  - where to place memory ?
    - app, kernel, DMA buffers, device metadata



Where NUMA is going

- NUMA everywhere
  - Sun, AMD and Intel platforms
  - Sun, IBM, HP, SGI, Bull and others offer NUMA machines
- NUMA and CMT
  - Increased CMT density
- Different topologies
  - support and optimize
- Observability
  - hardware performance counters
- Power Management
  - performance x PM



Questions ?

Interested ?

- OpenSolaris Performance Community
  - http://opensolaris.org/os/community/performance/
  - perf-discuss-subscribe@opensolaris.org
- NUMA Project
  - http://opensolaris.org/os/community/performance/numa/
- Tesla Project
  - http://opensolaris.org/os/project/tesla/
  - tesla-dev-subscribe@opensolaris.org

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オープン
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ανοικτό
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Thank you!

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