Chapel: A Parallel Language for Productive Scalable Computing

Brad Chamberlain, Chapel Team, Cray Inc.

SeaLang Meetup

December 6, 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.

My Background

Education:

- Earned Ph.D. from University of Washington CSE in 2001
  - focused on the ZPL data-parallel array language
- Remain associated with UW CSE as an Affiliate Professor

Industry:

- Currently a Principal Engineer at Cray Inc.
- Technical lead / founding member of the Chapel project

Who are you?

- **Workplace / Role?**
- **Programming Languages?**
  - Favorites?
  - Ones you work on / in?
- **Parallel Programming Experience?**
  - On desktop? At scale?
- **Anything else?**

Who are you? (My Answers)

- **Workplace / Role?** Cray / Chapel Technical Lead
- **Programming Languages?**
  - Favorites? Pascal (sentimental), Ada (safety), C (control / speed)
  - Ones you work on / in? Chapel, C/C++
- **Parallel Programming Experience?** just a tad
  - On desktop? At scale?
- **Anything else?** I don't consider myself a PL expert
  - more of a parallel expert who works in languages/compilers

Plan for Tonight

Elements:

- prepared overview talk
- from there, whatever you like…

  …interactive Chapel programming demo?

  …more in-depth presentation of some topic?

  …Q&A / discussion?

Ground Rules:

- please ask questions anytime
- if I get too hand-wavy, feel free to ask “got a visual for that?”

What is Chapel?

What is Chapel?

Chapel: A productive parallel programming language

- portable
- open-source
- a collaborative effort

Goals:

- Support general parallel programming
  - “any parallel algorithm on any parallel hardware”
- Make parallel programming at scale 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 and Other Languages

Chapel strives to be as…

…**programmable** as Python

…**fast** as Fortran

…**scalable** as MPI, SHMEM, or UPC

…**portable** as C

…**flexible** as C++

…**fun** as [your favorite programming language]

"The Audacity of Chapel"

audacity (according to Google):

/ɔːˈdasɪti/

noun

1. a willingness to take bold risks.

   "I applaud the *audacity* of the Chapel team in attempting to create a new language given how hard it is for new languages to succeed."

2. rude or disrespectful behaviour; impudence.

   "I can't believe the Chapel team has the *audacity* to create a new language when we already have [C++ | MPI | OpenCL | Python | …]!"

Scalable Parallel Programming Concerns

Q: What do HPC programmers need from a language?

A: *Serial Code:* Software engineering and performance

Parallelism: What should execute simultaneously?

Locality: Where should those tasks execute?

Mapping: How to map the program to the system?

Separation of Concerns: Decouple these concerns

These are first-order concerns, yet…

existing languages have not treated all of them as such.

The Challenge

Q: So why don't we already have such a language?

A: ~~Technical challenges?~~

- while they exist, we don't think this is the main issue…

A: Due to a lack of…

…long-term efforts

…resources

…co-design between developers and users

…community will

…patience

Chapel is our attempt to reverse this trend

The Chapel Team at Cray (May 2017)

14 full-time employees + 2 summer interns + 2–4 GSoC students

The Chapel Team at Cray (May 2017)

You? A friend?
(hiring a manager-evangelist)

14 full-time employees + 2 summer interns + 2–4 GSoC students

Chapel Community Partners

HAVERFORD COLLEGE

AMD

THE GEORGE WASHINGTON UNIVERSITY WASHINGTON, DC

WESTERN WASHINGTON UNIVERSITY

東京大学 THE UNIVERSITY OF TOKYO

THE UNIVERSITY OF ARIZONA

RICE

UNIVERSITY OF MARYLAND

BERKELEY LAB

Lawrence Berkeley National Laboratory

Lawrence Livermore National Laboratory

Sandia National Laboratories

DEPARTMENT OF DEFENSE UNITED STATES OF AMERICA

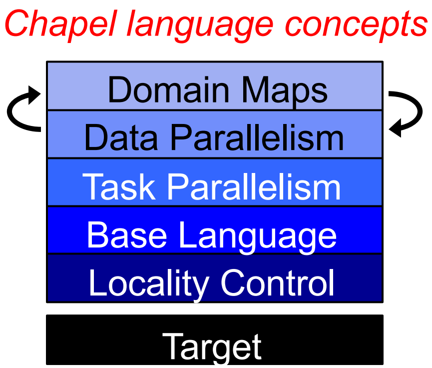
Yale

(and several others…)

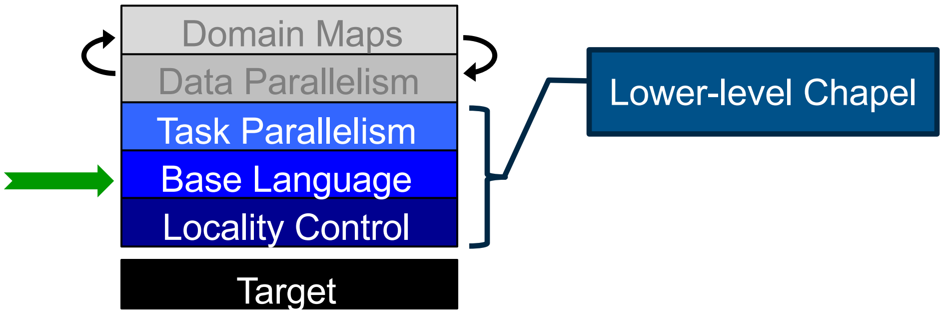
https://chapel-lang.org/collaborations.html

A Chapel Sampler

Chapel language feature areas



Base Language



Base Language Features, by example

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

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

```
config const n = 10;

for f in fib(n) do
  writeln(f);
```

```
0
1
1
2
3
5
8
…
```

Base Language Features, by example

Modern iterators

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

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

```
config const n = 10;

for f in fib(n) do
  writeln(f);
```

```
0
1
1
2
3
5
8
…
```

Base Language Features, by example

Configuration declarations
(to avoid command-line argument parsing)
`./a.out --n=1000000`

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

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

```
config const n = 10;

for f in fib(n) do
  writeln(f);
```

```
0
1
1
2
3
5
8
…
```

Base Language Features, by 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;
  }
}
```

```
config const n = 10;

for f in fib(n) do
  writeln(f);
```

```
0
1
1
2
3
5
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;
  }
}
```

Zippered iteration

```
config const n = 10;

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

Range types and operators

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

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

```
config const n = 10;

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

tuples

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

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

```
config const n = 10;

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;

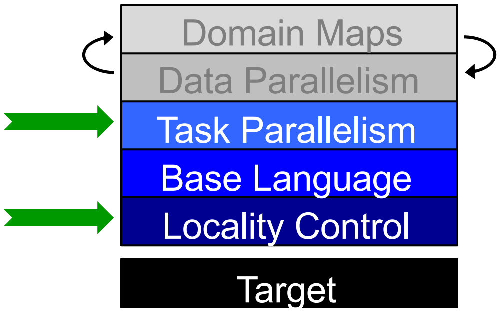
  for i in 1..n {
    yield current;
    current += next;
    current <=> next;
  }
}
```

```
config const n = 10;

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 and Locality Control



Task Parallelism and Locality, by example

taskParallel.chpl

```
coforall loc in Locales do
  on loc {
    const numTasks = here.numPUs();
    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
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Task Parallelism and Locality, by example

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    coforall tid in 1..numTasks do
      writef("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 and Locality, by example

High-Level
Task Parallelism

taskParallel.chpl

```
coforall loc in Locales do
  on loc {
    const numTasks = here.numPUs();
    coforall tid in 1..numTasks do
      writef("Hello from task %n of %n "+
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  }
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Hello from task 1 of 2 running on n1033
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Hello from task 1 of 2 running on n1032
```

Task Parallelism and Locality, by example

taskParallel.chpl

```
coforall loc in Locales do
  on loc {
    const numTasks = here.numPUs();
    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
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```

Task Parallelism and Locality, by example

Abstraction of System Resources

taskParallel.chpl

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Task Parallelism and Locality, by example

High-Level
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taskParallel.chpl

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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
```

Task Parallelism and Locality, by example

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.numPUs();
    coforall tid in 1..numTasks do
      writef("Hello from task %n of %n "+
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```

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Task Parallelism and Locality, by example

taskParallel.chpl

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

```
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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: Distinct 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:

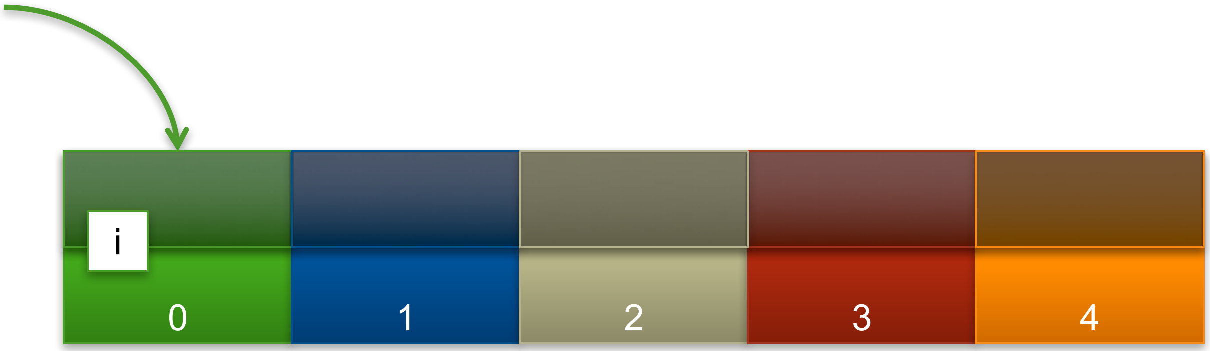
```
writeln("Hello from locale 0!");
on Locales[1] do writeln("Hello from locale 1!");
on Locales[2] do writeln("Hello from locale 2!");
```

- 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);
```

Chapel: Scoping and Locality

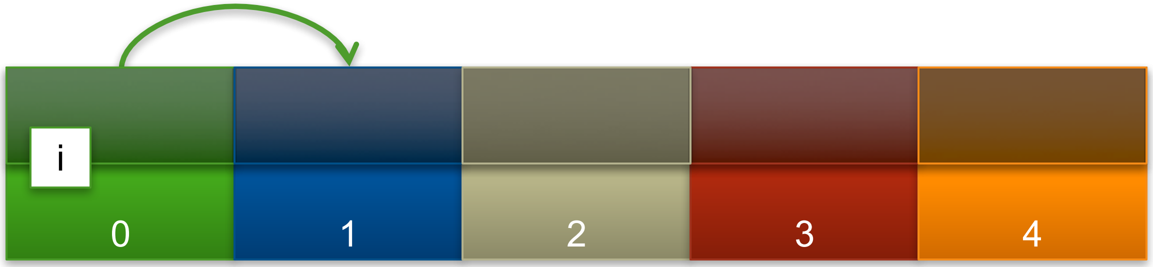
```
var i: int;
```



Locales (think: “compute nodes”)

Chapel: Scoping and Locality

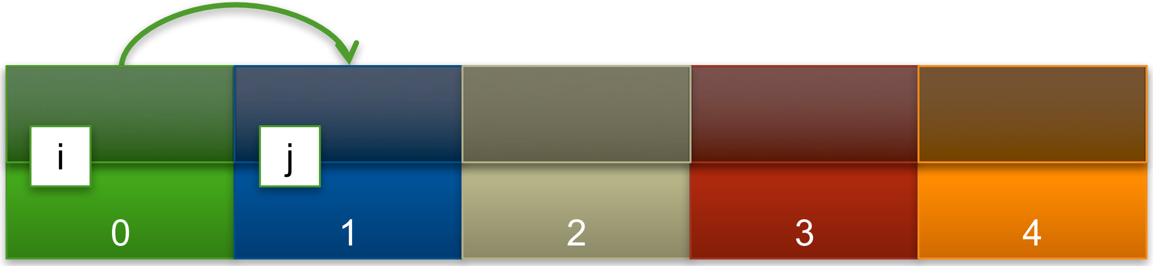
```
var i: int;
on Locales[1] {
```



Locales (think: "compute nodes")

Chapel: Scoping and Locality

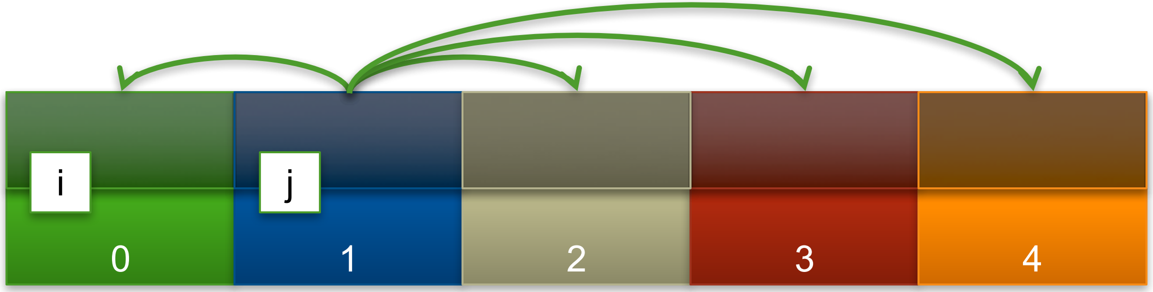
```
var i: int;
on Locales[1] {
  var j: int;
```



Locales (think: "compute nodes")

Chapel: Scoping and Locality

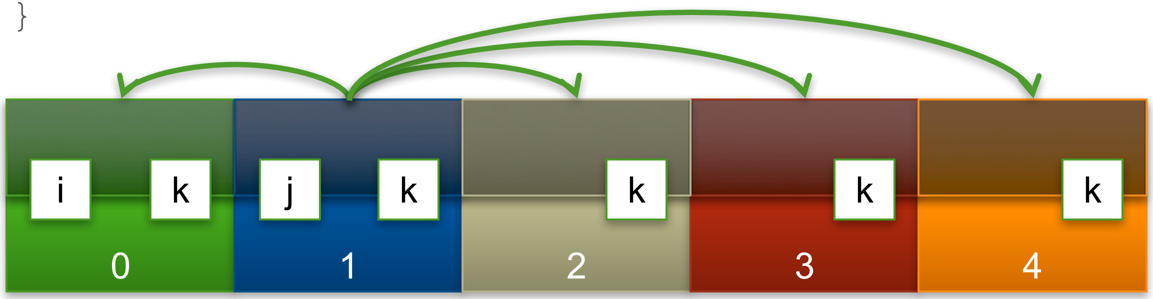
```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
```



Locales (think: "compute nodes")

Chapel: Scoping and Locality

```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
      var k: int;
      …
    }
  }
}
```

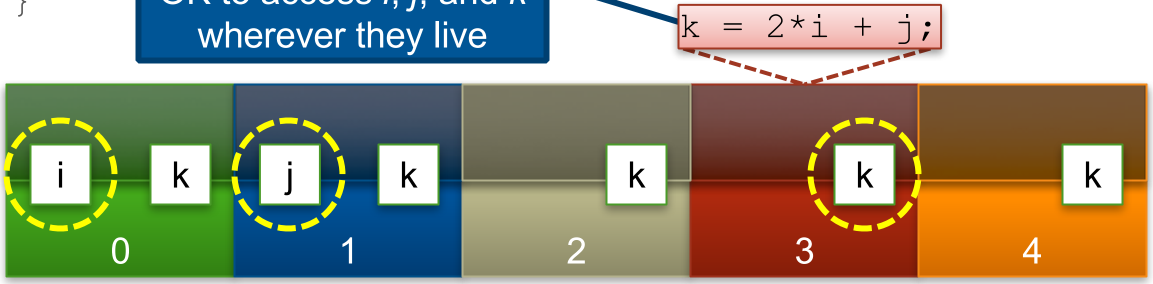


Locales (think: “compute nodes”)

Chapel: Scoping and Locality

```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
      var k: int;
      k = 2*i + j;
    }
  }
}
```

OK to access *i*, *j*, and *k* wherever they live

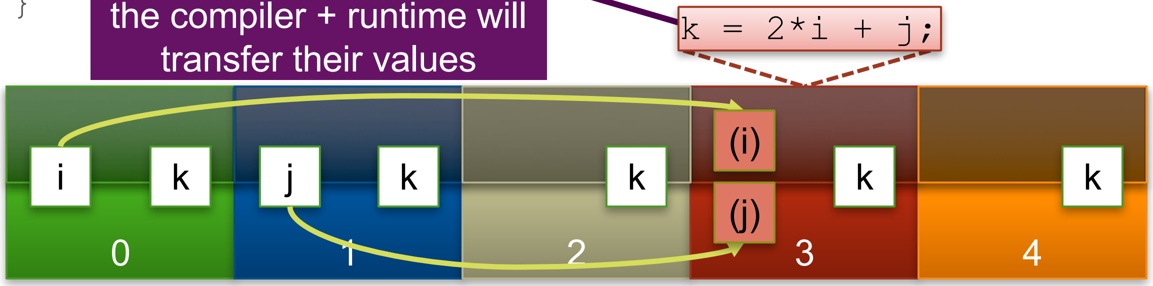


Locales (think: “compute nodes”)

Chapel: Scoping and Locality

```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
      var k: int;
      k = 2*i + j;
    }
  }
}
```

here, *i* and *j* are remote, so the compiler + runtime will transfer their values

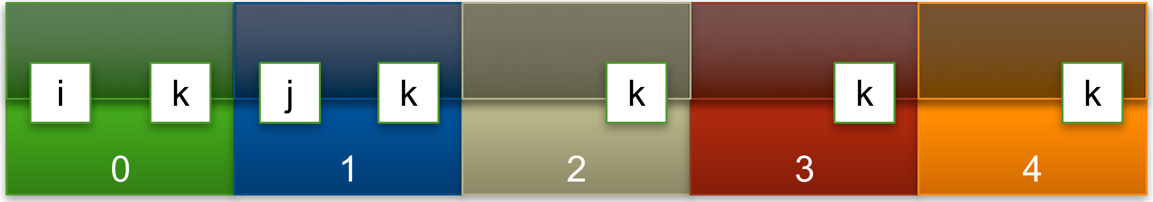


Locales (think: “compute nodes”)

Chapel: Locality queries

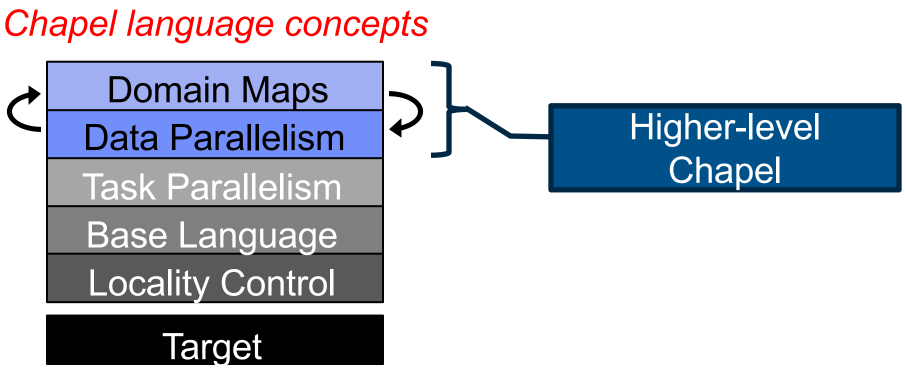
```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
      var k: int;

      …here…          // query the locale on which this task is running
     …j.locale…       // query the locale on which j is stored
    }
  }
```



Locales (think: “compute nodes”)

Higher-Level Features



Data Parallelism, by example

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, by example

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, by example

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
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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

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
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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
```

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);
```

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

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 Evaluations

Computer Language Benchmarks Game (CLBG)

The Computer Language Benchmarks Game

64-bit quad core data set

Will your toy benchmark program be faster if you write it in a different programming language? It depends how you write it!

Which programs are fast?

Which are succinct? Which are efficient?

Ada C Chapel C# C++ Dart

Erlang F# Fortran Go Hack

Haskell Java JavaScript Lisp Lua

OCaml Pascal Perl PHP Python

Racket Ruby JRuby Rust Smalltalk

Swift TypeScript

{ for researchers } fast-faster-fastest

stories

Website supporting cross-language comparisons

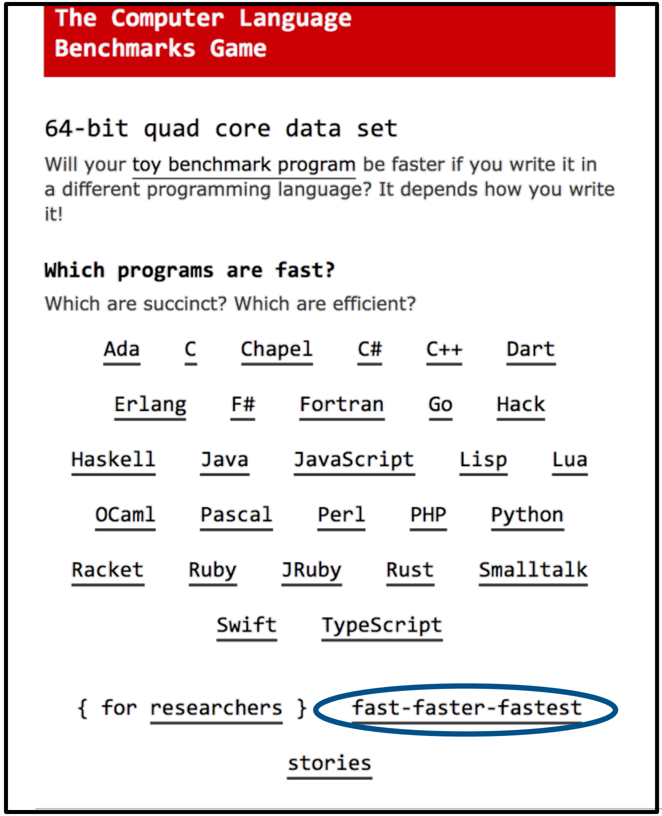
- 13 toy benchmark programs x ~28 languages x many implementations
  - exercise key computational idioms
  - specific approach prescribed

Take results with a grain of salt

- your mileage may vary

That said, it is one of the only such games in town…

Computer Language Benchmarks Game (CLBG)



The Computer Language Benchmarks Game

64-bit quad core data set

Will your toy benchmark program be faster if you write it in a different programming language? It depends how you write it!

Which programs are fast?

Which are succinct? Which are efficient?

Ada C Chapel C# C++ Dart

Erlang F# Fortran Go Hack

Haskell Java JavaScript Lisp Lua

OCaml Pascal Perl PHP Python

Racket Ruby JRuby Rust Smalltalk

Swift TypeScript

{ for researchers } fast-faster-fastest

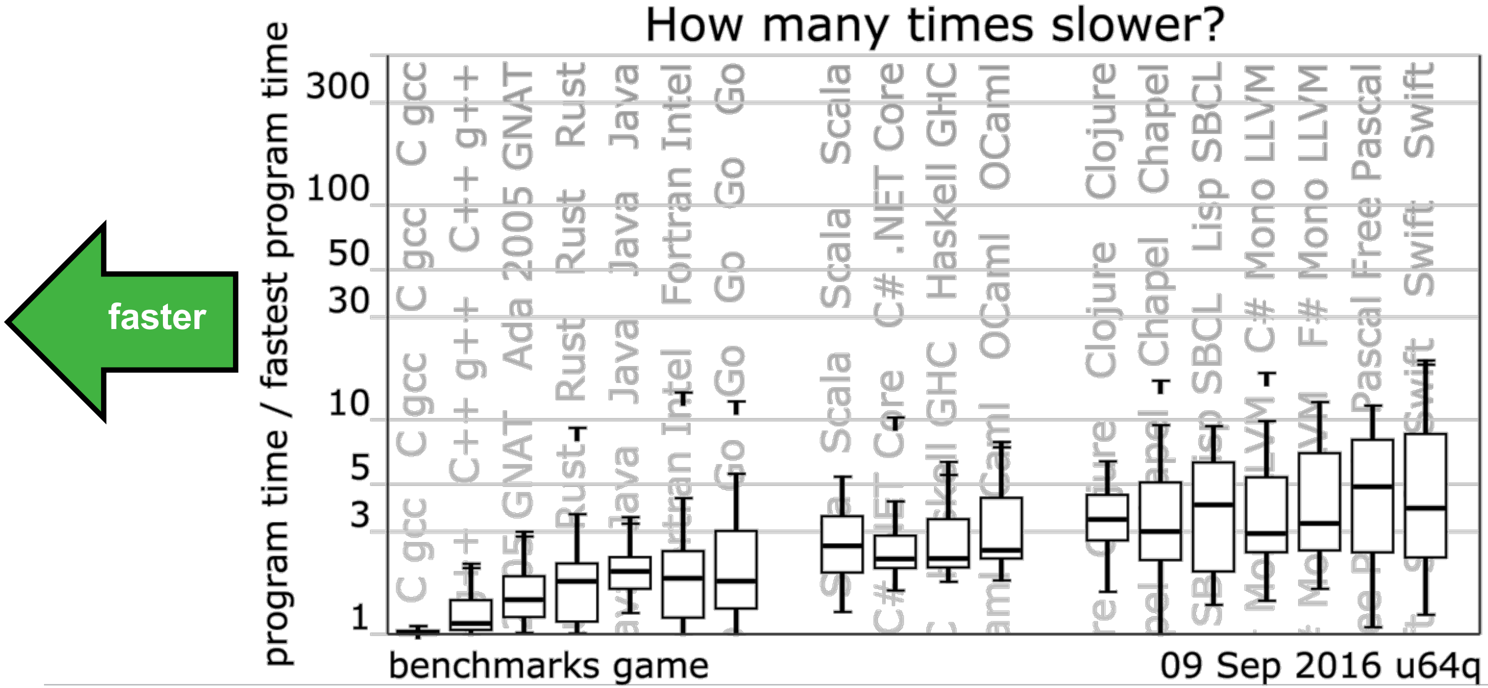
stories

Chapel's approach to the CLBG:

- striving for elegance over heroism
  - ideally: "Want to learn how program *xyz* works? Read the Chapel version."

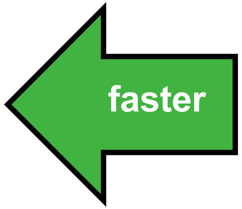
CLBG: Fast-faster-fastest graph (Sep 2016)

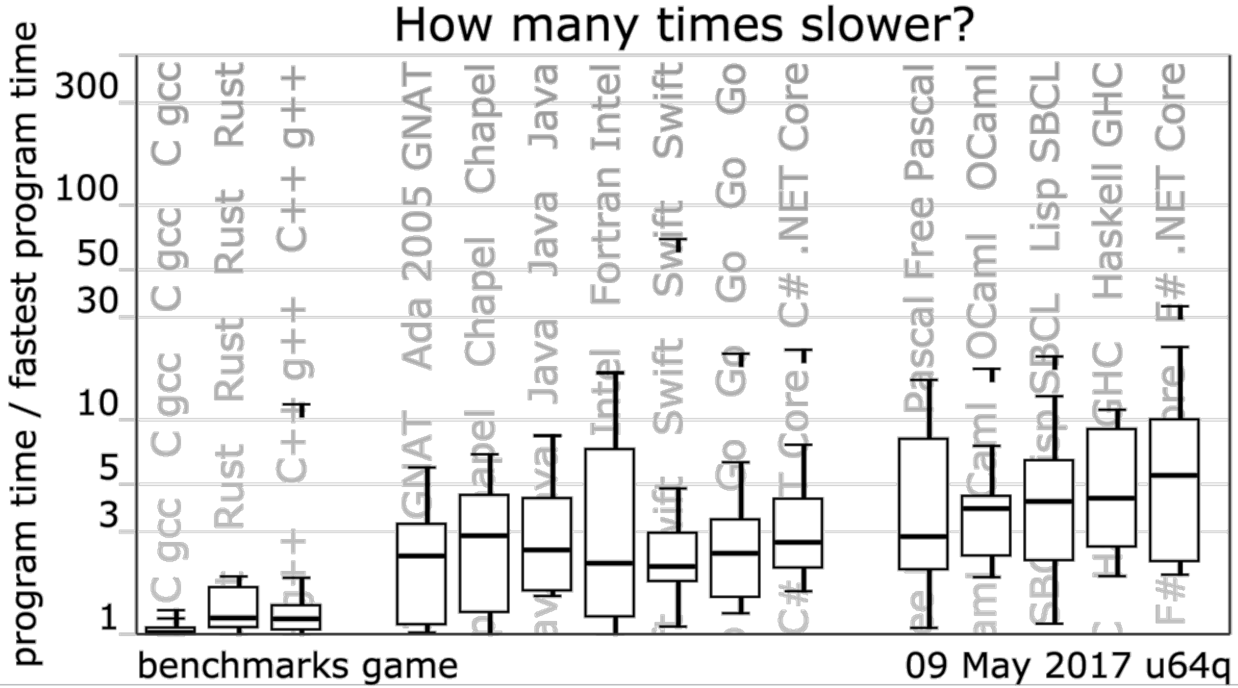
Relative performance, sorted by geometric mean



CLBG: Fast-faster-fastest graph (May 2017)

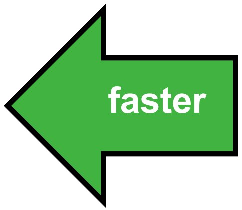
Relative performance, sorted by geometric mean

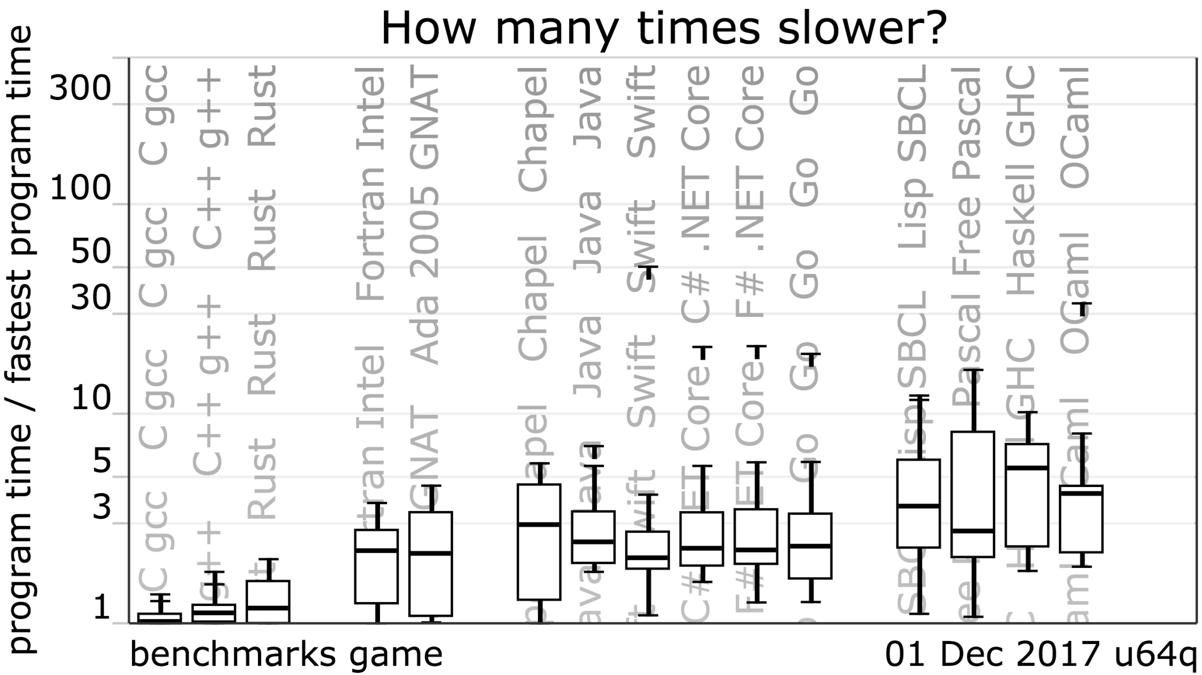




CLBG: Fast-faster-fastest graph (Dec 2017)

Relative performance, sorted by geometric mean





CLBG: Website

Can sort results by execution time, code size, memory or CPU use:

The Computer Language Benchmarks Game

pidigits

description

program source code, command-line and measurements

×	source	secs	mem	gz	cpu	cpu load
1.0	**Chapel** #2	**1.62**	34,024	423	1.64	99% 3% 1% 4%
1.0	Chapel	1.62	33,652	501	1.64	100% 0% 1% 1%
1.1	**Pascal** Free Pascal #3	**1.73**	2,284	482	1.72	1% 100% 1% 1%
1.1	**C** gcc	**1.73**	2,116	448	1.73	1% 99% 1% 0%
1.1	**Ada** 2005 GNAT #2	**1.74**	3,776	1065	1.73	1% 0% 100% 0%
1.1	**Rust** #2	**1.74**	7,876	1306	1.74	1% 100% 1% 1%
1.1	Rust	1.74	7,892	1420	1.74	100% 1% 2% 1%
1.1	**Swift** #2	**1.75**	8,532	601	1.75	100% 1% 1% 0%
1.1	**Lisp** SBCL #4	**1.79**	25,164	940	1.79	3% 2% 1% 100%
1.2	**C++** g++ #4	**1.89**	3,868	508	1.89	100% 1% 2% 1%
1.2	**Lua** #5	**1.94**	3,248	479	1.93	1% 1% 1% 99%
1.2	**Go** #3	**2.02**	10,744	603	2.02	2% 0% 5% 96%
1.3	**PHP** #5	**2.15**	9,884	394	2.15	1% 0% 100% 1%
1.3	PHP #4	2.16	9,856	384	2.16	100% 0% 0% 2%
1.3	**Racket** #2	**2.17**	27,660	1122	2.17	100% 0% 1% 0%

The Computer Language Benchmarks Game

pidigits

description

program source code, command-line and measurements

×	source	secs	mem	gz	cpu	cpu load
1.0	**Perl** #4	3.53	6,836	**261**	3.52	0% 0% 1% 100%
1.5	**Python 3** #2	3.51	10,344	**382**	3.50	0% 2% 1% 100%
1.5	**PHP** #4	2.16	9,856	**384**	2.16	100% 0% 0% 2%
1.5	Perl #2	3.92	6,784	385	3.92	1% 0% 33% 68%
1.5	PHP #5	2.15	9,884	394	2.15	1% 0% 100% 1%
1.6	**Chapel** #2	1.62	34,024	**423**	1.64	99% 3% 1% 4%
1.7	**C** gcc	1.73	2,116	**448**	1.73	1% 99% 1% 0%
1.7	Perl	15.87	9,032	452	15.86	1% 100% 1% 1%
1.7	**Racket**	25.63	130,528	**453**	25.58	100% 0% 1% 1%
1.8	**Lua** #7	3.76	3,192	**477**	3.75	1% 100% 0% 2%
1.8	**Ruby** #5	3.14	477,092	**478**	3.12	0% 100% 2% 1%
1.8	Lua #5					% 1% 1% 99%
1.8	**Pascal** Free Pas					% 100% 1% 1%
1.9	**Lisp** SBCL #3					% 1% 100% 1%
1.9	PHP #3					0% 0% 0% 1%

gz == code size metric
strip comments and extra whitespace, then gzip

CLBG: Website

Can also compare languages pair-wise:

- but only sorted by execution speed…

The Computer Language Benchmarks Game

Chapel programs versus Fortran Intel

all other Chapel programs & measurements

by benchmark task performance

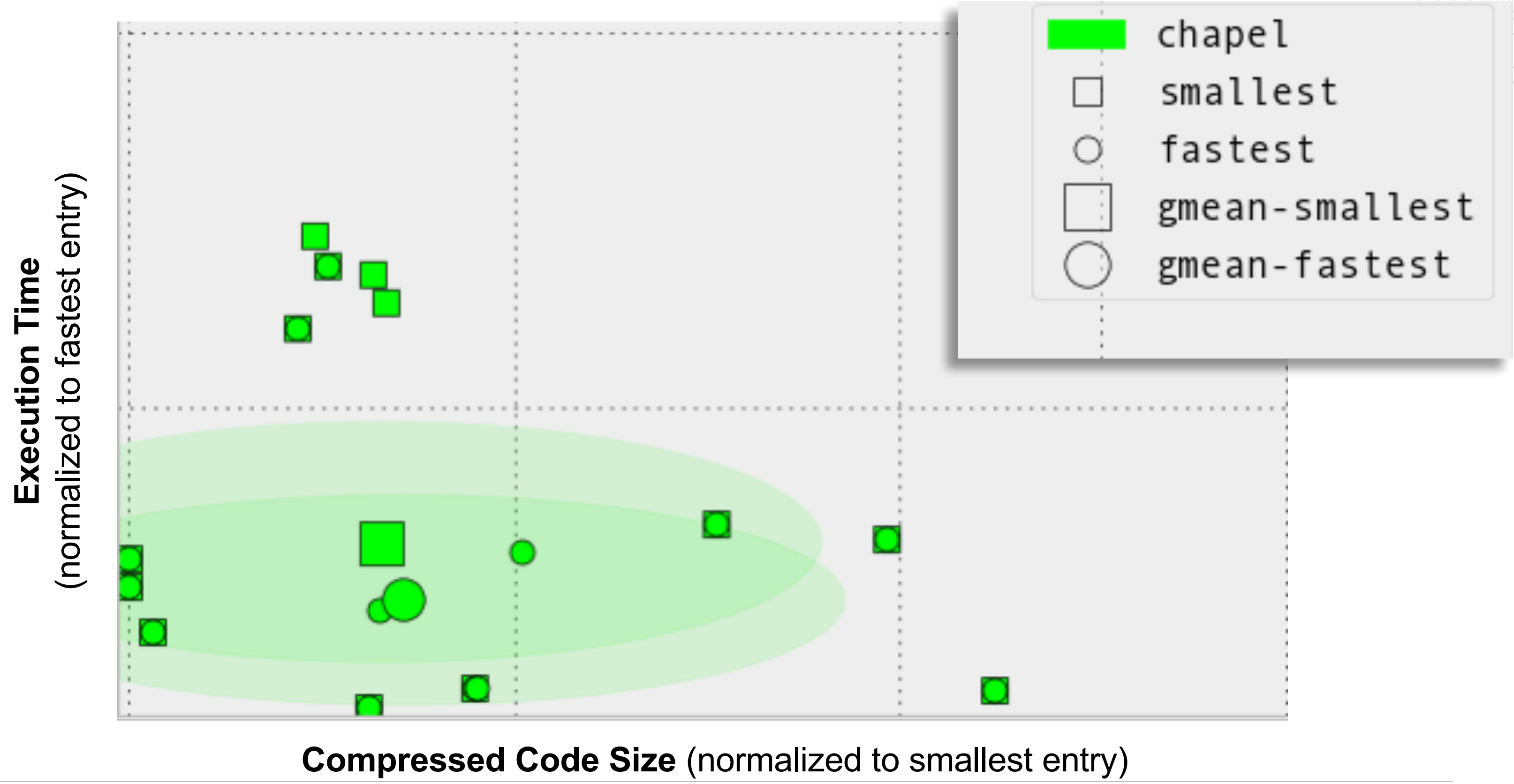
k-nucleotide

source	secs	mem	gz	cpu	cpu load
Chapel	**16.69**	350,432	1063	62.96	100% 92% 93% 93%
Fortran Intel	87.62	203,604	2238	87.57	1% 0% 100% 0%

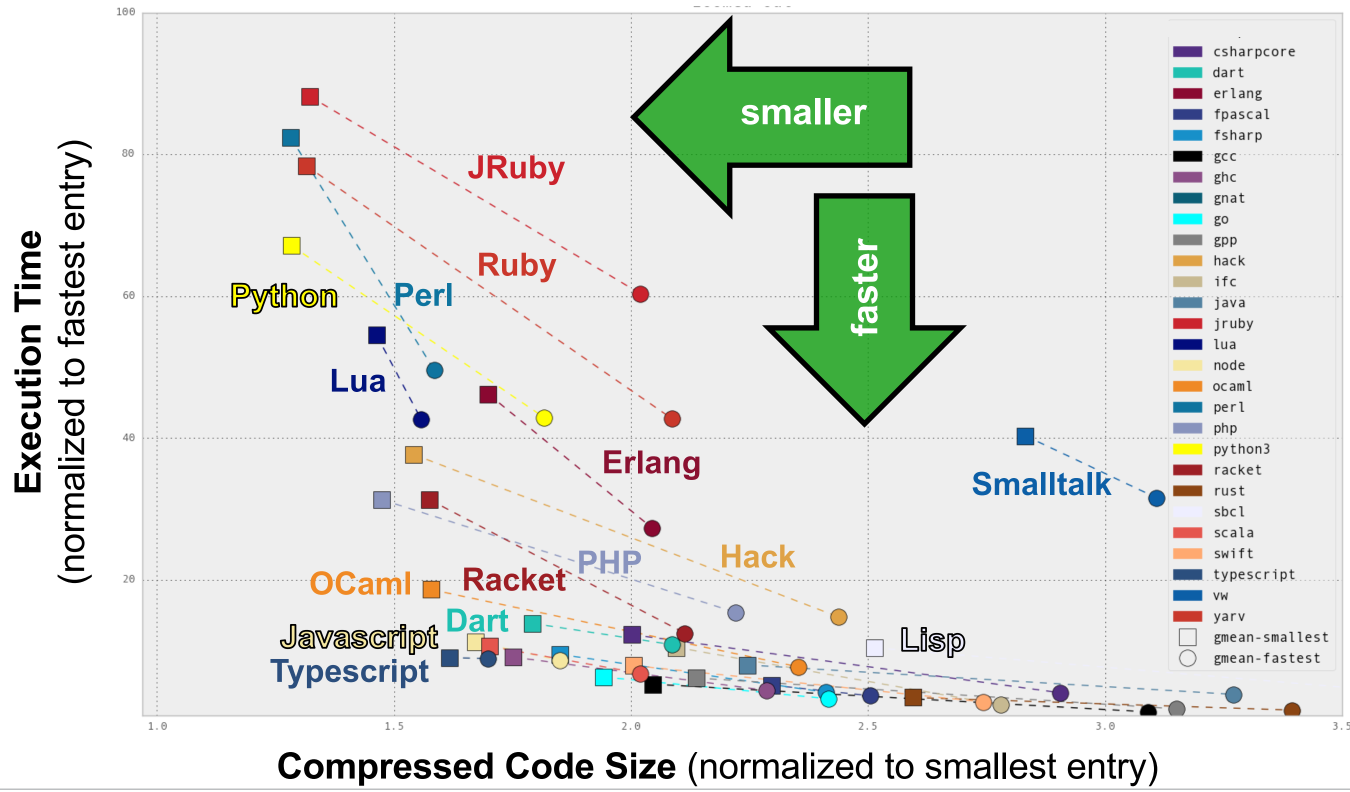
fasta

source	secs	mem	gz	cpu	cpu load
Chapel	**1.71**	52,184	1392	5.90	99% 82% 83% 82%
Fortran Intel	2.53	8	1327	2.53	0% 1% 0% 100%

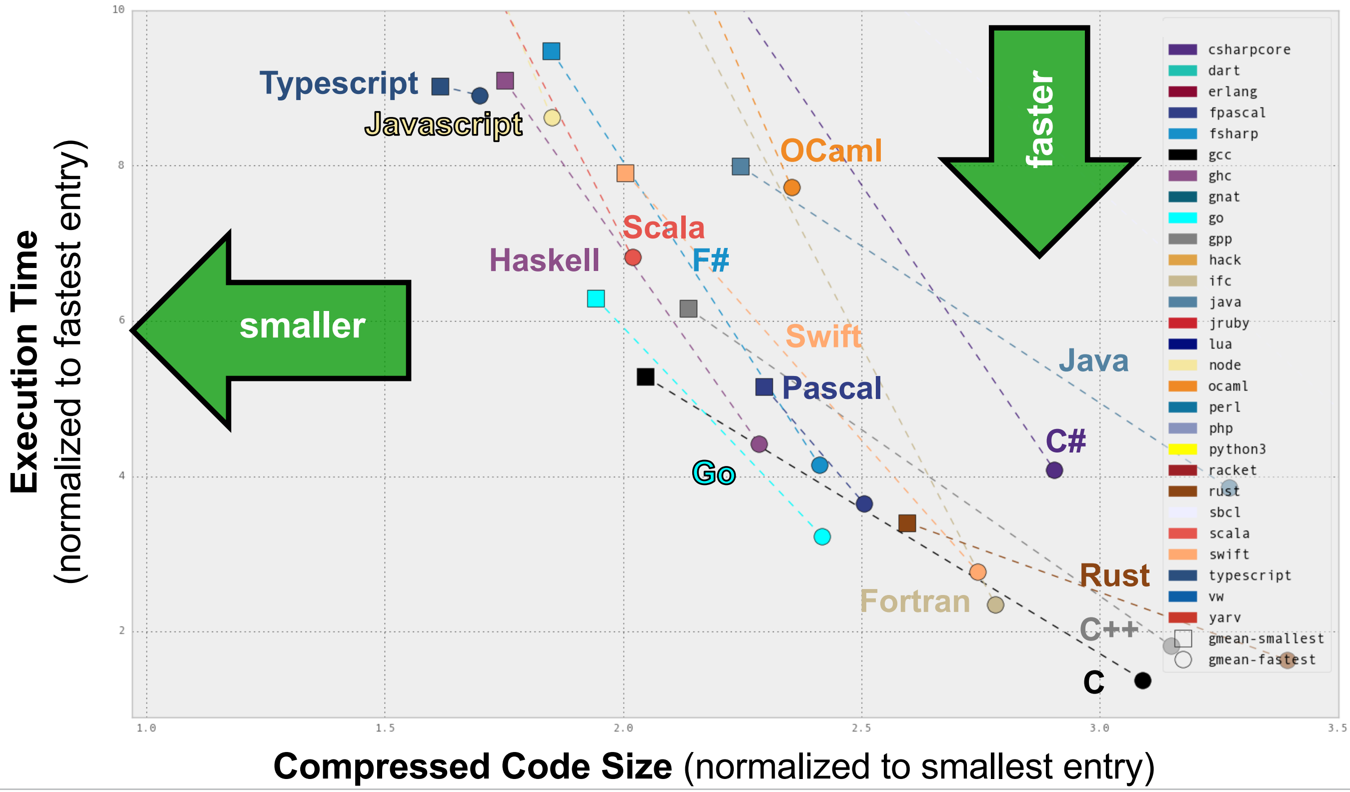
Scatter plots of CLBG code size x speed



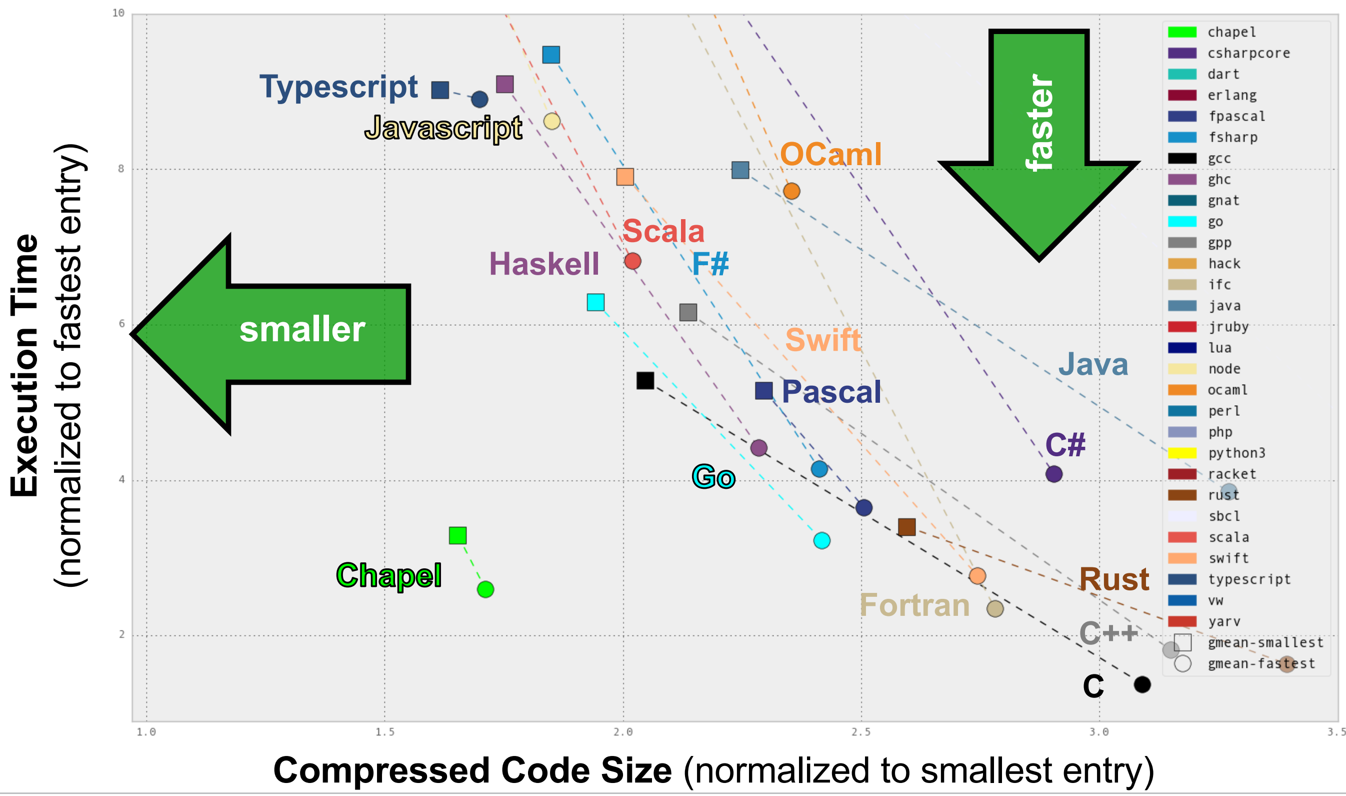
CLBG Cross-Language Summary
(Oct 2017 standings)



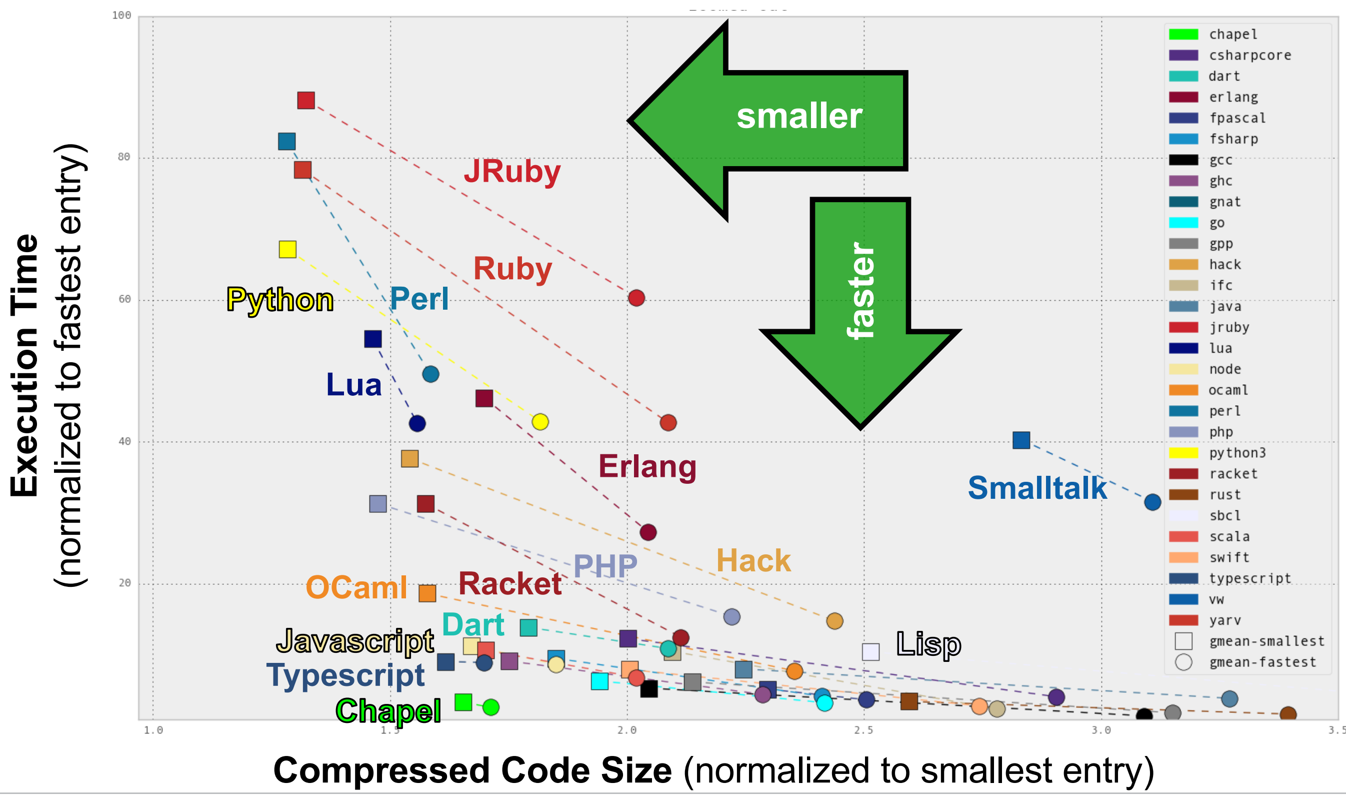
CLBG Cross-Language Summary
(Oct 2017 standings, zoomed in)



CLBG Cross-Language Summary
(Oct 2017 standings, zoomed in)



CLBG Cross-Language Summary
(Oct 2017 standings)



CLBG: Qualitative Comparisons

Can also browse program source code *(but this requires actual thought!)*:

```
proc main() {
  printColorEquations();

  const group1 = [i in 1..popSize1] new Chameneos(i, ((i-1)%3):Color);
  const group2 = [i in 1..popSize2] new Chameneos(i, colors10[i]);

  cobegin {
    holdMeetings(group1, n);
    holdMeetings(group2, n);
  }

  print(group1);
  print(group2);

  for c in group1 do delete c;
  for c in group2 do delete c;
}


//
// Print the results of getNewColor() for all color pairs.
//
proc printColorEquations() {
  for c1 in Color do
    for c2 in Color do
      writeln(c1, " + ", c2, " -> ", getNewColor(c1, c2));
  writeln();
}


//
// Hold meetings among the population by creating a shared meeting
// place, and then creating per-chameneos tasks to have meetings.
//
proc holdMeetings(population, numMeetings) {
  const place = new MeetingPlace(numMeetings);

  coforall c in population do           // create a task per chameneos
    c.haveMeetings(place, population);

  delete place;
}
```

excerpt from 1210 gz Chapel entry

```
void get_affinity(int* is_smp, cpu_set_t* affinity1, cpu_set_t* affinity2)
{
    cpu_set_t                   active_cpus;
    FILE*                       f;
    char                        buf [2048];
    char const*                 pos;
    int                         cpu_idx;
    int                         physical_id;
    int                         core_id;
    int                         cpu_cores;
    int                         apic_id;
    size_t                      cpu_count;
    size_t                      i;

    char const*                 processor_str       = "processor";
    size_t                      processor_str_len   = strlen(processor_str);
    char const*                 physical_id_str     = "physical id";
    size_t                      physical_id_str_len = strlen(physical_id_str);
    char const*                 core_id_str         = "core id";
    size_t                      core_id_str_len     = strlen(core_id_str);
    char const*                 cpu_cores_str       = "cpu cores";
    size_t                      cpu_cores_str_len   = strlen(cpu_cores_str);

    CPU_ZERO(&active_cpus);
    sched_getaffinity(0, sizeof(active_cpus), &active_cpus);
    cpu_count = 0;
    for (i = 0; i != CPU_SETSIZE; i += 1)
    {
        if (CPU_ISSET(i, &active_cpus))
        {
            cpu_count += 1;
        }
    }

    if (cpu_count == 1)
    {
        is_smp[0] = 0;
        return;
    }

    is_smp[0] = 1;
    CPU_ZERO(affinity1);
```

excerpt from 2863 gz C gcc entry

CLBG: Qualitative Comparisons

Can also browse program source code *(but this requires actual thought!)*:

```
proc main() {
  printColorEquations();

  const group1 = [i in 1..popSize1] new Chameneos(i, (
  const group2 = [i in 1..popSize2] new Chameneos(i, c

  cobegin {
    holdMeetings(group1, n);
    holdMeetings(group2, n);
  }

  print(group1);
  print(group2);

  for c in group1 do delete c;
  for c in group2 do delete c;
}

//
// Print the results of getNewColor() for all color pa
//
proc printColorEquations() {
  for c1 in Color do
    for c2 in Color do
      writeln(c1, " + ", c2, " -> ", getNewColor(c1, c
  writeln();
}

//
// Hold meetings among the population by creating a sh
// place, and then creating per-chameneos tasks to hav
//
proc holdMeetings(population, numMeetings) {
  const place = new MeetingPlace(numMeetings);

  coforall c in population do           // create a ta
    c.haveMeetings(place, population);

  delete place;
}
```

```
cobegin {
  holdMeetings(group1, n);
  holdMeetings(group2, n);
}
```

```
proc holdMeetings(population, numMeetings) {
  const place = new MeetingPlace(numMeetings);

  coforall c in population do           // creat
    c.haveMeetings(place, population);

  delete place;
}
```

excerpt from 1210 gz Chapel entry

```
void get_affinity(int* is_smp, cpu_set_t* affinity1, cpu_set_t* affinity2)

                             active_cpus;
                             f;
                             buf [2048];
                             pos;
                             cpu_idx;
                             physical_id;
                             core_id;
                             cpu_cores;
                             apic_id;
                             cpu_count;
                             i;

                             processor_str        = "processor";
    size_t                   processor_str_len    = strlen(processor_str);
    char const*              physical_id_str      = "physical id";
    size_t                   physical_id_str_len  = strlen(physical_id_str);
    char const*              core_id_str          = "core id";
                                                   n(core_id_str);
                                                   cores";
                                                   n(cpu_cores_str);

    is_smp[0] = 1;
    CPU_ZERO(affinity1);
```

excerpt from 2863 gz C gcc entry

CLBG: Qualitative Comparisons

Can also browse program source code *(but this requires actual thought!)*:

```
proc main() {
```

```
char const*                core_id_str            = "core id"
size_t                     core_id_str_len        = strlen(co
char const*                cpu_cores_str          = "cpu core
size_t                     cpu_cores_str_len      = strlen(cpu

CPU_ZERO(&active_cpus);
sched_getaffinity(0, sizeof(active_cpus), &active_cpus);
cpu_count = 0;
for (i = 0; i != CPU_SETSIZE; i += 1)
{
    if (CPU_ISSET(i, &active_cpus))
    {
        cpu_count += 1;
    }
}

if (cpu_count == 1)
{
    is_smp[0] = 0;
    return;
}
```

excerpt from 1210 gz Chapel entry

```
void get_affinity(int* is_smp, cpu_set_t* affinity1, cpu_set_t* affinity2)
{
    cpu_set_t                   active_cpus;
    FILE*                       f;
    char                        buf [2048];
    char const*                 pos;
    int                         cpu_idx;
    int                         physical_id;
    int                         core_id;
    int                         cpu_cores;
    int                         apic_id;
    size_t                      cpu_count;
    size_t                      i;

    char const*                 processor_str       = "processor";
    size_t                      processor_str_len   = strlen(processor_str);
    char const*                 physical_id_str     = "physical id";
    size_t                      physical_id_str_len = strlen(physical_id_str);
    char const*                 core_id_str         = "core id";
    size_t                      core_id_str_len     = strlen(core_id_str);
    char const*                 cpu_cores_str       = "cpu cores";
    size_t                      cpu_cores_str_len   = strlen(cpu_cores_str);

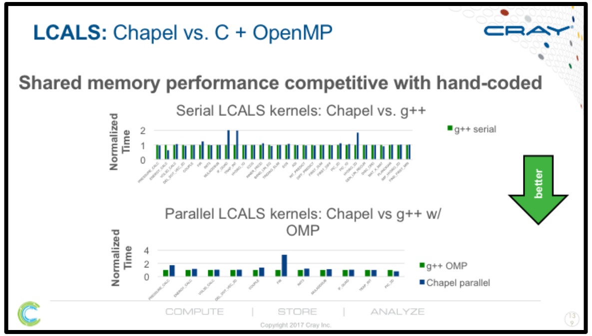
    CPU_ZERO(&active_cpus);
    sched_getaffinity(0, sizeof(active_cpus), &active_cpus);
    cpu_count = 0;
    for (i = 0; i != CPU_SETSIZE; i += 1)
    {
        if (CPU_ISSET(i, &active_cpus))
        {
            cpu_count += 1;
        }
    }

    if (cpu_count == 1)
    {
        is_smp[0] = 0;
        return;
    }

    is_smp[0] = 1;
    CPU_ZERO(affinity1);
```

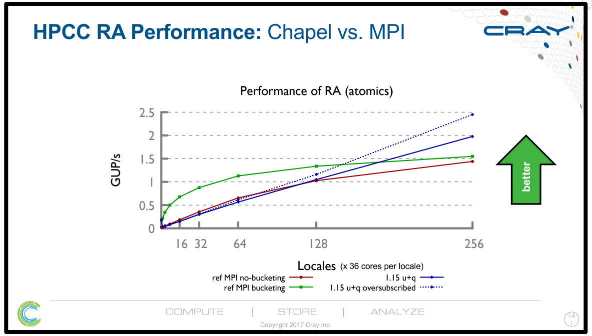
excerpt from 2863 gz C gcc entry

Chapel Performance: HPC Benchmarks



LCALS

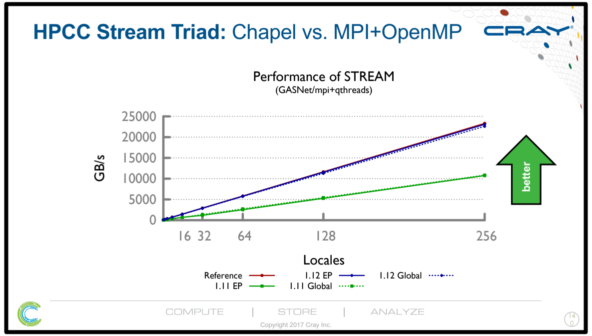
HPCC RA

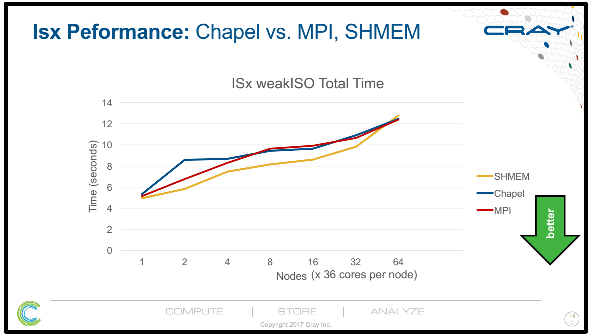


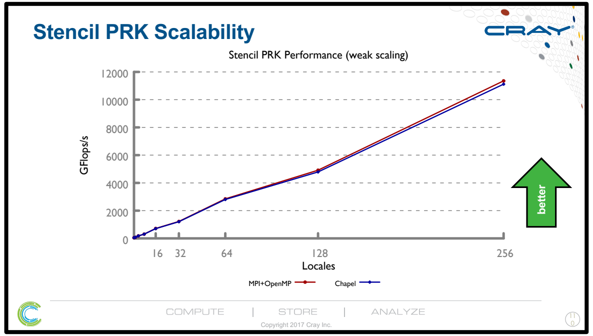
STREAM Triad

ISx

PRK Stencil



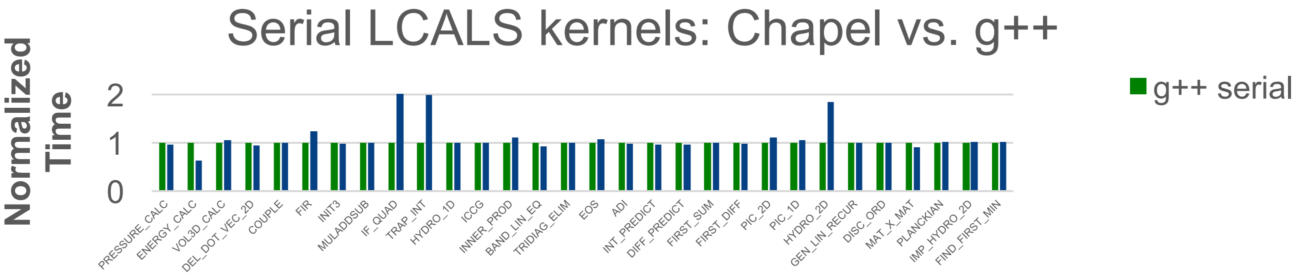


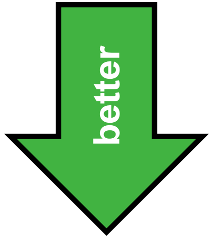


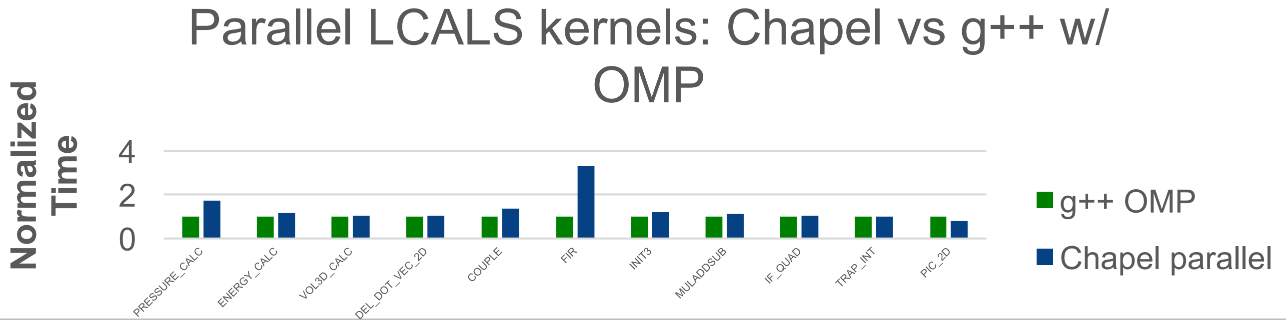
Nightly performance graphs online at: https://chapel-lang.org/perf

LCALS: Chapel vs. C + OpenMP

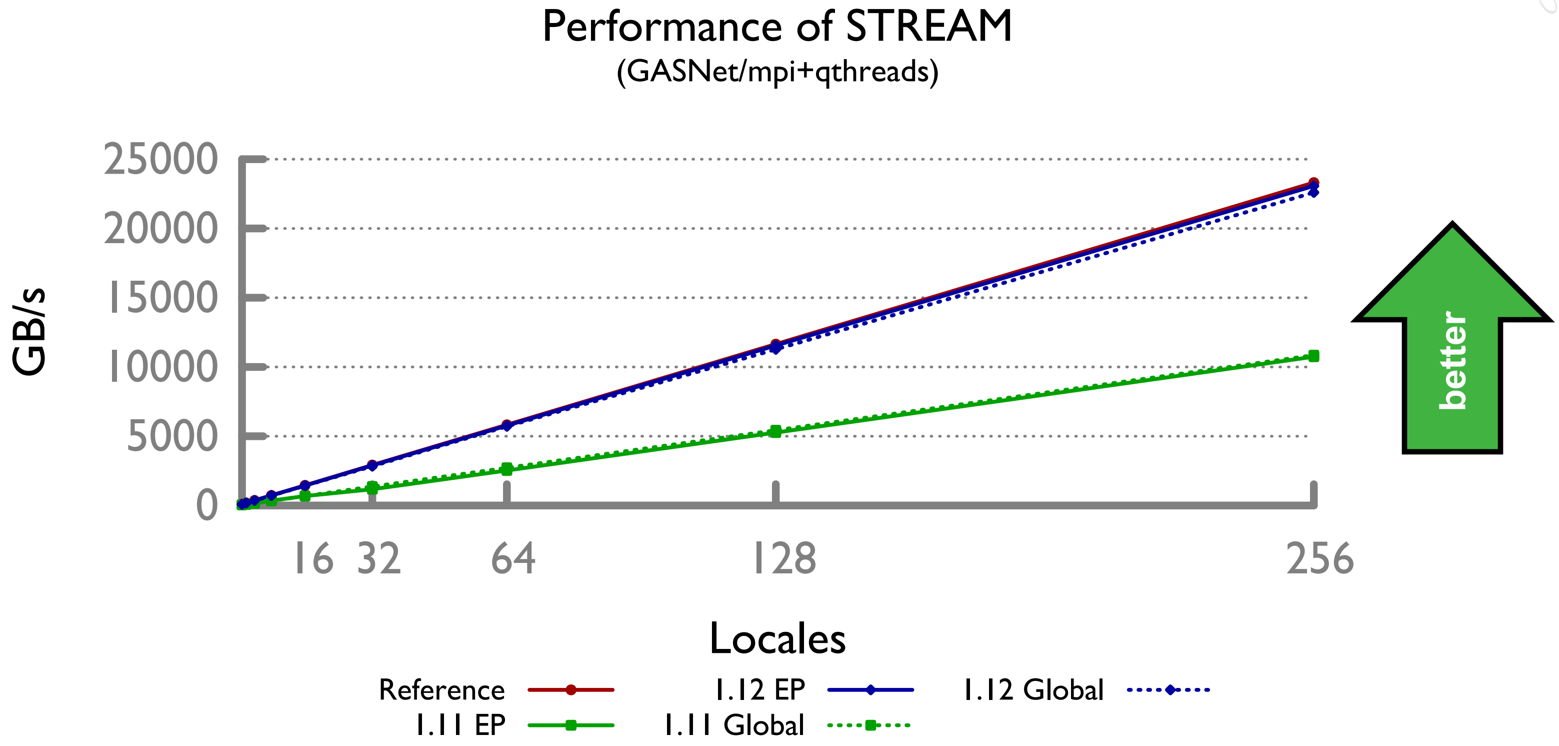
Shared memory performance competitive with hand-coded



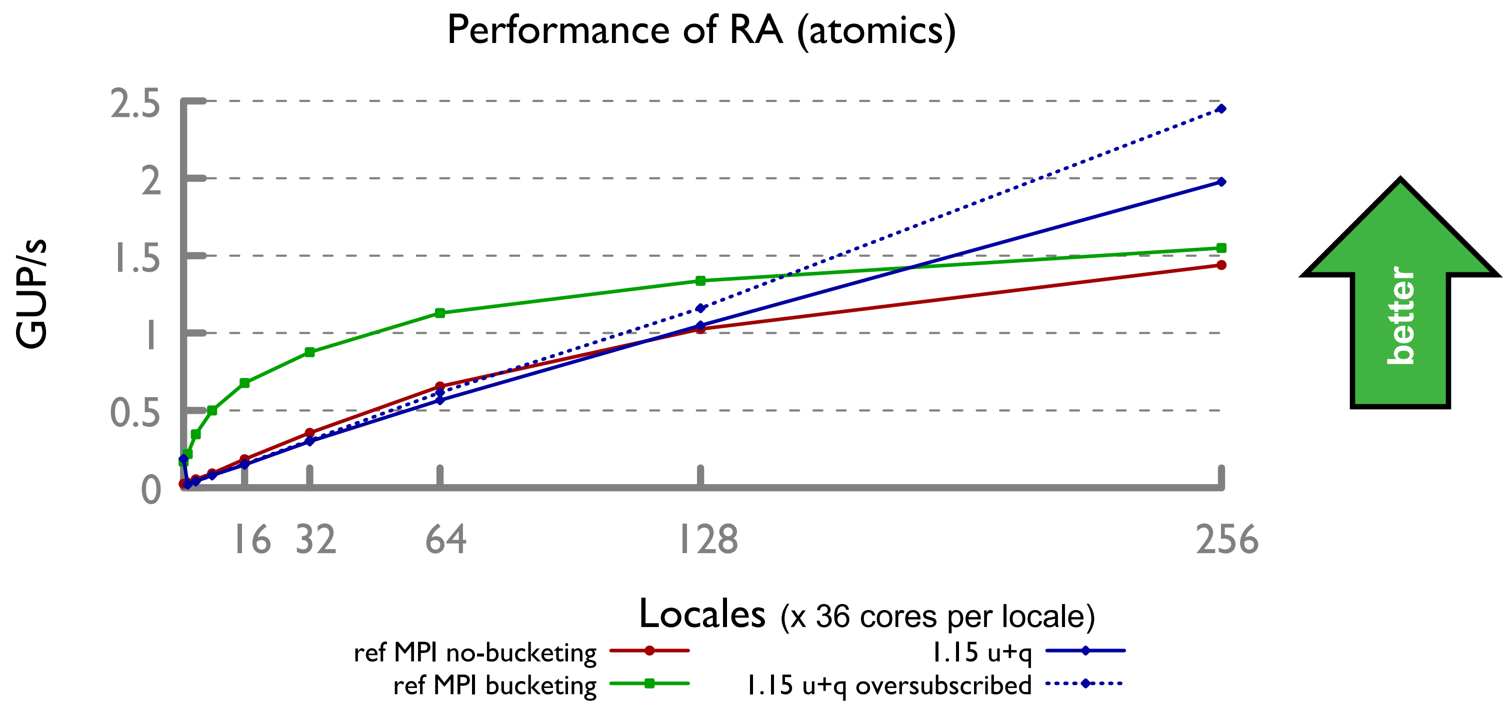




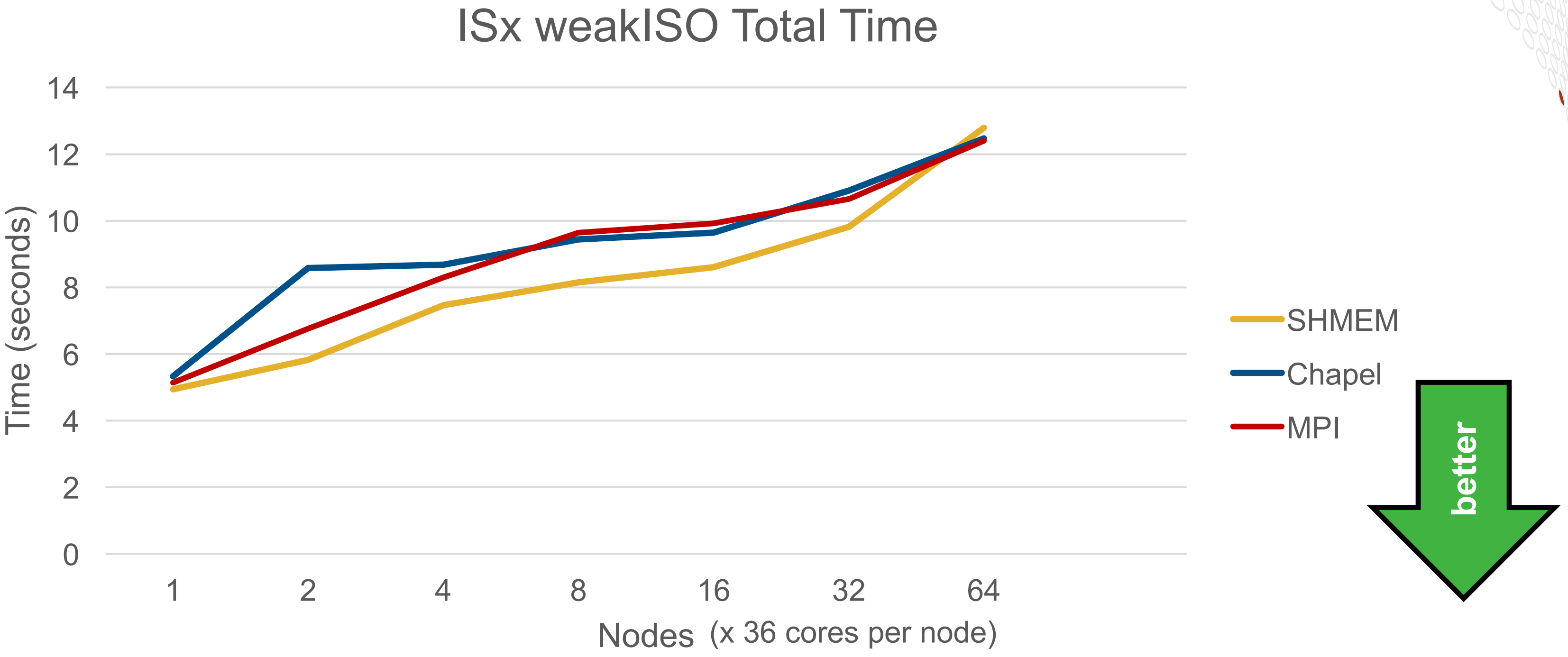
HPCC Stream Triad: Chapel vs. MPI+OpenMP



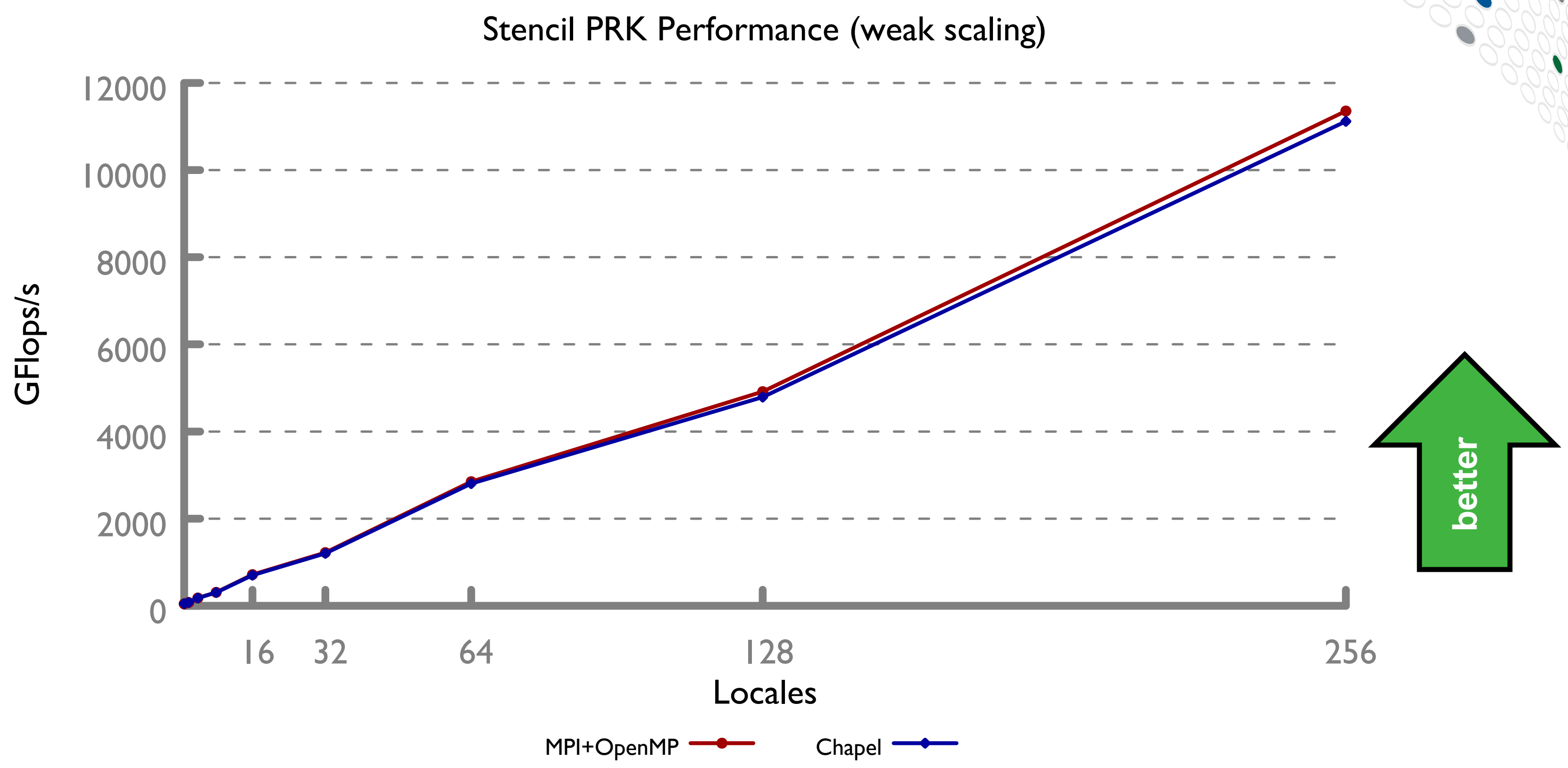
HPCC RA Performance: Chapel vs. MPI



ISx Peformance: Chapel vs. MPI, SHMEM



Stencil PRK Scalability

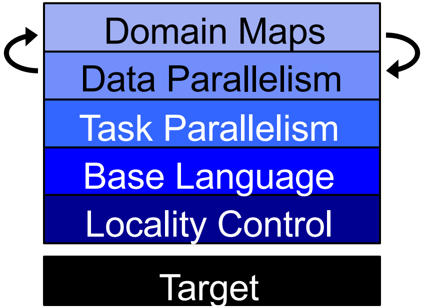


Chapel's Multiresolution Features

Chapel's Multiresolution Philosophy

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

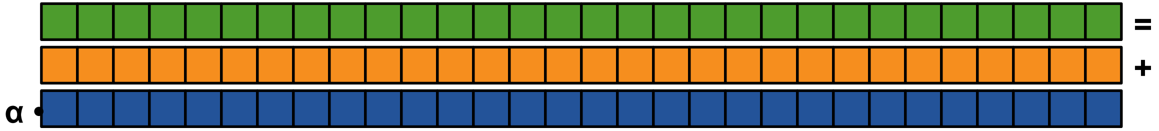
- higher levels for programmability, productivity
- lower levels for greater degrees of control



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

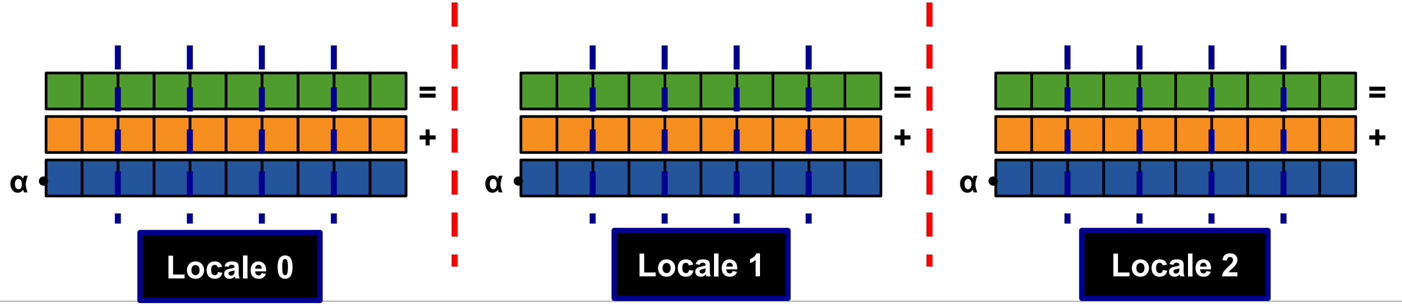
Domain Maps: A Multiresolution Feature

Domain maps are "recipes" that instruct the compiler how to map the global view of a computation…



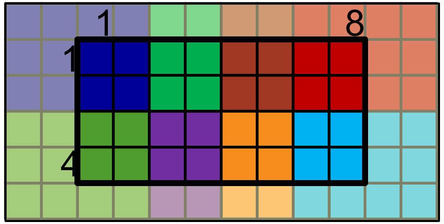

```
A = B + alpha * C;
```

…to the target locales' memory and processors:



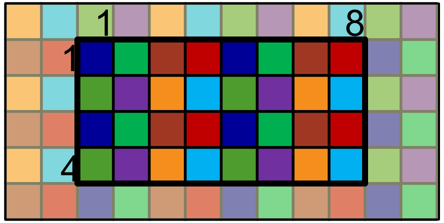
Sample Domain Maps: Block and Cyclic

```
var Dom = {1..4, 1..8} dmapped Block( {1..4, 1..8} );
```



distributed to


```
var Dom = {1..4, 1..8} dmapped Cyclic( startIdx=(1,1) );
```



distributed to

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
5.1 5.3 5.5 5.7 5.9
```

Distributed Data Parallelism, by example

magic? HPF-like?
descriptive?

Not in the slightest…

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
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```

```
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
```

Distributed Data Parallelism, by example

Chapel's prescriptive approach:

```
forall (i,j) in D do…
```

⇒ invoke D's default parallel iterator

- defined by D's type / domain map

default domain map

- create a task per local core
- chunk indices across tasks

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 --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

Chapel's prescriptive approach:

```
forall (i,j) in D do…
```

⇒ invoke and inline D's default parallel iterator

- defined by D's type / domain map

default domain map

cyclic domain map

on each target locale…
- create a task per core
- chunk local indices across tasks

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

Chapel's prescriptive approach:

```
forall (i,j) in D do…
```

⇒ i…

What if I don't like D's iteration strategy?

• d…
domain map

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;
```

- Write and call your own parallel iterator:

```
forall (i,j) in myParIter(D) do…
```

- Or, use a different domain map:

```
var D = {1..n, 1..n} dmapped Block(…);
```

- Or, write your own domain map and use it:

```
var D = {1..n, 1..n} dmapped MyDomMap(…);
```

Domain Maps specify…
…mapping of indices to locales
…layout of domains / arrays in memory
…parallel iteration strategies
…core operations on arrays / domains

Chapel and Performance Portability

- **Avoid locking key policy decisions into the language**
  - Array memory layout?
  - Sparse storage format?
  - Parallel loop policies?

Chapel and Performance Portability

- **Avoid locking key policy decisions into the language**
  - Array memory layout? **not defined by Chapel**
  - Sparse storage format? **not defined by Chapel**
  - Parallel loop policies? **not defined by Chapel**

- **Instead, permit users to specify these *in Chapel itself***
  - goal: to make Chapel a future-proof language

Another Key Multiresolution Feature

locale models: User-specified locale types for new node architectures

- how do I allocate memory, create tasks, communicate, …

Like domain maps, these are…

…written in Chapel by expert users using lower-level features

…targeted by the compiler as it lowers code

…available to the end-user via higher-level abstractions

Wrapping Up

What's Next? (Big Ticket Items)

- **LLVM back-end as the default**
- **Work towards Chapel 2.0 release**
  - goal: no changes thereafter that break backwards compatibility
- **Support for delete-free computation**
- **GPU support**
- **Application studies / application partnerships**

Crossing the Stream of Adoption

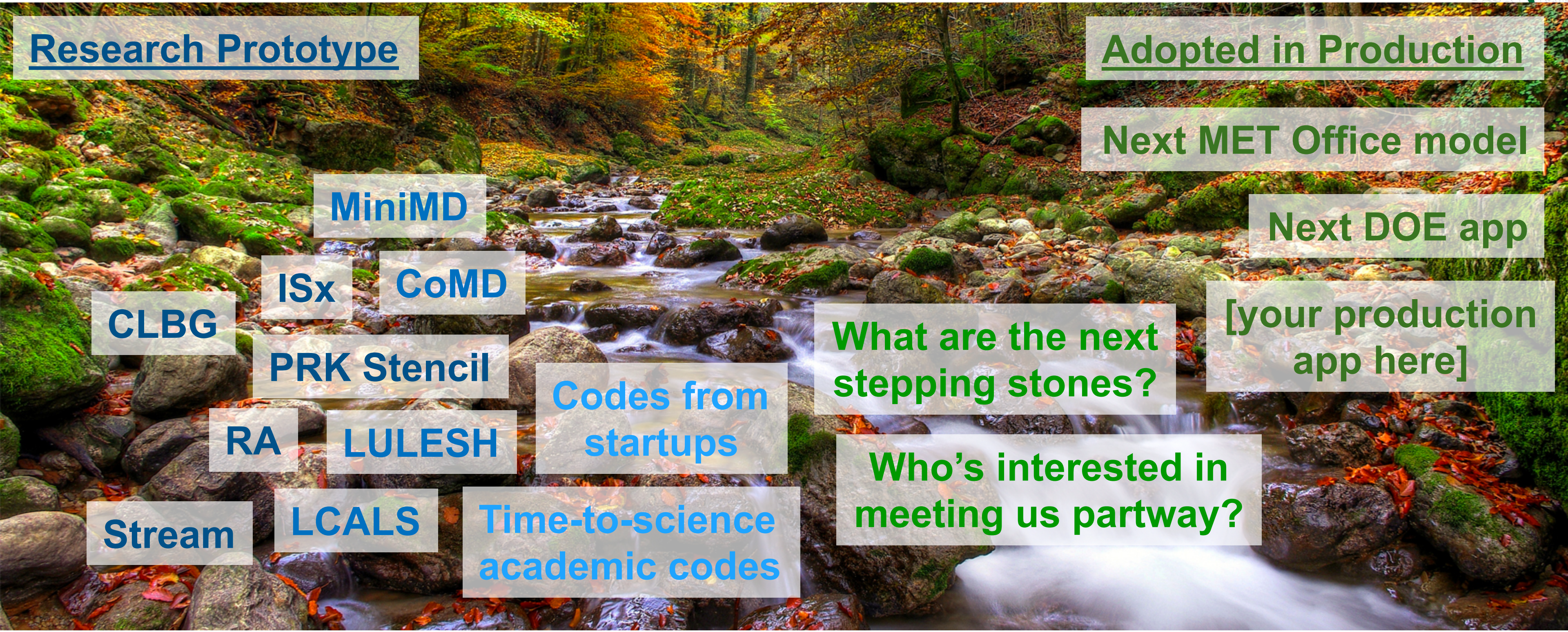
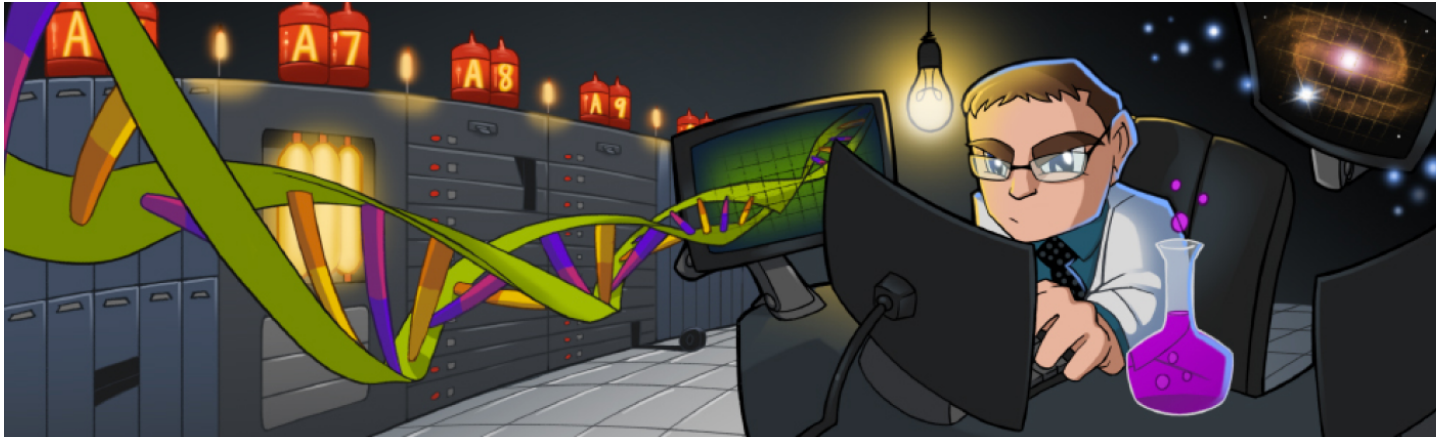


image source: http://feelgrafix.com/813578-free-stream-wallpaper.html

CHIUW 2017 Keynote

Chapel's Home in the Landscape of New Scientific Computing Languages
(and what it can learn from the neighbours)

Jonathan Dursi, *The Hospital for Sick Children, Toronto*



Quote from CHIUW 2017 keynote

"My opinion as an outsider…is that Chapel is important, Chapel is mature, and Chapel is just getting started.

"If the scientific community is going to have frameworks for solving scientific problems that are actually designed for our problems, they're going to come from a project like Chapel.

"And the thing about Chapel is that the set of all things that are 'projects like Chapel' is 'Chapel.'"

–Jonathan Dursi

Chapel's Home in the New Landscape of Scientific Frameworks
(and what it can learn from the neighbours)
CHIUW 2017 keynote

https://ljdursi.github.io/CHIUW2017 / https://www.youtube.com/watch?v=xj0rwdLOR4U

Chapel Resources

Chapel Central: https://chapel-lang.org/

The Chapel Parallel Programming Language

- Home
- Chapel Overview
- What's New?
- Upcoming Events
- Job Opportunities
- How Can I Learn Chapel?
- Documentation
- Download Chapel
- Try It Now
- Release Notes
- User Resources
- Educator Resources
- Developer Resources
- Social Media / Blog Posts
- Press
- Presentations
- Tutorials
- Publications and Papers
- CHIUW
- CHUG
- Lightning Talks
- Contributors / Credits
- Research Groups
- License

chapel-lang.org
chapel_info@cray.com

What is Chapel?

Chapel is a modern programming language that is...

- **parallel:** contains first-class concepts for concurrent and parallel computation
- **productive:** designed with programmability and performance in mind
- **portable:** runs on laptops, clusters, the cloud, and HPC systems
- **scalable:** supports locality-oriented features for distributed memory systems
- **open-source:** hosted on GitHub, permissively licensed

New to Chapel?

As an introduction to Chapel, you may want to...

- read a blog article or book chapter
- watch an overview talk or browse its slides
- download the release
- browse sample programs
- view other resources to learn how to trivially write distributed programs like this:

```
use CyclicDist;              // use the Cyclic distribution library
config const n = 100;        // use ./a.out --n=<val> to override this default

forall i in {1..n} dmapped Cyclic(startIdx=1) do
  writeln("Hello from iteration ", i, " of ", n, " running on node ", here.id);
```

What's Hot?

- **Chapel 1.16** is now available—**download** a copy today!
- The **CHIUW 2018** call for participation is now available!
- A recent **Cray blog post** reports on highlights from CHIUW 2017.
- Chapel is now one of the supported languages on **Try It Online**!
- Watch talks from **ACCU 2017**, **CHIUW 2017**, and **ATPESC 2016** on **YouTube**.
- Browse slides from **PADAL**, **EAGE**, **EMBRACE**, **ACCU**, and other recent talks.
- See also: **What's New?**

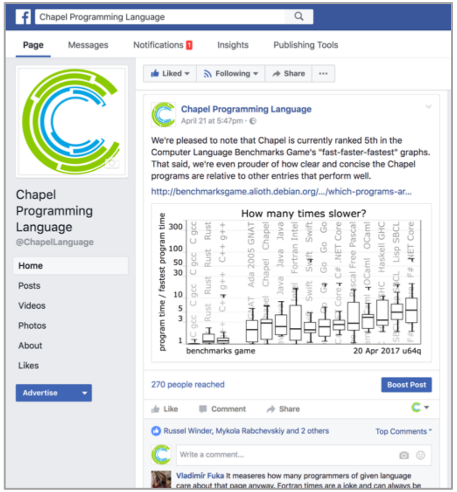
How to Stalk Chapel

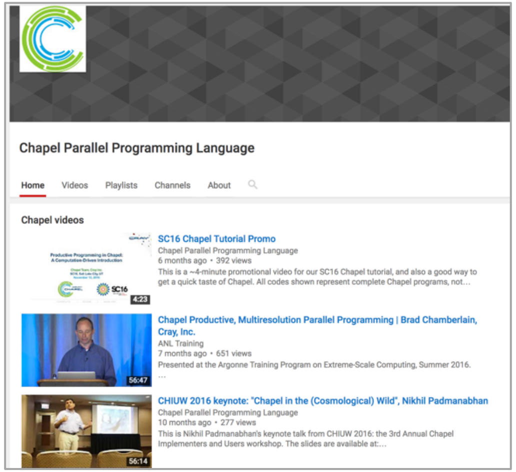
http://facebook.com/ChapelLanguage

http://twitter.com/ChapelLanguage

https://www.youtube.com/channel/UCHmm27bYjhknK5mU7ZzPGsQ/

chapel-announce@lists.sourceforge.net

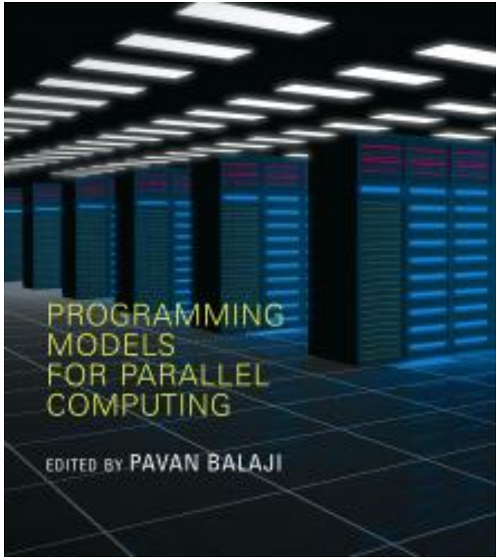




Suggested Reading (healthy attention spans)

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

- a detailed overview of Chapel's history, motivating themes, features
- published by MIT Press, November 2015
- edited by Pavan Balaji (Argonne)
- chapter is now also available online



Other Chapel papers/publications available at **https://chapel-lang.org/papers.html**

Suggested Reading (short attention spans)

CHIUW 2017: Surveying the Chapel Landscape, Cray Blog, July 2017.

- *a run-down of recent events*

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*

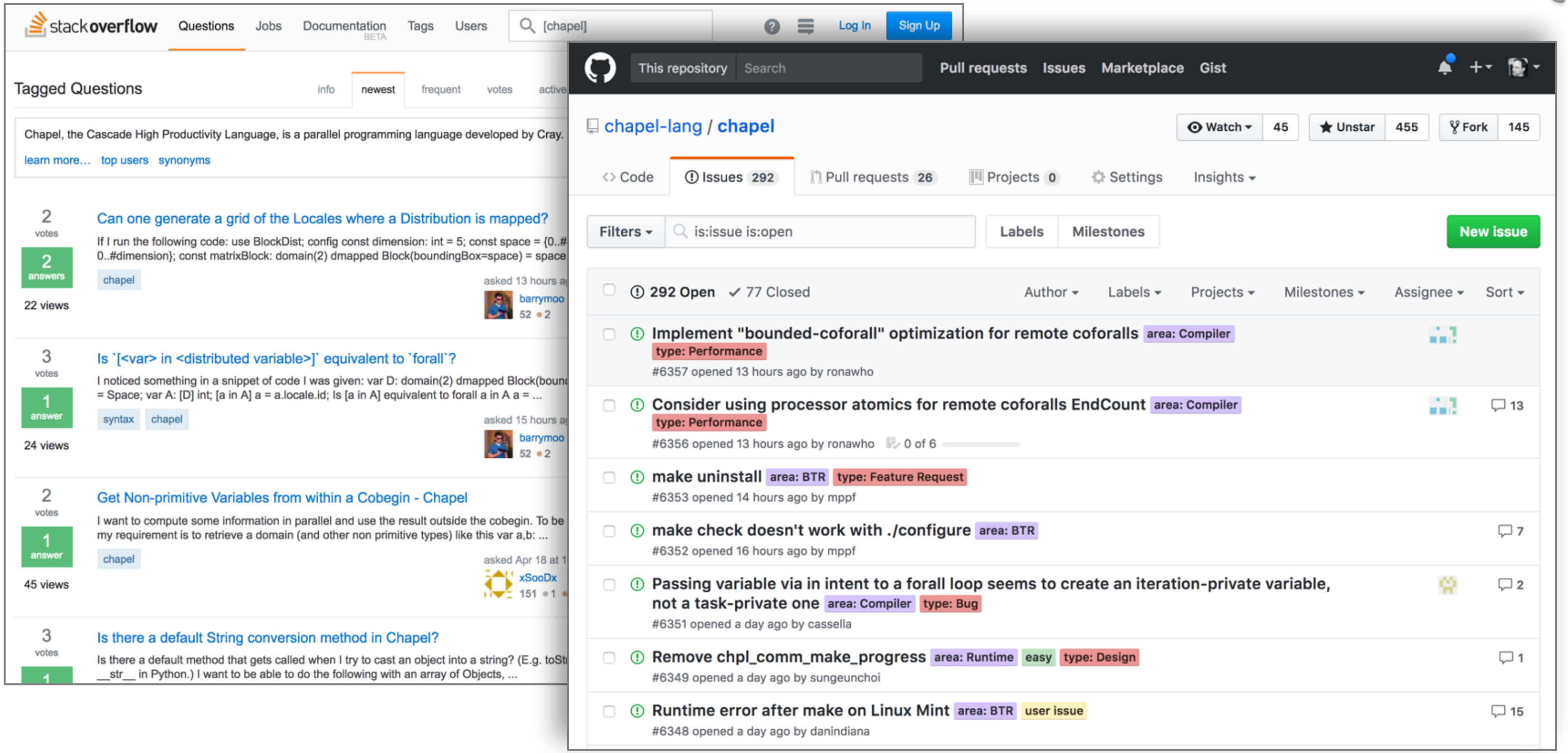
Why Chapel? **(parts 1, 2, 3)**, Cray Blog, Jun-Oct 2014.

- *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-lang.org "blog posts" 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 StackOverflow and GitHub Issues



Where to..

Submit bug reports:

- GitHub issues for chapel-lang/chapel: public bug forum
- chapel_bugs@cray.com: for reporting non-public bugs

Ask User-Oriented Questions:

- StackOverflow: when appropriate / other users might care
- #chapel-users (irc.freenode.net): user-oriented IRC channel
- chapel-users@lists.sourceforge.net: user discussions

Discuss Chapel development

- chapel-developers@lists.sourceforge.net: developer discussions
- #chapel-developers (irc.freenode.net): developer-oriented IRC channel

Discuss Chapel's use in education

- chapel-education@lists.sourceforge.net: educator discussions

Directly contact Chapel team at Cray: chapel_info@cray.com

Questions?

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