Topology-Aware Job Scheduling Strategies for Torus Networks

Cray User Group
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Adaptive Computing
Outline

- Application run time variability due to task placement
- Mitigation attempts
  - New ALPS node ordering scheme
  - Predefined node allocation shapes
- Topology-Aware scheduling in Moab
  - Goals & design
  - Synthetic workload
  - Preliminary results on utilization, application performance, throughput
- Leveraging Topaware task layout tool
  - New scheduler & Topaware features enable near-optimal layouts
  - Performance improvements for halo exchanges
  - Performance improvements for MILC
- Conclusions and next steps
Application Run Time Variability

- **Blue Waters torus**
  - 24x24x24 gemini routers, 2 nodes each
  - XEs plus 15x6x24 XK block
  - Scattered service nodes
  - Links along x & z dimensions 2X faster than links along y

- **Run times varied widely**
  - More if communication intensive (PSDNS, MILC)
  - Up to 4X longer than ideal
  - ALPS favored lower bandwidth yz slabs
  - Allocations often fragmented, increases link contention
New Node Ordering Scheme

● Default ALPS node ordering
  ● Favors yz slabs 4 thick in x
  ● Lower bisection bandwidth than xz slabs due to link speeds
  ● PSDNS runs 1.6X faster in 24x6x24 gemini prism than in 6x24x24 prism

● Developed new scheme
  ● Major help from Cray’s C. Albing
  ● Favors xz slabs, 2 or 4 thick in y
  ● Reverses direction when jumping to next level in y
  ● Does not reduce job-job interference
  ● Helps application performance
New Node Ordering Scheme

- Workload test: speedups for 7-8 concurrent applications

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<th>App</th>
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<th>Nov.11 4Y</th>
<th>Nov.4 2Y</th>
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Predefined Node Allocation Shapes

● Uses Moab “nodesets”
  ● Favorable shapes like 24x6x24, 12x12x12, 12x6x12 geminis
  ● Shapes can overlap
  ● Same shape can be replicated throughout system
    ● E.g., several different 24x6x24 prisms in 24x24x24 torus

● Target nodesets at time of job submission
  ● #PBS –l nodeset=ONEOF:FEATURE:s1_24x6x24,s2_24x6x24,…
  ● Job will run in first available requested feature
  ● Good run time consistency for PSDNS in 24x8x24 nodeset
  ● Queue wait times can be long
  ● Special arrangements needed to reserve a specific nodeset
  ● Limited number of predefined shapes to choose from
  ● Number of compute nodes in each nodeset differs
  ● Job-job interference reduced but not eliminated
Topology-Aware Scheduling in Moab

● NCSA/Cray/Adaptive collaboration

● Goals
  ● Improve application performance on large XE and XK systems through better-localized job placement
  ● Improve application run-time consistency by eliminating job-job interference due to application communication
  ● Improve system throughput and maintain reasonably high utilization

● Approach
  ● Allocations are regular right prisms
  ● Eliminate interference: allocation either spans a torus dimension, or spans $< \frac{1}{2}$ of geminis in a dimension
  ● Favor xz slabs
  ● Boost utilization by more freely placing jobs that perform/are not affected by application communication
  ● Allow applications to request specific allocation shapes (Topaware)
Workload Test

● **Synthetic workload with representative applications**
  ● MILC, PSDNS, NAMD, NWCham, Changa, QMCPACK, DNS_distuf, WRF, SpecFEM3D_globe
  ● Broad range of communication patterns
  ● Numerous representative node counts and run times based on actual Blue Waters production logs
  ● Small node counts much more numerous than large node counts, but bulk of service units consumed by larger jobs
  ● Tested at scale on Blue Waters
  ● Matches backlog, job submission timing, node count distribution, requested run time distribution (scaled to 3 hr test window), node type
  ● Matches scheduler policies, priorities, limitations
  ● Starting state matches fragmentation of production environment

● **Measure utilization, app performance & consistency**
Preliminary Workload Test Results

- Topology aware test conducted Apr 22-23
- 1544 jobs run in two hour window
  - Gemini network failure 2 hours into 3 hour scale test
  - Hardware warm-swapped later – aborted non-topology ‘control’ test
- Good scheduler performance (71.1% average utilization)
  - Backfill constrained by workload – utilization could have been better
    - 200 jobs per submission cycle (38% of jobs 8 nodes or less)
    - Backlog too small (184 jobs avg in test vs ~300 for production operation)
    - Job durations too consistent (91% of all jobs had same duration)
Preliminary Workload Test Results

Utilization and Backlog

Graph showing the utilisation and backlog for Moab iteration number from 0 to 45. The utilisation is represented by a line graph with markers, while the backlog is represented by a line graph without markers. The x-axis represents the Moab iteration number, ranging from 15 to 45. The y-axis on the left represents the number of jobs in backlog, ranging from 0 to 450. The y-axis on the right represents the utilisation, ranging from 0% to 100%.
Preliminary Workload Test Results

- **Application Consistency**
  - Worst Application run time CoV is less than 2%
  - Worst ‘Per Shape’ Application CoV is less than 1.25%
Preliminary Workload Test Results
Application Run Time Comparison

- Limited default scheduler results for comparison
  - Sample size too small, but gives example speedups

![Bar chart showing relative performance of MILC 324 XE and PSDNS 3072 XE with default and topology aware scheduler results.](chart.png)
Default vs. Topology Runs (using grid_order)

- Avg. run time w/default scheduler 79% higher (8 samples)
- CoV < 5% w/topology-aware scheduler (2 samples)
Effective Throughput Estimate

- Effective Throughput = \( \% \text{scheduling performance} \times \% \text{application performance} \)
- Biggest improvements in application performance seen for largest jobs
- Over 76% of Blue Waters compute cycles delivered to jobs > 512 nodes
- Scheduling efficiency in benchmark and simulation runs \(~75-85\%\) vs. \(90\%\) for default scheduler
- Sample size too small without ‘control run’, but >40% improvement in large application performance is common
- Assuming 77% scheduling performance and 140% weighted application performance boost, throughput improvement = \((77/90) \times 1.40 = 1.19X\)
Topaware Node Selection and Task Layout Tool

- Provides near optimal task mapping for 2, 3, & 4D Cartesian grid virtual topologies
  - In each z-pencil, set of selected geminis along z is extended if needed to skip unavailable nodes
  - Determines multiple valid layouts and evaluates layout quality
  - Allows unbalanced layouts
    - Nodes on prism boundaries may have fewer tasks
    - Enables more good layouts for more virtual topology sizes
  - Scheduler ensures allocation has desired gemini count in each z-pencil
## Topaware Unbalanced Layouts

- Halo exchanges for virtual topology: 32 by 32 by 32

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<thead>
<tr>
<th>Placement</th>
<th>Iter time (ms)</th>
<th>Max hops</th>
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<tbody>
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<td>Default 8x8x8</td>
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Topaware and Real Apps

● MILC
  ● Virtual topology 21 by 2 by 21 by 24
  ● 1764 nodes, 12 tasks each
  ● 21x2x21 geminis
  ● 2.2x faster with Topaware than with grid_order –c 2,2,2,2 on same nodes

<table>
<thead>
<tr>
<th>Placement</th>
<th>Run Time (10 iterations)</th>
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<tr>
<td>Grid_order</td>
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<td>Topaware</td>
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Conclusions and Next Steps

- New ALPS node ordering scheme favors xz slabs & improves application performance by 12-19%
- New topology-aware Moab scheduler provides prism-shaped allocations which further improve application performance
  - Maximize bisection bandwidth, reduce latency
  - Eliminate job-job interference
- Workload test demonstrates 40% better overall large application performance and 4X better run time consistency
  - Utilization averages 71%, expect this to increase to ~77%
  - Expected system throughput improvement estimated at 19%
- Topaware provides impressive speedups for nearest-neighbor communication
  - MILC 2.2X faster than with grid_order on same nodes
- New scheduler provides prism allocations required for near-optimal Topaware layouts
- Workload retest needed to compare default scheduler and new scheduler + Topaware for MILC runs