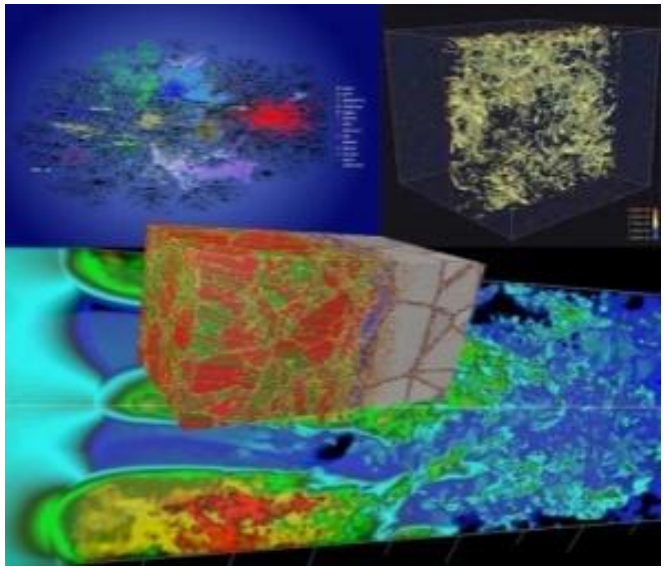


Programming Models at the Exascale

(and programming environments)

Brad Chamberlain, Cray Inc.

Cross-cutting Technologies for Computing at the Exascale

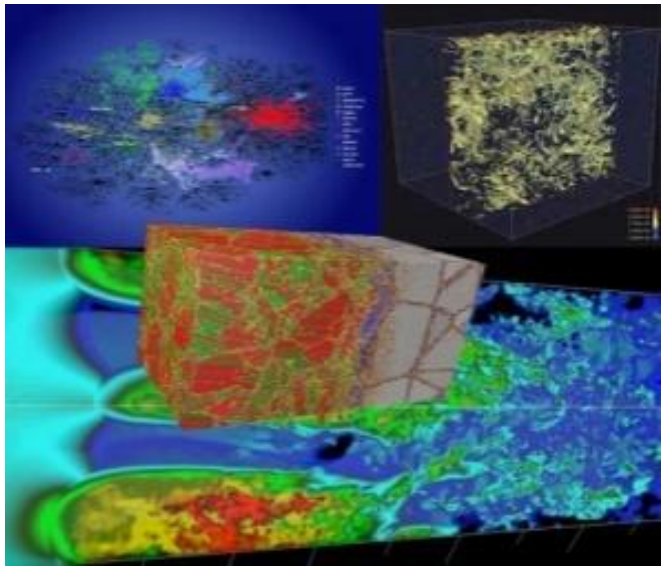
February 2nd 2010

Rockville, MD

The solution to all exascale's woes

Chapel!!!

Brad Chamberlain, Cray Inc.
Chapel technical lead and bigot



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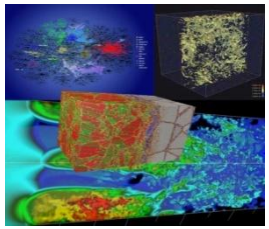


Purpose of this Talk

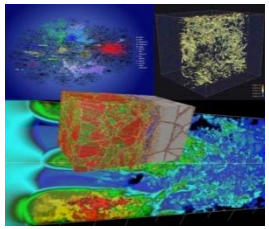
Goal: Summarize programming environment issues for exascale computing to set the stage for breakout sessions

Primary Input:

- December `09 workshop: Architectures and Technology

Additional Inputs:

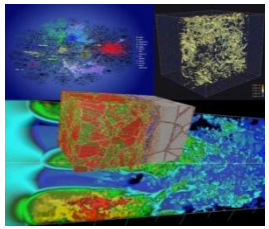
- March `09 workshop: Fusion Energy Sciences
- Exchanges with colleagues (most notably Yelick, Lusk, Sarkar)
- My own thoughts and biases



Definition of Terms

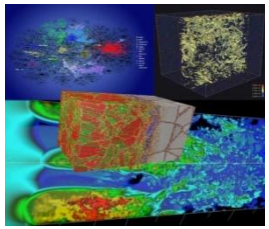
Programming Environment: the things that a user deals with when programming a computer

- *programming models (abstract):* user models for how the machine, execution, memory, communication, etc. will work
- *programming models (concrete):* notations used to write programs: languages, libraries, pragmas/annotations, …
- *tools:* debuggers, performance tools, editors, IDEs, …



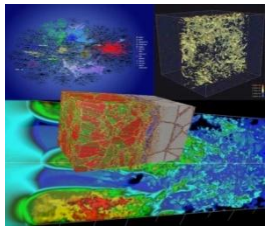
Outline

- ✓ Terms of engagement
- ➢ Exascale hardware: summary and implications
- Selected Timeline
- Programming Models: proposed directions
- Exascale Tools: a brief interlude
- Programming Models: more details
- Some questions



Exascale Hardware in a Nutshell

- *#nodes, network:* no dramatic changes expected
- *system size/complexity:* expected to grow
- *node architecture:* expected to undergo dramatic changes
  - massively parallel
  - multiple processor types
  - multiple memory types, including programmable (scratchpad)
  - generally more heterogeneous/hierarchical than today
- *memory:FLOPS ratio:* expected to get worse



Exascale Hardware Implications I

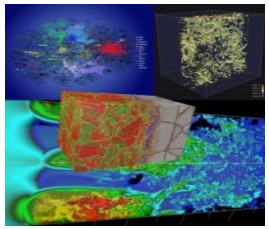
- *#nodes, network:* no dramatic change expected

  ⇒ MPI should continue to be useful on exascale systems

- *system size/complexity:* expected to grow

  ⇒ programs will need to be resilient to failures

  ⇒ tools will need to aggregate and synthesize information to prevent information overload



Exascale Hardware Implications II

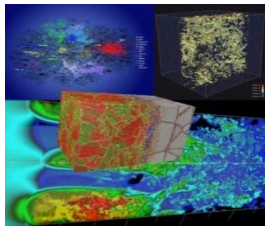
- *node architecture:* expected to undergo dramatic changes
  - massively parallel
  - multiple processor types
  - multiple memory types, including programmable (scratchpad)
  - generally more heterogeneous/hierarchical than today

⇒ we will need new abstract node models

(for programmers as well as for compilers)

⇒ applications will need to generate and manage more parallelism and map it to the appropriate resources

⇒ we will need new programming notations for nodes

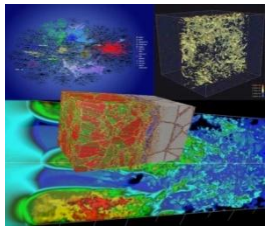


Exascale Hardware Implications III

- *memory:FLOPS ratio:* expected to get worse

  ⇒ will need to be more attentive to how memory is used

  e.g., a renaissance of out-of-core computations at multiple scales?



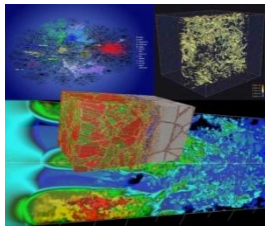
The Big Question

Which of these changes will directly impact the end user?

Or, put another way:

Which of these challenges can additional R&D ameliorate?

(Note that the answers are likely to vary depending on how you're willing to trade off level of control vs. portability vs. performance vs. …)



Anticipated Exascale Timeline (excerpts)

2010-2011: develop abstract node/machine model

2010-2012: initial programming models development

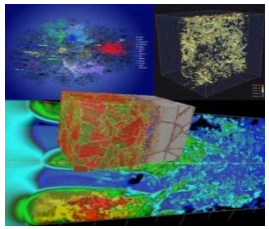
2012-2013: early demonstration of programming models, generating course corrections

2013-2015: continued programming models development

2013-2015: application development in programming models

2015: deployment on 100 petaflop systems

2018: deployment on exaflop systems



Timeline Implications

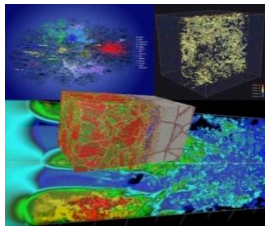
…

2013-2015: application development in programming models

2015: deployment on 100 petaflop systems

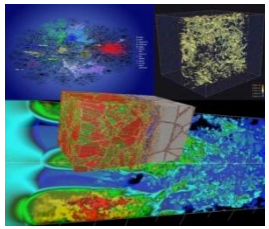
…

⇒ insufficient time to develop new notations from scratch; rather, evolve/extend existing programming models



Expected Characteristics of Exascale Programming Models

- **parallelism:** nested, dynamic, loosely-coupled, data-driven
  (*i.e.*, "post-SPMD" programming/execution models)
  - to take advantage of the architecture
  - to better support load balancing and resilience
- **locality:** concepts for *vertical* control as well as *horizontal*
  (*i.e.*, locality within a node rather than simply between nodes)

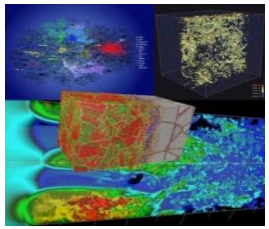


Programming Model Approaches

The December working group proposed investing in two major styles of programming models:

1) *hybrid/evolutionary:* MPI + _____?
   (MPI for inter-node programming, something else for intra-)

2) *unified/holistic:* _____?
   (a single notation for inter- and intra-node programming)

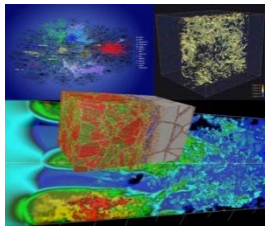


Hybrid Programming Models: MPI

MPI + [intra-node model]

- because #nodes, inter-node concerns not expected to change dramatically
- yet MPI probably still needs to evolve and improve:
  - support for hybrid programming/interoperability
  - better scalability, especially in terms of memory utilization, especially for collectives
  - improved resilience features
  - purer one-sided communication; active messages
  - asynchronous collectives
  - …

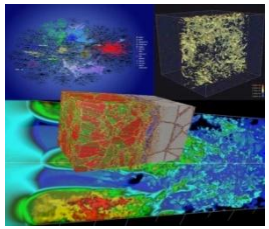
(these efforts are already well underway as part of MPI 3.0)



Hybrid Programming Models: [intra-node]

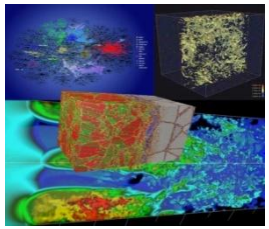
MPI + **[intra-node model]**

- OpenMP
  - would require extensions to support accelerator programming
    - e.g., similar to directives from PGI, CAPS
  - may require the introduction of locality-oriented concepts
  - these efforts are already underway as part of OpenMP 3.0
- PGAS languages
  - already support a notion of locality in a shared namespace
  - UPC/CAF would need to relax strictly SPMD execution model
- Sequoia: supports a strong notion of vertical locality
- CUDA/OpenCL: lower level than ideal for an end user



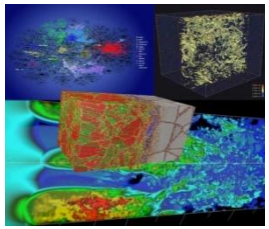
Unified/Holistic Programming Models

- traditional PGAS languages: UPC, CAF, Titanium
  - would likely require extensions to handle nested parallelism, vertical locality
- HPCS languages: Chapel, X10, Fortress(?)
  - designed with locality and post-SPMD parallelism in mind
- other candidates: Charm++, Global Arrays, ParalleX, …



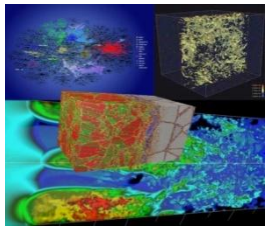
But what about…?

- mainstream multicore/GPU languages: exascale program should track, but not fund (without sufficient promise)
- domain-specific languages:
  - great if they fit your problem, but if they don't, a non-starter
  - exascale program should focus on more general solutions
- functional languages:
  - have never been heavily adopted in mainstream or HPC
  - their abundant parallelism is nice, yes, but…
  - copy-on-write optimization is the dual of alias analysis (?)
- parallel scripting languages: sound attractive to me



Exascale Tools: Debuggers, Perf. Analysis

- Primary challenges:
  - Given massive amounts of parallelism, need aggregation to avoid overwhelming the user with details
  - Given higher-level and/or loosely-coupled programming models, need to report information in the user's terms
- Timeline:
  - **2014:** integration with emerging programming models
- In all honesty…
  - tools have probably not received enough workshop time
  - seems like a good area for innovation (e.g., execution visualizations to understand mapping of code to hardware)



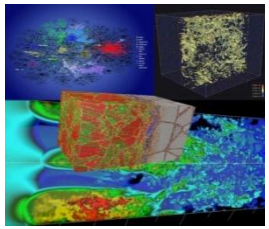
Programming Models Desiderata

- **Interoperability:** need to preserve legacy code even if it isn't mapped optimally to the exascale hardware

  [**ad:** watch for 2010 parallel language interoperability workshop being organized by Tom Epperly/Jim McGraw (LLNL)]

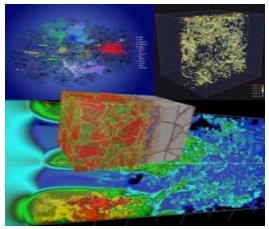
- **Multiresolution design:** ideally, a programmer should be able to program at more abstract or explicit levels within a single language as their needs require/schedule permits
  - support division of labor: science vs. parallel mapping
- **Autotuning:** given the huge parameter space at exascale, compiler assistance to help search it would be useful

These seem like no-brainers to support to me, though R&D is probably required to do them well



Programming Models Challenges

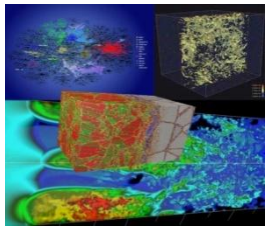
- **Resilience:** How can programming models help?
  - *checkpoint/restart:* may not be sufficient at exascale
  - *redundancy control:*
    - give user dials/abstractions to request redundancy in key areas
    - requires hooks from system software to gracefully catch failures
- **Power Management:**
  - given its impact at exascale, can programming models help?
- **Memory Consistency Models:**
  - we barely understand them now as a community
  - seems they will only get worse?
- **Out-of-Core:** Back-in-style? How can prog. models help?



Metrics for Success

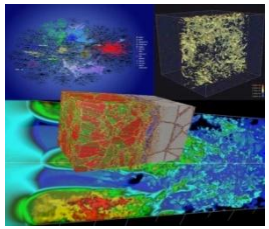
- # of apps that can effectively make use of exascale
- portability of those applications across machines (exascale and non-)
- utilization levels of most precious resources
  - i.e., probably not FLOPS; more likely bandwidths

- 10x productivity?
  - on one hand, it's a catchphrase we've leaned on heavily while still unable to define metrics for it very well, leaving people skeptical
  - on the other hand, it's still a highly desirable concept



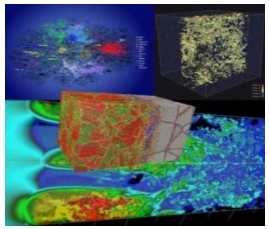
The Adoption Problem

- Most of us prefer not to have to learn new things
  - (though sometimes doing so can be liberating)
- Given that all of the models described here involve changes, how should we best support that effort?
- HPCS languages case study:
  - How to turn skeptical community into believers, esp. given that most opinions are from the gut, not investigation?
  - How to transition from “How will *you* do xyz in Chapel/X10?” to “How will *our community* do xyz in Chapel/X10?”
  - What demonstrations/stepping stones to build confidence?
  - Is dedicated funding for evaluation & study useful/necessary?
  - How to avoid the mistakes of Ada/HPF?



My Questions for apps/algs folks I

- What is your application's dream wishlist for prog. models?
  - i.e., "If only we could…" or "If only we didn't have to…"
- Are SPMD programming models natural for your algorithms or simply what you've been given to work with?
- To what extent do you want explicit control over every detail vs. automation at some cost vs. the ability to vary this choice for different program phases?
- What benchmarks do you look to as stand-ins for your applications? Is there a need for new benchmarks (a la the NPB) for your application area?



My Questions for apps/algs folks II

- What would motivate you to consider new programming models? (Is the carrot or the stick the bigger motivator?)
- Do you currently use out-of-core programming? Why/why not?
- Do you currently use checkpoint/restart (or other resilience techniques)? Why/why not?
- Which parts of this talk made you think “amen”? Which parts made you curse the December workshop attendees?