Algebraic Multigrid on a Dragonfly Network: First Experiences on a Cray XC30

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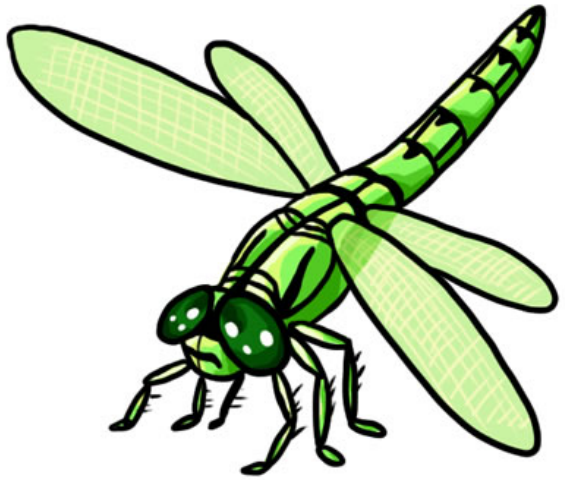
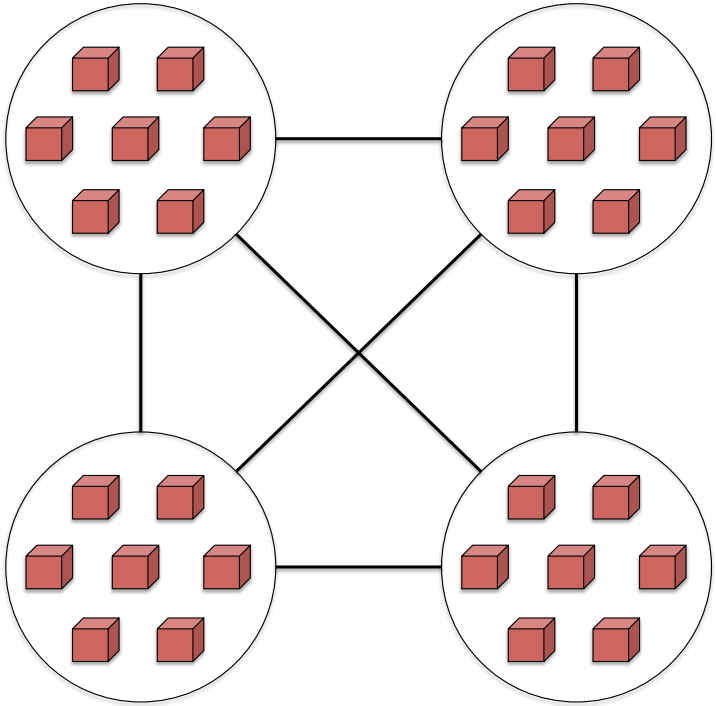
Introduction

- So we have a new interconnect topology making the rounds
- First major appearance in Cray XC30
- Questions to answer:
  - How do applications perform on this topology?
  - Advantages and disadvantages?
  - Prospects for larger future machines?
- We examine the performance of one application on an XC30 to see what insights we can gain



Dragonfly Interconnect

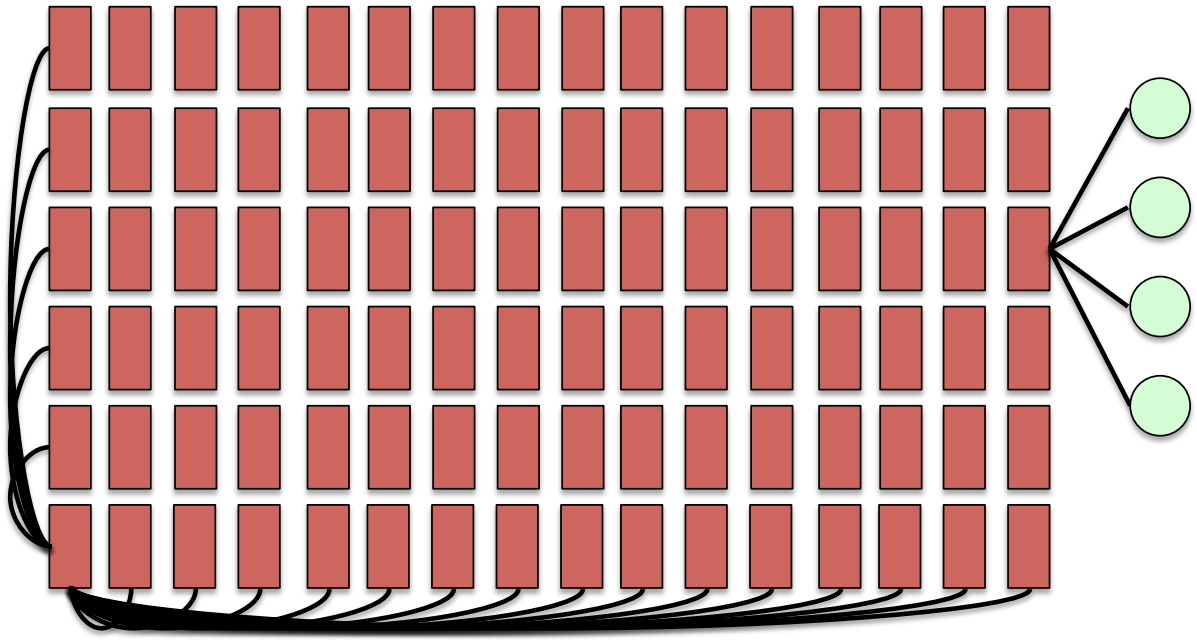
- Groups of routers fully connected by optical links:



- Routers in each group connected through their own topology

Cray XC30 Dragonfly

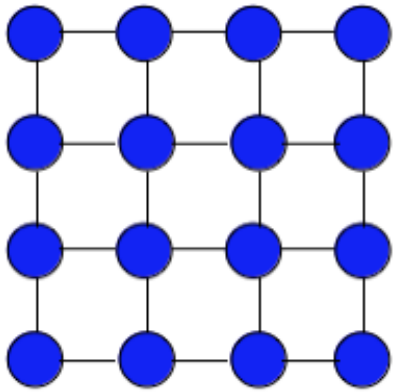
- Routers in each group arranged in a 2D grid with all-to-all links in each dimension:



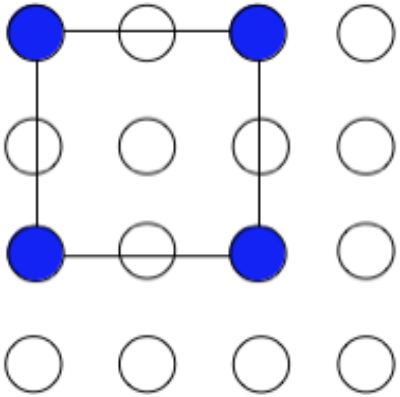
- Four nodes connected to each router

Algebraic Multigrid

Apply multigrid concept:

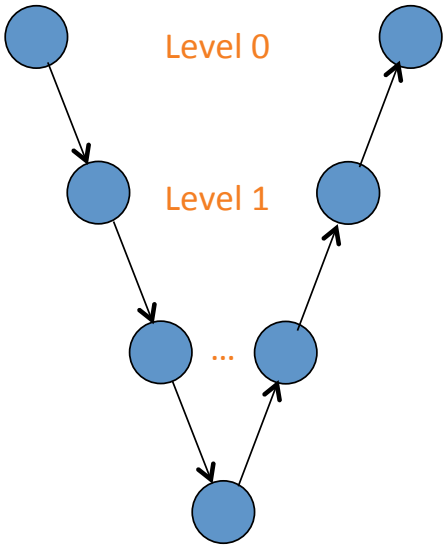


Solve original "fine" problem

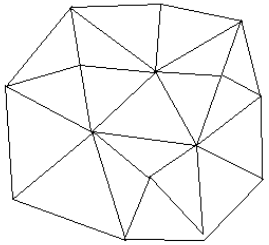


With information from smaller "coarse" problems

And cycle:



To unstructured grid problems:



Requires two phases:

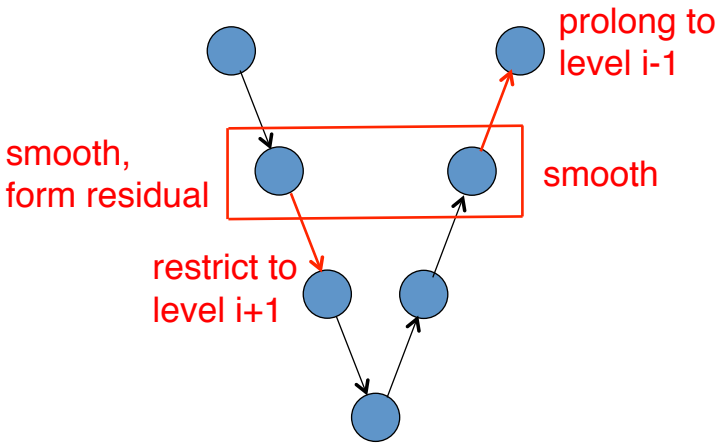
1. Setup hierarchy of grids
2. Solve problem

Performance Modeling

- In past work, developed a performance model for the AMG solve cycle
- Used it to analyze performance on several machines and guide improvements on a number of them
  - Fat-tree Linux clusters
  - Blue Gene/P, Blue Gene/Q
  - Cray XT5, XK6, XK7
- Extend work to XC30 to analyze dragonfly

Performance Modeling

- Approach: work level-by-level, with α-β model (T_{send}=α+nβ for message of length n) as baseline



- Fundamental operations at each level shown in red
- Treat each operation as MatVec with appropriate operator

- Machine parameters for network and computation rate measured using benchmarks
- Communication, computation counts are available from solver data structures

Performance Modeling

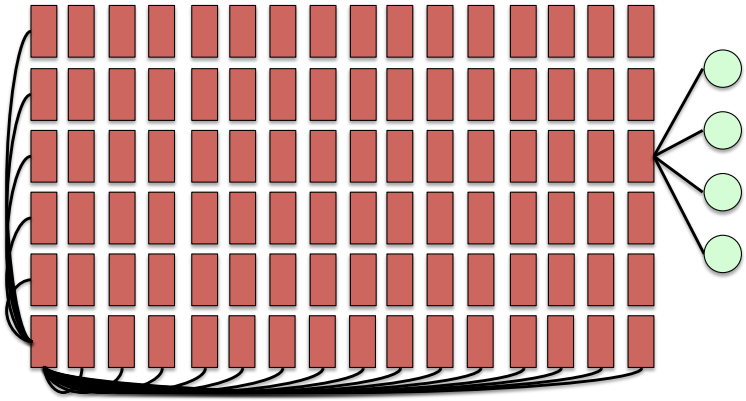
- To the baseline models, we add penalties to take architecture into account:
  - Distance of communication: introduce time per hop γ
    - Measured from worst-case, best-case latencies and global network diameter
    - Distance of diam(P) charged to each message
  - Lower effective bandwidth: multiply β by $\frac{\text{Hardware Bandwidth}}{\text{MPI Bandwidth}}$ or $\frac{\text{Hardware Bandwidth}}{\text{MPI Bandwidth}} + \frac{\text{nmsgs}}{\text{nlinks}}$, depending on machine
  - Multicore penalties:
    - c = number of cores per node
    - P_i = number of "active" processes on level i
    - Multicore latency penalty: multiply α by $\left\lceil \frac{cP_i}{P} \right\rceil$
    - Multicore distance penalty: multiply γ by $\left\lceil \frac{cP_i}{P} \right\rceil$
  - Hybrid MPI/OpenMP: if using j threads, multiply time per flop by (Mem BW for 1 thread)/(Mem BW for j threads)

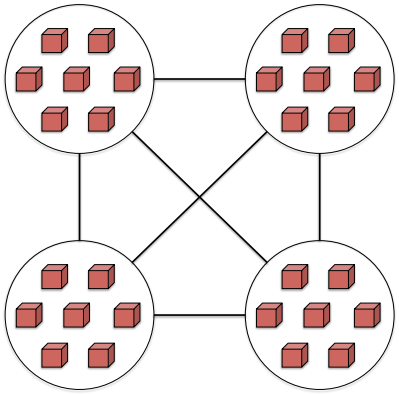
Extending to Dragonfly

- # of links and distance for penalties are computed based on the interconnect
- Torus networks: compute from geometry
- Fat-trees: distance = going up and down the tree, # links = midpoint between best and worst cases
- What to do for dragonfly?

Extending to Dragonfly

- Message distance: use maximum shortest path between nodes
- On XC30:

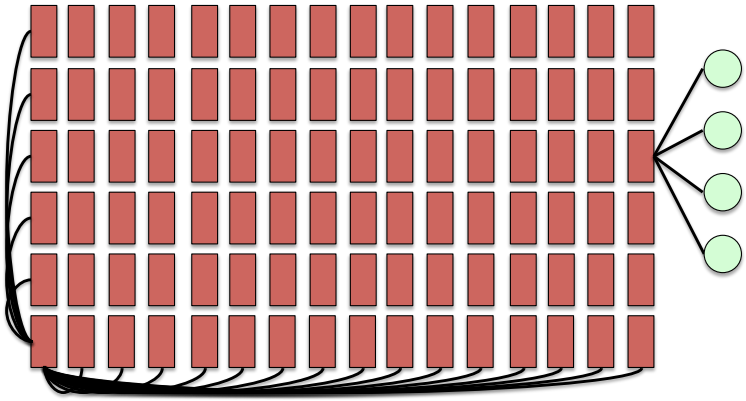


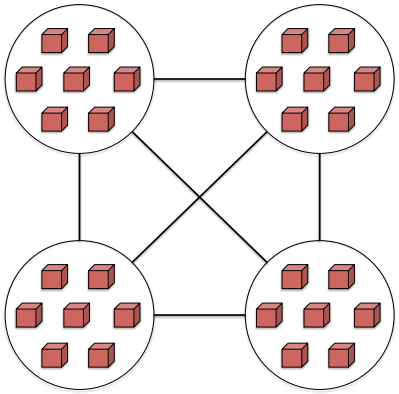


- 1 link to routers
- 2 router links to access optical network (not every router has access)
- 1 optical link
- 2 router links to router attached to target node
- 1 link to target node

Extending to Dragonfly

- Number of links: like fat-tree, midpoint between minimum and maximum
- On XC30:



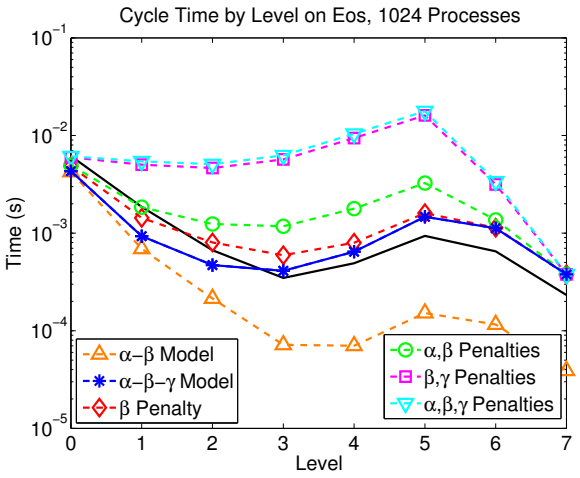


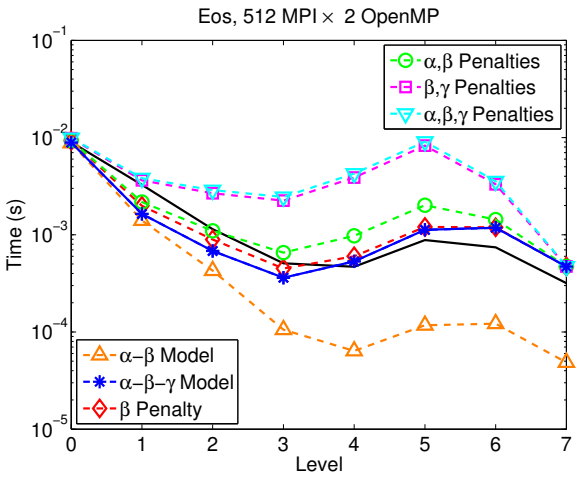
- Optical links have 4x bandwidth, so treat as 4 links
- Minimum: all nodes in a group are taken before moving to the next one
- Maximum: each node is in a new group, until all groups are in use

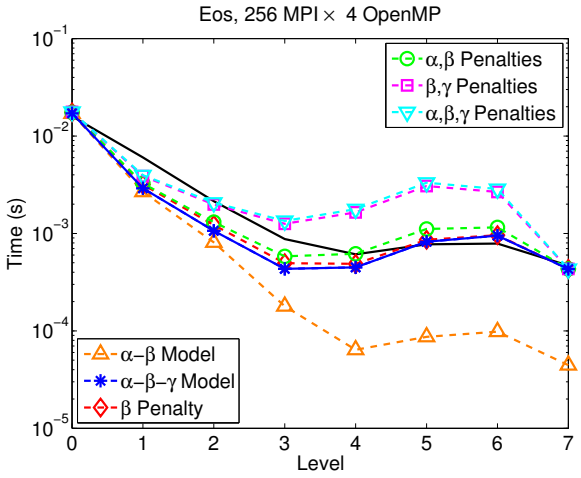
Modeling Results

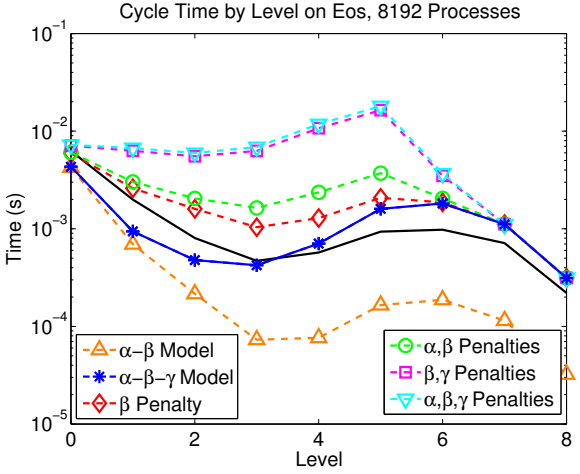
- Tested model on Eos, an XC30 at ORNL
  - 744 nodes with two 8-core processors per node
  - Ran experiments on 1024 and 8192 cores
- Test problem: 3D Laplace with 50 x 50 x 25 points per core
- Compared actual performance (black line in plots) with different model scenarios (colored lines); best fit highlighted

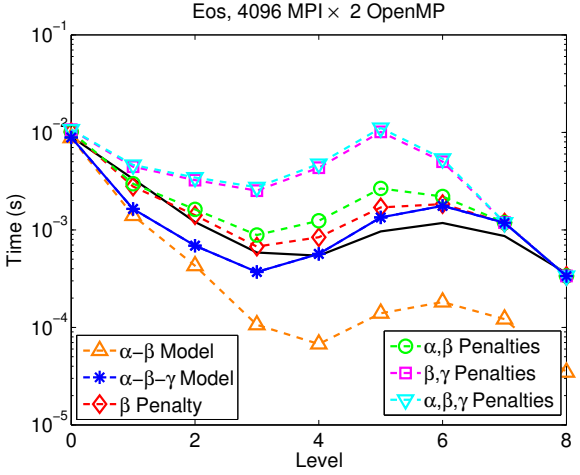
Modeling Results

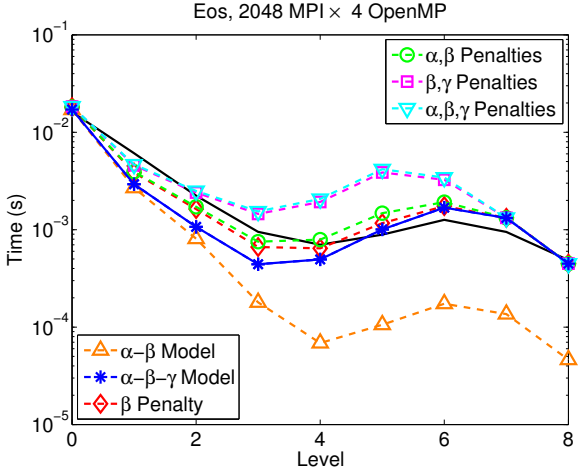




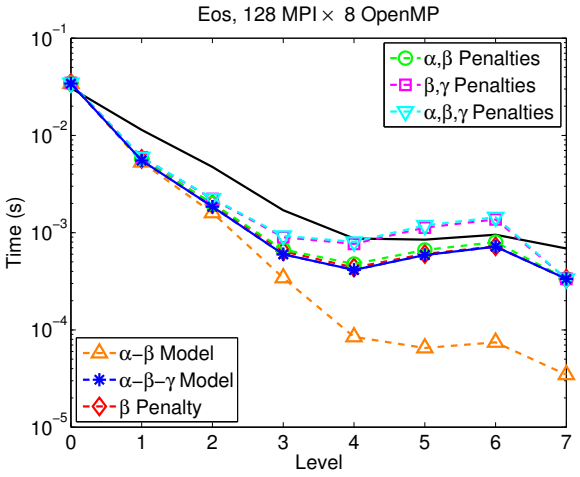


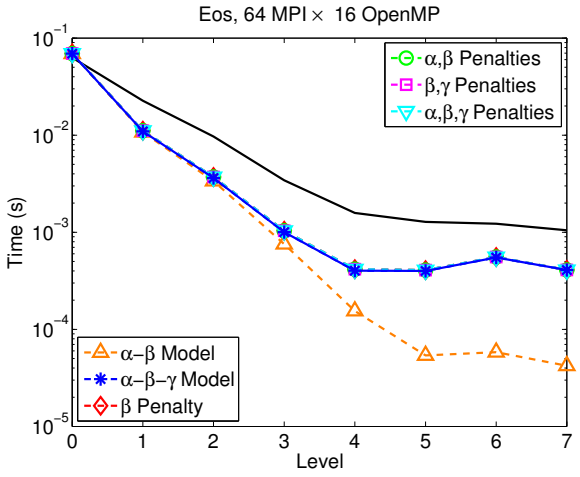


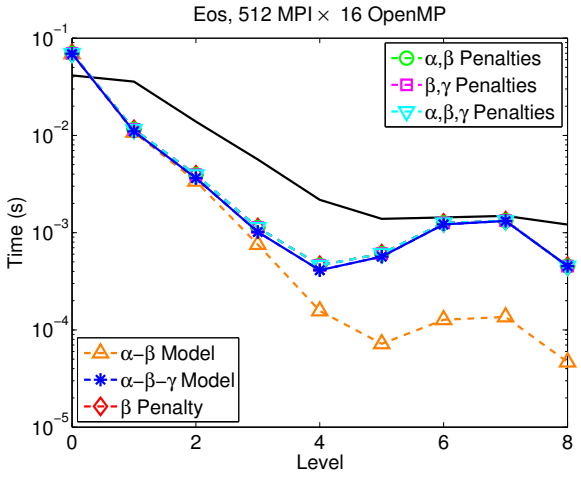


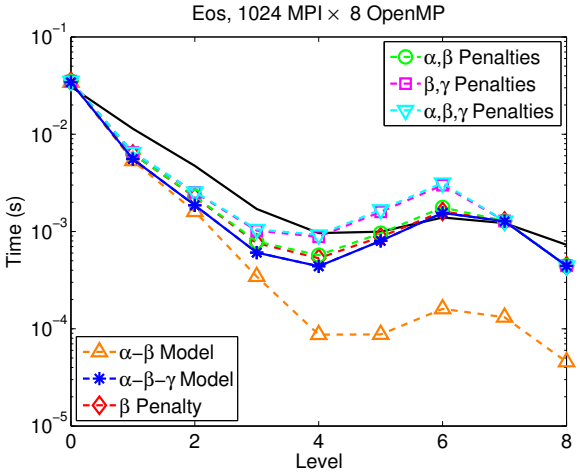


Modeling Results









Cycle Time Prediction Accuracies

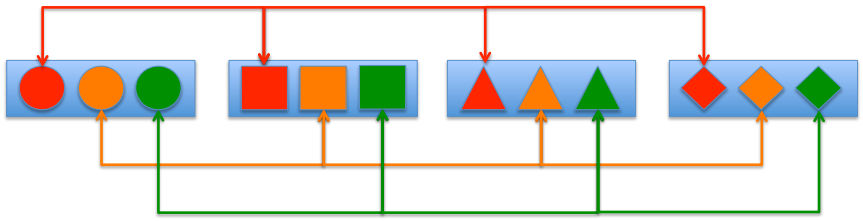
Mix	1024 Cores			8192 Cores		
	Modeled	Measured	Accuracy	Modeled	Measured	Accuracy
16 × 1	9.75 ms	11.3 ms	86.0%	11.7 ms	13.0 ms	90.4%
8 × 2	14.9 ms	16.3 ms	91.3%	16.8 ms	18.1 ms	92.8%
4 × 4	24.2 ms	27.6 ms	87.4%	26.5 ms	29.7 ms	89.2%
2 × 8	44.2 ms	51.8 ms	85.3%	46.7 ms	53.9 ms	86.6%
1 × 16	86.4 ms	104 ms	83.4%	88.4 ms	104 ms	85.9%

Modeling Results

- The good:
  - Best fit was α-β-γ with no additional penalties
  - No other machine we've tested was this good
  - Very little slowdown in cycle time going from 1K to 8K cores
- The concerning:
  - Substantial gap between α-β and best fit
  - γ (0.42 µs) was measured to be on par with α (0.24 µs), similar to a prior fat-tree machine which suffered from a lot of contention
  - Hybrid MPI/OpenMP performance also disappointing

Data Redistribution in AMG

- Idea that has gained traction:
  - Concentrate data on coarse grids so that fewer messages are sent
  - Has been done with or without redundant replication
- Illustration of redistribution strategy:



- Split problem domain into C chunks (blue boxes)
- Processes within a chunk have same part of domain
- Redundant version shown with 12 processes and 4 chunks
- Nonredundant version would keep just one color group

- Performance model can be adjusted to model this:
  - At level where redistribution is performed, charge for needed collective operations
  - On this and coarser levels, communication is with at most C-1 partners. Adjust computation based on amount of data concentrated
  - Adjust time per flop based on “problem size classification” (parts of data that fit in cache)

Guiding Data Redistribution

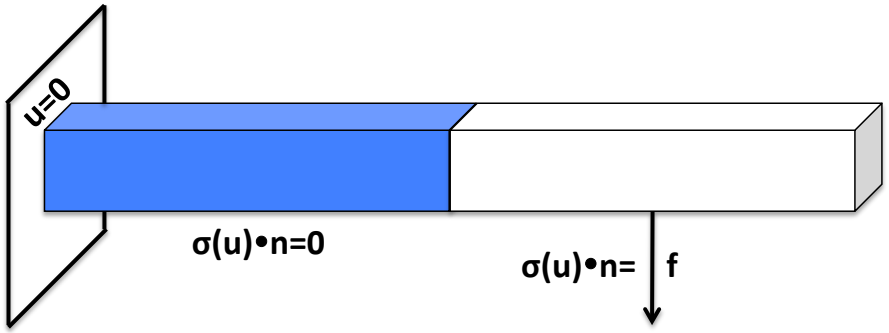
- At each coarse grid in setup phase, use model to estimate:
  1. Time spent at that level in solve cycle when redistributing (T_{switch})
  2. And when not redistributing ($T_{noswitch}$)
  3. If $T_{switch} < T_{noswitch}$, then redistribute

- Requires extra information:
  - Interpolation operator unavailable: substitute MatVec with solve operator
  - Time per flop unknown: measure with MatVecs using local portion of parallel data

- Other concerns:
  - Time per flop changes after redistribution: do not change it in model, but prevent redistribution if problem size classification increases
  - Hybrid MPI/OpenMP use? Requires essentially no change! Implicit in measurement of time per flop
  - Number of chunks to carve problem into? For quick setup, search powers of 2 <= max # sends
  - Possible overeager switching: keep track of running estimated cycle time, do not switch if overall modeled improvement is < 5%

Redistribution Experiments

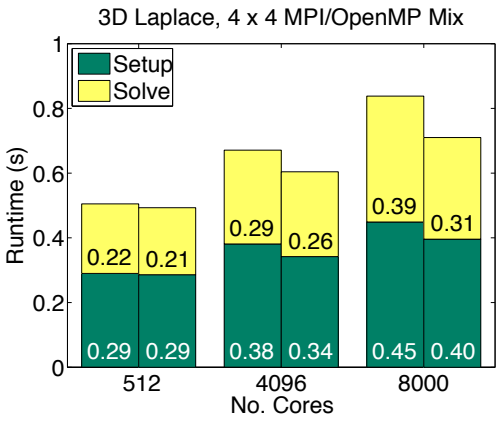
- Pair of test problems:
  1. 3D Laplace with 30 x 30 x 30 points/core
  2. Linear Elasticity with ~6,300 points/core:



- Used nonredundant redistribution owing to issues with large numbers of MPI communicators at scale
- Ran on Eos, like before

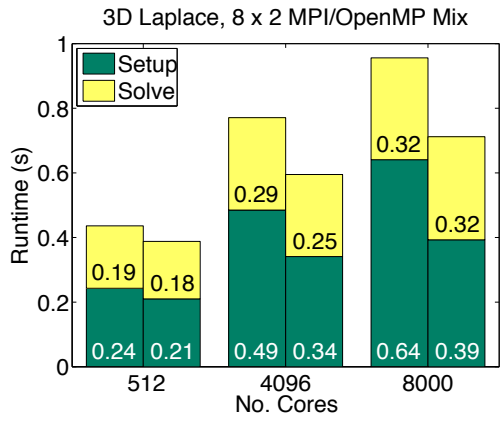
Redistribution Results

Laplace:



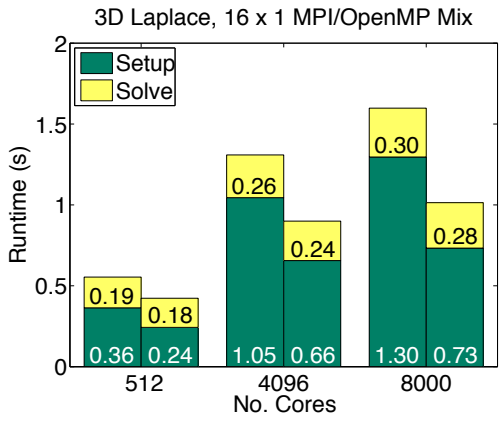
Speedups:

Cores	Setup	Solve	Overall
512	1.00	1.05	1.02
4096	1.12	1.12	1.12
8000	1.12	1.26	1.18



Speedups:

Cores	Setup	Solve	Overall
512	1.14	1.06	1.10
4096	1.44	1.16	1.32
8000	1.64	1.00	1.35



Speedups:

Cores	Setup	Solve	Overall
512	1.50	1.06	1.31
4096	1.59	1.08	1.46
8000	1.78	1.07	1.58

Linear Elasticity (all MPI):

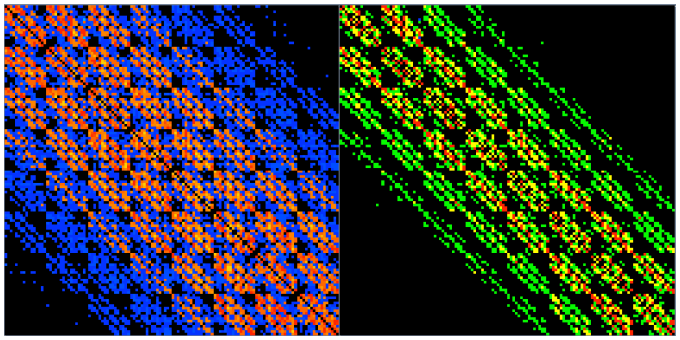
	1024 Cores			8192 Cores		
	Setup	Solve	Total	Setup	Solve	Total
No Redistribution	0.78 s	1.06 s	1.84 s	6.72 s	2.64 s	9.36 s
With Redistribution	0.75 s	0.82 s	1.58 s	2.99 s	1.55 s	4.54 s
Speedup	1.04	1.29	1.16	2.25	1.93	2.06

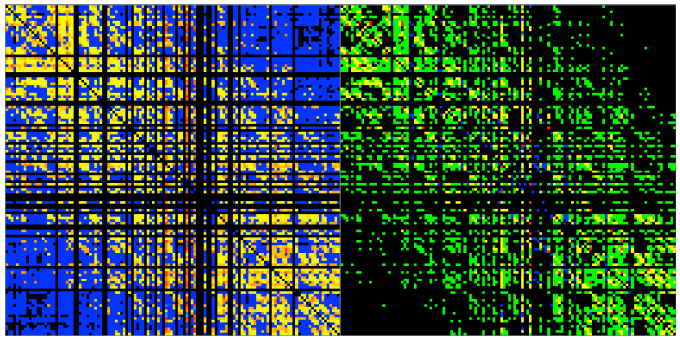
Observations

- Laplace problem: overall performance and redistribution benefit depended on phase
  - Solve phase: all-MPI was best, small gain from redistribution
  - Setup phase: introducing OpenMP helped performance; more MPI-rich configurations showed substantial gains from redistribution
- Linear elasticity problem: big redistribution benefit in both phases on 8K cores

Observations

- Common thread: bigger benefits from OpenMP or redistribution came in higher-communication settings
  - Laplace problem: setup vs. solve communication patterns for test problem from model validation on 128 cores on two most communication-intensive levels. Setup communicates much more:





  - Linear elasticity problem: much larger stencils (up to 500 nnz/row) than Laplace (up to 100 nnz/row)
- So even with interconnect's favorable rating by the model, its performance can dramatically degrade when communication is high

Conclusions and Future Work

- XC30 interconnect rated well in terms of contention penalties
- There were still, however, big benefits from reducing the number of messages sent
- Future work on XC30:
  - Model AMG setup phase
  - See if there is communication threshold at which substantial performance degradation occurs and map it if found

Conclusions and Future Work

- Results hint at dragonfly networks having problems with communication heavy applications:
  - Unifying feature of router groups with all-to-all links
  - Performance degradation and improvement from communication reduction was most pronounced when running on 8K cores (majority of the machine)
  - Large distance term in performance model
- Risk of slowdowns when communicating between different router groups that will need to be addressed to make topology effective at scale

Questions?

Acknowledgements

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