Chapel Comes of Age: Productive Parallelism at Scale

CUG 2018

Brad Chamberlain, Chapel Team, Cray Inc.

Or: What's Chapel been up to since CUG 2013?

CUG 2018

Brad Chamberlain, Chapel Team, Cray Inc.

What is Chapel?

Chapel: A productive parallel programming language

- portable & scalable
- open-source & collaborative

Goals:

- Support general parallel programming
  - “any parallel algorithm on any parallel hardware”
- Make parallel programming at scale far more productive

Chapel and Productivity

Chapel aims to be as…

…**programmable** as Python

…**fast** as Fortran

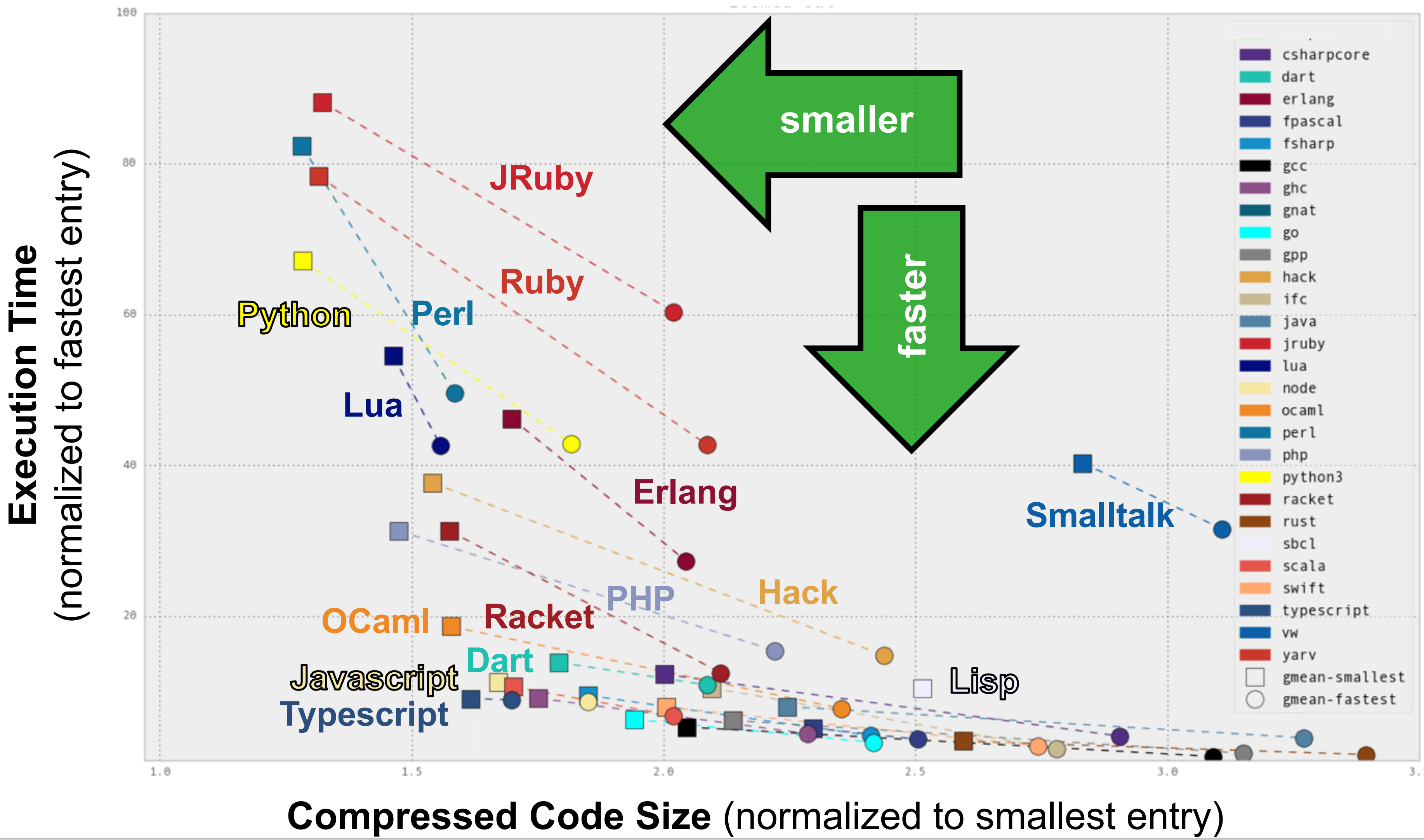
…**scalable** as MPI, SHMEM, or UPC

…**portable** as C

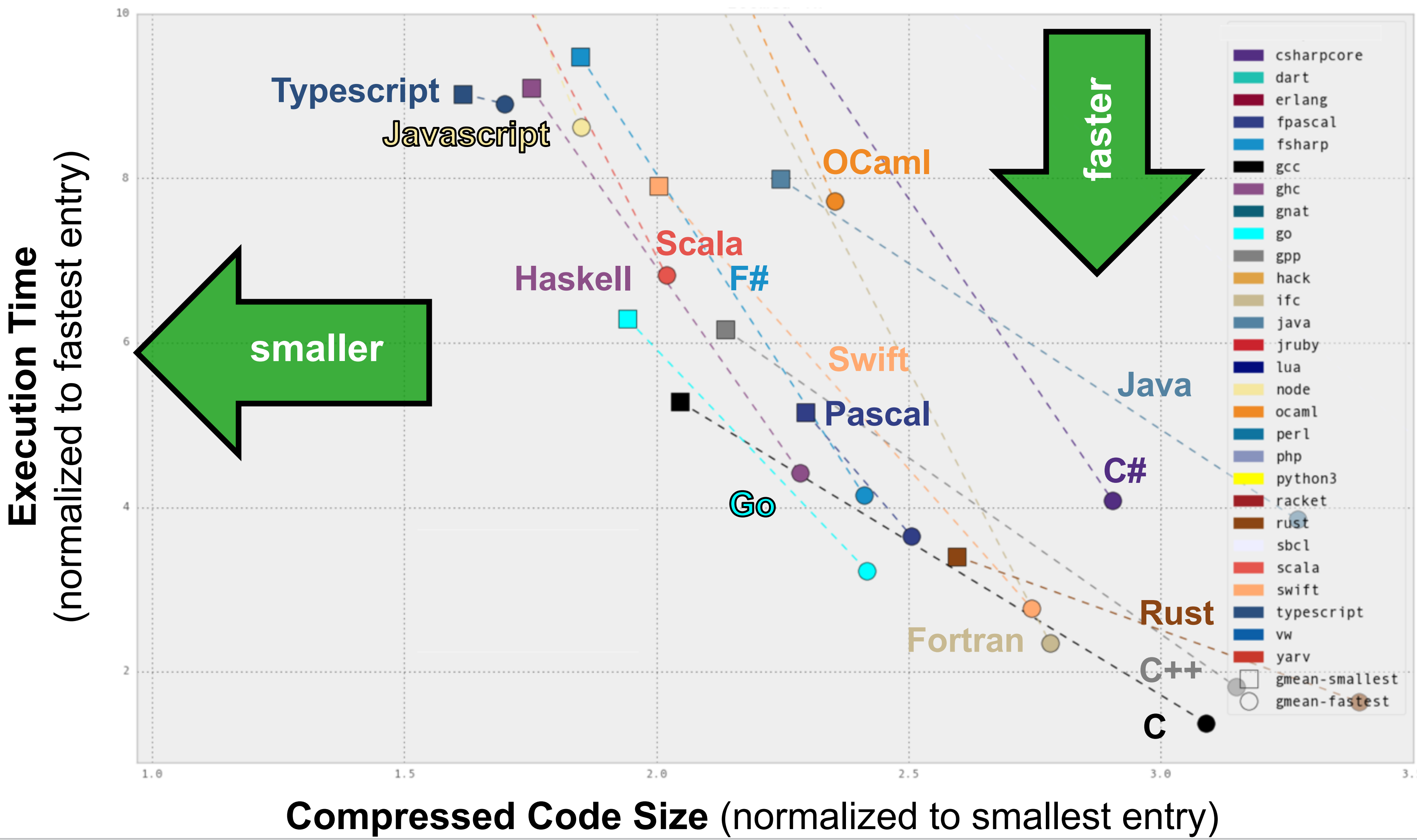
…**flexible** as C++

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

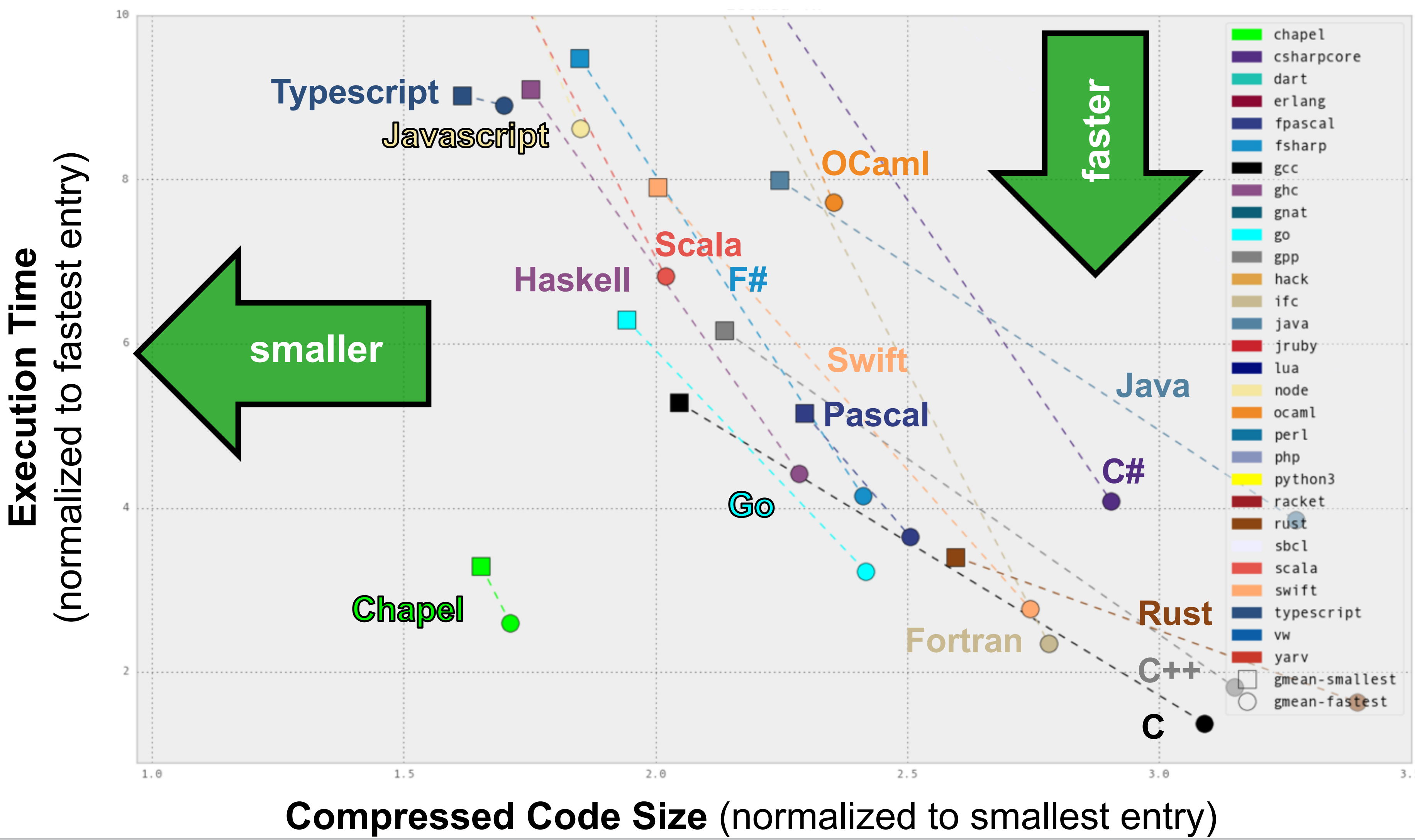
CLBG Cross-Language Summary
(Oct 2017 standings)



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



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



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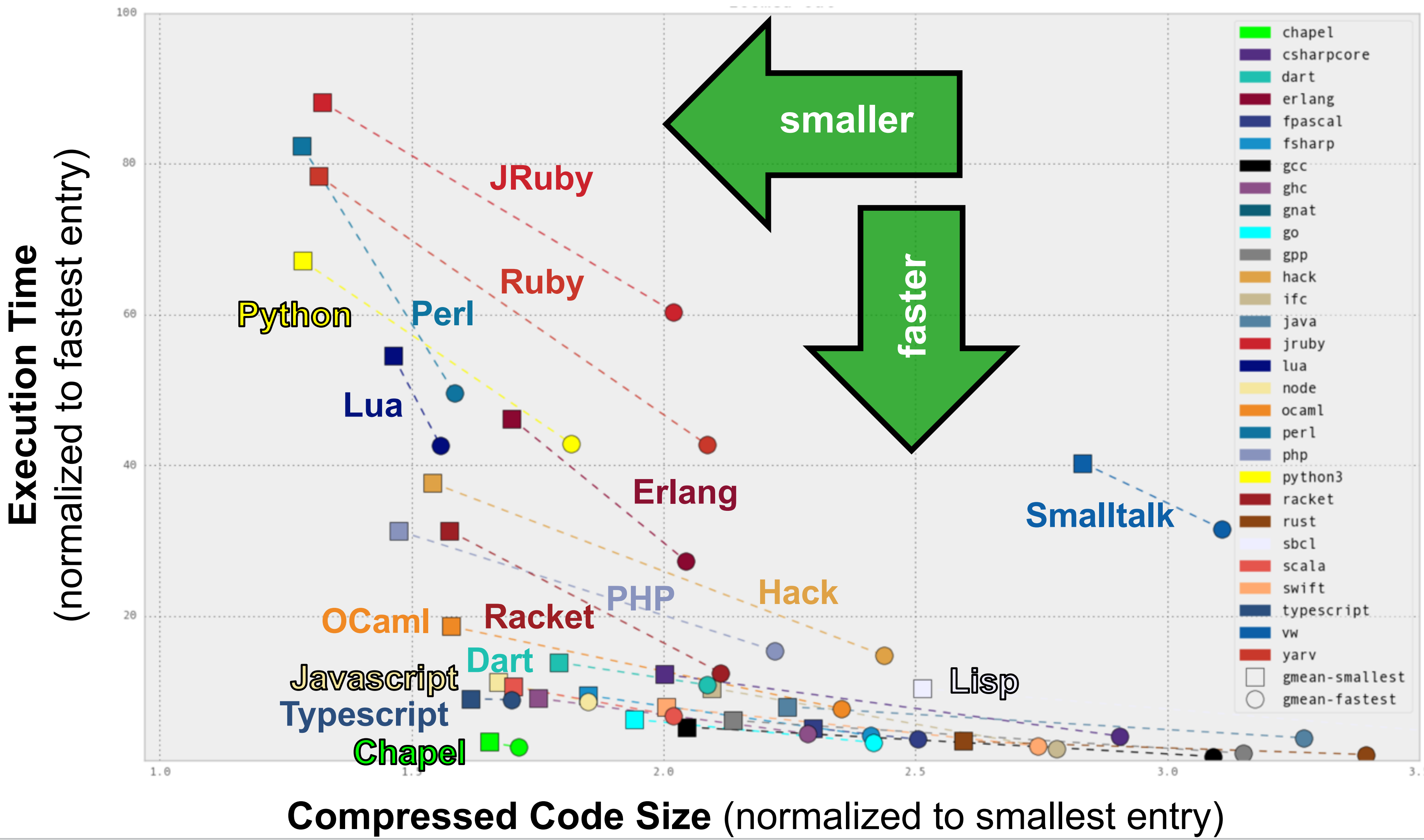

CLBG: Qualitative Code Comparisons

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 Code Comparisons

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  cobegin {
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    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();
}

//
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//
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 Code 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;

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    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

The Chapel Team at Cray (May 2018)

13 full-time employees + ~2 summer interns

Chapel Community Partners

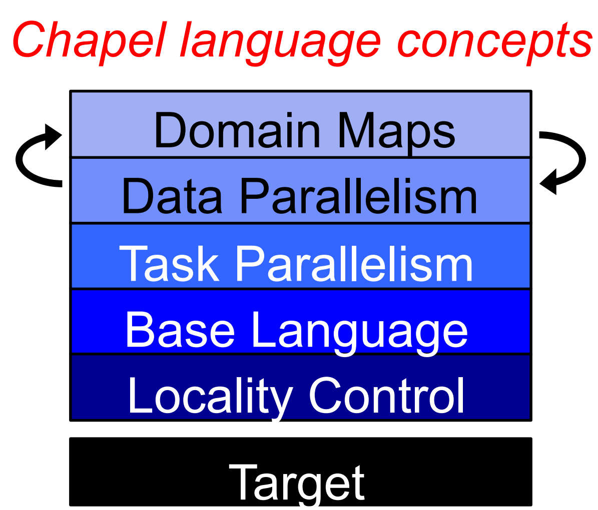
(and several others…)

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

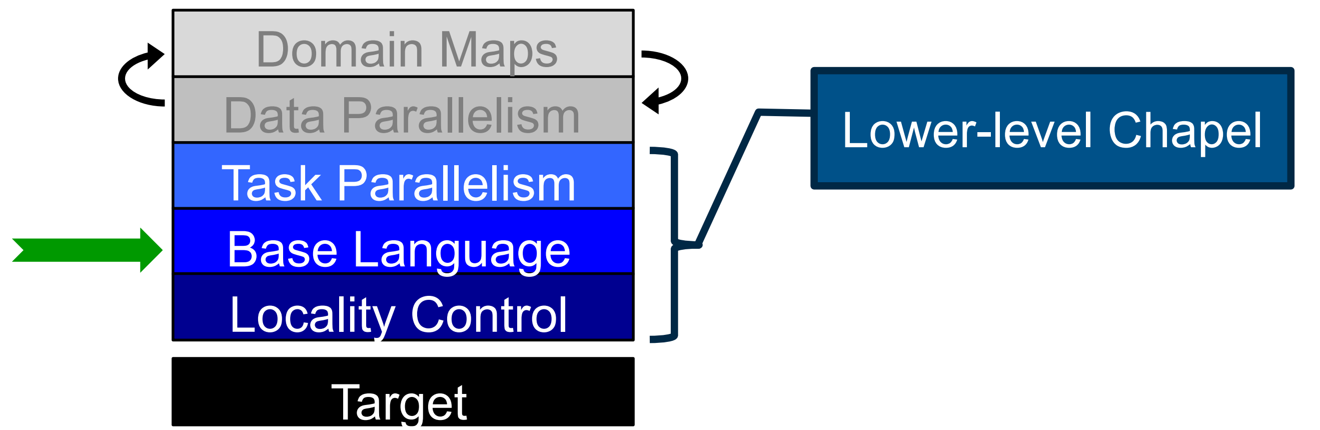
Outline

- ✓ What is Chapel?
- ➢ Chapel Overview
- Chapel: Then vs. Now
- Chapel User Profiles
- What's Next?

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

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

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

Explicit types also permitted

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

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

```
config const n: int = 10;

for f: int 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;
  }
}
```

```
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;
  }
}
```

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config const n = 10;

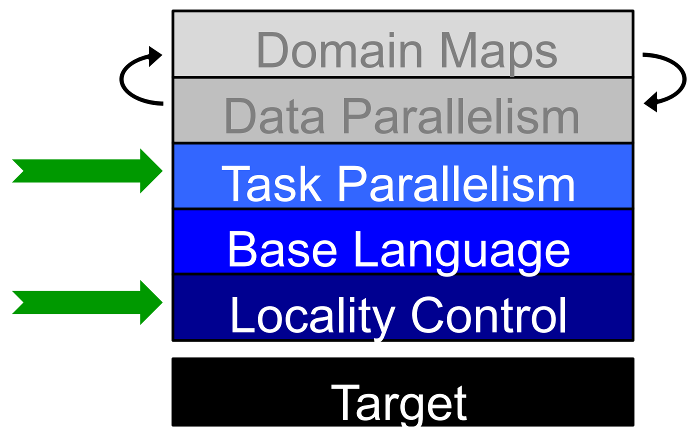
for (i,f) in zip(0..#n, fib(n)) do
  writeln("fib #", i, " is ", f);
```

```
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
…
```

Other Base Language Features

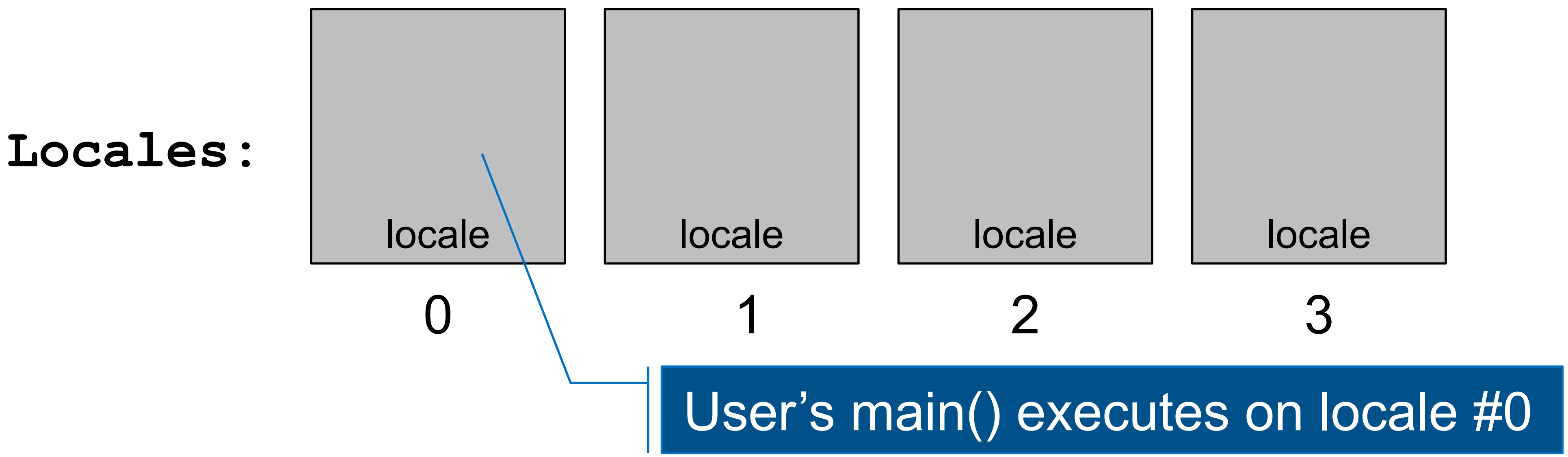
- Object-oriented features
- Generic programming / polymorphism
- Procedure overloading / filtering
- Default args, arg intents, keyword-based arg passing
- Argument type queries / pattern-matching
- Compile-time meta-programming
- Modules (namespaces)
- Error-handling
- and more…

Task Parallelism and Locality Control



Locales, briefly

- Locales can run tasks and store variables
  - Think “compute node”



Task Parallelism and Locality, by example

taskParallel.chpl

```
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
prompt> ./taskParallel
Hello from task 2 of 2 running on n1032
Hello from task 1 of 2 running on n1032
```

Task Parallelism and Locality, by example

Abstraction of System Resources

taskParallel.chpl

```
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);
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```
prompt> chpl taskParallel.chpl
prompt> ./taskParallel
Hello from task 2 of 2 running on n1032
Hello from task 1 of 2 running on n1032
```

Task Parallelism and Locality, by example

High-Level
Task Parallelism

taskParallel.chpl

```
const numTasks = here.numPUs();
coforall tid in 1..numTasks do
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         tid, numTasks, here.name);
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```
prompt> chpl taskParallel.chpl
prompt> ./taskParallel
Hello from task 2 of 2 running on n1032
Hello from task 1 of 2 running on n1032
```

Task Parallelism and Locality, by example

This is a shared memory program

Nothing has referred to remote locales, explicitly or implicitly

taskParallel.chpl

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

```
prompt> chpl taskParallel.chpl
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Hello from task 2 of 2 running on n1032
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);
  }
```

```
prompt> chpl taskParallel.chpl
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

Abstraction of System Resources

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
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

taskParallel.chpl

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coforall loc in Locales do
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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);
  }
```

Control of Locality/Affinity

```
prompt> chpl taskParallel.chpl
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

taskParallel.chpl

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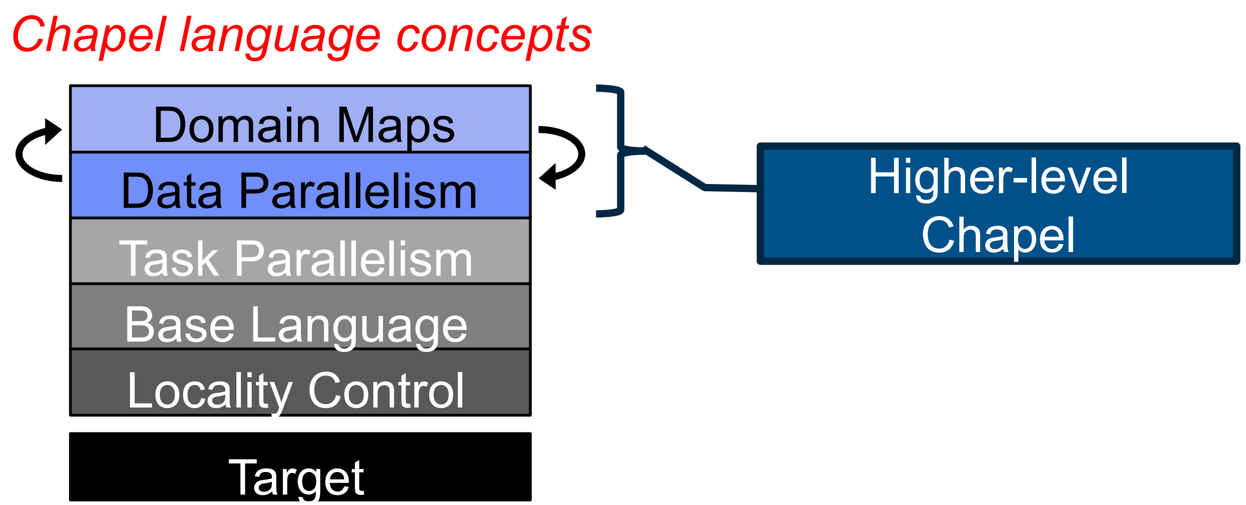
    coforall tid in 1..numTasks do
      writef("Hello from task %n of %n "+
             "running on %s\n",
             tid, numTasks, here.name);
  }
```

```
prompt> chpl taskParallel.chpl
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
```

Data Parallelism in Chapel



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
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
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

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
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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
```

Data Parallelism, by example

Data-Parallel Forall Loops

dataParallel.chpl

```
config const n = 1000;
var D = {1..n, 1..n};

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

```
prompt> chpl dataParallel.chpl
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1.1 1.3 1.5 1.7 1.9
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Data Parallelism, by example

This is a shared memory program

Nothing has referred to remote locales, explicitly or implicitly

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
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
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
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
```

A Brief History of Chapel

A Brief History of Chapel: Infancy

Chapel's Infancy: DARPA HPCS (2003–2012)

- ~6–7 FTEs
- Research focus:
  - distinguish locality from parallelism
  - seamlessly mix data- and task-parallelism
  - support user-defined distributed arrays, parallel iterators
- CUG 2013 paper captured post-HPCS project status:

  The State of the Chapel Union

  Chamberlain, Choi, Dumler, Hildebrandt, Iten, Litvinov, Titus

Crossing the Stream of Adoption

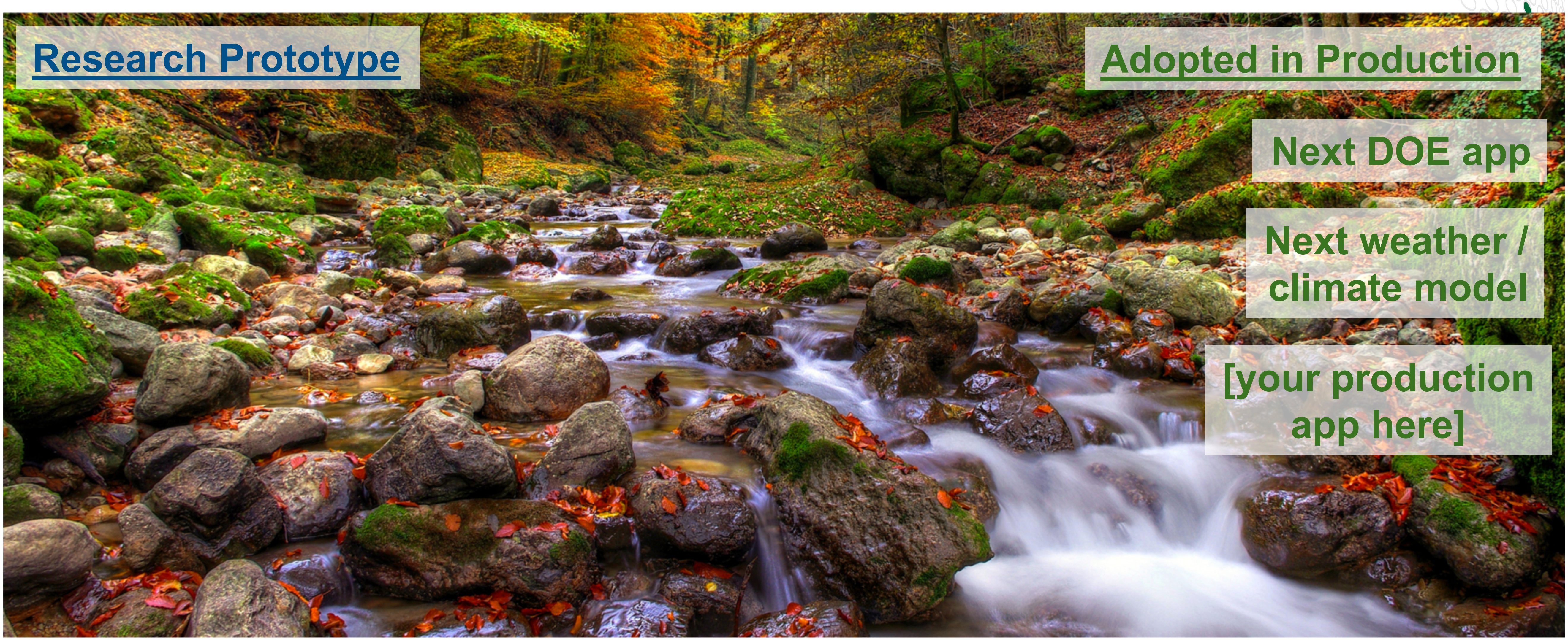


image credit: http://feelgrafix.com/813578-free-stream-wallpaper.html

Crossing the Stream of Adoption: Post-HPCS Barriers

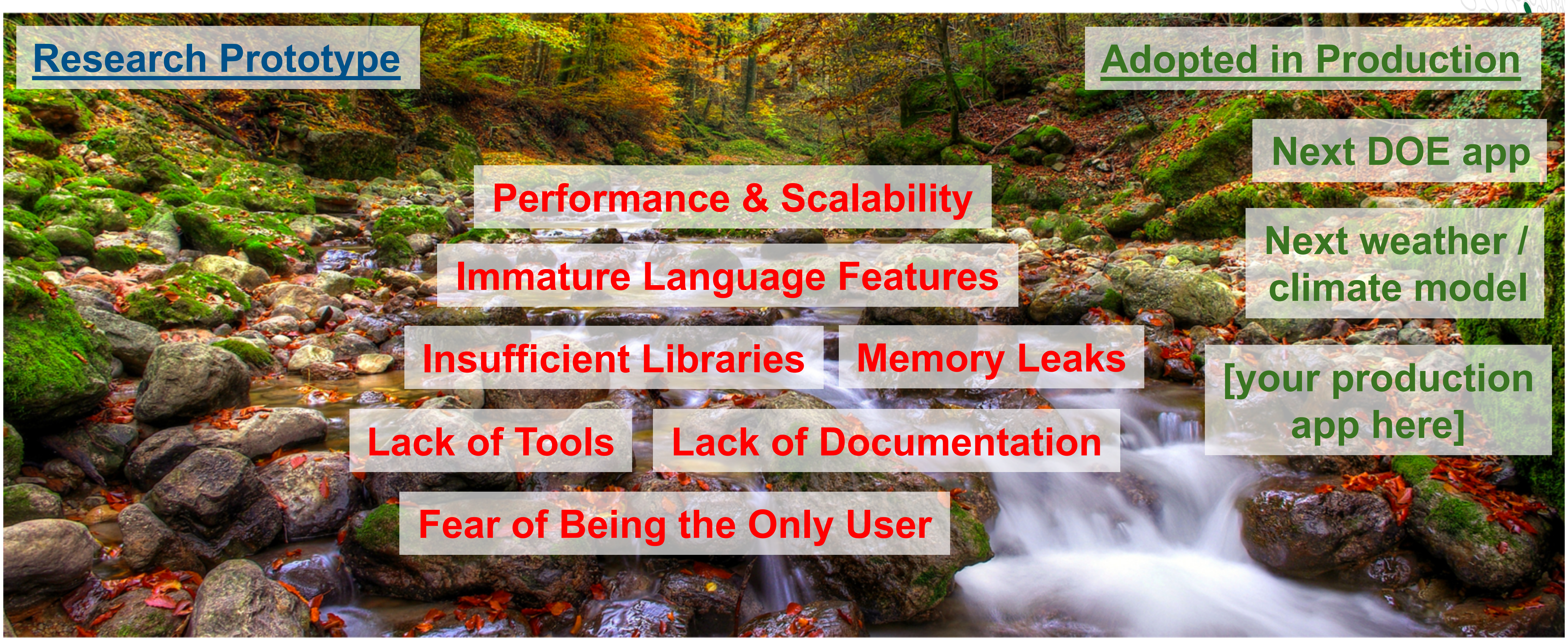


image credit: http://feelgrafix.com/813578-free-stream-wallpaper.html

A Brief History of Chapel: Adolescence

Chapel's Adolescence: "the five-year push" (2013–2018)

Then Now

- Motivated by user enthusiasm for Chapel
- Development focus:
  - address weak points in HPCS prototype
  - support and grow the Chapel community
- ~13–14 FTEs
- This CUG 2018 talk & paper reports on progress during this time

Chapel Performance: Then vs. Now vs. Reference

Performance Focus Areas (during 5-year push)

Array Optimizations:

- shifted data optimization (eliminates arbitrary indexing overhead)
- loop-invariant code motion (eliminates meta-data overhead)
- eliminated multiply in indexing for 1D (and innermost dim of 2D+) arrays

Runtime Library Improvements:

- scalable parallel memory allocator
- tasks mapped to affinity aware user-level threads
- native/optimized comm with RDMA and limited software overhead

Optimized Communication:

- compiler locality analysis improvements
- bulk array assignments
- remote-value-forwarding, new distributions, fast-ons, …

Experimental Methodology

Methodology for the next several slides:

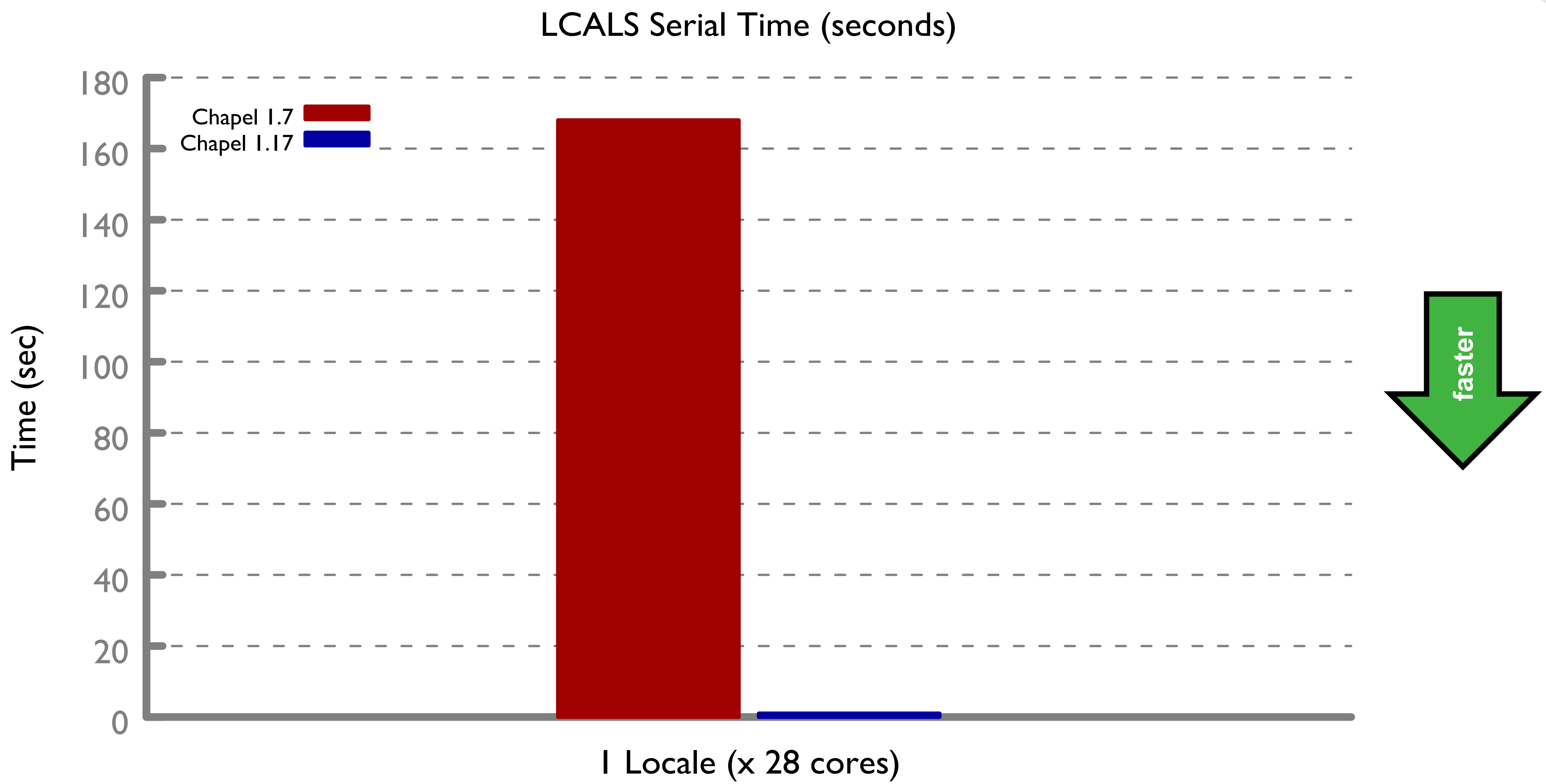
- Resurrected a copy of Chapel 1.7
  - updated it to build with current versions of gcc/g++
- Compared it to Chapel 1.17, released April 2018
- Used today's Cray systems
- Used today's benchmark codes
  - with modest edits for 1.7 in response to language changes

LCALS Serial Kernel

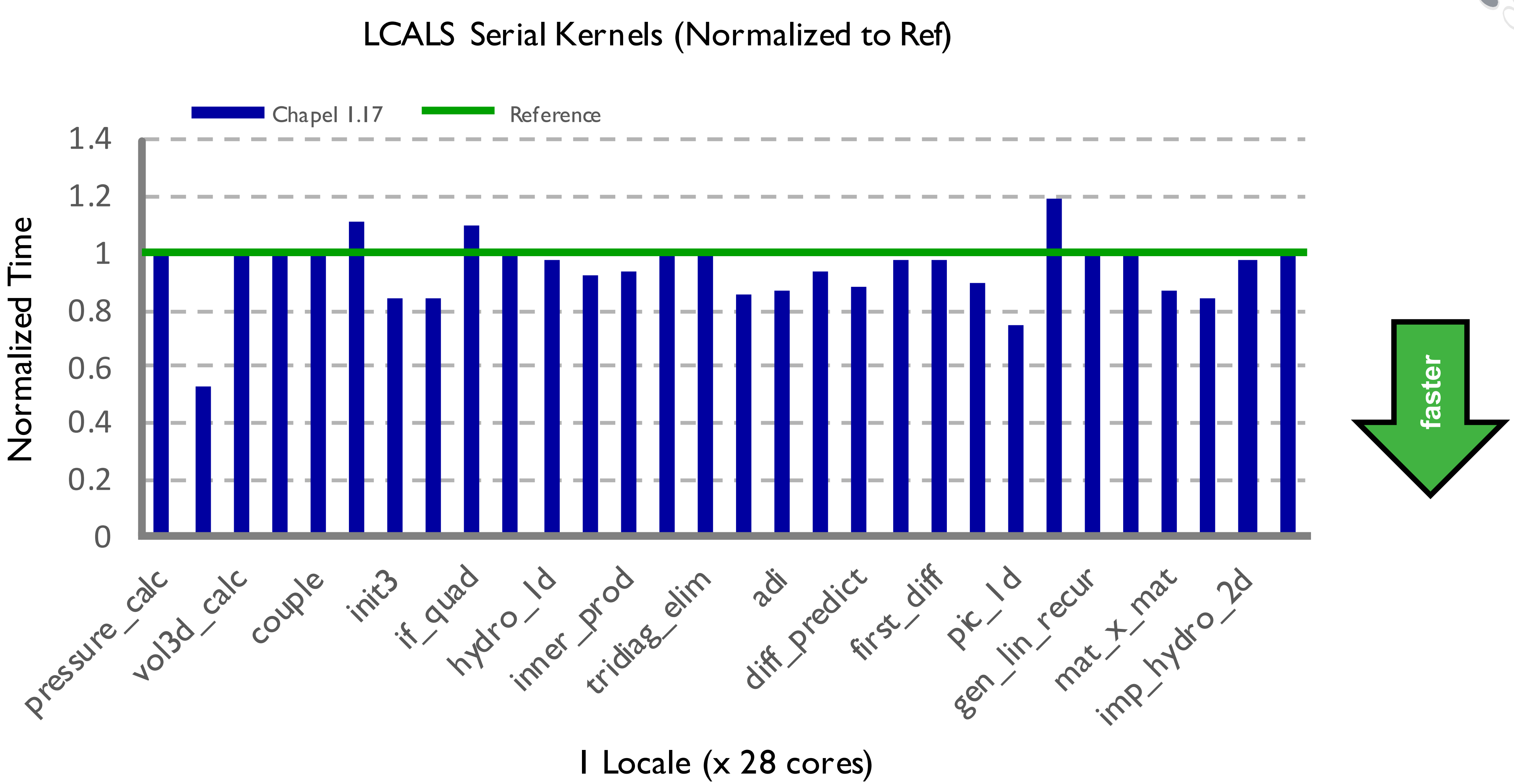
- **Chapel source:**

```
for i in 0..#len do
  bvc[i] = cls * (compression[i] + 1.0);
```

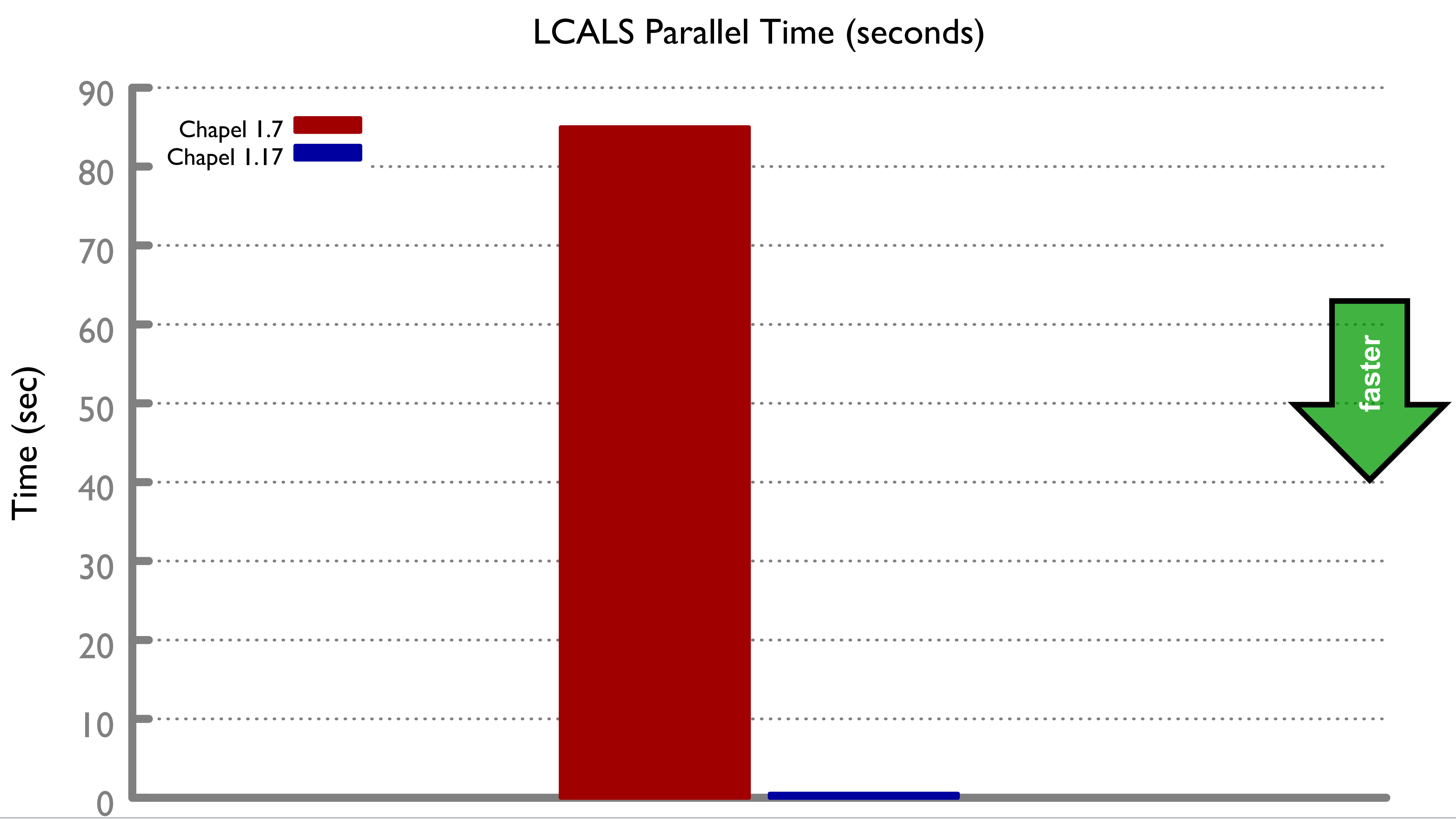
LCALS Serial Kernel: Chapel Then vs. Now



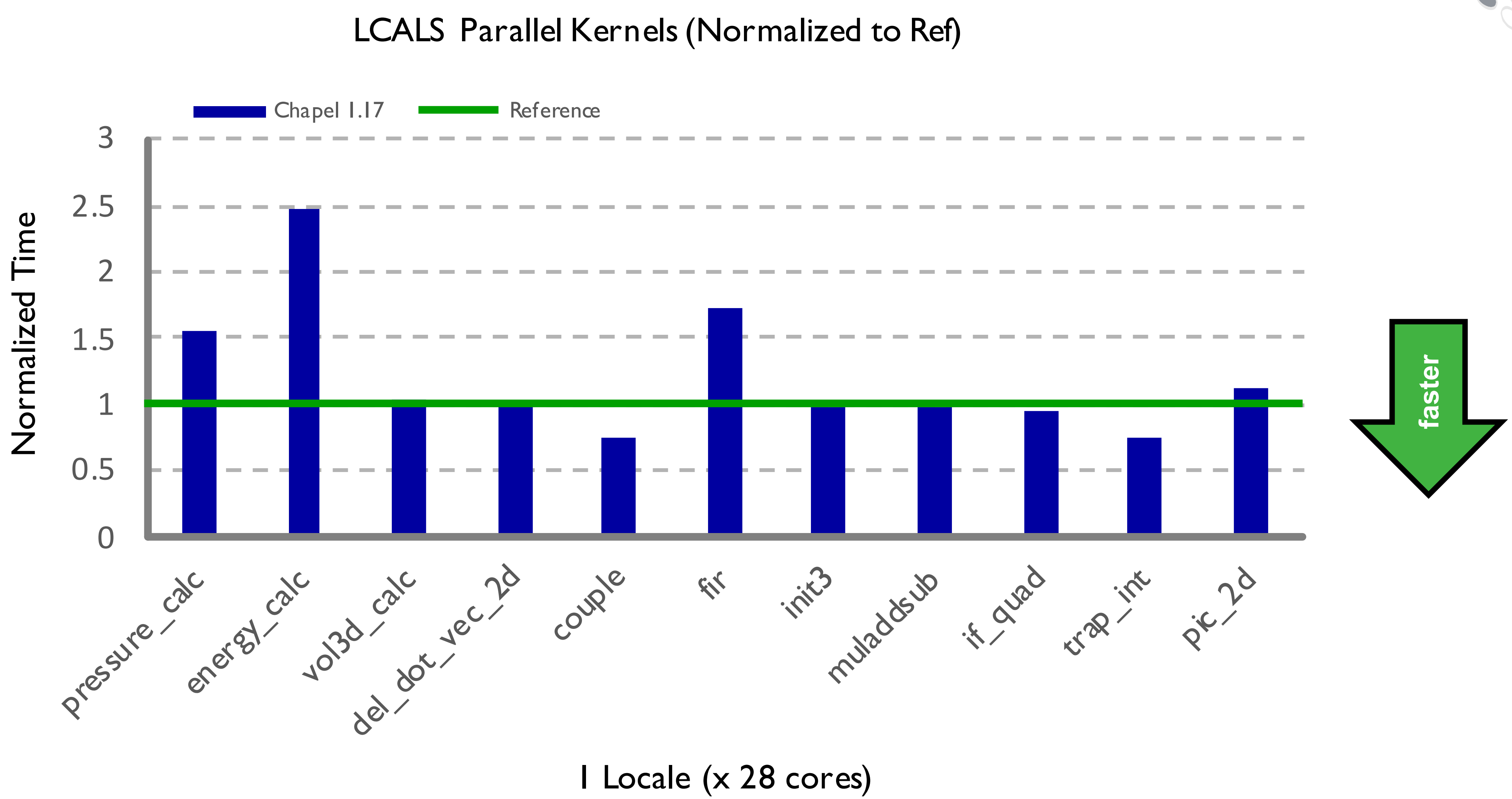
LCALS Serial Kernels: Chapel Now vs. Ref



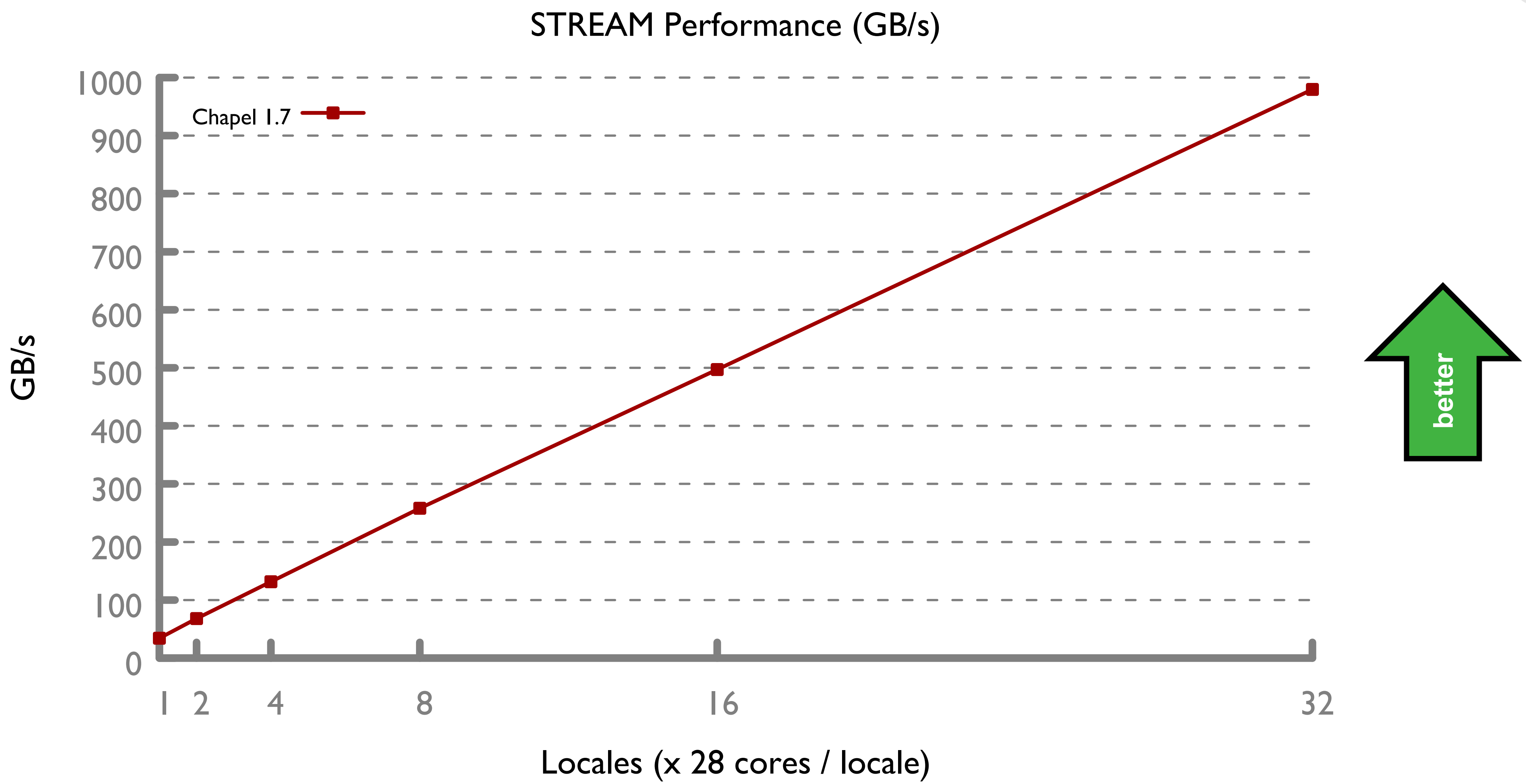
LCALS Parallel Kernel: Chapel Then vs. Now



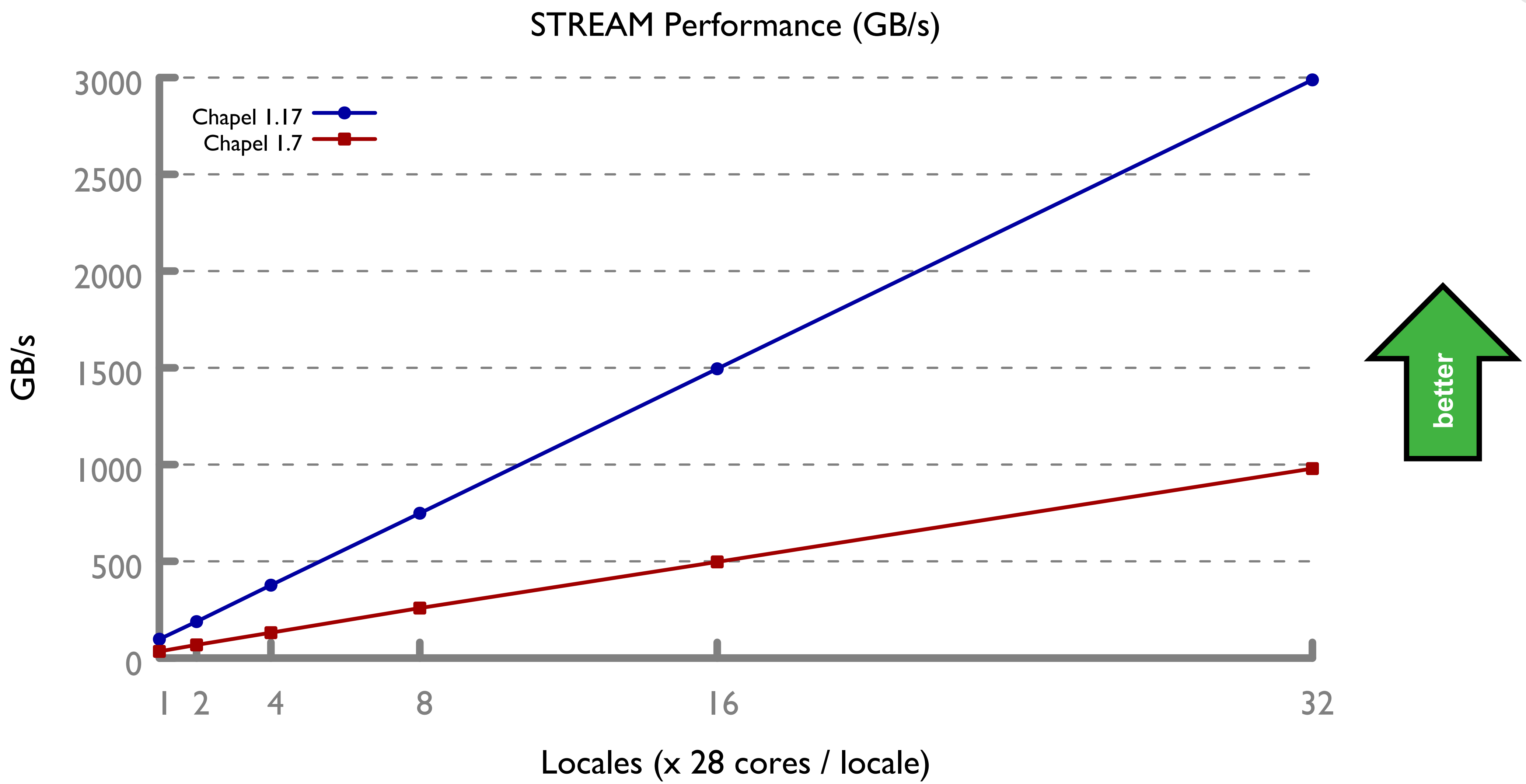
LCALS Parallel Kernels: Chapel Now vs. Ref



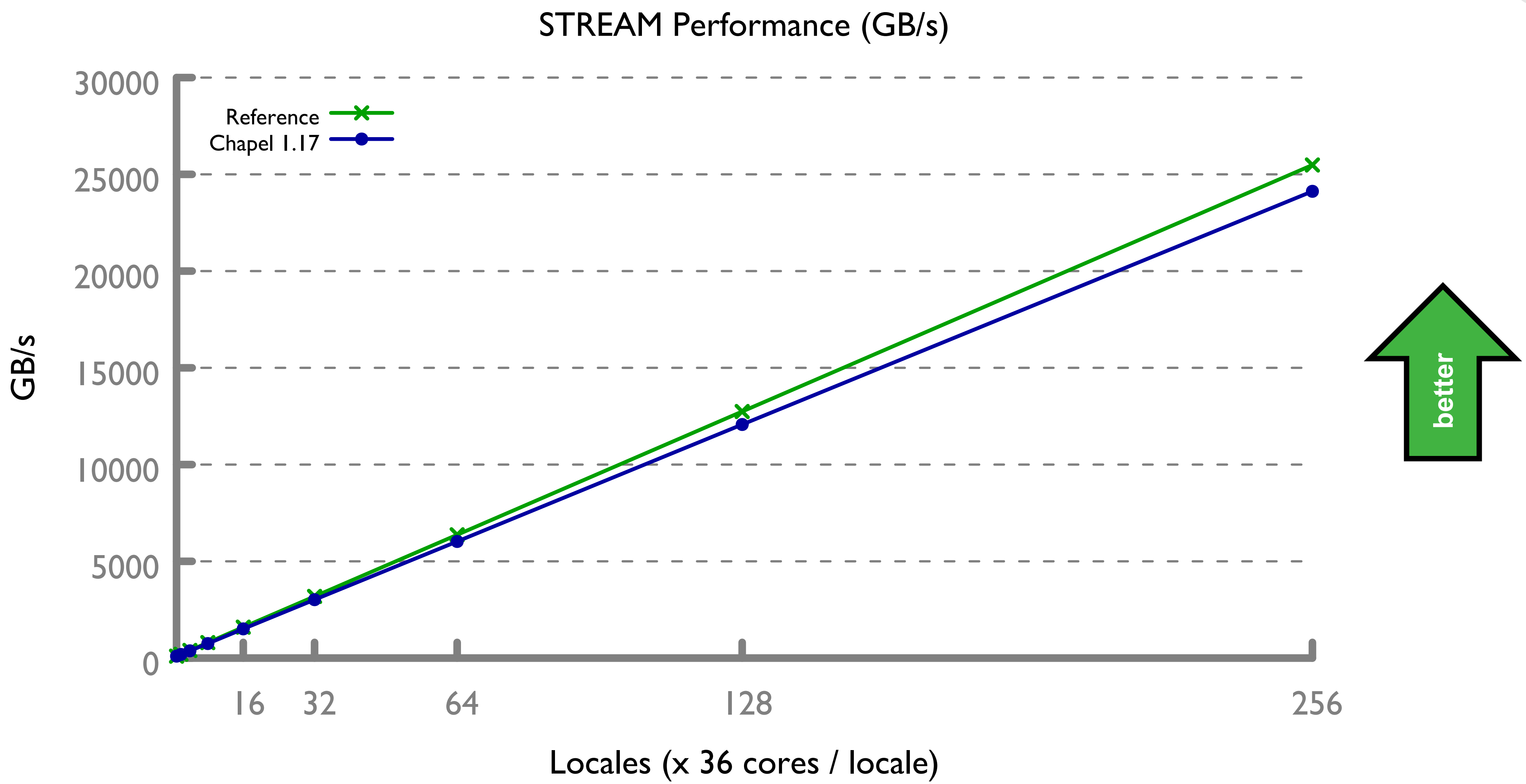
HPCC STREAM Triad: Chapel Then



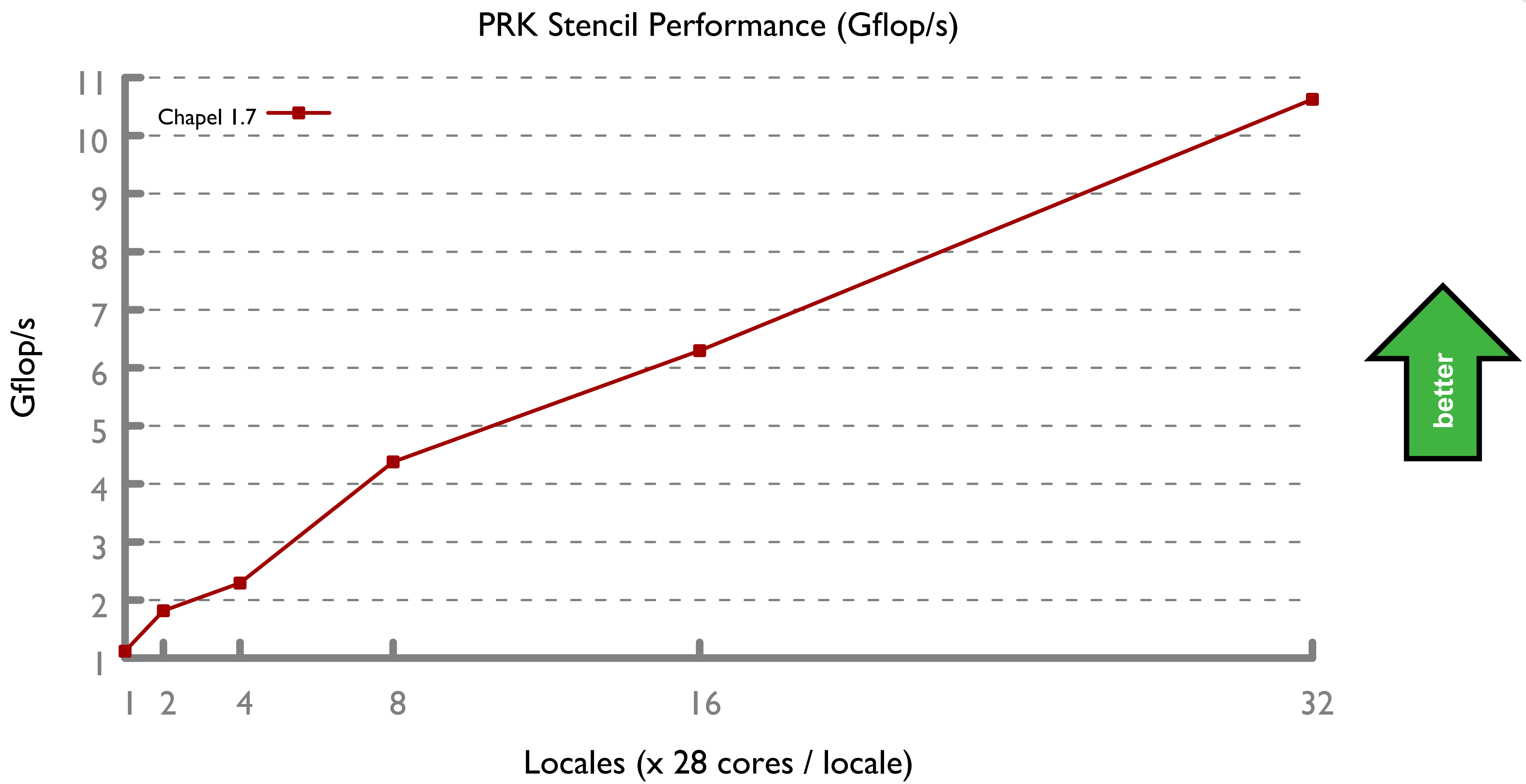
HPCC STREAM Triad: Chapel Then vs. Now



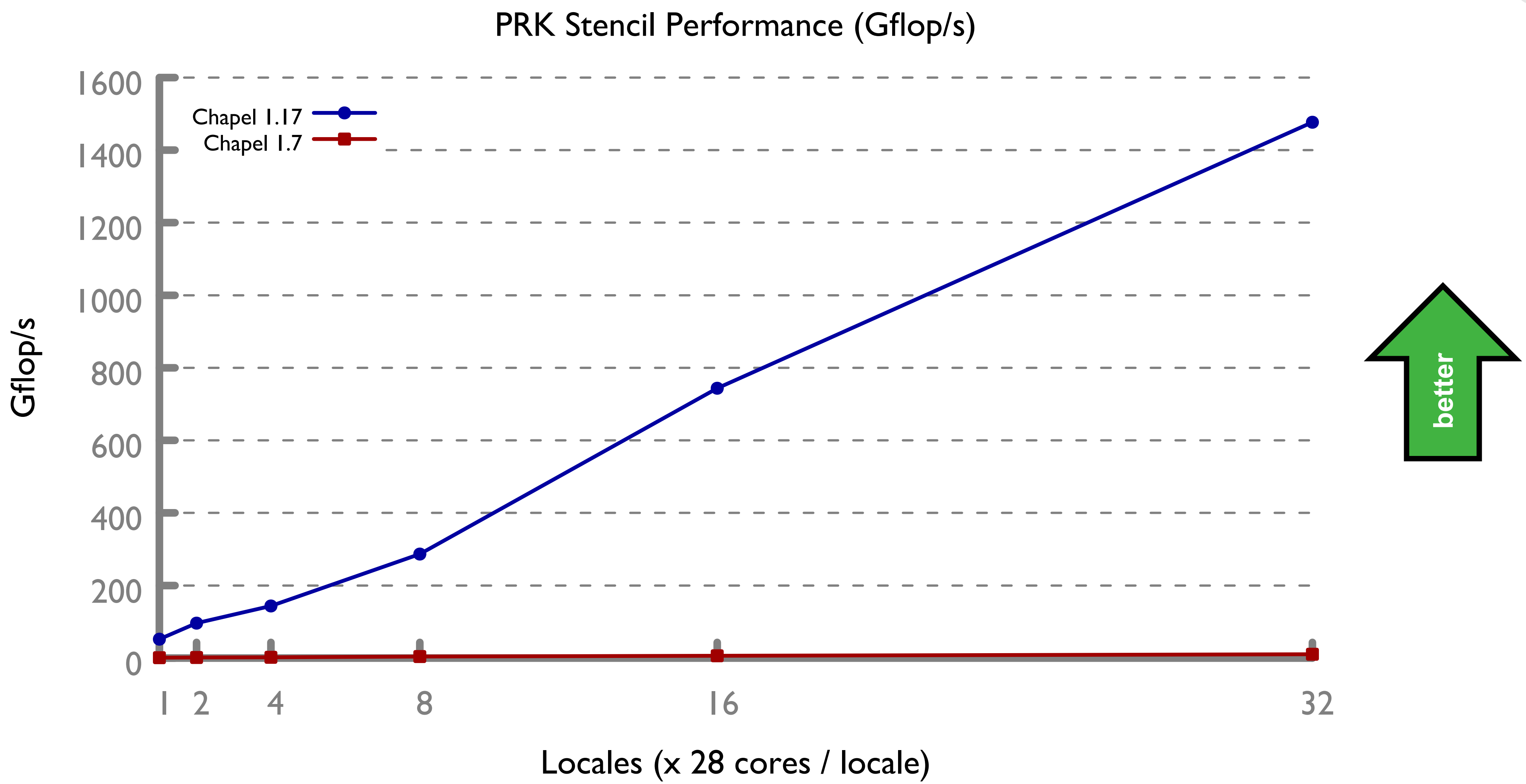
HPCC STREAM Triad: Chapel Now vs. Ref



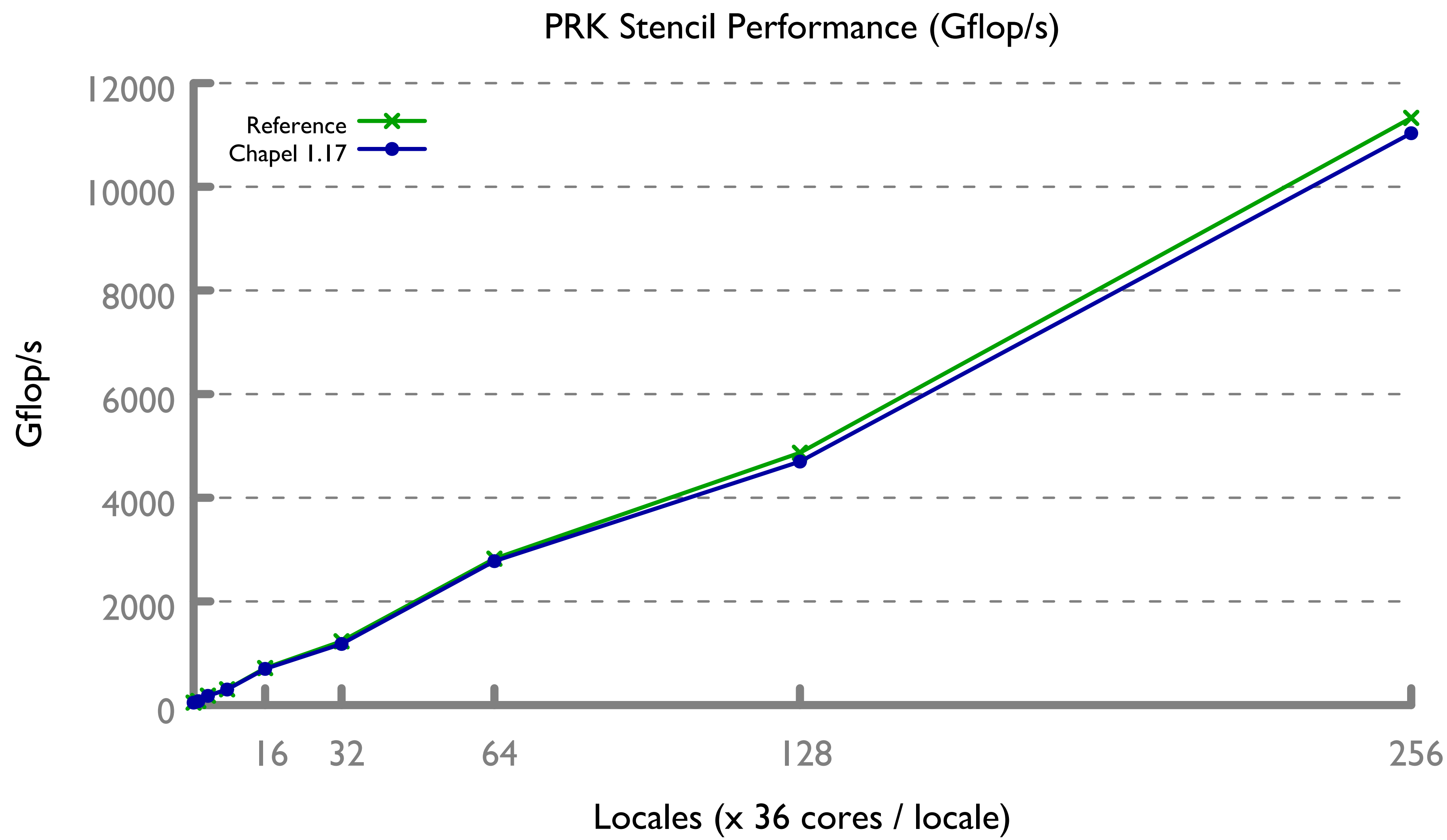
PRK Stencil: Chapel Then

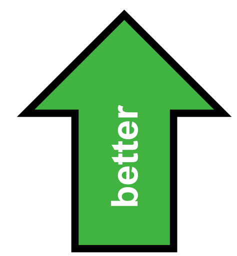


PRK Stencil: Chapel Then vs. Now



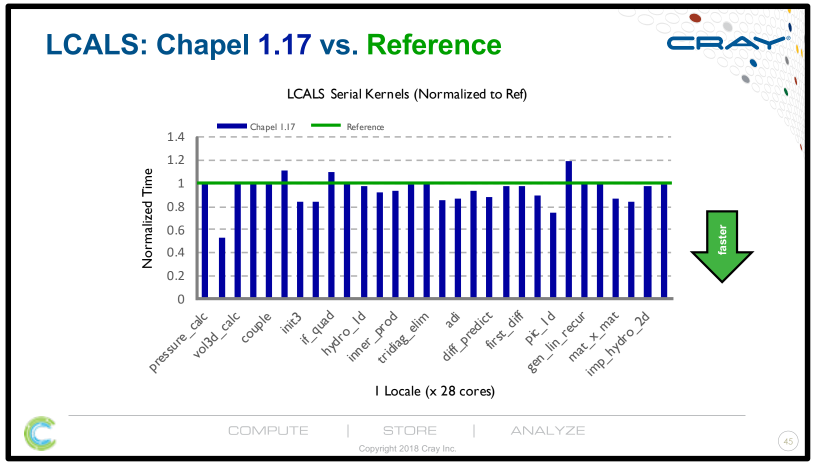
PRK Stencil: Chapel Now vs. Ref



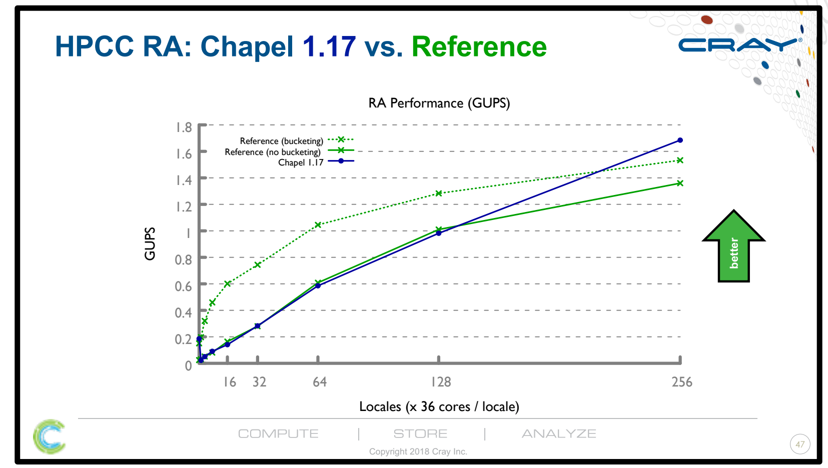


HPC Patterns: Chapel Now vs. reference

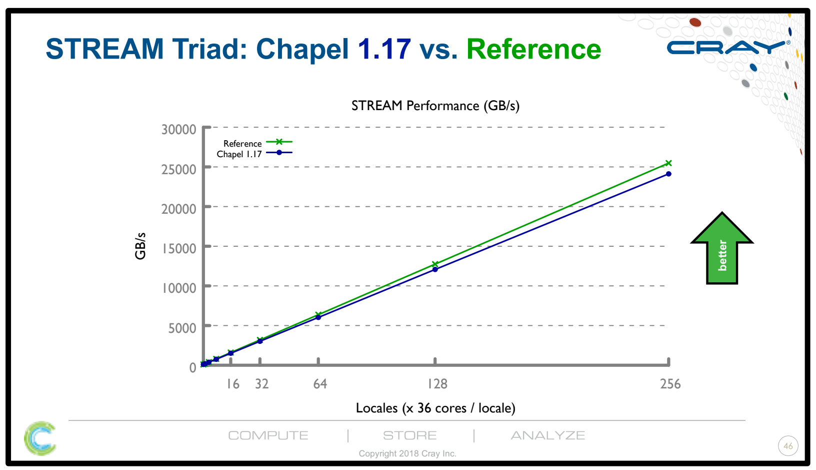
LCALS



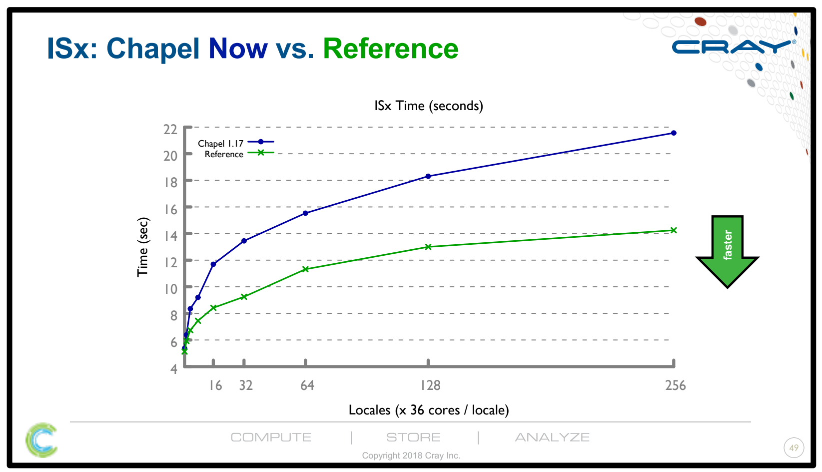
HPCC RA



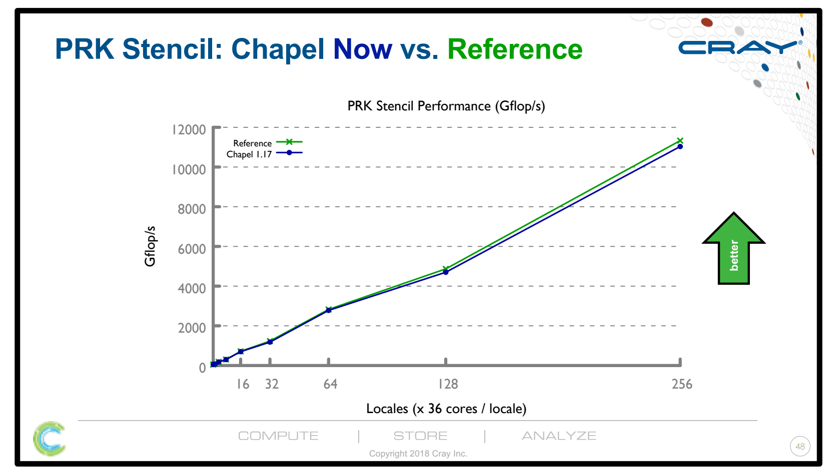
STREAM Triad



ISx

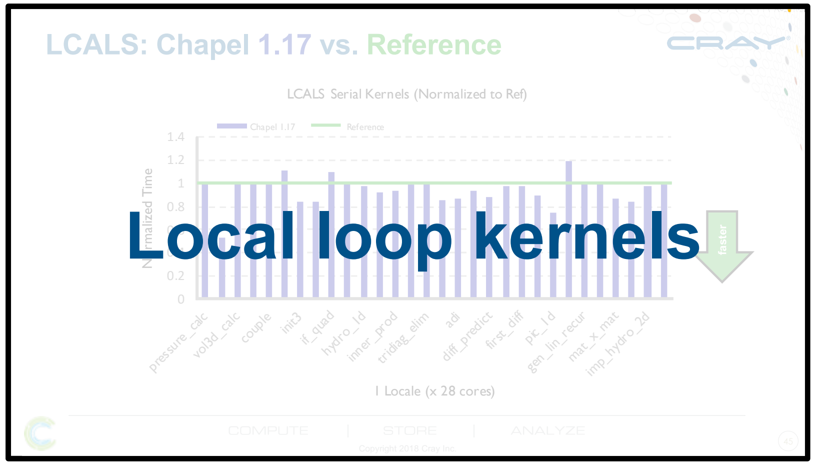


PRK Stencil



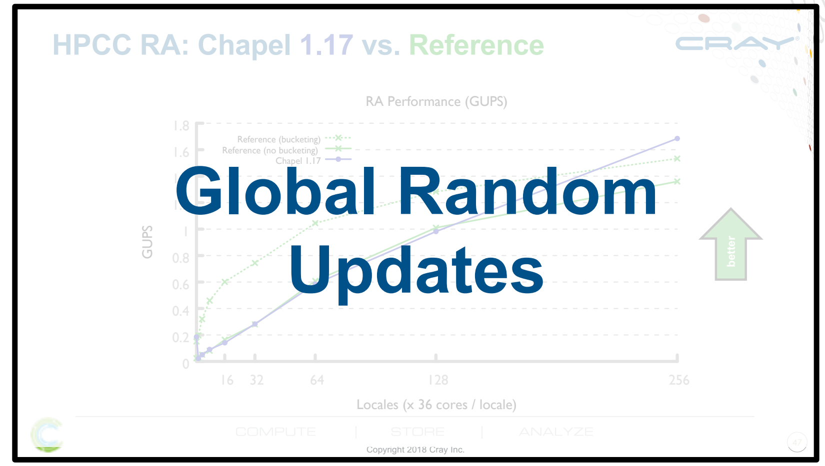
Nightly performance tickers online at:
https://chapel-lang.org/perf-nightly.html

HPC Patterns: Chapel Now vs. reference



LCALS

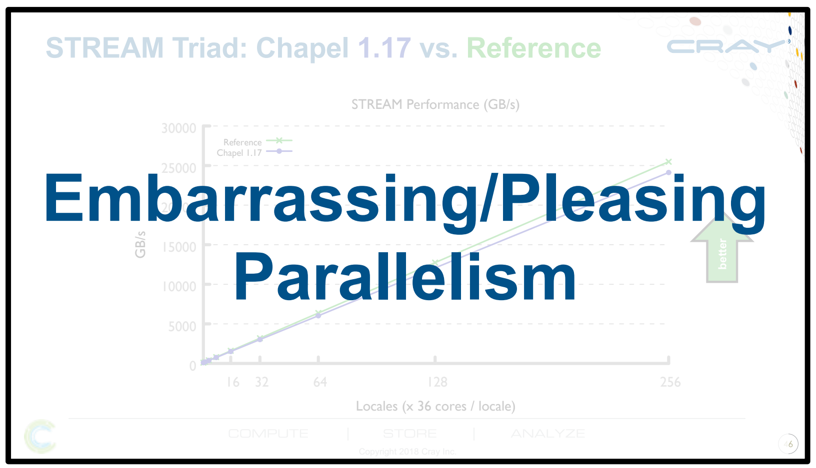
HPCC RA

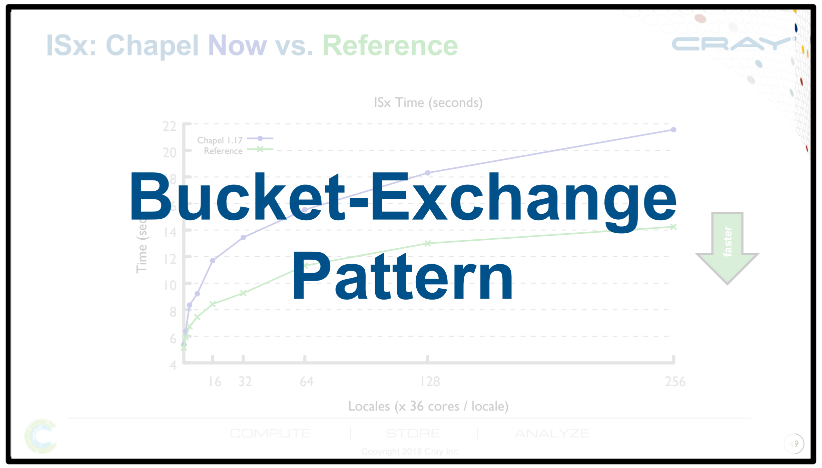


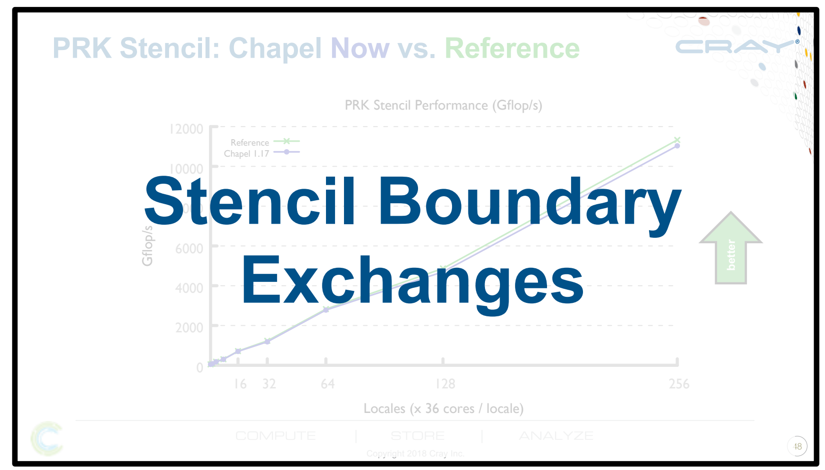
STREAM Triad

ISx

PRK Stencil







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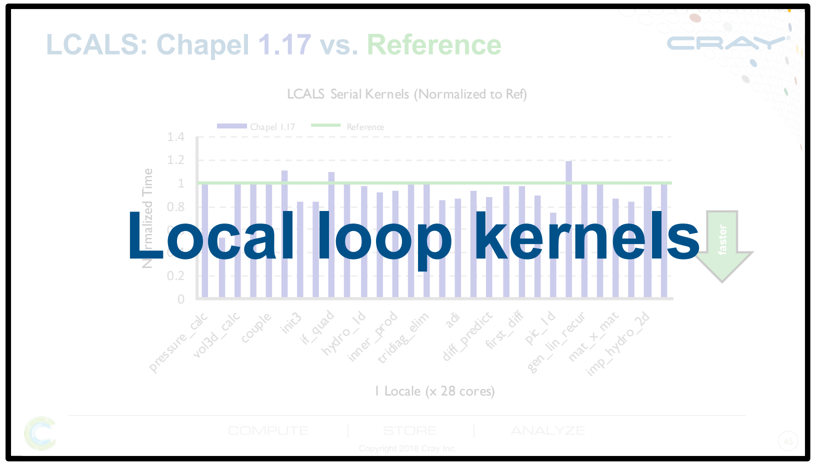
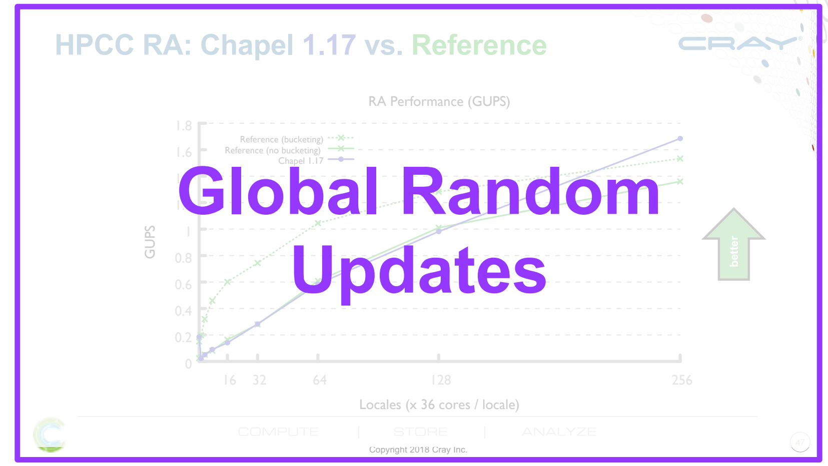
HPC Patterns: Chapel Now vs. reference



LCALS

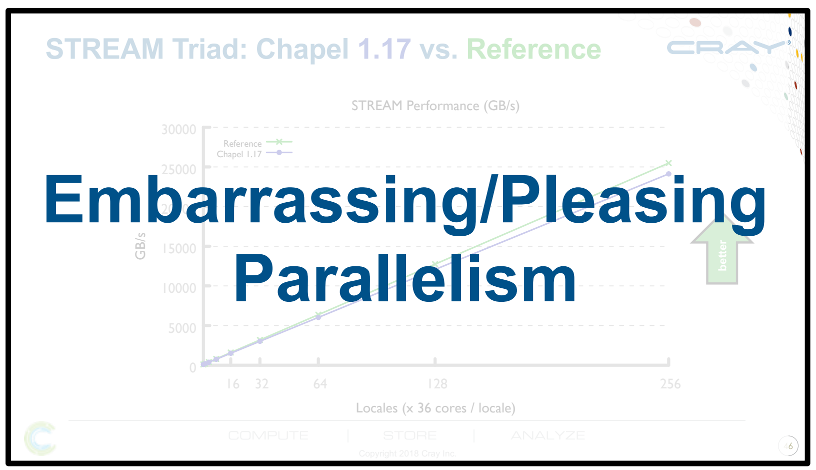
HPCC RA

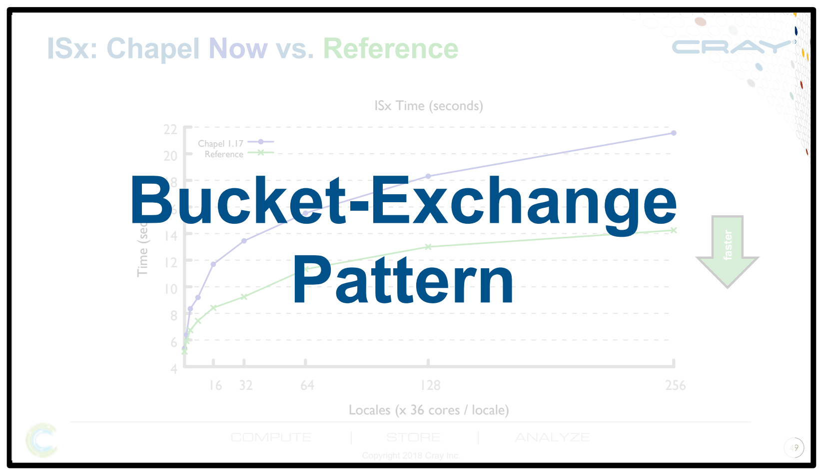


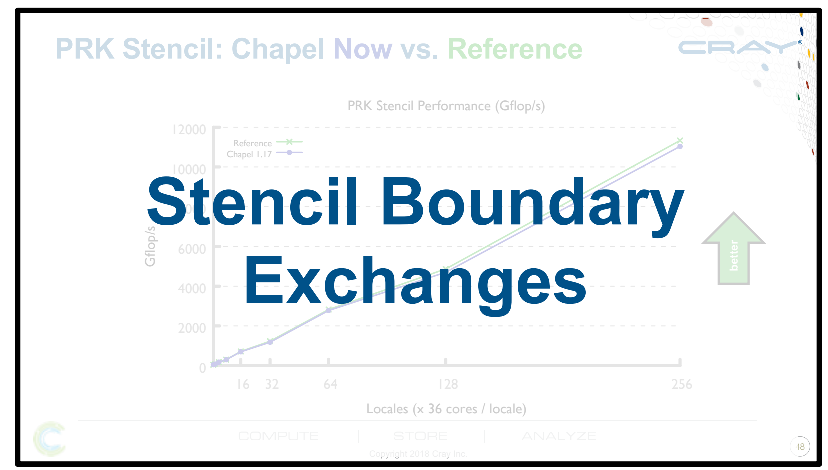
STREAM Triad

ISx

PRK Stencil







Nightly performance tickers online at:
https://chapel-lang.org/perf-nightly.html

HPCC Random Access Kernel: MPI

```
/* Perform updates to main table.  The scalar equivalent is:
 *
 *   for (i=0; i<NUPDATE; i++) {
 *     Ran = (Ran << 1) ^ (((s64Int) Ran < 0) ? POLY : 0);
 *     Table[Ran & (TABSIZE-1)] ^= Ran;
 *   }
 */

MPI_Irecv(&LocalRecvBuffer, localBufferSize, tparams.dtype64,
          MPI_ANY_SOURCE, MPI_ANY_TAG, MPI_COMM_WORLD, &inreq);
 while (i < SendCnt) {
   /* receive messages */
   do {
     MPI_Test(&inreq, &have_done, &status);
     if (have_done) {
       if (status.MPI_TAG == UPDATE_TAG) {
         MPI_Get_count(&status, tparams.dtype64, &recvUpdates);
         bufferBase = 0;
         for (j=0; j < recvUpdates; j ++) {
           inmsg = LocalRecvBuffer[bufferBase+j];
           LocalOffset = (inmsg & (tparams.TableSize - 1)) -
                         tparams.GlobalStartMyProc;
           HPCC_Table[LocalOffset] ^= inmsg;
         }
       } else if (status.MPI_TAG == FINISHED_TAG) {
         NumberReceiving--;
       } else
         MPI_Abort( MPI_COMM_WORLD, -1 );
       MPI_Irecv(&LocalRecvBuffer, localBufferSize, tparams.dtype64,
                 MPI_ANY_SOURCE, MPI_ANY_TAG, MPI_COMM_WORLD, &inreq);
     }
   } while (have_done && NumberReceiving > 0);
   if (pendingUpdates < maxPendingUpdates) {
     Ran = (Ran << 1) ^ ((s64Int) Ran < ZERO64B ? POLY : ZERO64B);
     GlobalOffset = Ran & (tparams.TableSize-1);
     if ( GlobalOffset < tparams.Top)
       WhichPe = ( GlobalOffset / (tparams.MinLocalTableSize + 1) );
     else
       WhichPe = ( (GlobalOffset - tparams.Remainder) /
                  tparams.MinLocalTableSize );
     if (WhichPe == tparams.MyProc) {
       LocalOffset = (Ran & (tparams.TableSize - 1)) -
                     tparams.GlobalStartMyProc;
       HPCC_Table[LocalOffset] ^= Ran;
```

```
}  else {
    HPCC_InsertUpdate(Ran, WhichPe, Buckets);
     pendingUpdates++;
   }
   i++;
 }
 else {
   MPI_Test(&outreq, &have_done, MPI_STATUS_IGNORE);
   if (have_done) {
     outreq = MPI_REQUEST_NULL;
     pe = HPCC_GetUpdates(Buckets, LocalSendBuffer, localBufferSize,
                          &peUpdates);
     MPI_Isend(&LocalSendBuffer, peUpdates, tparams.dtype64, (int)pe,
               UPDATE_TAG, MPI_COMM_WORLD, &outreq);
     pendingUpdates -= peUpdates;
   }
 }
}
/* send remaining updates in buckets */
while (pendingUpdates > 0) {
  /* receive messages */
  do {
    MPI_Test(&inreq, &have_done, &status);
    if (have_done) {
      if (status.MPI_TAG == UPDATE_TAG) {
        MPI_Get_count(&status, tparams.dtype64, &recvUpdates);
        bufferBase = 0;
        for (j=0; j < recvUpdates; j ++) {
          inmsg = LocalRecvBuffer[bufferBase+j];
          LocalOffset = (inmsg & (tparams.TableSize - 1)) -
                        tparams.GlobalStartMyProc;
          HPCC_Table[LocalOffset] ^= inmsg;
        }
      } else if (status.MPI_TAG == FINISHED_TAG) {
        /* we got a done message.  Thanks for playing... */
        NumberReceiving--;
      } else {
        MPI_Abort( MPI_COMM_WORLD, -1 );
      }
      MPI_Irecv(&LocalRecvBuffer, localBufferSize, tparams.dtype64,
                MPI_ANY_SOURCE, MPI_ANY_TAG, MPI_COMM_WORLD, &inreq);
    }
  } while (have_done && NumberReceiving > 0);
```

```
  MPI_Test(&outreq, &have_done, MPI_STATUS_IGNORE);
  if (have_done) {
    outreq = MPI_REQUEST_NULL;
    pe = HPCC_GetUpdates(Buckets, LocalSendBuffer, localBufferSize,
                         &peUpdates);
    MPI_Isend(&LocalSendBuffer, peUpdates, tparams.dtype64, (int)pe,
              UPDATE_TAG, MPI_COMM_WORLD, &outreq);
    pendingUpdates -= peUpdates;
  }
}
/* send our done messages */
for (proc_count = 0 ; proc_count < tparams.NumProcs ; ++proc_count) {
  if (proc_count == tparams.MyProc) { tparams.finish_req[tparams.MyProc] =
                                      MPI_REQUEST_NULL; continue; }
  /* send garbage - who cares, no one will look at it */
  MPI_Isend(&Ran, 0, tparams.dtype64, proc_count, FINISHED_TAG,
            MPI_COMM_WORLD, tparams.finish_req + proc_count);
}
/* Finish everyone else up... */
while (NumberReceiving > 0) {
  MPI_Wait(&inreq, &status);
  if (status.MPI_TAG == UPDATE_TAG) {
    MPI_Get_count(&status, tparams.dtype64, &recvUpdates);
    bufferBase = 0;
    for (j=0; j < recvUpdates; j ++) {
      inmsg = LocalRecvBuffer[bufferBase+j];
      LocalOffset = (inmsg & (tparams.TableSize - 1)) -
                    tparams.GlobalStartMyProc;
      HPCC_Table[LocalOffset] ^= inmsg;
    }
  } else if (status.MPI_TAG == FINISHED_TAG) {
    /* we got a done message.  Thanks for playing... */
    NumberReceiving--;
  } else {
    MPI_Abort( MPI_COMM_WORLD, -1 );
  }
  MPI_Irecv(&LocalRecvBuffer, localBufferSize, tparams.dtype64,
            MPI_ANY_SOURCE, MPI_ANY_TAG, MPI_COMM_WORLD, &inreq);
}

MPI_Waitall( tparams.NumProcs, tparams.finish_req, tparams.finish_statuses);
```

HPCC Random Access Kernel: MPI

```
/* Perform updates to main table.  The scalar equivalent is:
 *
 *   for (i=0; i<NUPDATE; i++) {
 *     Ran = (Ran << 1) ^ (((s64Int) Ran < 0) ? POLY : 0);
 *     Table[Ran & (TABSIZE-1)] ^= Ran;
 *   }
 */
```

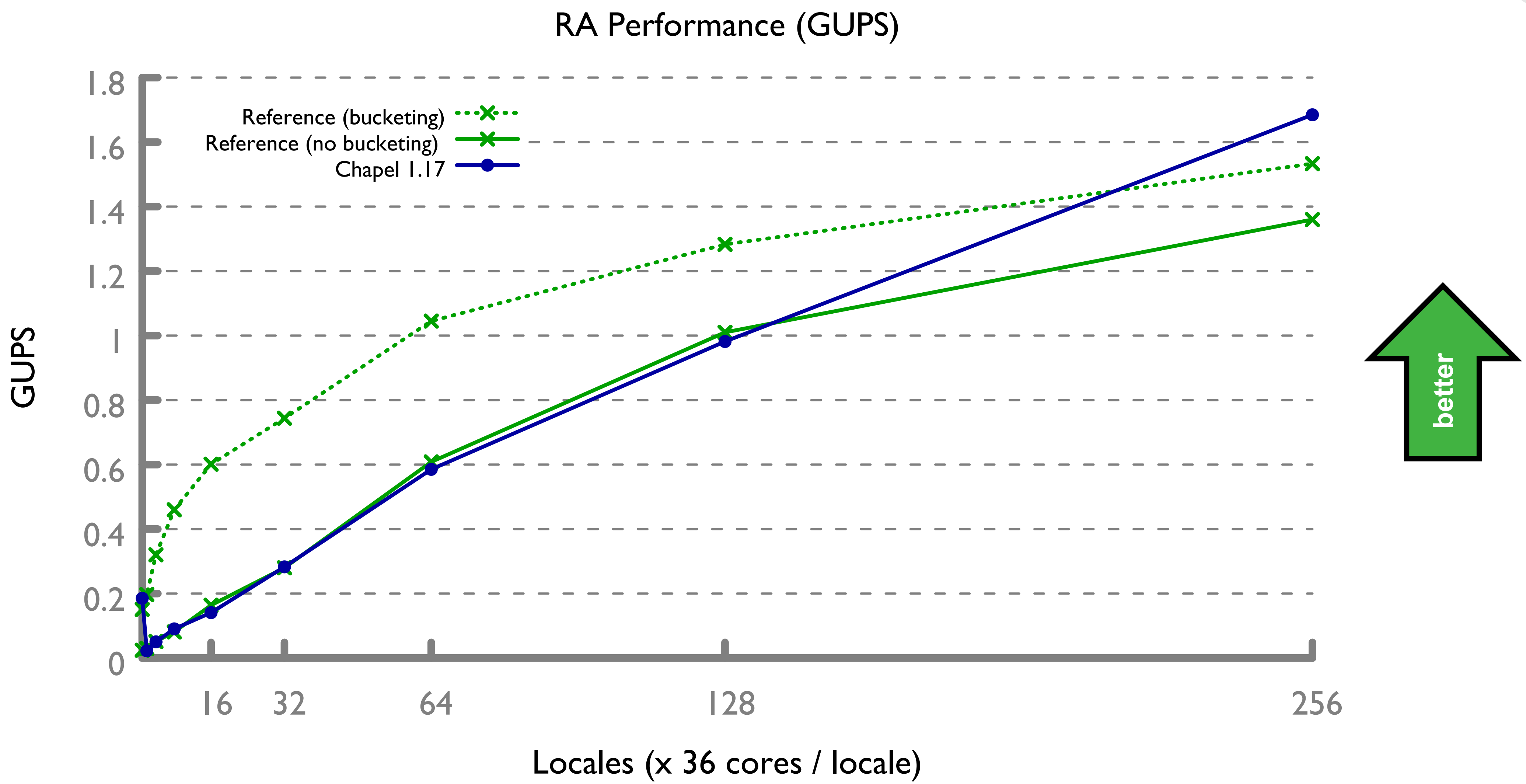
Chapel Kernel

```
forall (_, r) in zip(Updates, RAStream()) do
  T[r & indexMask] ^= r;
```

MPI Comment

```
/* Perform updates to main table. The scalar equivalent is:
 *
 *     for (i=0; i<NUPDATE; i++) {
 *       Ran = (Ran << 1) ^ (((s64Int) Ran < 0) ? POLY : 0);
 *       Table[Ran & (TABSIZE-1)] ^= Ran;
 *     }
 */
```

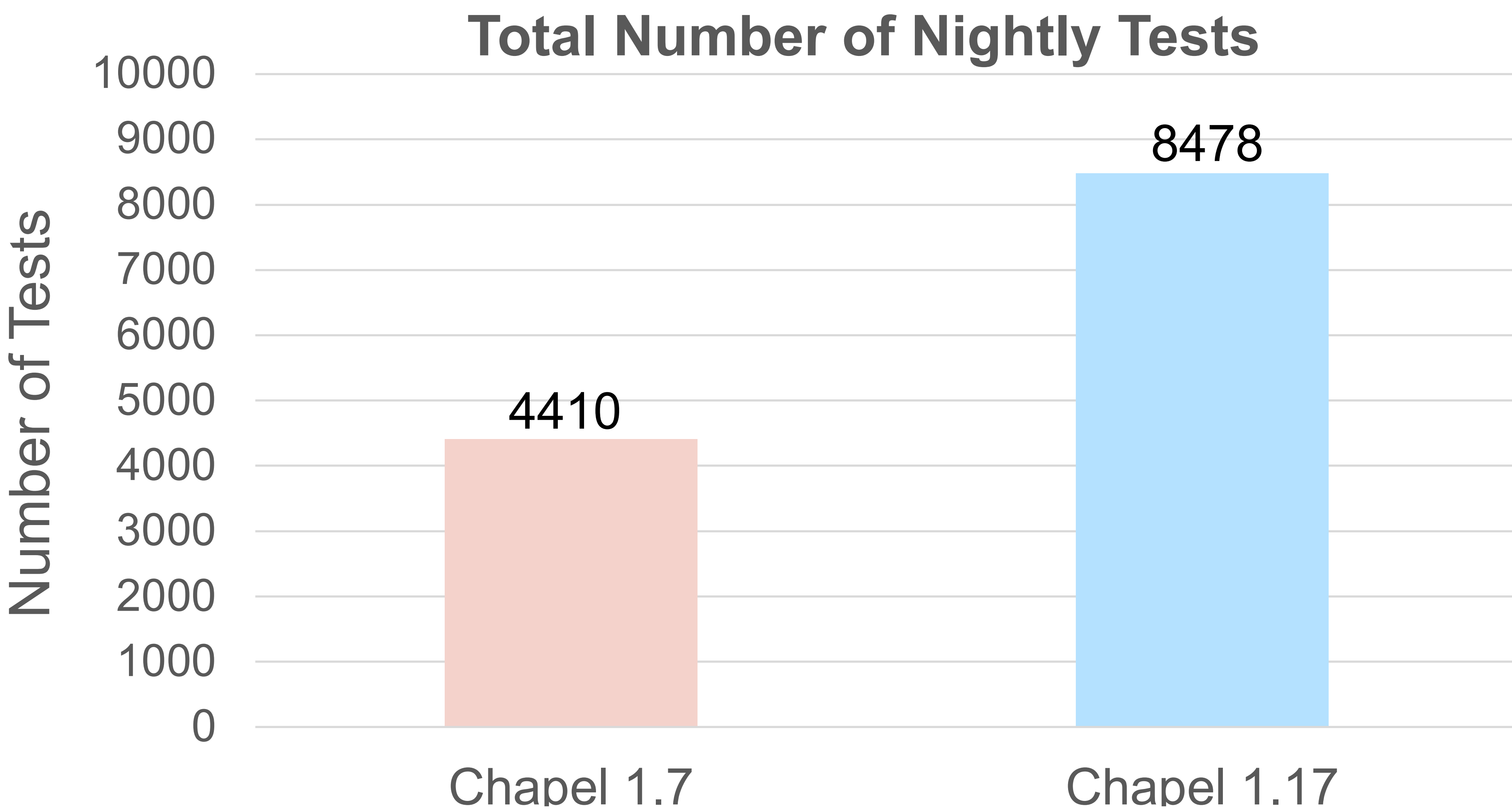
HPCC RA: Chapel Now vs. Ref



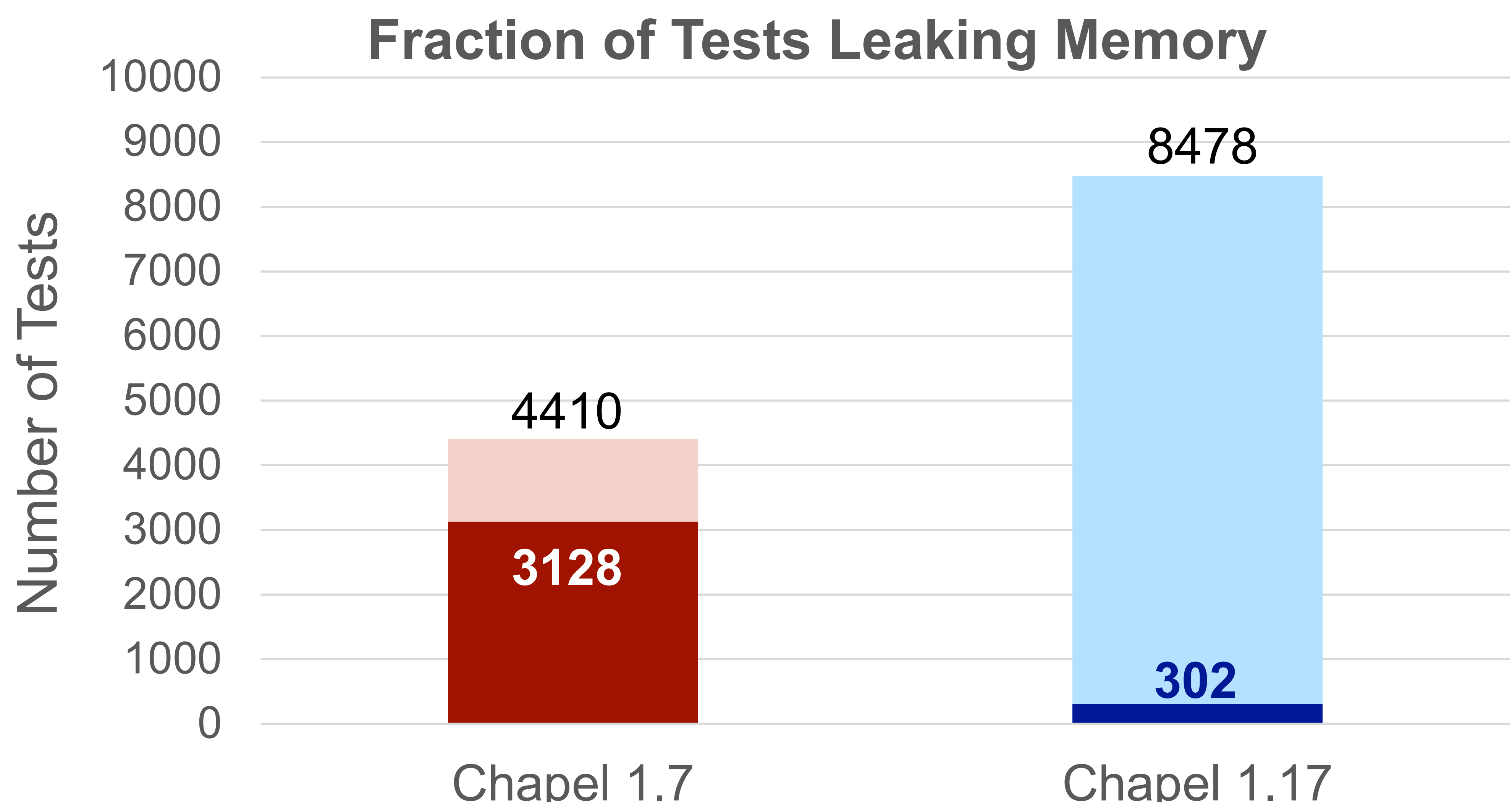
Memory Leaks: Then vs. Now

(skipped at CUG due to time constraints)

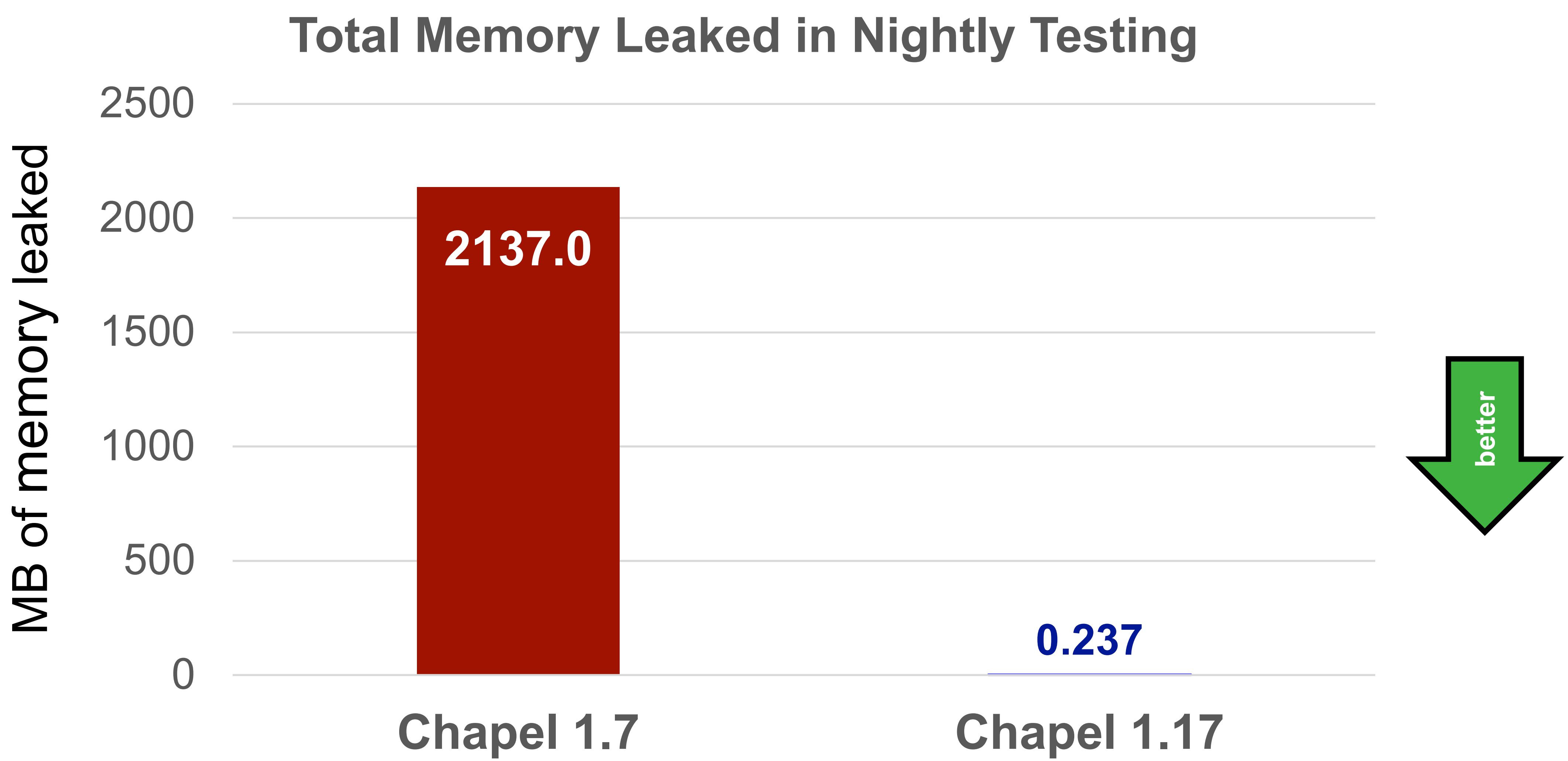
Memory Leaks: Chapel Then vs. Now



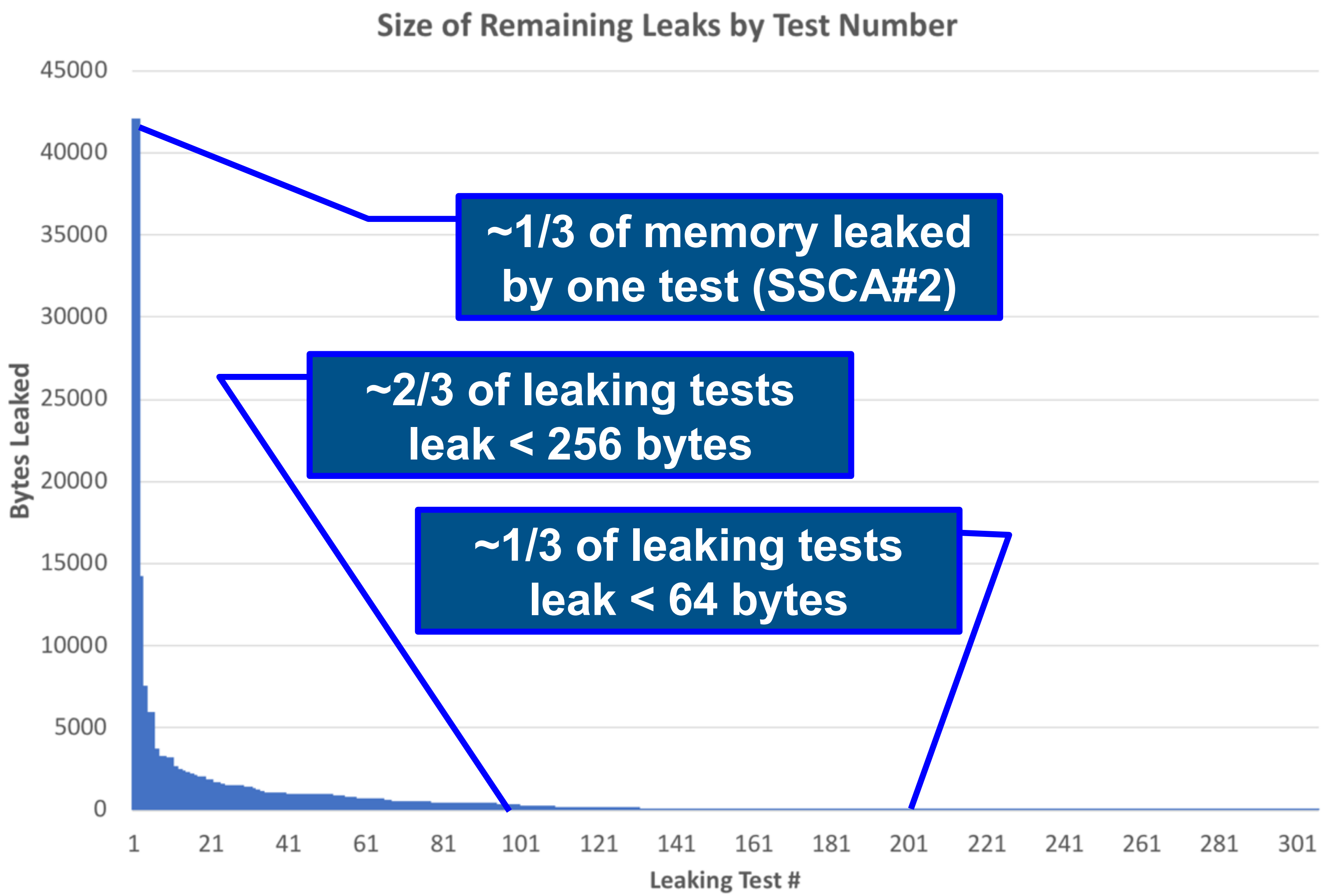
Memory Leaks: Chapel Then vs. Now



Memory Leaks: Chapel Then vs. Now



Memory Leaks: Remaining Leaks



Chapel Language: Then vs. Now

Language: Then

Parallelism and Locality: Generally in good shape

- not many changes here since HPCS

Base Language: Left much to be desired

- lots of focus here since HPCS

Language: Now

Parallelism and Locality

- introduced *task intents* to reduce chances of race conditions
- and *user-defined locale models* to support new node architectures

Base Language

- fixed a number of problems with object-oriented programming
  - **records:** poor memory management discipline
  - **classes:** problems with generic classes, class hierarchies
- made strings usable
- added error-handling features
- made namespace improvements

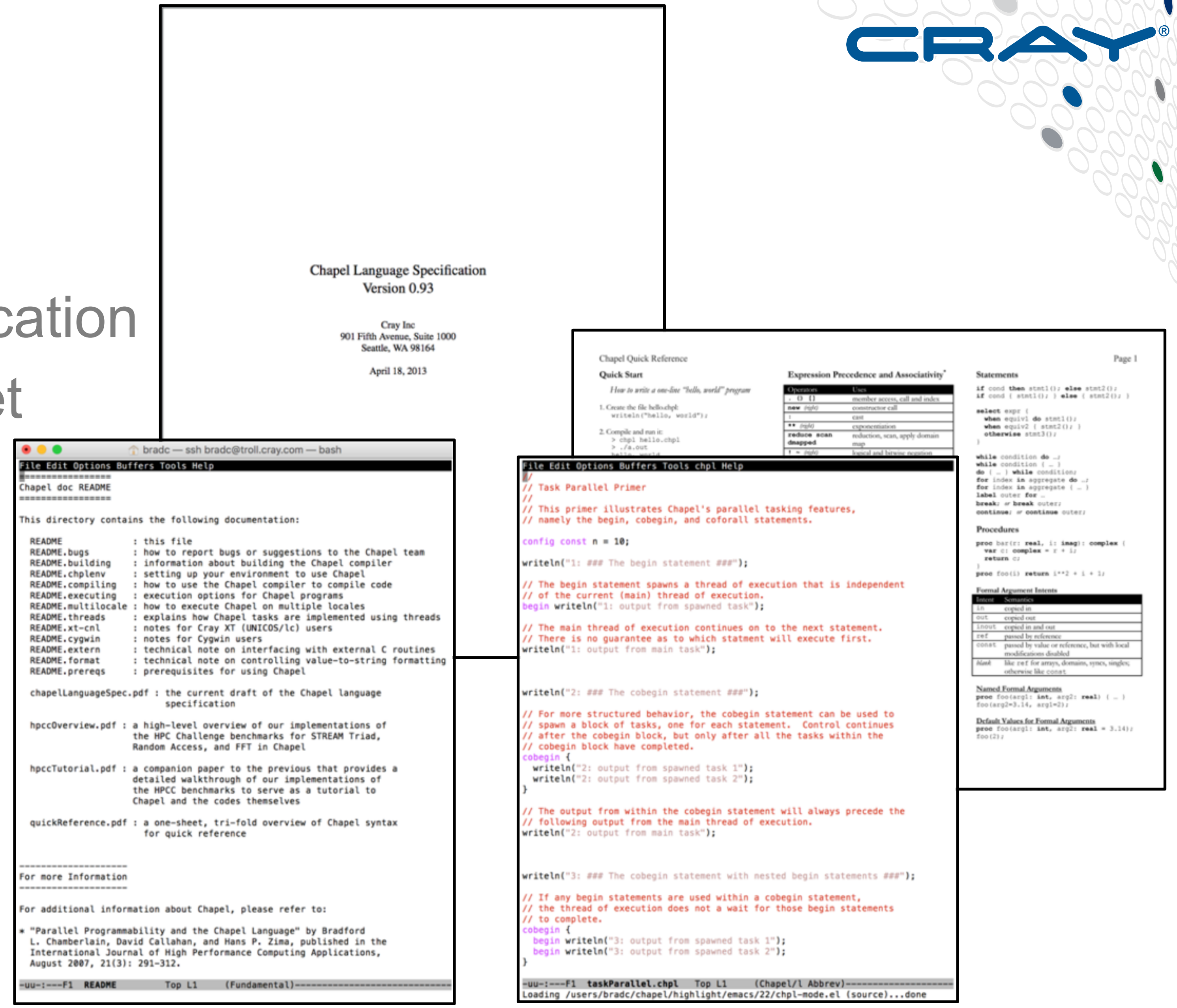
(and much more…)

Chapel Ecosystem: Then vs. Now

Documentation: Then

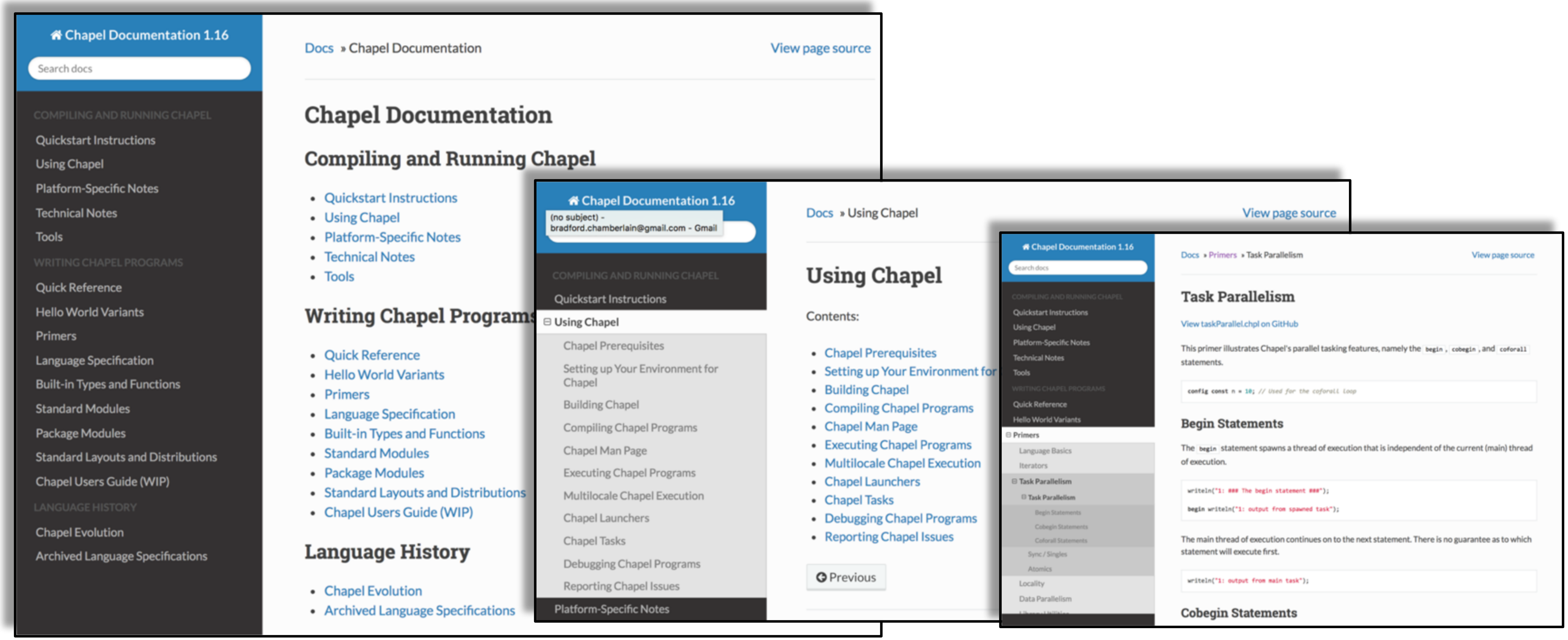
After HPCS:

- a PDF language specification
- a Quick Reference sheet
- a number of READMEs
- ~22 primer examples



Documentation: Now

Now: 200+ modern, hyperlinked, web-based documentation pages



Libraries: Then

After HPCS: ~25 library modules

- documented via source comments, if at all:

```
bradc — ssh bradc@troll.cray.com — bash
File Edit Options Buffers Tools chpl Help
// Copyright (c) 2004-2013, Cray Inc.  (See LICENSE file for more details)


//
// Random Module
//
// This standard module contains a random number generator based on
// the one used in the NPB benchmarks.  Tailoring the NPB comments to
// this code, we can say the following:
//
//   This generator returns uniform pseudorandom real values in the
//   range (0, 1) by using the linear congruential generator
//
//     x_{k+1} = a x_k  (mod 2**46)
//
//   where 0 < x_k < 2**46 and 0 < a < 2**46.  This scheme generates
//   2**44 numbers before repeating.  The seed value must be an odd
//   64-bit integer in the range (1, 2^46).  The generated values are
//   normalized to be between 0 and 1, i.e., 2**(-46) * x_k.
//
//   This generator should produce the same results on any computer
//   with at least 48 mantissa bits for real(64) data.
//
// Open Issues
//
// 1. We would like to support general serial and parallel iterators
// on the RandomStream class, but this is not possible with our
// current parallel iterator framework.
//
// 2. The random number generation functionality in this module is
// currently restricted to 64-bit real, 64-bit imag, and 128-bit
// complex values.  This should be extended to other primitive types
// for which this would make sense.  Coercions are insufficient.
//
// 3. Can the multiplier 'arand' be moved into the RandomStream class
// so that it can be changed by a user of this class.
//
// 4. By default, the random stream seed is initialized based on the
// current time in microseconds, allowing for some degree of
// randomness.  The intent of the SeedGenerator enumerated type is to
// provide a menu of options for initializing the random stream seed,
// but only one option is implemented to date.
//
// Note on Private
//
// It is the intent that once Chapel supports the notion of 'private',
// everything prefixed with RandomPrivate_ will be made private to
-uu-:---F1  Random.chpl    Top L1     (Chapel/l Abbrev)------------------------
Mark set
```

```
bradc — ssh bradc@troll.cray.com — bash
File Edit Options Buffers Tools chpl Help
// Copyright (c) 2004-2013, Cray Inc.  (See LICENSE file for more details)


extern type qio_regexp_t;

extern record qio_regexp_options_t {
  var utf8:bool;
  var posix:bool;
  var literal:bool;
  var nocapture:bool;
  // These ones can be set inside the regexp
  var ignorecase:bool; // (?i)
  var multiline:bool; // (?m)
  var dotnl:bool; // (?s)
  var nongreedy:bool; // (?U)
}

extern proc qio_regexp_null():qio_regexp_t;
extern proc qio_regexp_init_default_options(ref options:qio_regexp_options_t);
extern proc qio_regexp_create_compile(str:string, strlen:int(64), ref options:q\
io_regexp_options_t, ref compiled:qio_regexp_t);
extern proc qio_regexp_create_compile_flags(str:string, strlen:int(64), flags:s\
tring, flagslen:int(64), isUtf8:bool, ref compiled:qio_regexp_t);
extern proc qio_regexp_create_compile_flags_2(str:c_ptr, strlen:int(64), flags:\
c_ptr, flagslen:int(64), isUtf8:bool, ref compiled:qio_regexp_t);
extern proc qio_regexp_retain(ref compiled:qio_regexp_t);
extern proc qio_regexp_release(ref compiled:qio_regexp_t);

extern proc qio_regexp_get_options(ref regexp:qio_regexp_t, ref options: qio_re\
gexp_options_t);
extern proc qio_regexp_get_pattern(ref regexp:qio_regexp_t, ref pattern: string\
);
extern proc qio_regexp_get_ncaptures(ref regexp:qio_regexp_t):int(64);
extern proc qio_regexp_ok(ref regexp:qio_regexp_t):bool;
extern proc qio_regexp_error(ref regexp:qio_regexp_t):string;

extern const QIO_REGEXP_ANCHOR_UNANCHORED:c_int;
extern const QIO_REGEXP_ANCHOR_START:c_int;
extern const QIO_REGEXP_ANCHOR_BOTH:c_int;

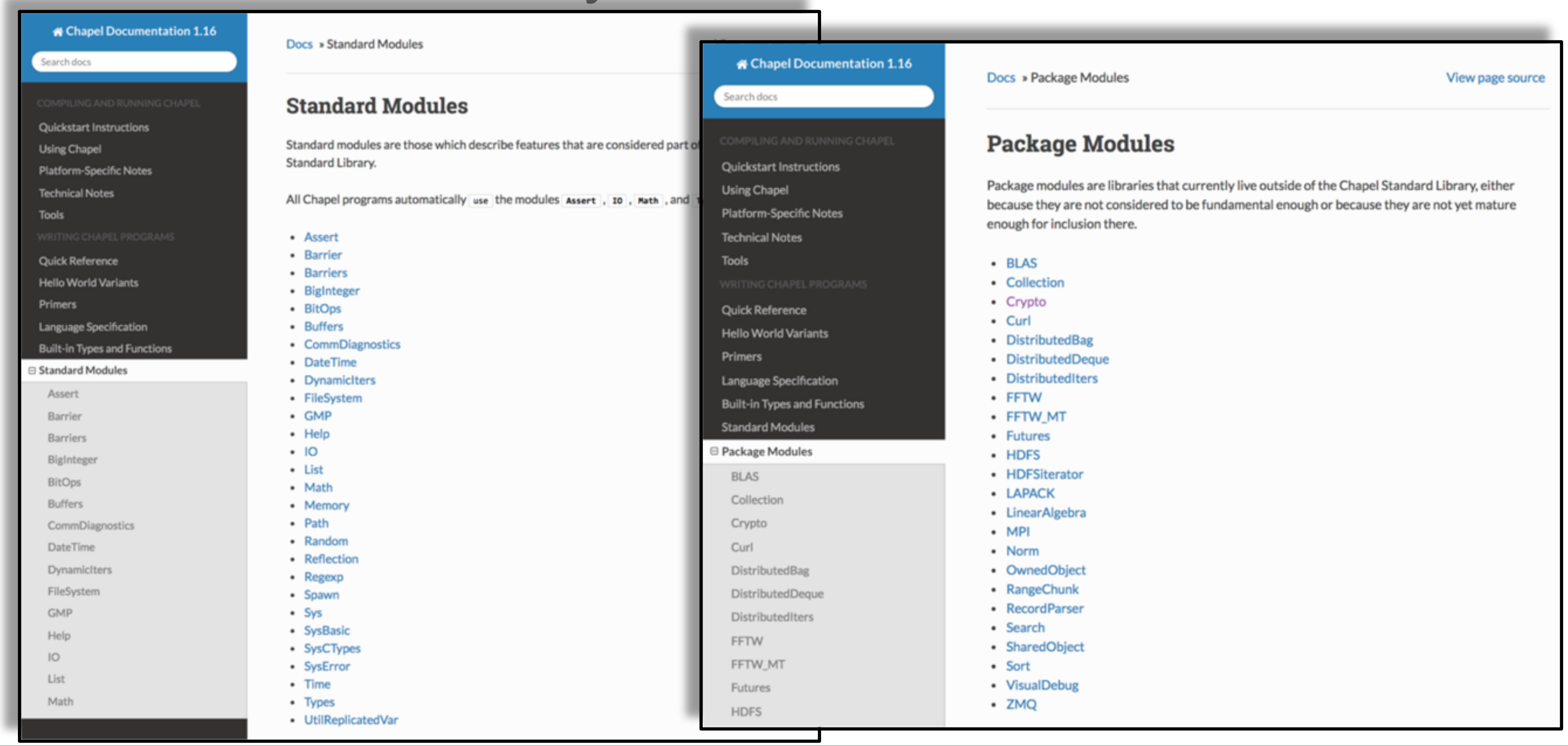
extern record qio_regexp_string_piece_t {
  var offset:int(64); // counting from 0, -1 means "NULL"
  var len:int(64);
}

extern proc qio_regexp_string_piece_isnull(ref sp:qio_regexp_string_piece_t):bo\
ol;
-uu-:---F1  Regexp.chpl    Top L1     (Chapel/l Abbrev)------------------------
```

Libraries: Now

Now: ~60 library modules

- web-documented, many user-contributed



Libraries: Now

Math: FFTW, BLAS, LAPACK, LinearAlgebra, Math

Inter-Process Communication: MPI, ZMQ (ZeroMQ)

Parallelism: Futures, Barrier, DynamicIters

Distributed Computing: DistributedIters, DistributedBag, DistributedDeque, Block, Cyclic, Block-Cyclic, …

File Systems: FileSystem, Path, HDFS

Others: BigInteger, BitOps, Crypto, Curl, DateTime, Random, Reflection, Regexp, Search, Sort, Spawn, …

Tools: Then

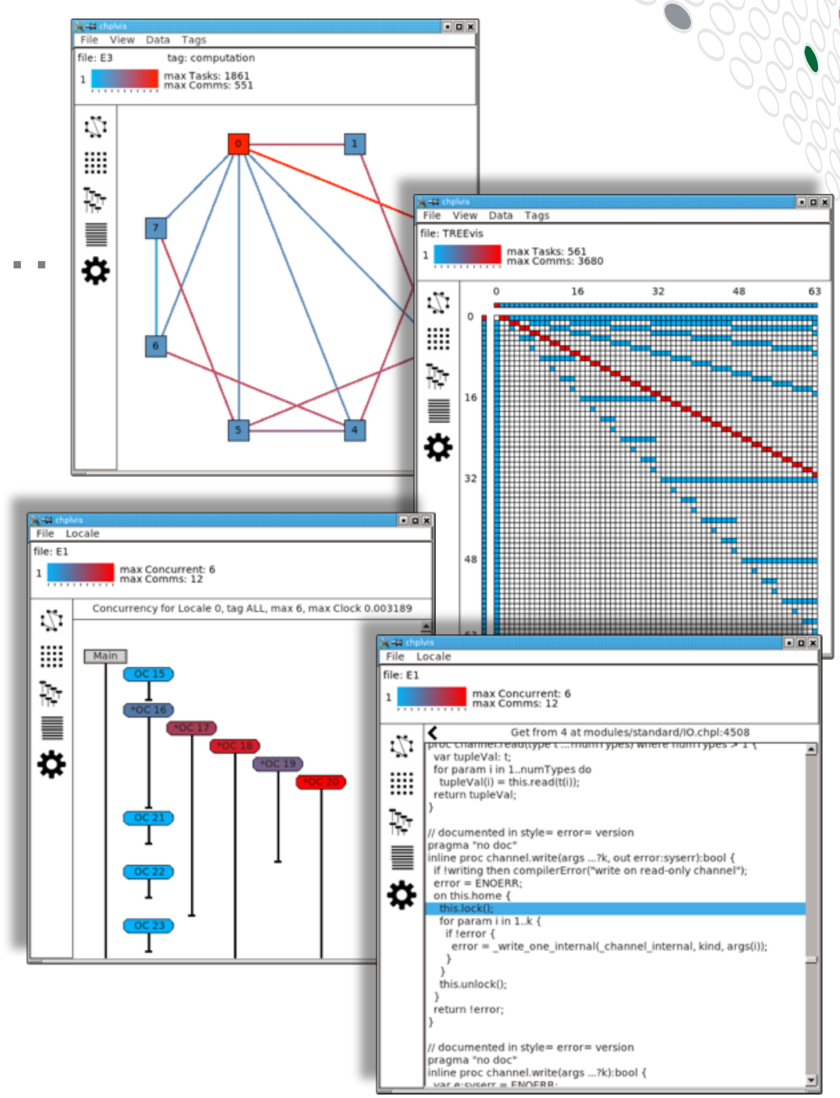
After HPCS:

- **highlighting modes** for emacs and vim
- **chpldoc:** documentation tool (early draft)

Tools: Now

Now:

- **highlighting modes** for emacs, vim, atom, …
- **chpldoc:** documentation tool
- **mason:** package manager
- **c2chapel:** interoperability aid
- **bash tab completion:** command-line help
- **chplvis:** performance visualizer / debugger



Then vs. Now: And so much more…

Interoperability:

- passing arrays & functions to C, working with C pointers, …

Development process:

- GitHub, Jenkins, Travis, interactive nightly performance graphs…

Social media: Twitter, Facebook, YouTube

User support: GitHub issues, StackOverflow, Gitter, email

Web presence: CLBG, Try It Online, CyberDojo, …

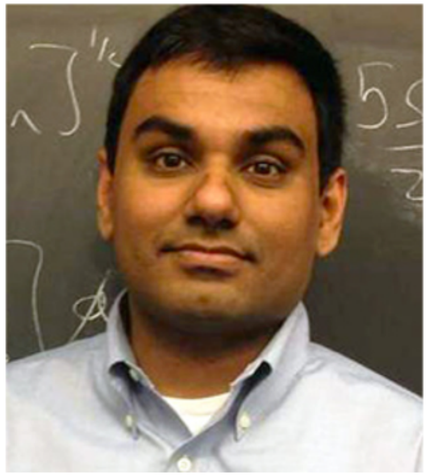
Memory Leaks: significantly reduced

CHIUW: annual community workshop

Chapel User Profiles

Chapel User Profiles

Current Users:



Time-to-science Cosmologist

Commercial AI Scientist

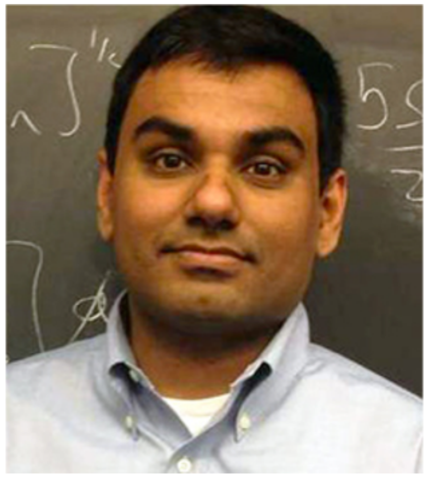
Potential Users:

Genomic Researcher

DOE Scientist

Chapel User Profiles

Current Users:

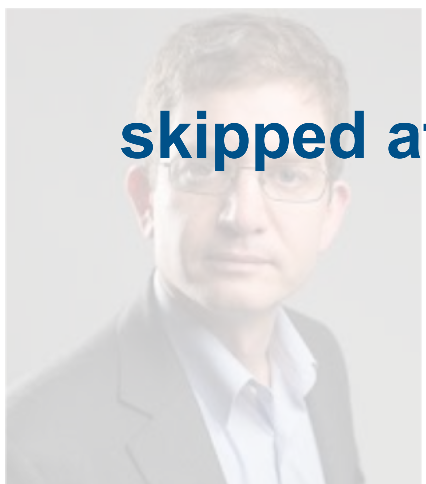


Time-to-science Cosmologist

Commercial AI Scientist

skipped at CUG due to time constraints

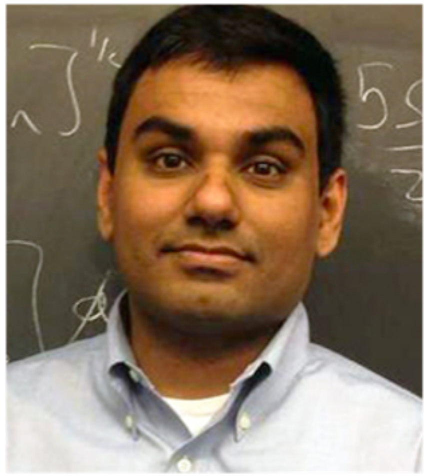
Potential Users:



Genomic Researcher

DOE Scientist

User Profile: Time-to-Science Cosmologist



Name: **Nikhil Padmanabhan**

Title: **Associate Professor of Physics and Astronomy, Yale University**

Computations: **Surveys of galaxies to constrain cosmological models, n-body simulations of gravity**

Why Chapel? "My interests in Chapel developed from a desire to have a lower barrier to writing parallel codes. In particular, I often find myself writing prototype codes (often serial), but then need to scale these codes to run on large numbers of simulations/datasets. **Chapel allows me to smoothly transition from serial to parallel codes with a minimal number of changes.**

"Another important issue for me is "my time to solution" (some measure of productivity vs performance). Raw performance is rarely the only consideration."

User Profile: Commercial AI Scientist

Name: Brian Dolan

Title: Co-Founder and Chief Scientist of Deep 6 AI

Computations: Natural language processing, AI and ML applications, network analysis, community detection, reinforcement learning in the form of Deep Q-Networks

Why Chapel? "I have used Fortran, R, Java and Python extensively. If I had to give up Chapel, I would probably move to C++. **I prefer Chapel due to the extreme legibility and performance.** We have abandoned Python on large problems for performance reasons.

"**We've now developed thousands of lines of Chapel code and a half dozen open source libraries** for things like database connectivity, numerical libraries, graph processing, and even a REST framework. We've done this because AI is about to face an HPC crisis, and the folks at Chapel understand the intersection of usability and scalability."

Potential User Profile: Genomic Researcher

Name: **Jonathan Dursi**

Title: **Senior Research Associate, The Hospital for Sick Children, Toronto**

Computations: **Human genomics, bioinformatics, and medical informatics**

Why Chapel? "My interest in Chapel lies in its potential for bioinformatics tools that are currently either written in elaborately crafted, threaded but single node, C++ code, or in Python. Either has advantages and disadvantages (performance vs rapid development cycles), but neither has a clear path to cross-node computation, for performance as well as larger memory and memory bandwidth. **Chapel has the potential to have some of the best of both worlds in terms of C++ and Python, as well as having a path to distributed memory.**"

Potential User Profile: DOE Scientist

Name: Anshu Dubey

Title: Computer Scientist, Argonne National Laboratory

Computations: Design and development of Multiphysics software that can serve multiple science domains; solvers for PDEs and ODEs

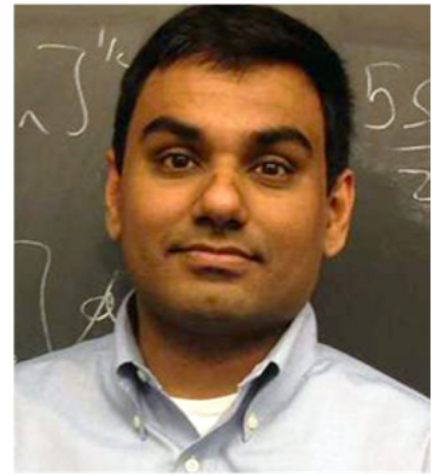
Why Chapel? "In Multiphysics applications separation of concerns and use of high level abstractions is critical for sustainable software. Chapel combines language features that would enable this for clean implementation.

"HPC Scientific software is made more complex than it needs to be because the only language designed for scientific work, Fortran, is losing ground for various reasons. Its object oriented features are clunky and make it nearly as unsuitable as other languages for scientific work. **Chapel appears to be parallel and modern Fortran done better, therefore has the potential to become a more suitable language.**"

Chapel and Productivity

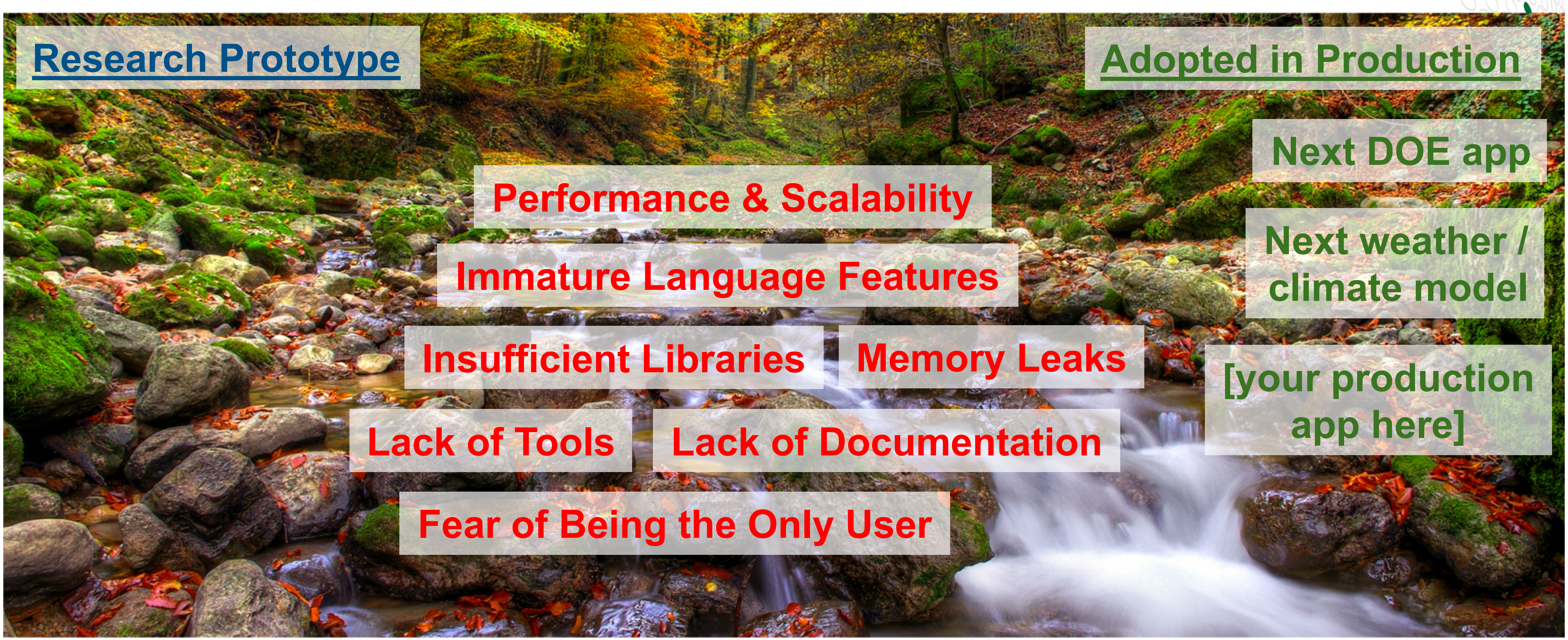
Chapel aims to be as…

- …**programmable** as Python
- …**fast** as Fortran
- …**scalable** as MPI, SHMEM, or UPC
- …**portable** as C
- …**flexible** as C++
- …**fun** as [your favorite language]



What's Next?

Crossing the Stream of Adoption



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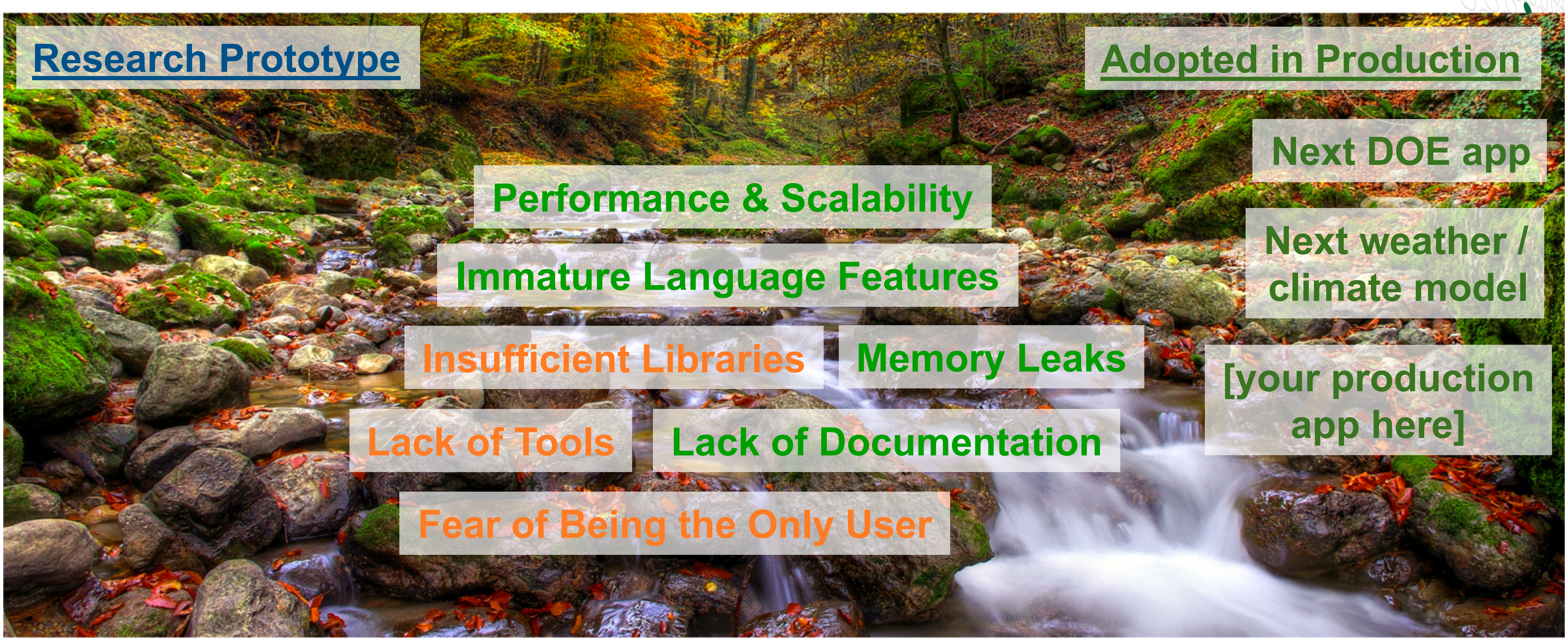
Crossing the Stream of Adoption



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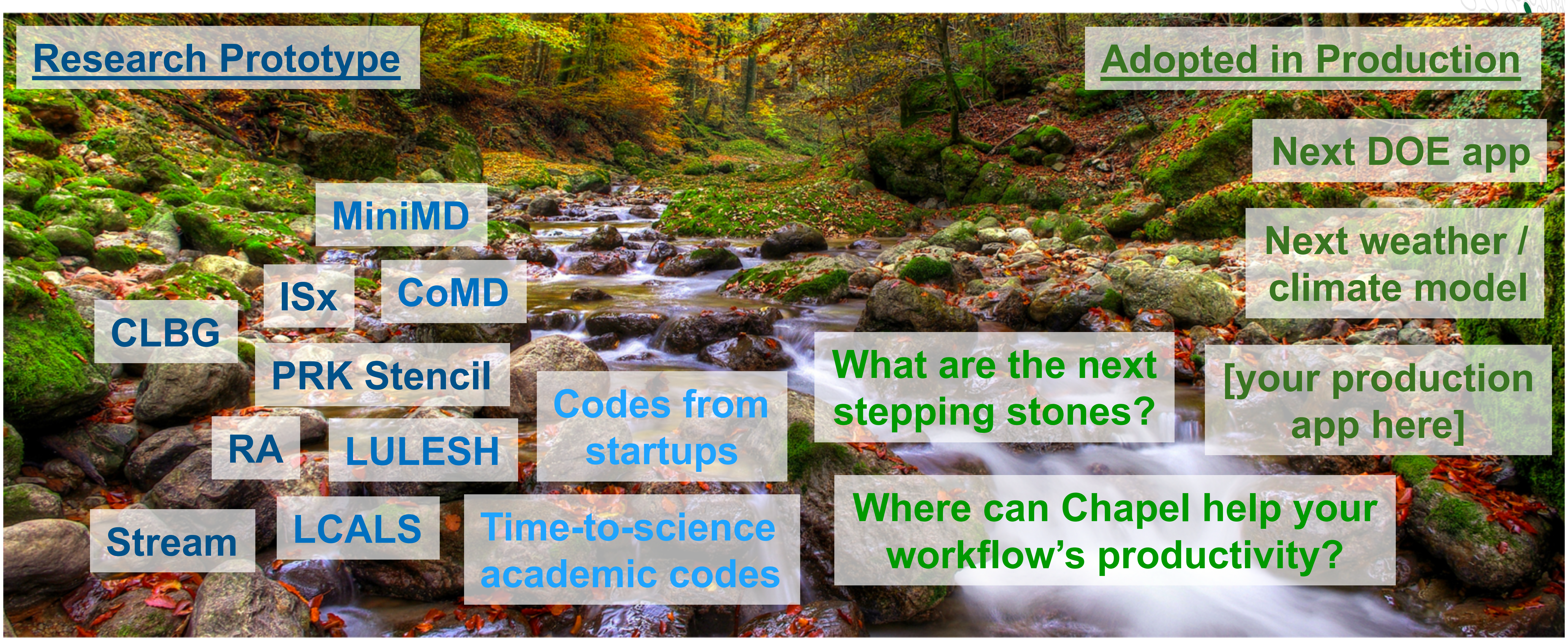
Crossing the Stream of Adoption



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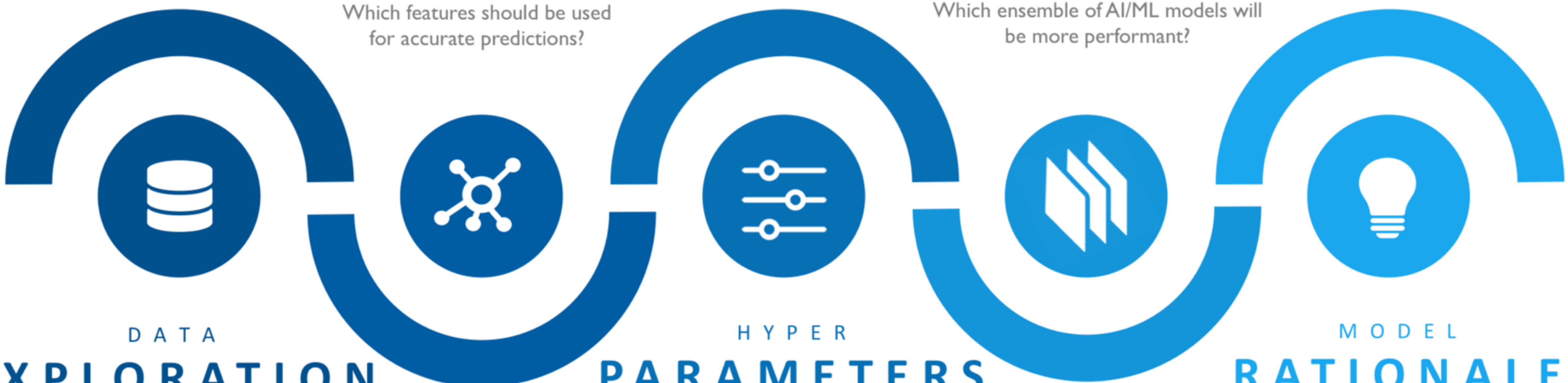
Discovery Roadblocks

Data Science Pain Points

SELECTING
FEATURES
Which features should be used for accurate predictions?

MODEL
ENSEMBLES
Which ensemble of AI/ML models will be more performant?

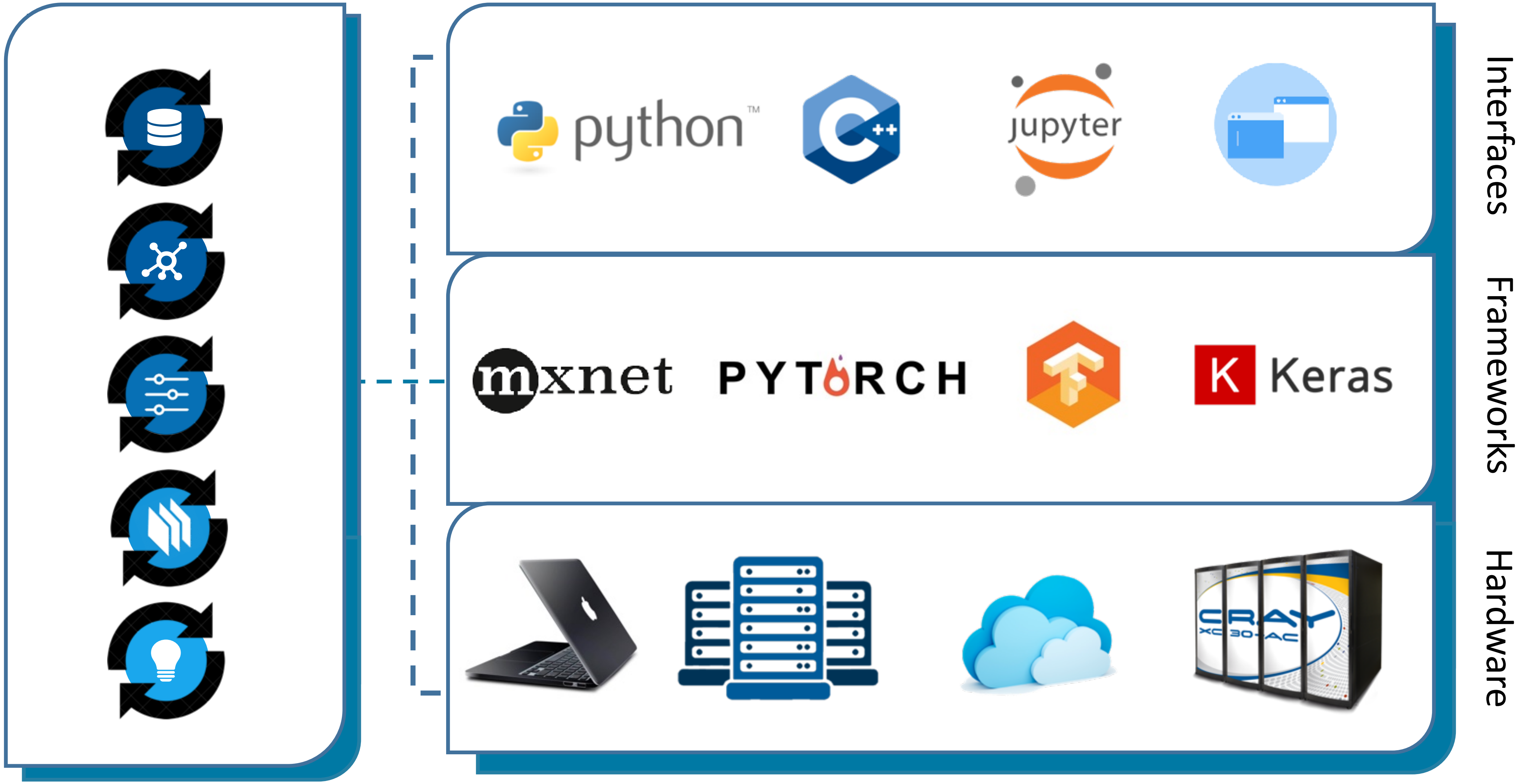


DATA
EXPLORATION
Do I fully understand my data? Does it need to be cleaned?

HYPER
PARAMETERS
What are the correct values to set the variables to before training?

MODEL
RATIONALE
Do I trust my model? Why does it predict that way?

Chapel AI Ecosystem



Sample Chapel AI Workflow

- **User works from within a Jupyter notebook**
- **Uses Chapel to ingest large HDF5 data files**
  - read in parallel
  - transformed / analyzed during ingestion
  - stored in a distributed Dataframe

- **Starts working on model locally on laptop**
- **As confidence in model grows, tunes it at scale**
  - feature selection
  - hyperparameter optimization

What's Next?

Chapel's college years: plans for 2018-2021

- **Language Core**
- **Interoperability / Usability**
- **Portability**
- **Data Ingestion**
- **Chapel AI**

What's Next?

Chapel's college years: plans for 2018-2021

- **Language Core**
  - Language stabilization: avoid backward-breaking changes
  - Sparse array improvements, partial reductions, delete-free features, …
  - Additional performance and scalability improvements
- **Interoperability / Usability**
- **Portability**
- **Data Ingestion**
- **Chapel AI**

What's Next?

Chapel's college years: plans for 2018-2021

- Language Core
- **Interoperability / Usability**
  - Python / C++ interoperability
  - Support for Jupyter notebooks / REPL
- Portability
- Data Ingestion
- Chapel AI

What's Next?

Chapel's college years: plans for 2018-2021

- **Language Core**
- **Interoperability / Usability**
- **Portability**
  - LLVM back-end
  - Target Libfabric/OFI
  - Target GPUs
  - Cloud computing support
- **Data Ingestion**
- **Chapel AI**

What's Next?

Chapel's college years: plans for 2018-2021

- **Language Core**
- **Interoperability / Usability**
- **Portability**
- **Data Ingestion**
  - Support HDF5, NetCDF, CSV, …
  - Transform-on-ingest
  - Distributed DataFrames support
- **Chapel AI**

What's Next?

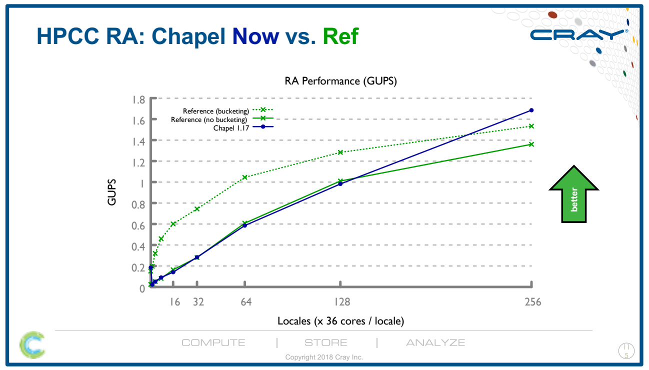
Chapel's college years: plans for 2018-2021

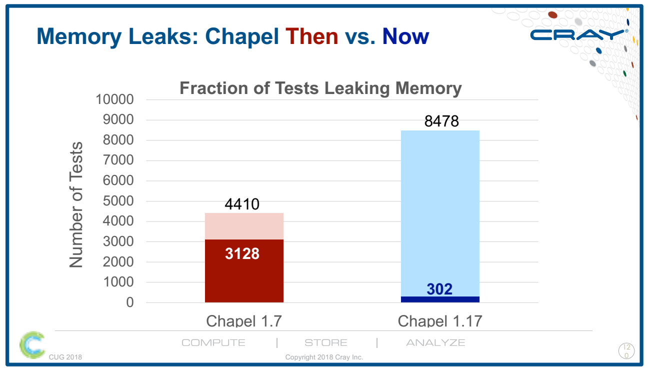
- **Language Core**
- **Interoperability / Usability**
- **Portability**
- **Data Ingestion**
- **Chapel AI**
  - Hyperparameter optimization
  - Deep Learning
  - …

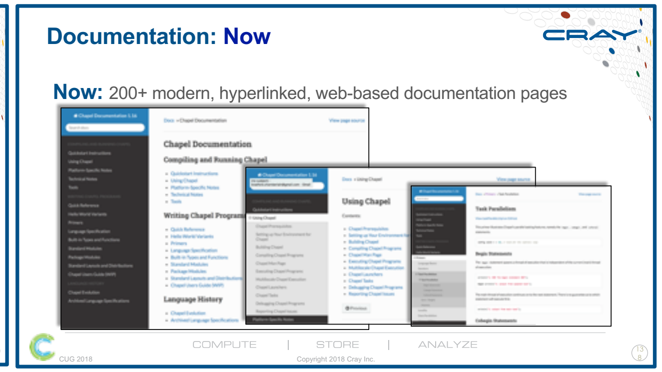
Summary

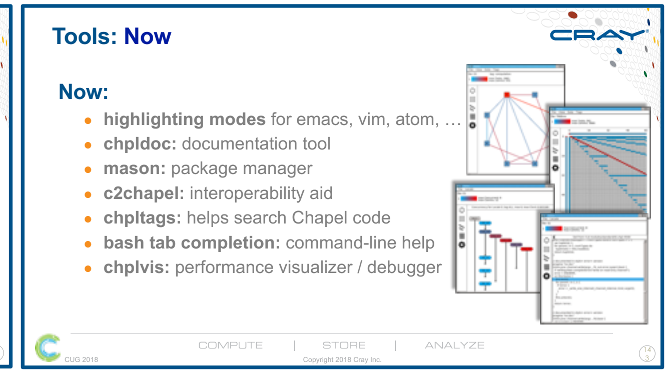
Chapel has made huge strides over the past five years

We've addressed many historical barriers to using Chapel









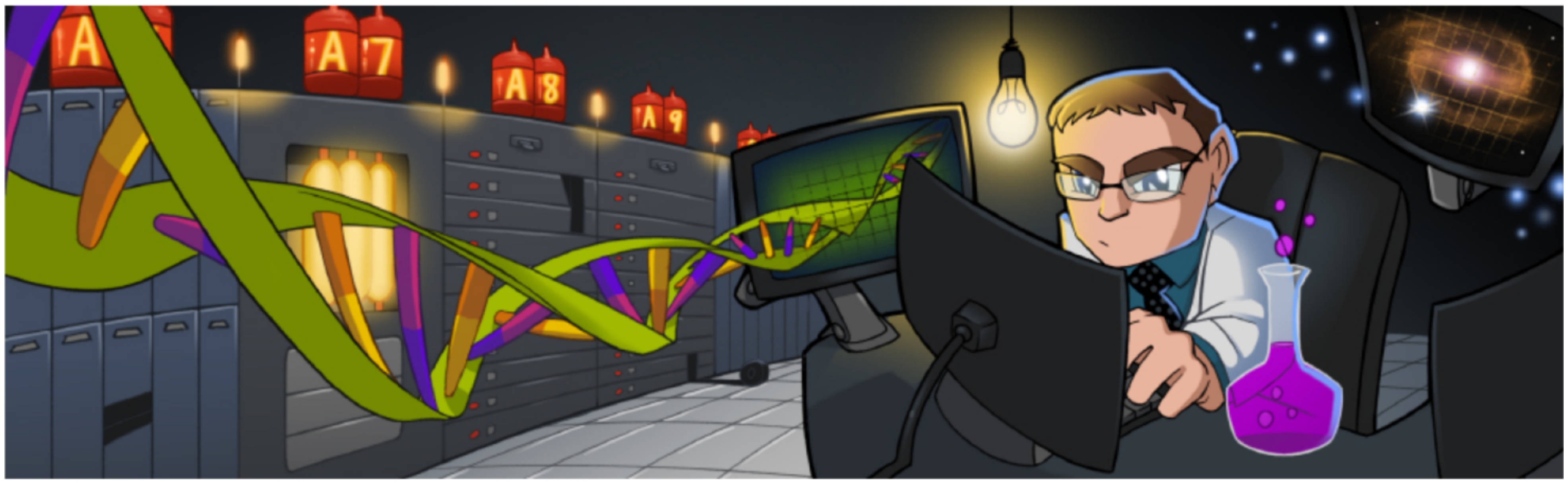
We're continuing our work to support and improve Chapel

We're looking for the next generation of Chapel users, as well as concrete use cases for AI / ML

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…that are actually designed for our problems, they’re going to come from a project like Chapel.

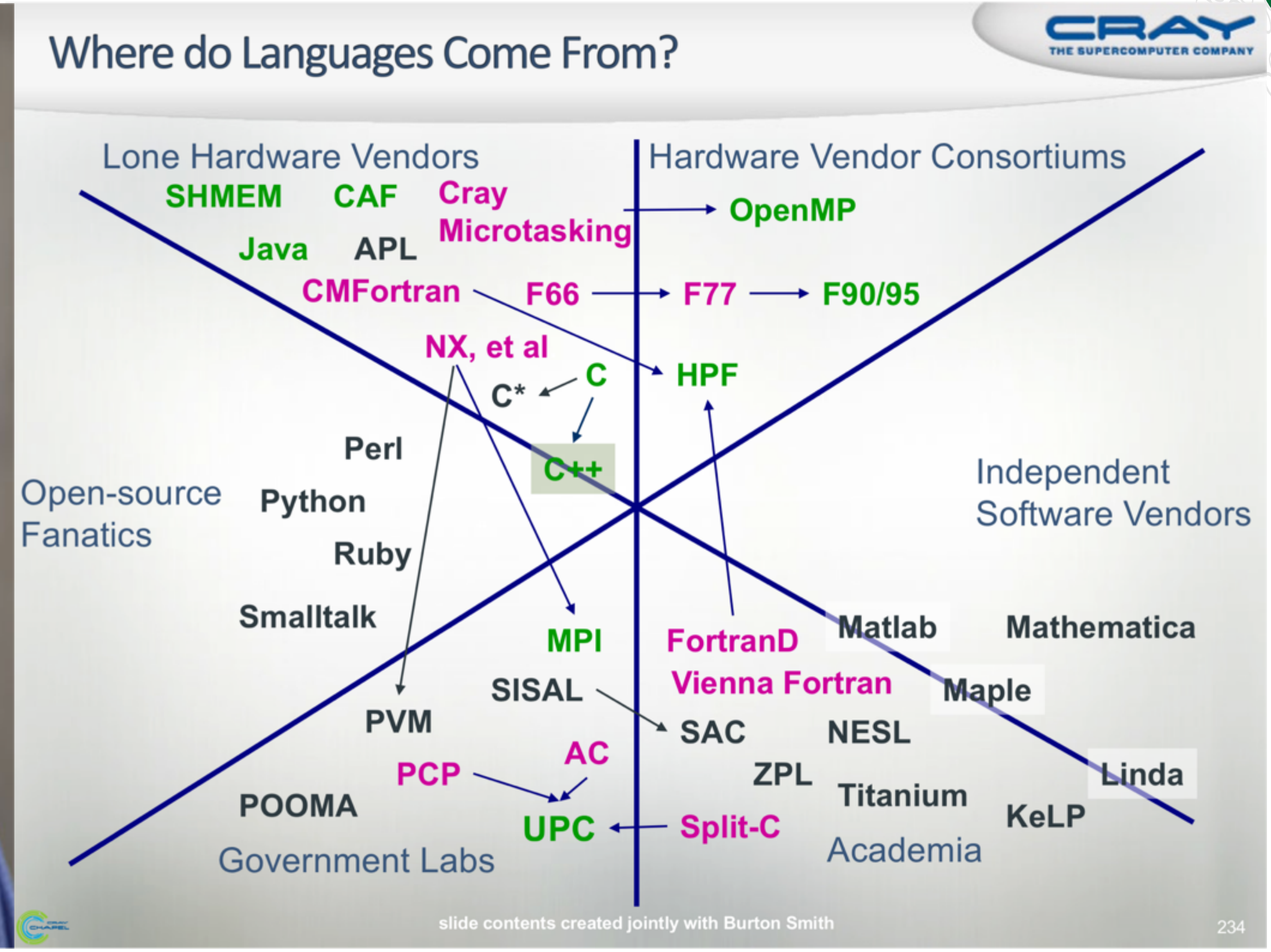
“And the thing about Chapel is that the set of all things that are ‘projects like Chapel’ is ‘Chapel.’”

–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

Dedicated to the Memory of Burton Smith

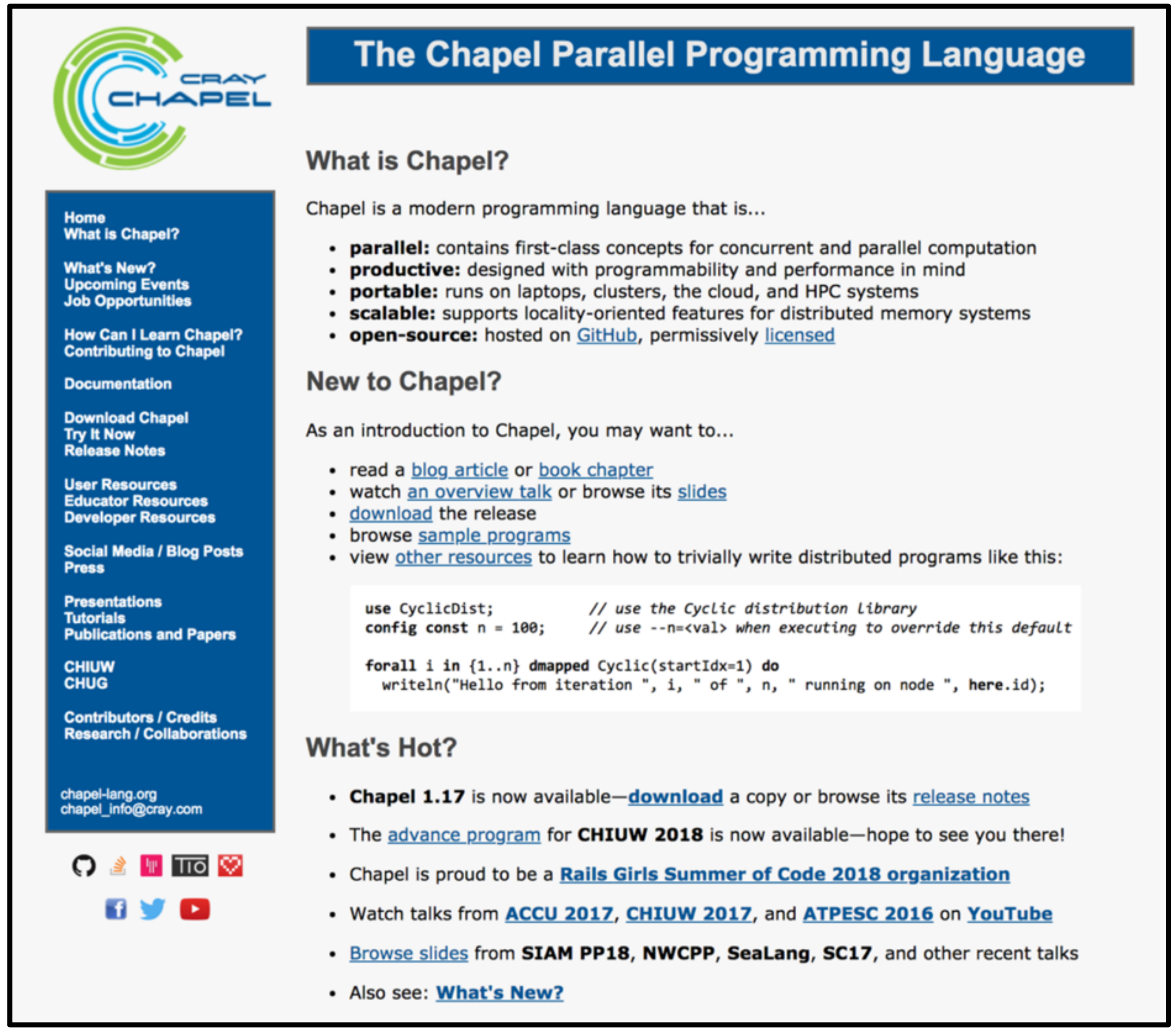


Chapel Resources

Chapel Central

https://chapel-lang.org

- downloads
- documentation
- resources
- presentations
- papers



Chapel Social Media (no account required)

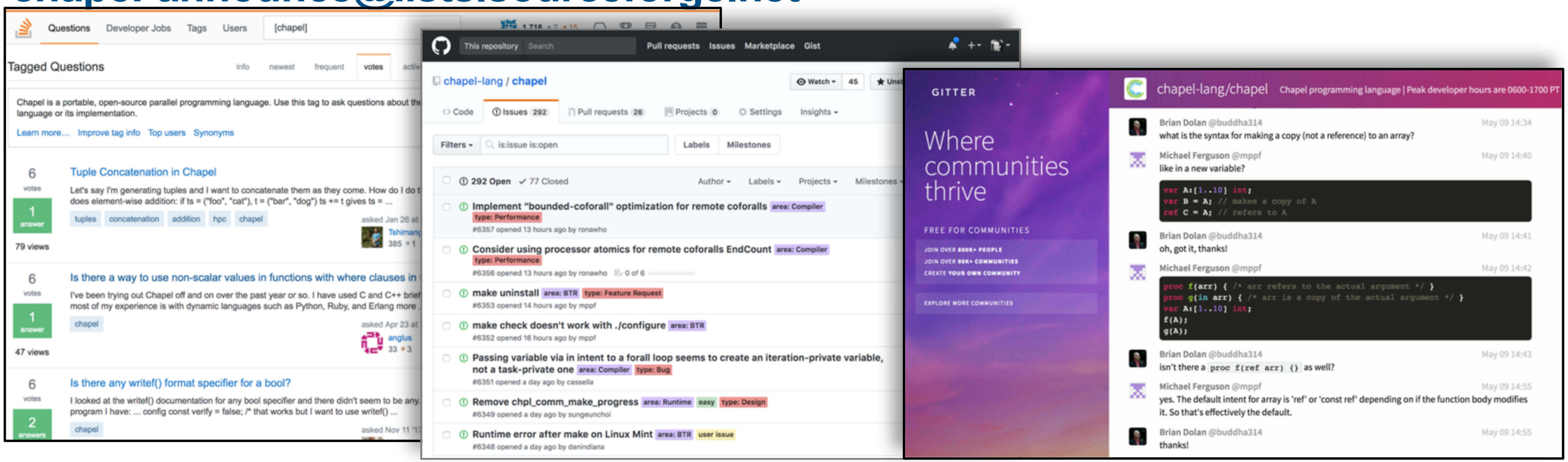
http://twitter.com/ChapelLanguage

http://facebook.com/ChapelLanguage

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

Chapel Community

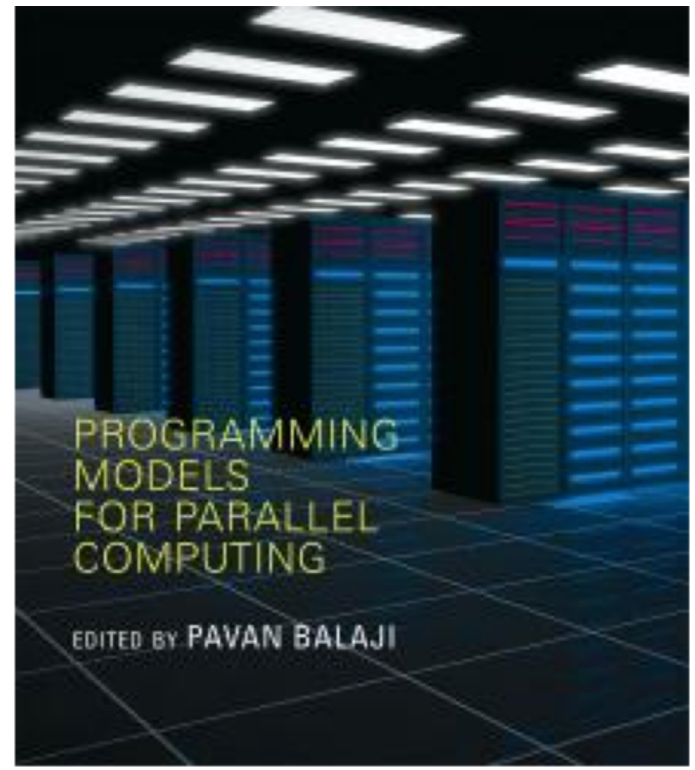
https://stackoverflow.com/questions/tagged/chapel
https://github.com/chapel-lang/chapel/issues
https://gitter.im/chapel-lang/chapel
chapel-announce@lists.sourceforge.net



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 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 (as of 2017)*

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*

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

Gitter (chapel-lang/chapel): community chat with archives

chapel-users@lists.sourceforge.net: user discussions

Discuss Chapel development

chapel-developers@lists.sourceforge.net: developer discussions

GitHub issues for chapel-lang/chapel: for feature requests, design discussions

Discuss Chapel's use in education

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

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

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Q&A

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