Chapel in Ten* Minutes

Brad Chamberlain, Chapel Team, Cray Inc.

NII Shonan Meeting: Putting Heterogeneous High-Performance Computing at the Fingertips of Domain Experts

November 17th, 2015

* mmmmaybe…

Safe Harbor Statement

This presentation may contain forward-looking statements that are based on our current expectations. Forward looking statements may include statements about our financial guidance and expected operating results, our opportunities and future potential, our product development and new product introduction plans, our ability to expand and penetrate our addressable markets and other statements that are not historical facts. These statements are only predictions and actual results may materially vary from those projected. Please refer to Cray's documents filed with the SEC from time to time concerning factors that could affect the Company and these forward-looking statements.

What is Chapel?

Chapel: An emerging parallel programming language

- extensible
- portable
- open-source
- a collaborative effort
- a work-in-progress

Goals:

- Support general parallel programming
  - "any parallel algorithm on any parallel hardware"
- Make parallel programming far more productive

What does “Productive” mean?

Recent Graduates:

“something similar to what I learned in school: Python, Matlab, Java, …”

Seasoned HPC Programmers:

“that sugary stuff that I can’t afford to use because I need full control to ensure optimal performance.”

Computational Scientists:

“something that lets me express my parallel computations without having to wrestle with architecture-specific details.”

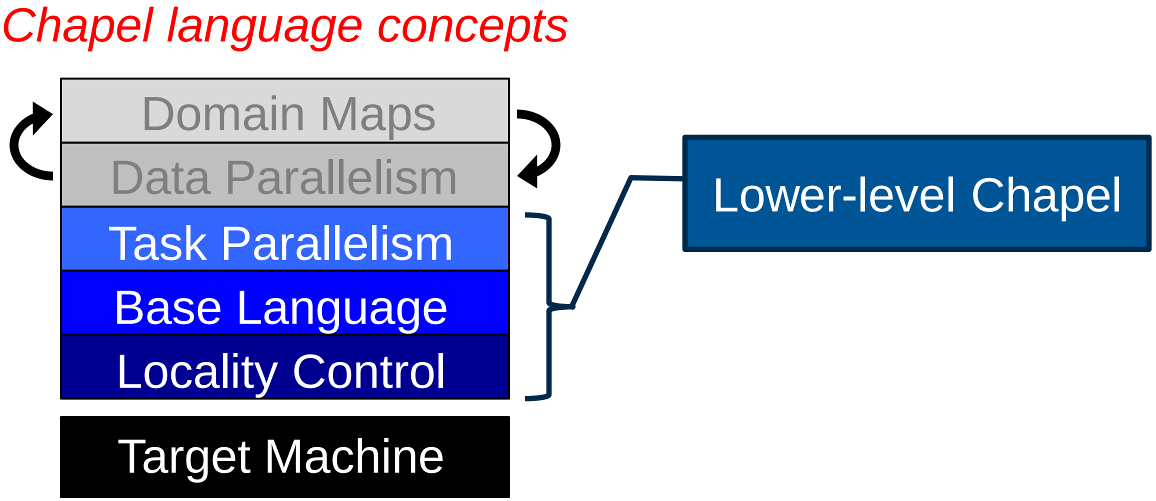
Chapel Team:

“something that lets computational scientists express what they want, without taking away the control that HPC programmers need, implemented in a language as attractive as recent graduates want.”

The Chapel Team at Cray (spring 2015)

Introduction to Chapel by Example

Lower-Level Features



Chapel by Example: Base Language

```
iter fib(n) {
  var current = 0,
      next = 1;

  for i in 1..n {
    yield current;
    current += next;
    current <=> next;
  }
}
```

```
for (i,f) in zip(0..#n, fib(n)) do
  writeln("fib #", i, " is ", f);
```

```
fib #0 is 0
fib #1 is 1
fib #2 is 1
fib #3 is 2
fib #4 is 3
fib #5 is 5
fib #6 is 8
…
```

Chapel by Example: Base Language

CLU-style iterators

```
iter fib(n) {
  var current = 0,
      next = 1;

  for i in 1..n {
    yield current;
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    current <=> next;
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…
```

Chapel by Example: Base Language

built-in range types and operators

```
iter fib(n) {
  var current = 0,
      next = 1;

  for i in 1..n {
    yield current;
    current += next;
    current <=> next;
  }
}
```

```
for (i,f) in zip(0..#n, fib(n)) do
  writeln("fib #", i, " is ", f);
```

```
fib #0 is 0
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Chapel by Example: Base Language

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  var current = 0,
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}
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zippered iteration

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for (i,f) in zip(0..#n, fib(n)) do
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```
fib #0 is 0
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fib #6 is 8
…
```

Chapel by Example: Base Language

tuples

```
iter fib(n) {
  var current = 0,
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  for i in 1..n {
    yield current;
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    current <=> next;
  }
}
```

```
for (i,f) in zip(0..#n, fib(n)) do
  writeln("fib #", i, " is ", f);
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fib #0 is 0
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```

Chapel by Example: Base Language

Static Type Inference for:

- arguments
- return types
- variables

```
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  var current = 0,
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  for i in 1..n {
    yield current;
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    current <=> next;
  }
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Chapel by Example: Base Language

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fib #6 is 8
…
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Chapel by Example: Task Parallelism, Locality

taskParallel.chpl

```
coforall loc in Locales do
  on loc {
    const numTasks = here.maxTaskPar;
    coforall tid in 1..numTasks do
      writef("Hello from task %n of %n "+
             "running on %s\n",
             tid, numTasks, here.name);
  }
```

```
prompt> chpl taskParallel.chpl -o taskParallel
prompt> ./taskParallel --numLocales=2
Hello from task 1 of 2 running on n1033
Hello from task 2 of 2 running on n1032
Hello from task 2 of 2 running on n1033
Hello from task 1 of 2 running on n1032
```

Chapel by Example: Task Parallelism, Locality

High-Level
Task Parallelism

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Chapel by Example: Task Parallelism, Locality

Abstraction of System Resources

taskParallel.chpl

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Chapel by Example: Task Parallelism, Locality

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    coforall tid in 1..numTasks do
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             "running on %s\n",
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  }
```

Control of Locality/Affinity

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prompt> chpl taskParallel.chpl -o taskParallel
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Chapel by Example: Task Parallelism, Locality

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Chapel by Example: Task Parallelism, Locality

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Task Parallelism

taskParallel.chpl

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Chapel by Example: Task Parallelism, Locality

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Hello from task 1 of 2 running on n1032
```

Parallelism and Locality: Orthogonal in Chapel

- This is a **parallel**, but local program:

```
coforall i in 1..msgs do
  writeln(“Hello from task ”, i);
```

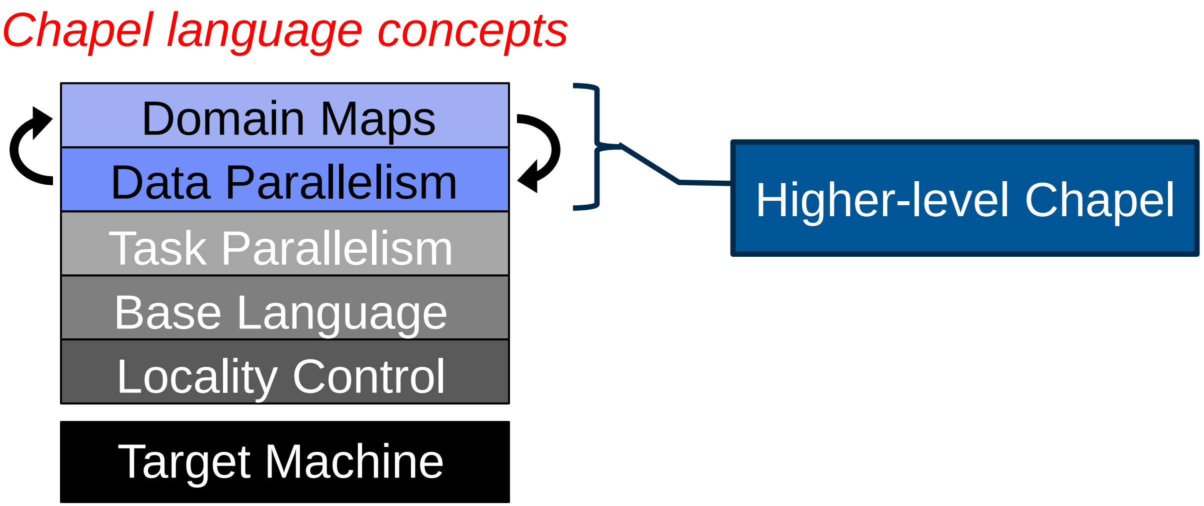
- This is a **distributed**, but serial program:

```
writeln(“Hello from locale 0!”);
on Locales[1] do writeln(“Hello from locale 1!”);
on Locales[2] do writeln(“Hello from locale 2!”);
```

- This is a **distributed parallel** program:

```
coforall i in 1..msgs do
  on Locales[i%numLocales] do
    writeln(“Hello from task ”, i,
            “ running on locale ”, here.id);
```

Higher-Level Features



Chapel language concepts

Domain Maps

Data Parallelism

Task Parallelism

Base Language

Locality Control

Target Machine

Higher-level Chapel

Chapel by Example: Data Parallelism

dataParallel.chpl

```
use CyclicDist;
config const n = 1000;
var D = {1..n, 1..n};

var A: [D] real;
forall (i,j) in D do
  A[i,j] = i + (j - 0.5)/n;
writeln(A);
```

```
prompt> chpl dataParallel.chpl -o dataParallel
prompt> ./dataParallel --n=5
1.1 1.3 1.5 1.7 1.9
2.1 2.3 2.5 2.7 2.9
3.1 3.3 3.5 3.7 3.9
4.1 4.3 4.5 4.7 4.9
5.1 5.3 5.5 5.7 5.9
```

Chapel by Example: Data Parallelism

Domains (Index Sets)

dataParallel.chpl

```
use CyclicDist;
config const n = 1000;
var D = {1..n, 1..n};

var A: [D] real;
forall (i,j) in D do
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4.1 4.3 4.5 4.7 4.9
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```

Chapel by Example: Data Parallelism

Arrays

dataParallel.chpl

```
use CyclicDist;
config const n = 1000;
var D = {1..n, 1..n};

var A: [D] real;
forall (i,j) in D do
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4.1 4.3 4.5 4.7 4.9
5.1 5.3 5.5 5.7 5.9
```

Chapel by Example: Data Parallelism

Data-Parallel Forall Loops

dataParallel.chpl

```
use CyclicDist;
config const n = 1000;
var D = {1..n, 1..n};

var A: [D] real;
forall (i,j) in D do
  A[i,j] = i + (j - 0.5)/n;
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Chapel by Example: Data Parallelism

dataParallel.chpl

```
use CyclicDist;
config const n = 1000;
var D = {1..n, 1..n}
            dmapped Cyclic(startIdx = (1,1));
var A: [D] real;
forall (i,j) in D do
   A[i,j] = i + (j - 0.5)/n;
writeln(A);
```

Domain Maps (Map Data Parallelism to the System)

```
prompt> chpl dataParallel.chpl -o dataParallel
prompt> ./dataParallel --n=5 --numLocales=4
1.1 1.3 1.5 1.7 1.9
2.1 2.3 2.5 2.7 2.9
3.1 3.3 3.5 3.7 3.9
4.1 4.3 4.5 4.7 4.9
5.1 5.3 5.5 5.7 5.9
```

Chapel by Example: Data Parallelism

dataParallel.chpl

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use CyclicDist;
config const n = 1000;
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var A: [D] real;
forall (i,j) in D do
  A[i,j] = i + (j - 0.5)/n;
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2.1 2.3 2.5 2.7 2.9
3.1 3.3 3.5 3.7 3.9
4.1 4.3 4.5 4.7 4.9
5.1 5.3 5.5 5.7 5.9
```
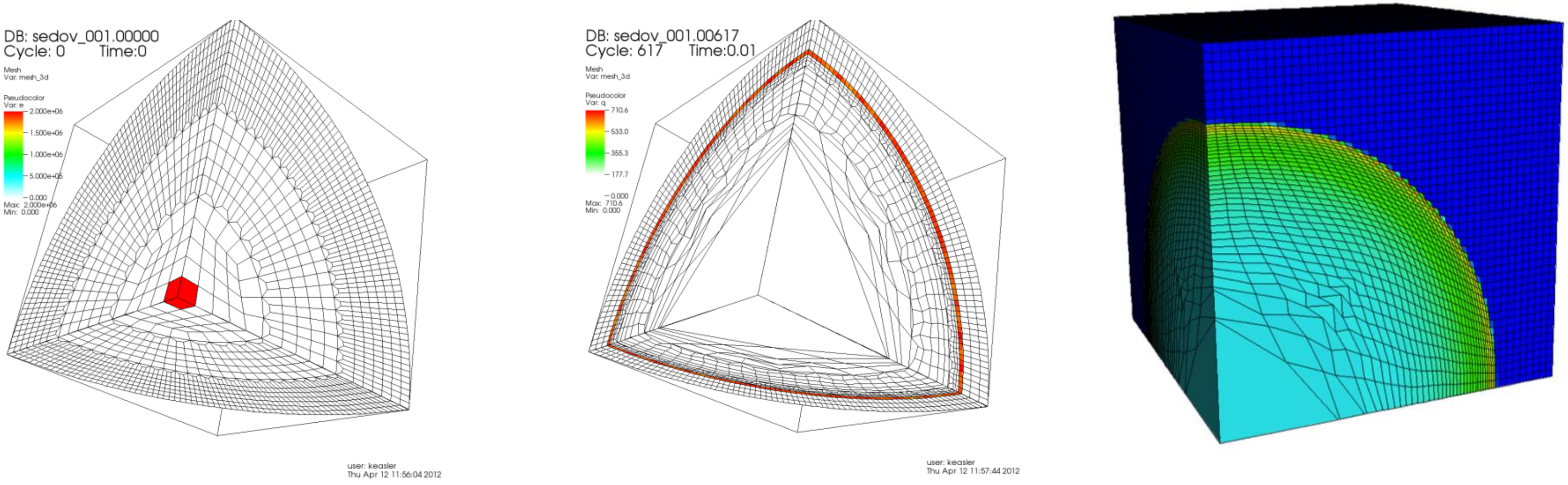

LULESH: a DOE Proxy Application

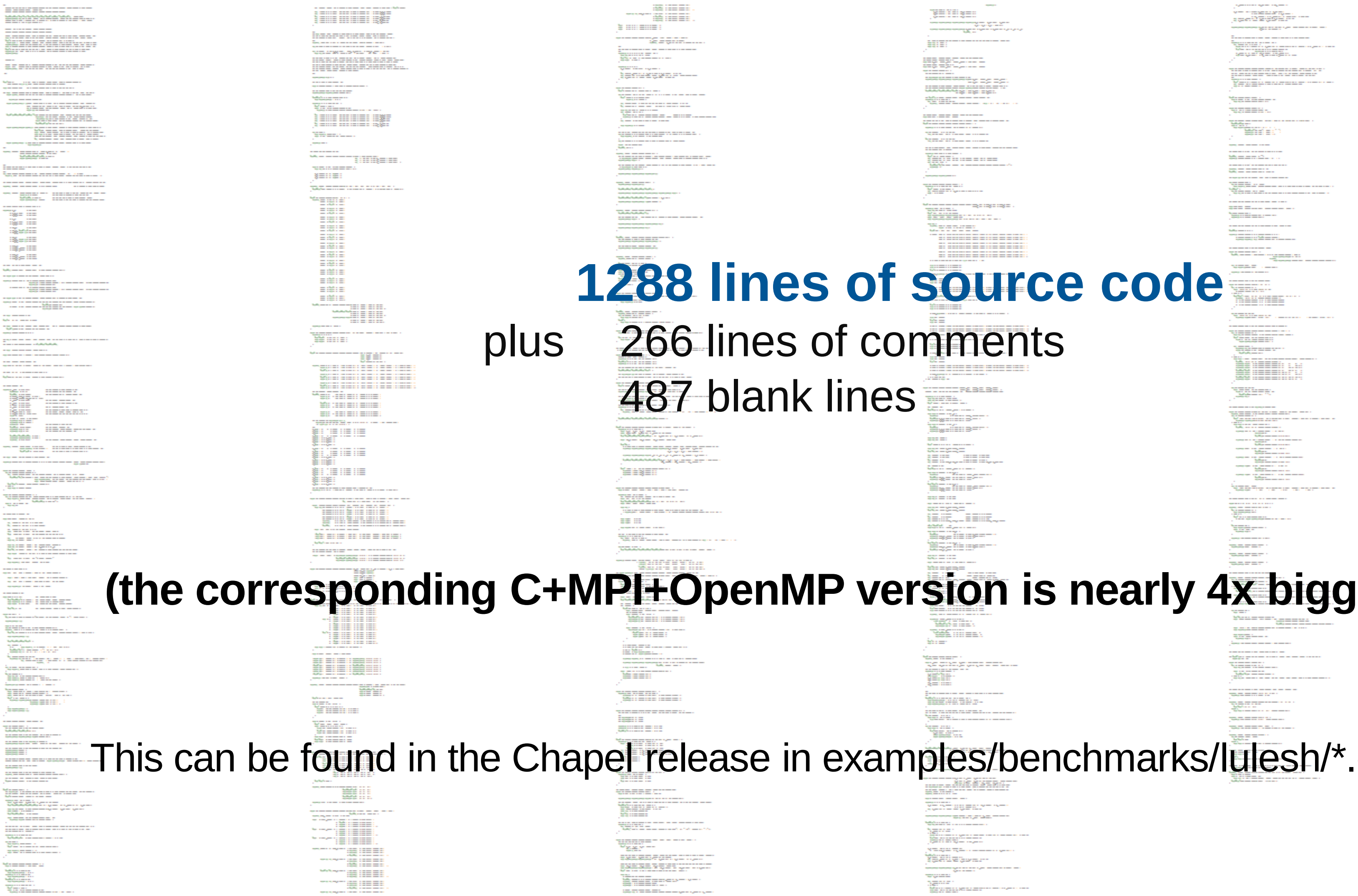
Goal: Solve one octant of the spherical Sedov problem (blast wave) using Lagrangian hydrodynamics for a single material



pictures courtesy of Rob Neely, Bert Still, Jeff Keasler, LLNL

LULESH in Chapel

LULESH in Chapel



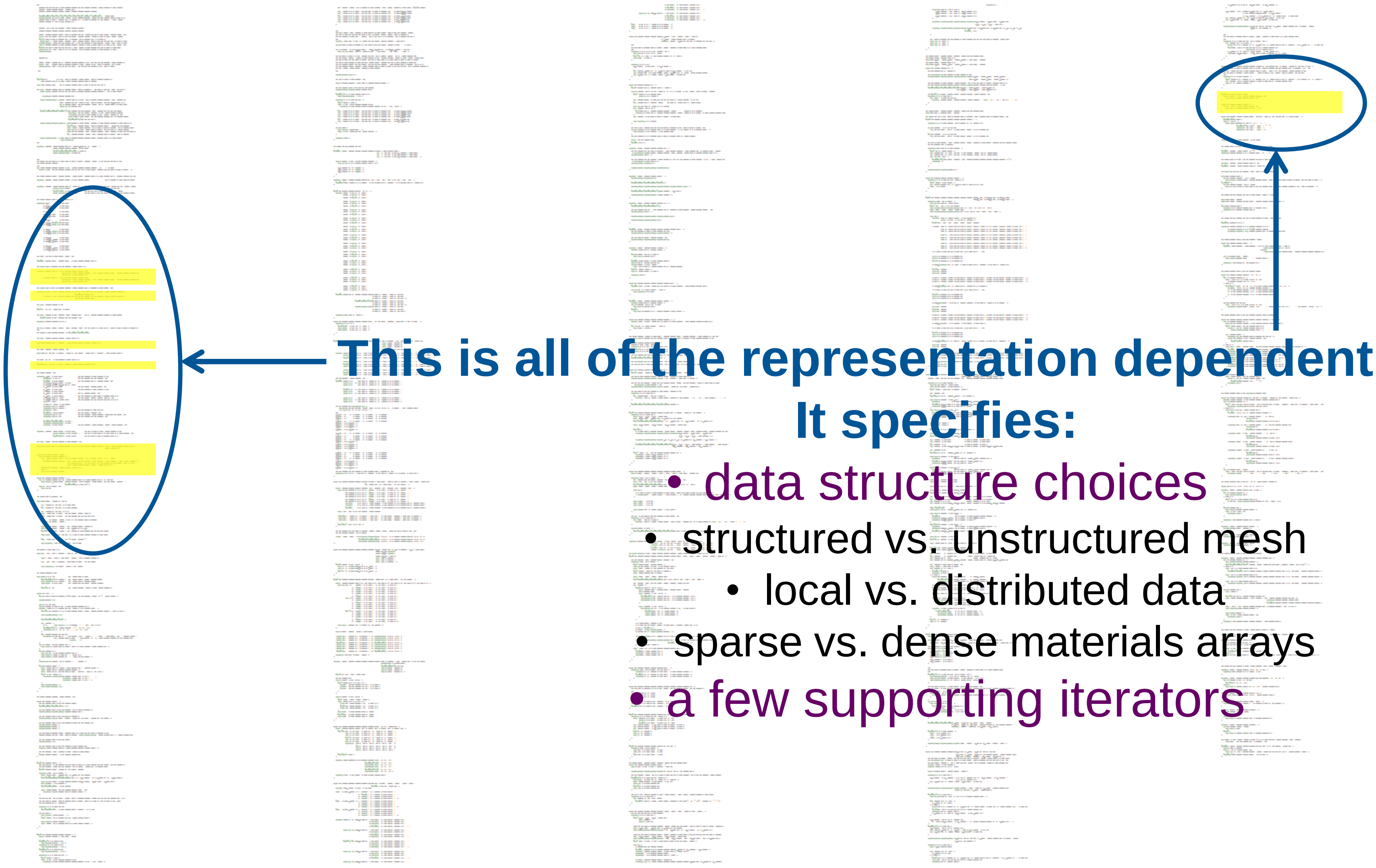
1288 lines of source code

plus 266 lines of comments
487 blank lines

(the corresponding C+MPI+OpenMP version is nearly 4x bigger)

This can be found in the Chapel release in examples/benchmarks/lulesh/*.chpl

LULESH in Chapel



This is all of the representation dependent code.

It specifies:

- data structure choices
  - structured vs. unstructured mesh
    - local vs. distributed data
  - sparse vs. dense materials arrays
- a few supporting iterators

Chapel Characterizations

Chapel is Extensible

Advanced users can create their own…

…forall-loop schedules…

…array layouts and distributions…

…abstract system models…

…as Chapel code, without modifying the compiler.

Why? Make a future-proof language.

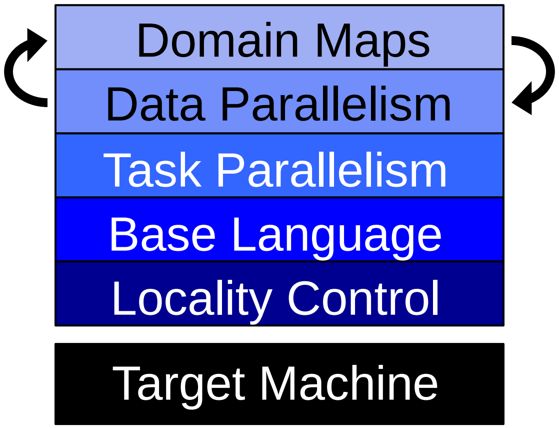
This has been our main research challenge: How to create a language that does not lock these policies into the implementation without sacrificing performance?

Chapel's Multiresolution Philosophy

Multiresolution Design: Support multiple tiers of features

- higher levels for programmability, productivity
- lower levels for greater degrees of control

Chapel language concepts



Domain Maps

Data Parallelism

Task Parallelism

Base Language

Locality Control

Target Machine

- build the higher-level concepts in terms of the lower
- permit the user to intermix layers arbitrarily

Chapel is Portable

- **Chapel's design is intended to be hardware-independent**

- **The current release requires:**
  - a C compiler
  - a *NIX environment
  - POSIX threads
  - (for distributed execution): support for RDMA, MPI, or UDP

- **Chapel can run on…**

  …laptops and workstations
  …commodity clusters
  …the cloud
  …HPC systems from Cray and other vendors
  …modern processors like Intel Xeon Phi, GPUs*, etc.

* = academic work only; not yet supported by the official release

Chapel is Open-Source

- **Chapel's development is hosted at GitHub**
  - https://github.com/chapel-lang
- **Chapel is licensed as Apache v2.0 software**
- **Download/install online**
  - see http://chapel.cray.com/download.html for instructions

Chapel is a Collaborative Effort

Colorado State University

RICE

LTS Laboratory for Telecommunications Sciences

ETH Zürich

Lawrence Livermore National Laboratory

Sandia National Laboratories

BERKELEY LAB

Lawrence Berkeley National Laboratory

Argonne NATIONAL LABORATORY

OAK RIDGE National Laboratory

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by **Battelle** *Since 1965*

東京大学 THE UNIVERSITY OF TOKYO

uma UNIVERSIDAD DE MÁLAGA

University of Maryland

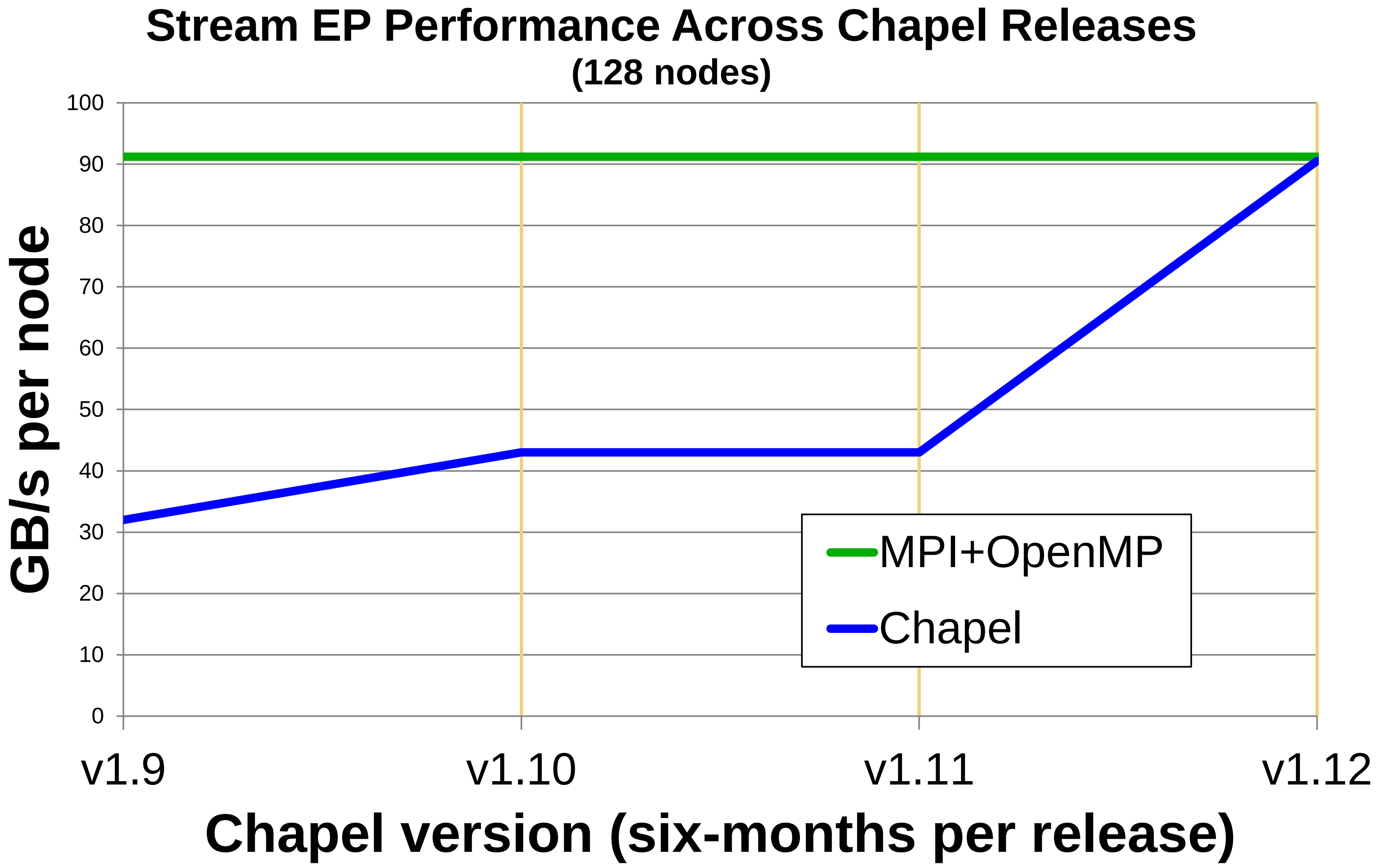
(and many others as well…)

http://chapel.cray.com/collaborations.html

Chapel is a Work-in-Progress

- **Currently being picked up by early adopters**
  - Users who try it generally like what they see
  - Last release got 1400+ downloads over six months
- **Most features are functional and working well**
  - some areas need improvements: strings, object-oriented features
- **Performance is hit-or-miss**
  - shared memory performance is often competitive with C+OpenMP
  - distributed memory performance needs more work
- **We are actively working to address these lacks**

Stream-EP Performance Over Time



Chapel: For More Information

Chapel Websites

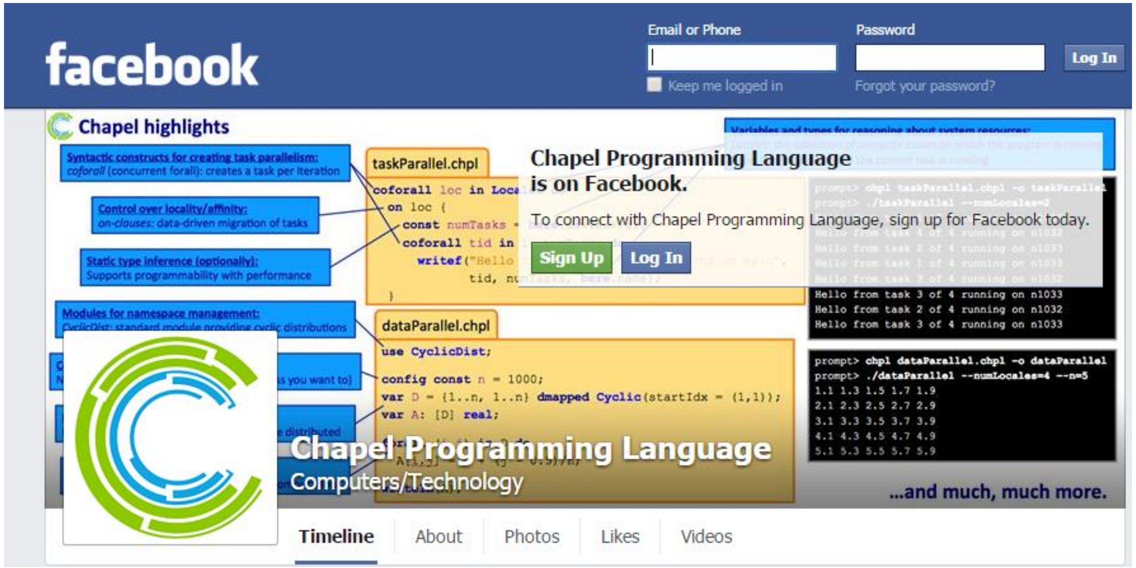
Project page: http://chapel.cray.com

- overview, papers, presentations, language spec, …

GitHub page: https://github.com/chapel-lang

- download Chapel; browse source repository; contribute code

Facebook page: https://www.facebook.com/ChapelLanguage



Chapel highlights

Syntactic constructs for creating task parallelism: *coforall* (concurrent forall): creates a task per iteration

Control over locality/affinity: *on-clauses:* data-driven migration of tasks

Static type inference (optionally): Supports programmability with performance

Modules for namespace management: *CyclicDist:* standard module providing cyclic distributions

Variables and types for reasoning about system resources:

taskParallel.chpl

```
coforall loc in Loca
  on loc {
    const numTasks =
    coforall tid in
      writef("Hello
             tid, nu
  }
```

dataParallel.chpl

```
use CyclicDist;

config const n = 1000;
var D = {1..n, 1..n} dmapped Cyclic(startIdx = (1,1));
var A: [D] real;
```

```
prompt> chpl taskParallel.chpl -o taskParallel
prompt> ./taskParallel --numLocales=2
Hello from task 4 of 4 running on n1032
Hello from task 2 of 4 running on n1033
Hello from task 1 of 4 running on n1033
Hello from task 3 of 4 running on n1032
Hello from task 3 of 4 running on n1033
Hello from task 2 of 4 running on n1032
Hello from task 3 of 4 running on n1033
```

```
prompt> chpl dataParallel.chpl -o dataParallel
prompt> ./dataParallel --numLocales=4 --n=5
1.1 1.3 1.5 1.7 1.9
2.1 2.3 2.5 2.7 2.9
3.1 3.3 3.5 3.7 3.9
4.1 4.3 4.5 4.7 4.9
5.1 5.3 5.5 5.7 5.9
```

…and much, much more.

Chapel Programming Language is on Facebook.

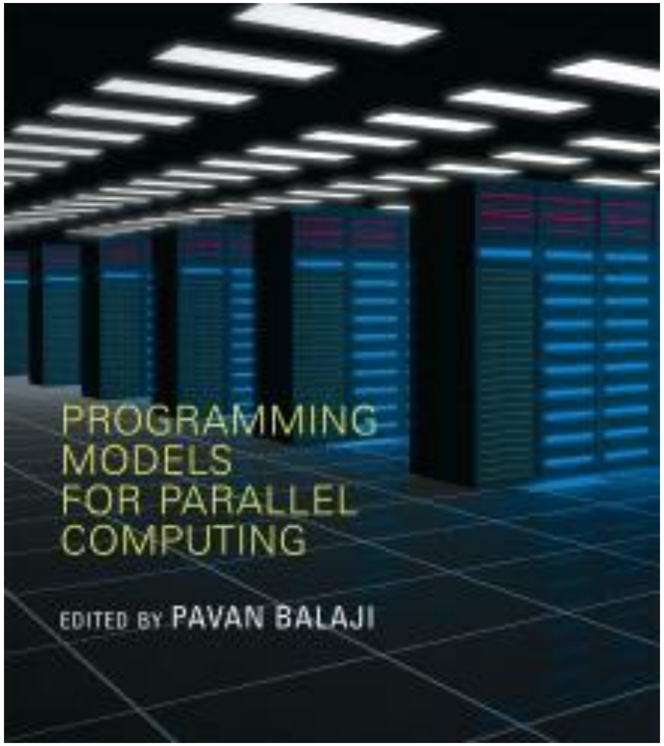
To connect with Chapel Programming Language, sign up for Facebook today.

Chapel Programming Language
Computers/Technology

Suggested Chapel Reading

A Brief Overview of Chapel

- *a detailed overview of Chapel's history, motivating themes, features*
- *early draft chapter for Programming Models for Parallel Computing, edited by Pavan Balaji, MIT Press*
- *buy the book to get the updated version*



Other Chapel papers/publications available at **http://chapel.cray.com/papers.html**

Chapel Blog Articles

Chapel: Productive Parallel Programming, Cray Blog, May 2013.

- *a short-and-sweet introduction to Chapel*

Six Ways to Say "Hello" in Chapel **(parts 1, 2, 3)**, Cray Blog, Sep-Oct 2015.

- *a series of articles illustrating the basics of parallelism and locality in Chapel*

Why Chapel? **(parts 1, 2, 3)**, Cray Blog, Jun-Oct 2014.

- *a series of articles answering common questions about why we are pursuing Chapel in spite of the inherent challenges*

[Ten] Myths About Scalable Programming Languages, IEEE TCSC Blog (index available on chapel.cray.com "blog articles" page), Apr-Nov 2012.

- *a series of technical opinion pieces designed to argue against standard reasons given for not developing high-level parallel languages*

Chapel Mailing Aliases

read-only:

chapel-announce@lists.sourceforge.net: announcements about Chapel

read/write:

chapel-users@lists.sourceforge.net: user-oriented discussion list
chapel-developers@lists.sourceforge.net: developer discussions
chapel-education@lists.sourceforge.net: educator discussions
chapel-bugs@lists.sourceforge.net: public bug forum

write-only:

chapel_info@cray.com: contact the team at Cray
chapel_bugs@cray.com: for reporting non-public bugs

Subscribe at SourceForge: http://sourceforge.net/p/chapel/mailman/

- (also serves as an alternate release download site to GitHub)

Questions?

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