Programming Models at the Exascale
(and programming environments)

Brad Chamberlain, Cray Inc.

Cross-cutting Technologies for Computing at the Exascale
February 2\textsuperscript{nd} 2010
Rockville, MD
The solution to all exascale’s woes

Chapel!!!

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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
• *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)
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?