Chapel:
Productive Parallel Programming at Scale
(a whirlwind introduction)

Brad Chamberlain, Chapel Team, Cray Inc.

HPDC 2016 TPC workshop

March 10th, 2016

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.

Motivation for Chapel

Q: **Why doesn't HPC programming have an equivalent to Python / Matlab / Java / <u>(your favorite programming language here)</u> ?**

A: **We believe this is due less to technical challenges, and more because of insufficient…**

…long-term efforts
…resources
…community will
…co-design between developers and users
…patience

Chapel is our attempt to change this

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 “Productivity” mean to you?

Recent Graduates:

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

Seasoned HPC Programmers:

“that sugary stuff that I don’t need because I ~~was born to suffer”~~ want full control to ensure 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 want, implemented in a language as attractive as recent graduates want.”

The Chapel Team at Cray (spring 2015)

Note: We currently have full-time, intern, and Google SoC opportunities available

The Broader Chapel Community

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

ma
Universidad de Málaga

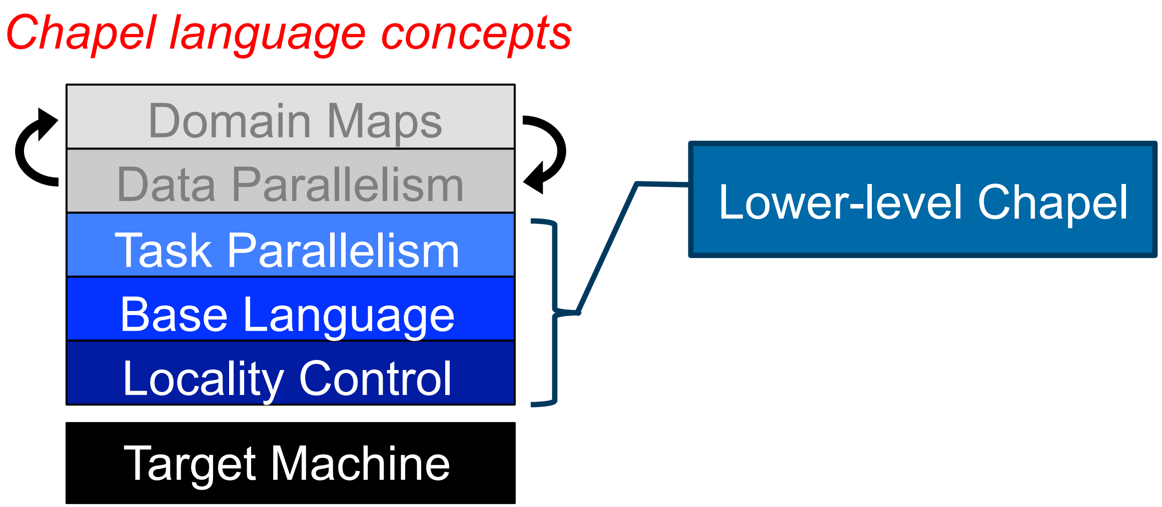
University of Maryland

(and many others as well…)

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

Introduction to Chapel by Example

Lower-Level Features



Base Language Features, by example

```
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
…
```

Base Language Features, by example

CLU-style iterators

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

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

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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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…
```

Base Language Features, by example

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;
  }
}
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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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```

Base Language Features, by example

zippered iteration

```
for (i,f) in zip(0..#n, fib(n)) do
  writeln("fib #", i, " is ", f);
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Base Language Features, by example

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

  for i in 1..n {
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  }
}
```

tuples

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

Base Language Features, by example

Static Type Inference for:
- arguments
- return types
- variables

```
iter fib(n) {
  var current = 0,
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…
```

Task Parallelism, Locality Control, by example

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
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```

Task Parallelism, Locality Control, by example

High-Level Task Parallelism

taskParallel.chpl

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Task Parallelism, Locality Control, by example

Abstraction of System Resources

taskParallel.chpl

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Control of Locality/Affinity

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Task Parallelism, Locality Control, by example

High-Level
Task Parallelism

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

Data-centric task coordination via atomic and F/E variables

(not seen here)

Parallelism and Locality: Orthogonal in Chapel

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

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

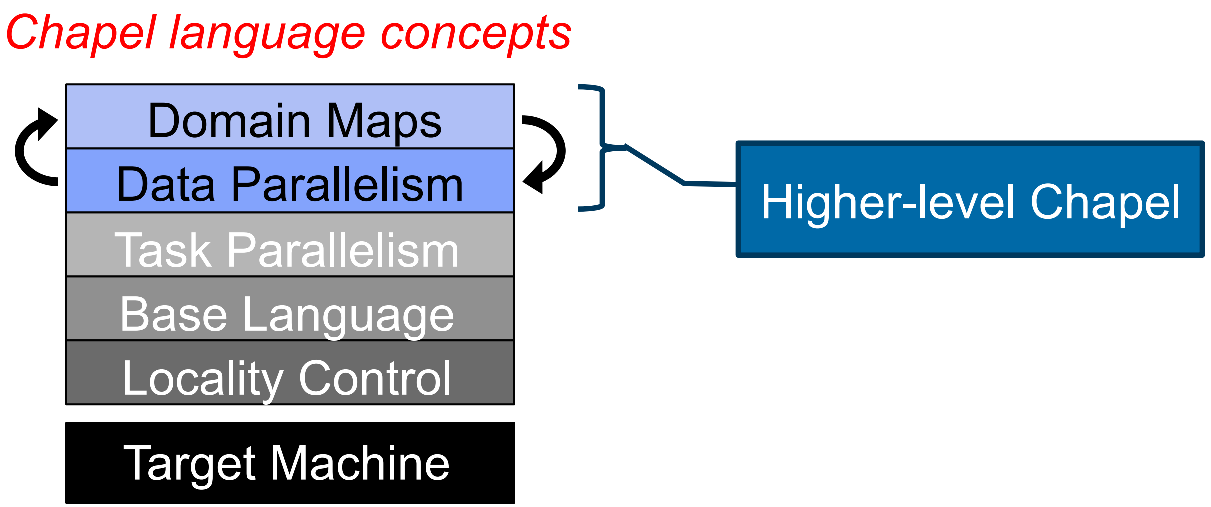
- This is a **distributed**, but serial program:

```
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 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
  A[i,j] = i + (j - 0.5)/n;
writeln(A);
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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

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
  A[i,j] = i + (j - 0.5)/n;
writeln(A);
```

```
prompt> chpl dataParallel.chpl -o dataParallel
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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

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;
writeln(A);
```

```
prompt> chpl dataParallel.chpl -o dataParallel
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1.1 1.3 1.5 1.7 1.9
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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

Domain Maps
(Map Data Parallelism to the System)

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);
```

```
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

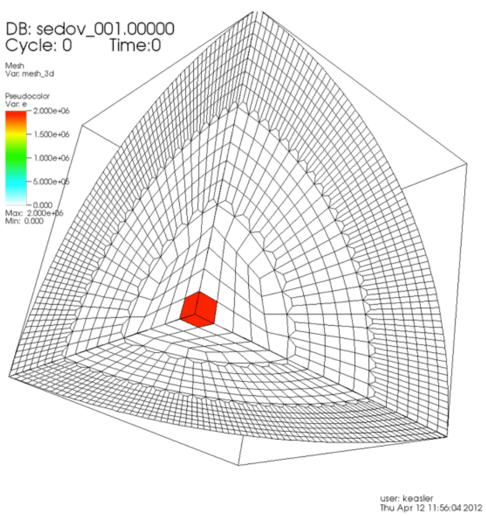
dataParallel.chpl

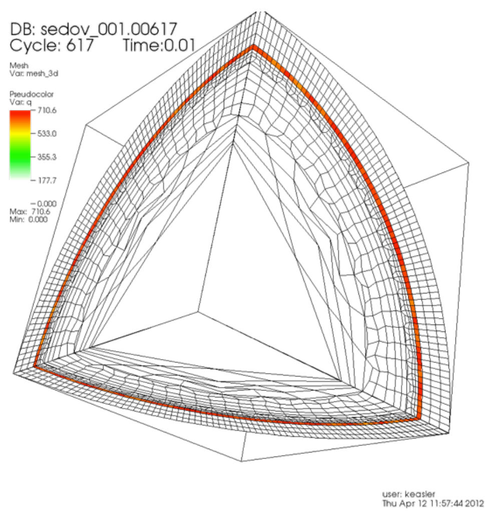
```
use CyclicDist;
config const n = 1000;
var D = {1..n, 1..n}
        dmapped Cyclic(startIdx = (1,1));
var A: [D] real;
forall (i,j) in D do
  A[i,j] = i + (j - 0.5)/n;
writeln(A);
```

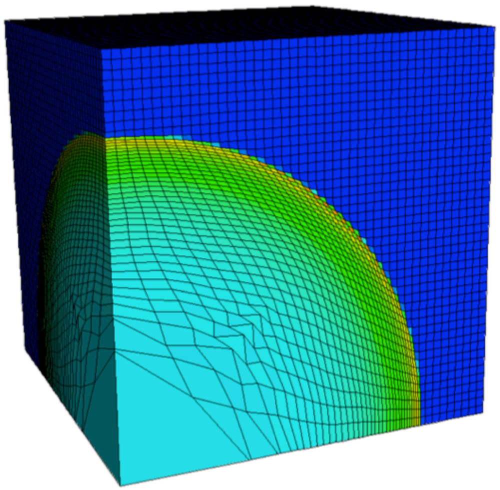
```
prompt> chpl dataParallel.chpl -o dataParallel
prompt> ./dataParallel --n=5 --numLocales=4
1.1 1.3 1.5 1.7 1.9
2.1 2.3 2.5 2.7 2.9
3.1 3.3 3.5 3.7 3.9
4.1 4.3 4.5 4.7 4.9
5.1 5.3 5.5 5.7 5.9
```

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

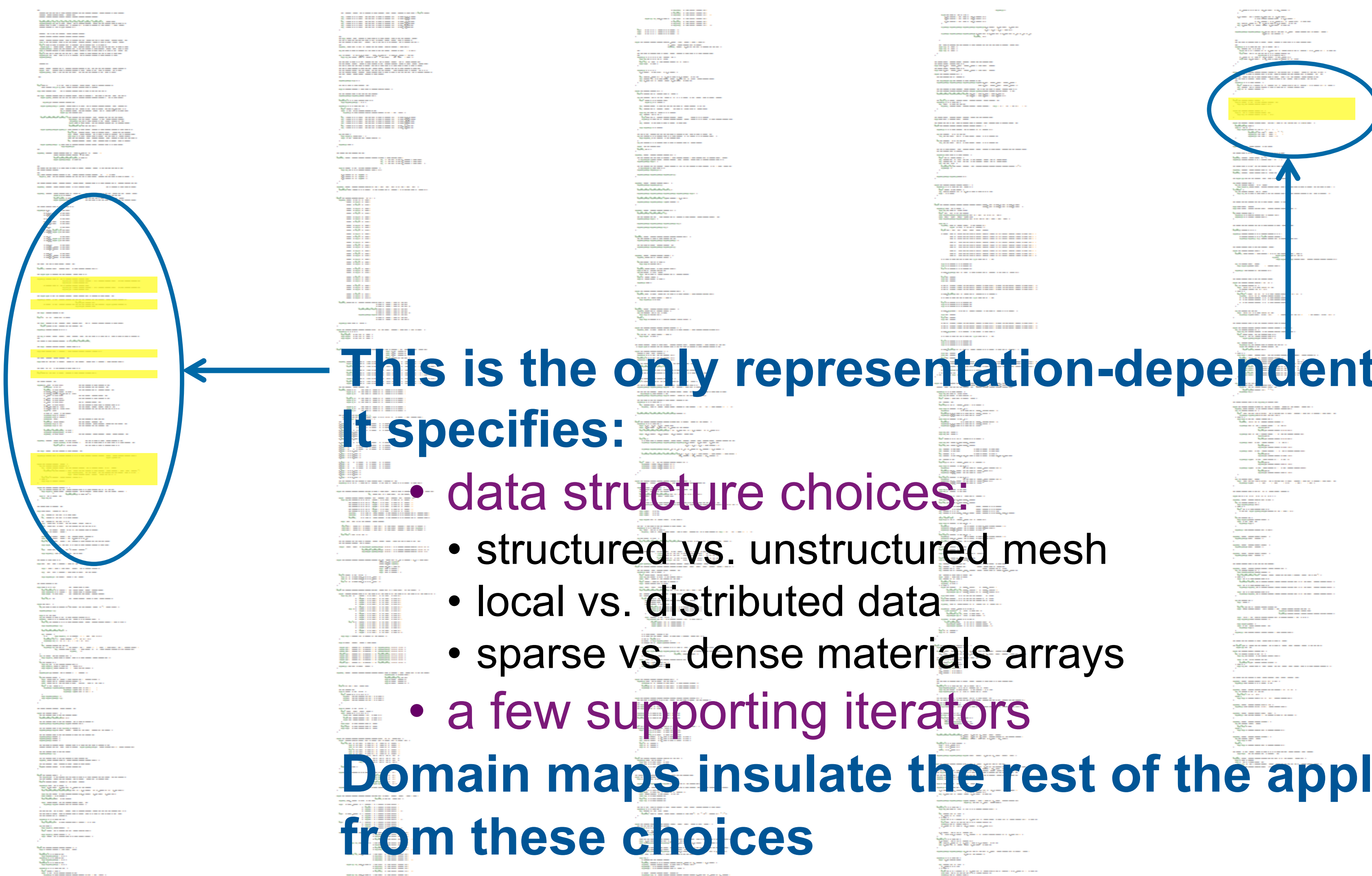
plus 266 lines of comments

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/

LULESH in Chapel



This is the only 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

Domain maps insulate the rest of the application from these choices

Chapel Characterizations

Chapel is Extensible

Advanced users can create their own…

…array layouts and distributions (domain maps)…
…scheduling policies for forall loops…
…architectural models and mappings…

…as Chapel code, without modifying the compiler.

Why? To make the language future-proof.

This is our main research challenge: How to create a language that does not lock these policies into its definition while obtaining competitive performance?

Chapel is a Work-in-Progress

- **Currently being picked up by early adopters**
  - Users who try it typically like what they see
  - Last release got 1400+ downloads over six months
- **Most features are functional and working well**
  - some areas need further attention: object-oriented features, strings
- **Performance is improving, but not yet optimal**
  - shared memory performance is typically competitive with C+OpenMP
  - distributed memory performance can be hit-or-miss
- **We are actively working to address these lacks**

Chapel is Portable

- **Chapel's design is hardware-independent**

- **The current release requires:**
  - a C/C++ compiler
  - a *NIX environment (Linux, OS X, BSD, Cygwin, …)
  - 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 in 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**
- **Instructions for download + install are online**
  - see http://chapel.cray.com/download.html

Chapel: For More Information

Chapel Websites

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

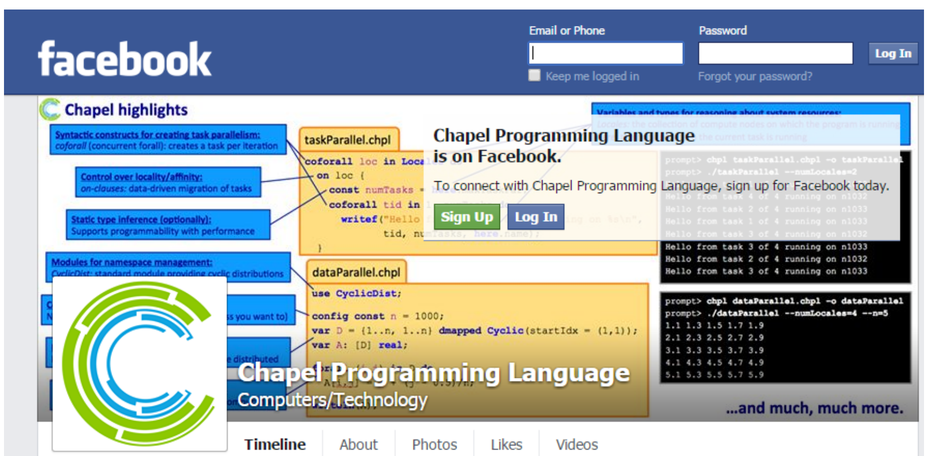
- overview, papers, presentations, language spec, …

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

- download Chapel; browse source repository; contribute code

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

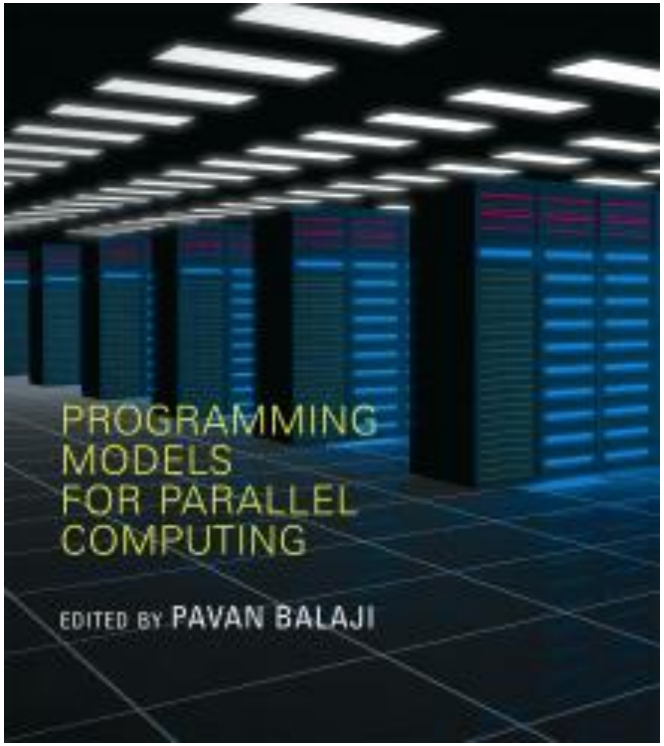
Twitter: https://twitter.com/ChapelLanguage



Suggested Reading

Chapel chapter from ***Programming Models for Parallel Computing***

- *a detailed overview of Chapel's history, motivating themes, features*
- *edited by Pavan Balaji, published by MIT Press*
- *an early draft is available online, entitled A Brief Overview of Chapel*



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

low-traffic (read-only):

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

community lists:

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

contact the Cray team:

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)

Get Involved!

Attend CHIUW 2016 at IPDPS (Chicago, May 27-28)

- 3rd annual Chapel Implementers and Users Workshop
- May 27th: mini-conference day
  - keynote: Nikhil Padmanabhan, Professor of Astrophysics, Yale Univ.
  - 4 research paper talks, 10 short talks, community discussion
- May 28th: code camp day

Send us your students!

- as Google Summer of Coders, interns, full-time employees

Propose a research collaboration

- join the growing Chapel community!

Questions?

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