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

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May 27, 2016

* that I can cram into 30 minutes
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](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](http://chapel.cray.com/download.html) to get started
14 full-time employees + 2 summer interns
(one of each started after photo taken)
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*

- 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

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Lower-Level Features

Chapel language concepts

- Domain Maps
- Data Parallelism
- Task Parallelism
- Base Language
- Locality Control
- Target Machine

Lower-level Chapel
Base Language Features, by example

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

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

```plaintext
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

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

```plaintext
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

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

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

```haskell
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

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

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

```r
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

```plaintext
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
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fib #4 is 3
fib #5 is 5
fib #6 is 8
...```
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

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

```python
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

```
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
...
```
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
            printff("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

```chpl
taskParallel.chpl

coforAll loc in Locales do
  on loc {
    const numTasks = here.maxTaskPar;
    coforall tid in 1..numTasks do
      printf("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

```
taskParallel.chpl

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

Abstraction of System Resources

```
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

```
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, by example

```
taskParallel.chpl

coforall loc in Locales do
  on loc {
    const numTasks = here.maxTaskPar;
    coforall tid in 1..numTasks do
      printf("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
```

Abstraction of System Resources
Task Parallelism, Locality Control, by example

High-Level Task Parallelism

```chpl
coforall loc in Locales do
  on loc {
    const numTasks = here.maxTaskPar;
    coforall tid in 1..numTasks do
      printf("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

```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

Not seen here:
Data-centric task coordination via atomic and full/empty vars
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
```
Parallelism and Locality: Orthogonal in Chapel

- This is a **parallel**, but local program:
  
  ```chapel
  coforall i in 1..msgs do
  writeln(“Hello from task ”, i);
  ```

- This is a **distributed**, but serial program:
  
  ```chapel
  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:
  
  ```chapel
  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
Data Parallelism, by example

```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

```
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

```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

```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

```
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
```
Distributed Data Parallelism, by example

```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 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
Outline

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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
- chapter is now also available [online](http://chapel.cray.com/papers.html)

Other Chapel papers/publications available at [http://chapel.cray.com/papers.html](http://chapel.cray.com/papers.html)
Chapel Blog Articles

- 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

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

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Chapel Mailing Lists

low-traffic (read-only):
chapel-announce@lists.sourceforge.net: announcements about Chapel user-oriented discussion list

community lists:
chapel-users@lists.sourceforge.net: developer discussions
chapel-developers@lists.sourceforge.net: educator discussions
chapel-education@lists.sourceforge.net: public bug forum

(subscribe at SourceForge: [link](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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