Chapel Boot Camp

(everything you need to know about Chapel for CHIUW 2016*)

Brad Chamberlain

Chapel Team, Cray Inc.

May 27, 2016

* that I can cram into 30 minutes

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
…co-design between developers and users
…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, …)
  - 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.

* = 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 to get started

The Chapel Team at Cray (May 2016)

Chapel Community R&D Efforts

(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

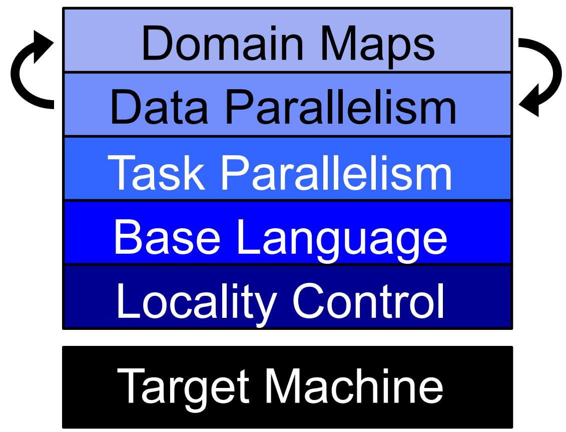
- Chapel Project: Past, Present, Future
- Chapel Resources

Chapel's Multiresolution Philosophy

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

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

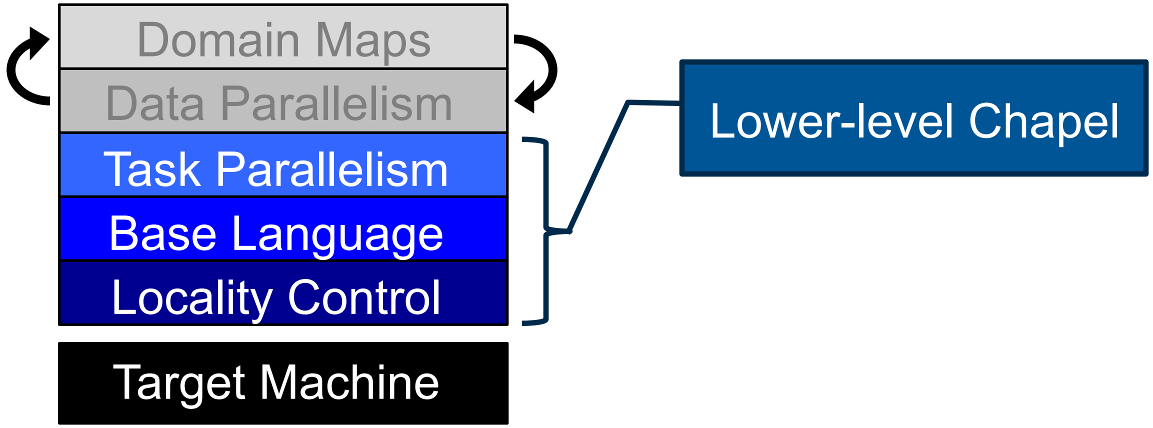
Chapel language concepts



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

Lower-Level Features

Chapel language concepts



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
fib #1 is 1
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fib #5 is 5
fib #6 is 8
…
```

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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Base Language Features, by example

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

zippered iteration

```
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

tuples

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

  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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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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  for i in 1..n {
    yield current;
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    current <=> next;
  }
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  var current = 0,
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swap operator

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for (i,f) in zip(0..#n, fib(n)) do
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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
Hello from task 1 of 2 running on n1032
```

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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             tid, numTasks, here.name);
  }
```

Control of Locality/Affinity

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Hello from task 1 of 2 running on n1033
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Task Parallelism, Locality Control, by example

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Task Parallelism, Locality Control, by example

Not seen here:

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

taskParallel.chpl

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coforall loc in Locales do
  on loc {
    const numTasks = here.maxTaskPar;
    coforall tid in 1..numTasks do
      writef("Hello from task %n of %n "+
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Task Parallelism, Locality Control, by example

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    coforall tid in 1..numTasks do
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             tid, numTasks, here.name);
  }
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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);
```

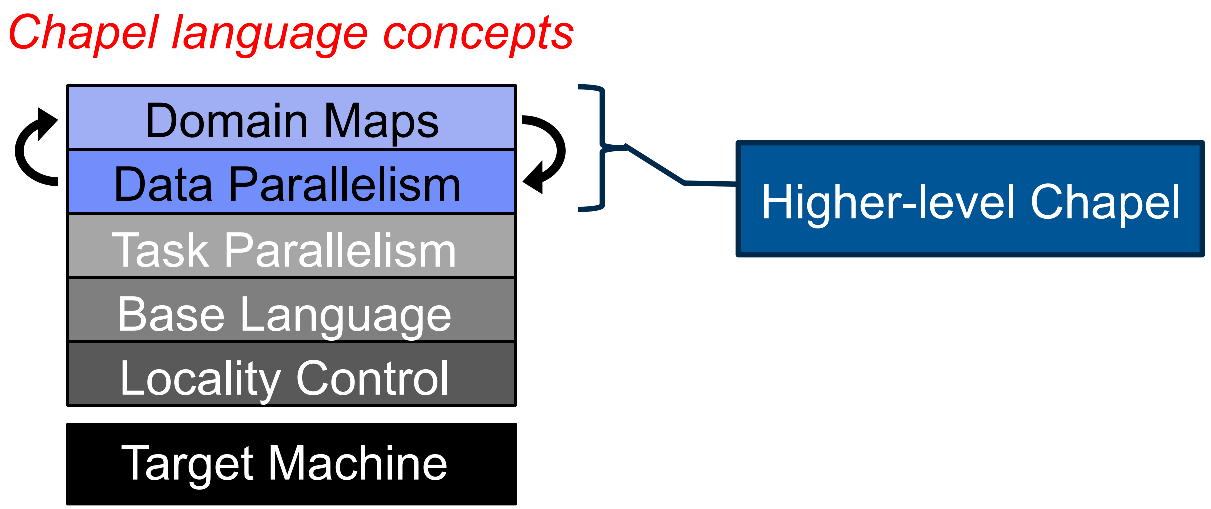
- This is a **distributed**, but serial program:

```
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, by example

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
```

Data Parallelism, by example

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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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, by example

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
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, by example

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
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, by example

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, by example

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
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```

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- ➢ 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 under HPCS: Major Successes

Clean, general parallel language design

- unified data-, task-, concurrent-, nested-parallelism
- distinct concepts for parallelism and locality
- multiresolution language design philosophy

SSCA#2 demonstration on the prototype Cray XC30

- unstructured graph-based compact application
- clean separation of computation from data structure choices
- fine-grain latency-hiding runtime
- use of Cray XC30™ network AMOs via Chapel's 'atomic' types
- ran stably on full-scale demo system for significant length of time

Portable design and implementation

- while still being able to take advantage of Cray-specific features

Revitalization of Community Interest in Parallel Languages

- HPF-disenchantment became interest, cautious optimism, enthusiasm

Chapel under HPCS: Shortcomings

Performance was hit-or-miss (and mostly "miss" at scale)
- a litmus test for the HPC community

Focused on a narrow set of benchmarks (mostly SSCA#2)
- several key idioms and language features were neglected

Contract milestones were set too far in advance
- unable to respond effectively to needs of real users
- changes required contract renegotiations

Insufficient focus on emerging node architectures
- unable to effectively leverage NUMA nodes, GPUs

Didn't get over the tipping point of adoption
- but, we got far enough to make it to the next level…

Chapel's 5-year push

- **Based on positive user response to Chapel under HPCS, Cray undertook a five-year effort to improve it**
  - we've just completed our third year
- **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
  - Last two releases got ~3500 downloads total in a year
- **Most current features are functional and working well**
  - some areas need improvements, particularly object-oriented features
- **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
- **We are actively working to address these lacks**

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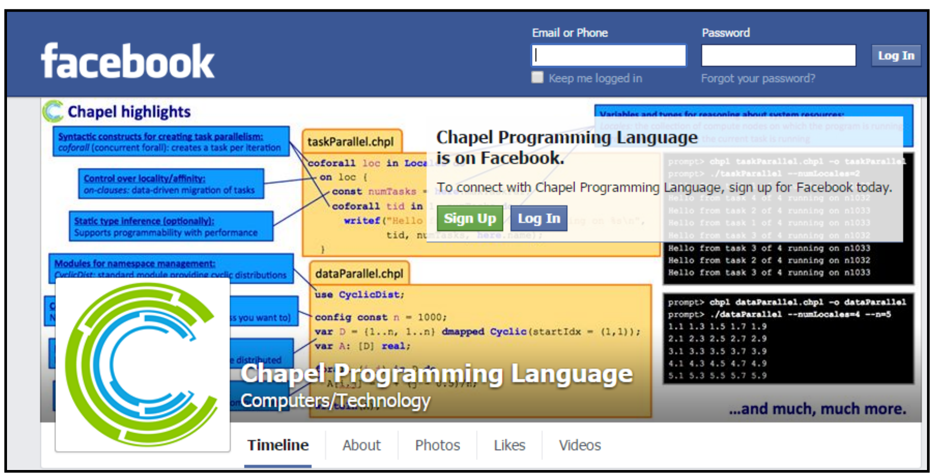
Chapel Websites

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

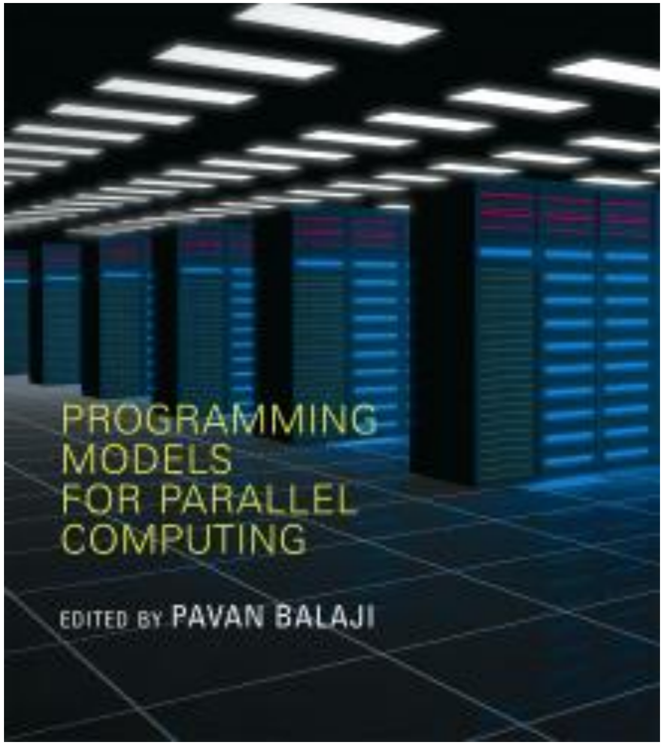
Twitter: https://twitter.com/ChapelLanguage



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, 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*

Chapel 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
chapel-bugs@lists.sourceforge.net: public bug forum

(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

Questions about Chapel?

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