Chapel Boot Camp

Ben Albrecht

Chapel Team, Cray Inc.

June 2, 2017

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 / C++ / __(your favorite programming language here)__?

- one that makes it easy to get programs up and running quickly
- one that is portable across system architectures and scales
- one that bridges the HPC, data analysis, and mainstream communities

A: We believe this is due not to any particular technical challenge, but rather a lack of sufficient…

…long-term efforts

…resources

…community will

…patience

Chapel is our attempt to reverse this trend!

What is Chapel?

Chapel: An emerging parallel programming language

- 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."

Chapel is Portable

- **Chapel is designed to be hardware-independent**

- **The current release requires:**
  - a C/C++ compiler
  - a *NIX environment (Linux, OS X, BSD, Cygwin, WSL, …)
  - POSIX threads
  - RDMA, MPI, or UDP (for distributed memory execution)

- **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.

* = 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
  - http://chapel.cray.com/download.html

The Chapel Team at Cray (May 2017)

Chapel Community R&D Efforts

HERIOT WATT UNIVERSITY

AMD

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

WESTERN WASHINGTON UNIVERSITY

東京大学
THE UNIVERSITY OF TOKYO

Colorado State University

RICE

UNIVERSITY OF MARYLAND

BERKELEY LAB
Lawrence Berkeley National Laboratory

Lawrence Livermore National Laboratory

Sandia National Laboratories

DEPARTMENT OF DEFENSE · UNITED STATES OF AMERICA

Yale

(and several others, some of whom you will hear from today…)

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

Outline

✓ Chapel Motivation and Background

➢ Chapel in a Nutshell

● Chapel Project: Past, Present, Future

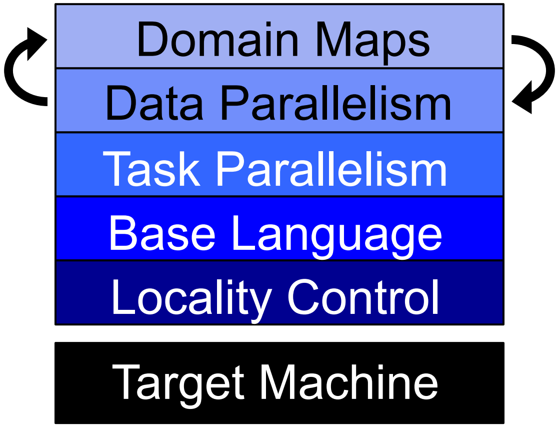
● Chapel Resources

Chapel’s Multiresolution Philosophy

Multiresolution Design: **Support multiple tiers of features**

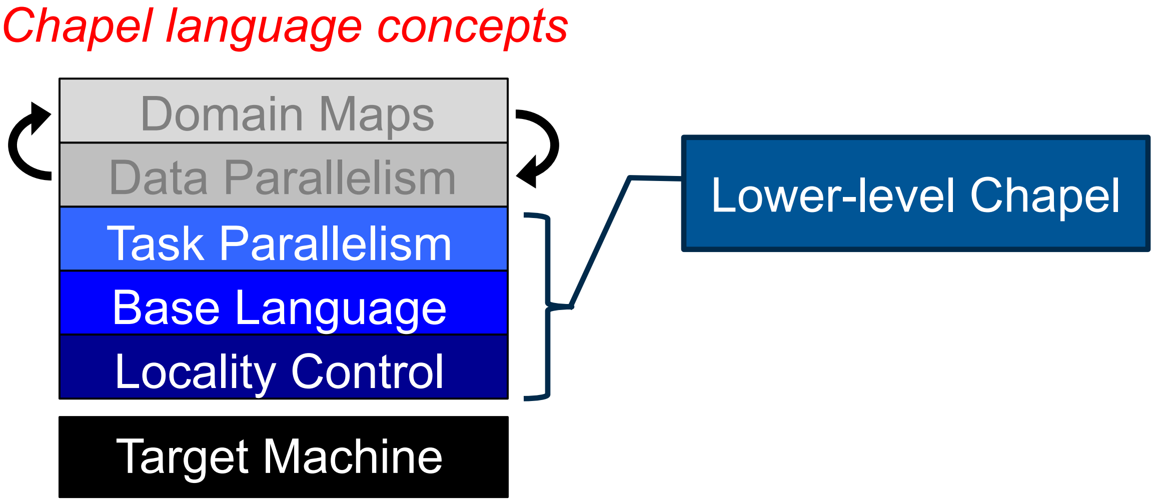
- higher levels for programmability, productivity
- lower levels for greater degrees of control

Chapel language concepts

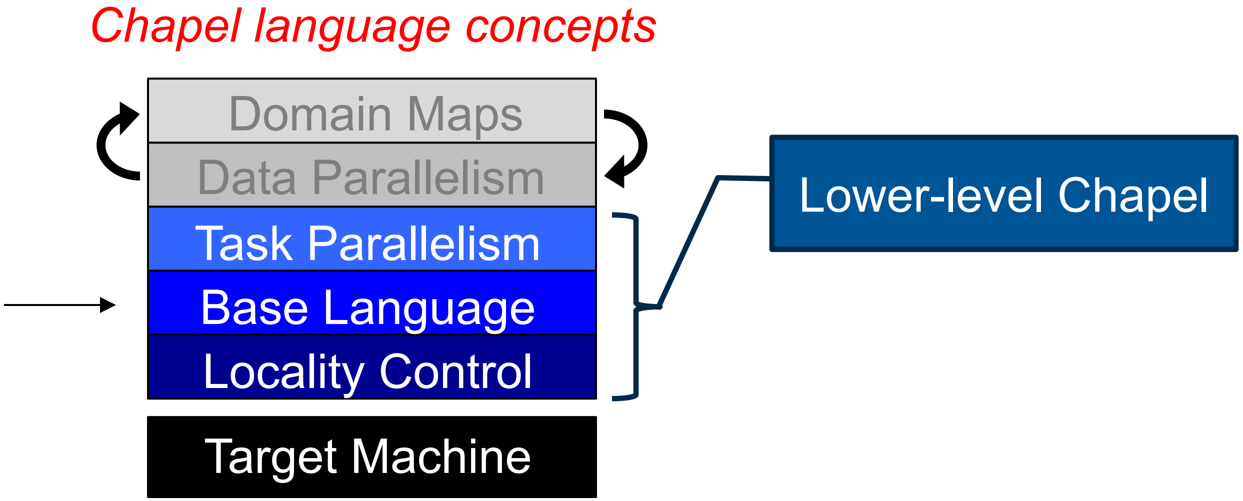


- build the higher-level concepts in terms of the lower
- permit the user to intermix layers arbitrarily

Lower-Level Features



Lower-Level Features



Base Language Features: Fibonacci 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: Fibonacci Example

iterators

```
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: Fibonacci 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;
  }
}
```

```
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: Fibonacci Example

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

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

zippered iteration

```
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: Fibonacci Example

tuples

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

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

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

```
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: Fibonacci Example

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

```
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: Fibonacci Example

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

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

swap operator

```
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: Fibonacci Example

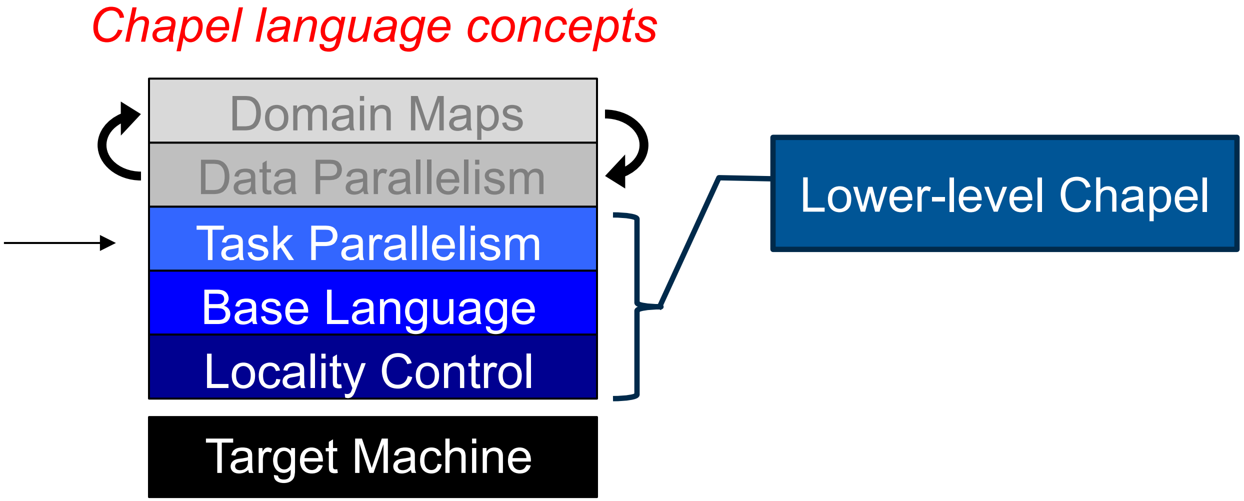
```
iter fib(n) {
  var current = 0,
      next = 1;

  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
…
```

Lower-Level Features



Task Parallelism

beginTask.chpl

```
begin writeln("Hello!");
writeln(”Goodbye...");
```

```
prompt> chpl beginTask.chpl -o beginTask
prompt> ./beginTask
Hello!
Goodbye...
prompt> ./beginTask
Goodbye...
Hello!
```

Task Parallelism

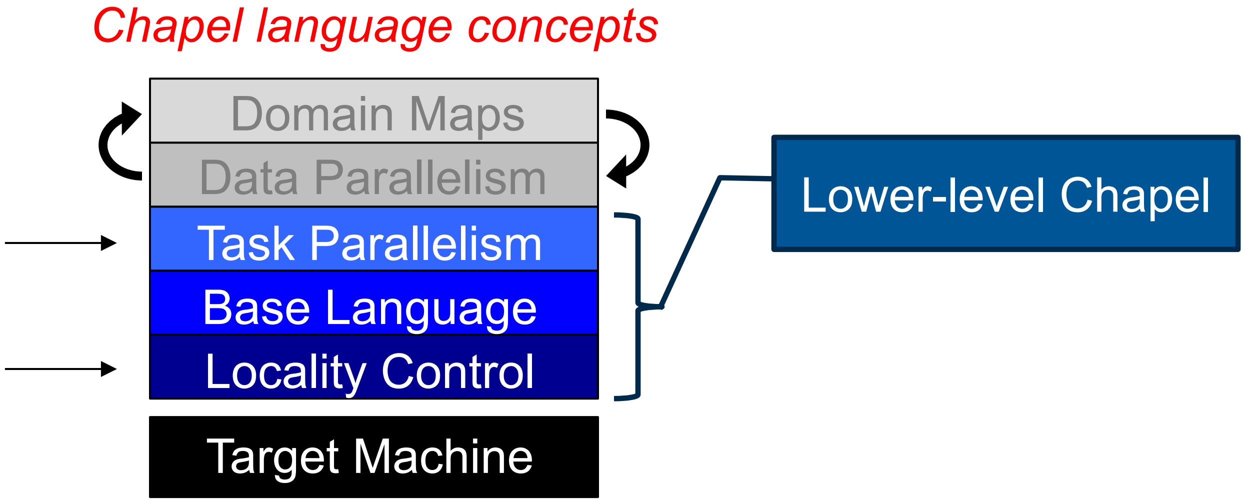
Creates a new task

beginTask.chpl

```
begin writeln("Hello!");
writeln(”Goodbye...");
```

```
prompt> chpl beginTask.chpl -o beginTask
prompt> ./beginTask
Hello!
Goodbye...
prompt> ./beginTask
Goodbye...
Hello!
```

Lower-Level Features



Task Parallelism & Locality Control

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
```

Task Parallelism & Locality Control

High-Level
Task Parallelism

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
```

Task Parallelism & Locality Control

Abstraction of System Resources

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
```

Task Parallelism & Locality Control

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);
  }
```

Control of Locality/Affinity

```
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
```

Task Parallelism & Locality Control

Abstraction of System Resources

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
```

Task Parallelism & Locality Control

High-Level
Task Parallelism

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
```

Task Parallelism & Locality Control

Not seen here:

Data-centric task coordination via atomic and full/empty vars

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
```

Parallelism and Locality: Orthogonal in Chapel

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

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

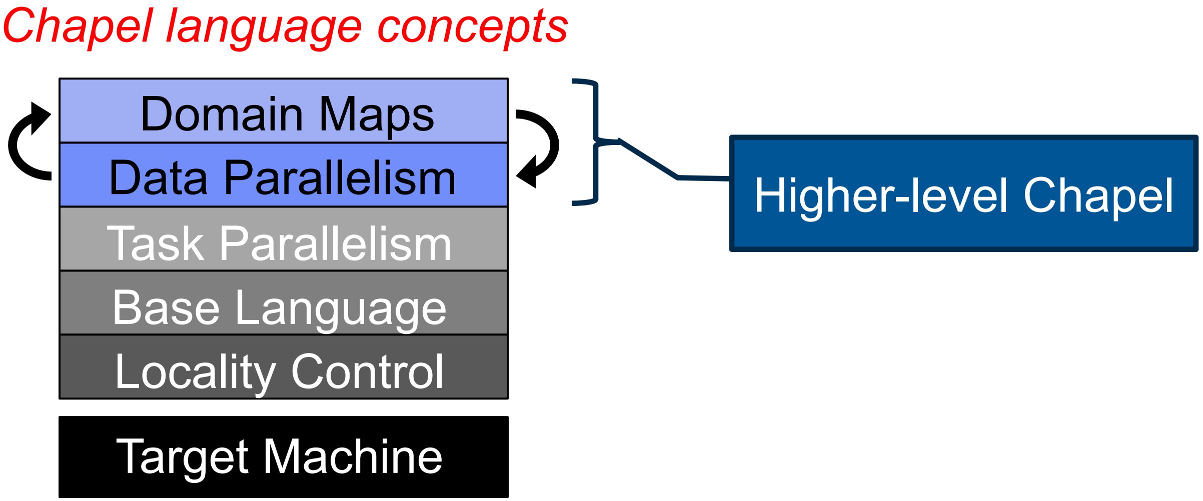
- This is a **distributed**, but serial program:

```
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



Data Parallelism

dataParallel.chpl

```
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
```

Data Parallelism

Domains (Index Sets)

dataParallel.chpl

```
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
```

Data Parallelism

Arrays

dataParallel.chpl

```
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
```

Data Parallelism

Data-Parallel Forall Loops

dataParallel.chpl

```
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
```

Distributed 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
```

Distributed Data Parallelism

Distributions

- BlockCycDist
- BlockDist
- CyclicDist
- DimensionalDist2D
- PrivateDist
- ReplicatedDist
- SparseBlockDist
- StencilDist

Layouts

- CSR

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
```

Outline

- ✓ Chapel Motivation and Background
- ✓ Chapel in a Nutshell
- ➢ Chapel Project: Past, Present, Future
- ● Chapel Resources

Chapel's Origins: HPCS

DARPA HPCS: High Productivity Computing Systems

- **Goal:** improve productivity by a factor of 10x
- **Timeframe:** Summer 2002 – Fall 2012
- Cray developed a new system architecture, network, software stack…
  - this became the very successful Cray XC30™ Supercomputer Series

…and a new programming language: Chapel

Chapel's focus areas

- **Based on positive user response to Chapel under HPCS, Cray undertook a longer-term effort to improve it**
  - we've just completed our fourth year of this effort

- **Focus Areas:**
  1. Improving **performance** and scaling
  2. **Fixing** immature aspects of the language and implementation
     - e.g., strings, memory management, error handling, …
  3. **Porting** to emerging architectures
     - Intel Xeon Phi, accelerators, heterogeneous processors and memories, …
  4. Improving **interoperability**
  5. Growing the Chapel user and developer **community**
     - including non-scientific computing communities
  6. Exploring transition of Chapel **governance** to a neutral, external body

Chapel is a Work-in-Progress

- **Currently being picked up by early adopters**
  - Users who try it generally like what they see

- **Most current features are functional and working well**
  - some areas under active development, particularly:
    - Initializers
    - Error handling

- **Performance is improving, but remains hit-or-miss**
  - shared memory performance is often competitive with C+OpenMP
  - distributed memory performance continues to need more work

Outline

- ✓ Chapel Motivation and Background
- ✓ Chapel in a Nutshell
- ✓ Chapel Project: Past, Present, Future
- ➢ Chapel Resources

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

facebook
Email or Phone
Password
Log In
☐ Keep me logged in
Forgot your password?
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
dataParallel.chpl
Sign Up
Log In
Chapel Programming Language
Computers/Technology
Timeline
About
Photos
Likes
Videos

Chapel Programming Language is on Facebook.

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

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

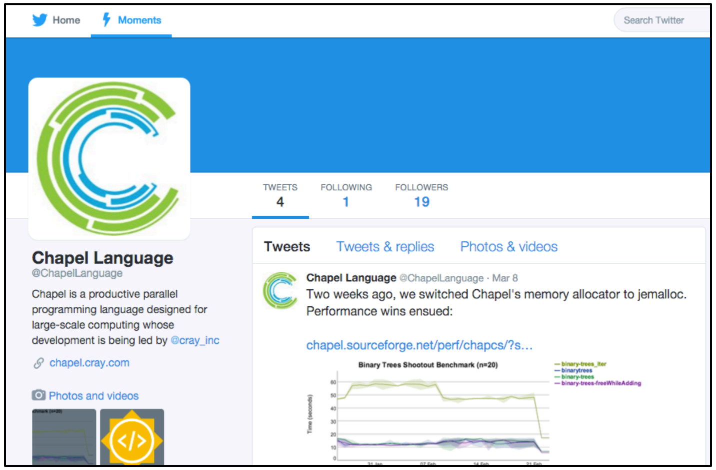
```
use CyclicDist;

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

```
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 Language
@ChapelLanguage

Chapel is a productive parallel programming language designed for large-scale computing whose development is being led by @cray_inc

chapel.cray.com

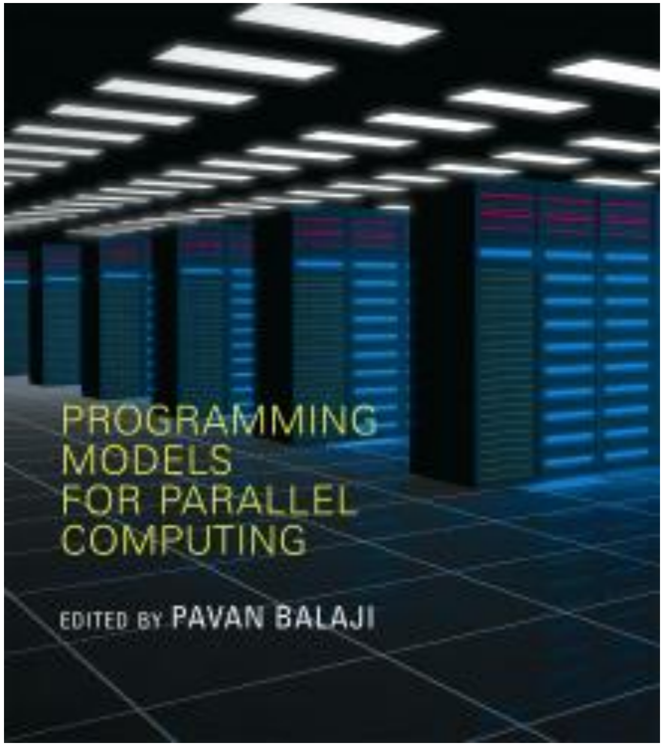
Chapel Language @ChapelLanguage · Mar 8
Two weeks ago, we switched Chapel's memory allocator to jemalloc. Performance wins ensued:

chapel.sourceforge.net/perf/chapcs/?s…

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, November 2015
- chapter is now also available online



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*

Chapel Springs into a Summer of Code, Cray Blog, April 2016.

- *a run-down of some current events*

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*

Mailing Lists

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

(subscribe at SourceForge: http://sourceforge.net/p/chapel/mailman/**)**

To contact the Cray team:

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

Other Community Resources

IRC channels (freenode.net):

#chapel: user-oriented discussions

#chapel-developers: developer discussions

Stack Overflow

stackoverflow.com: [chapel] tag monitored by core team

GitHub Issues:

github.com/chapel-lang/chapel/issues: bug reports & feature requests

Questions about Chapel?

Legal Disclaimer

Information in this document is provided in connection with Cray Inc. products. No license, express or implied, to any intellectual property rights is granted by this document.

Cray Inc. may make changes to specifications and product descriptions at any time, without notice.

All products, dates and figures specified are preliminary based on current expectations, and are subject to change without notice.

Cray hardware and software products may contain design defects or errors known as errata, which may cause the product to deviate from published specifications. Current characterized errata are available on request.

Cray uses codenames internally to identify products that are in development and not yet publically announced for release. Customers and other third parties are not authorized by Cray Inc. to use codenames in advertising, promotion or marketing and any use of Cray Inc. internal codenames is at the sole risk of the user.

Performance tests and ratings are measured using specific systems and/or components and reflect the approximate performance of Cray Inc. products as measured by those tests. Any difference in system hardware or software design or configuration may affect actual performance.

The following are trademarks of Cray Inc. and are registered in the United States and other countries: CRAY and design, SONEXION, and URIKA. The following are trademarks of Cray Inc.: ACE, APPRENTICE2, CHAPEL, CLUSTER CONNECT, CRAYPAT, CRAYPORT, ECOPHLEX, LIBSCI, NODEKARE, THREADSTORM. The following system family marks, and associated model number marks, are trademarks of Cray Inc.: CS, CX, XC, XE, XK, XMT, and XT. The registered trademark LINUX is used pursuant to a sublicense from LMI, the exclusive licensee of Linus Torvalds, owner of the mark on a worldwide basis. Other trademarks used in this document are the property of their respective owners.

CRAY CHAPEL

CRAY

THE SUPERCOMPUTER COMPANY