Benchmarks and Performance Optimizations

Chapel Team, Cray Inc.

Chapel version 1.16

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Outline

- **PRK Case Study**
  - Bounded Coforall Optimization
  - StencilDist updateFluff() Optimization
  - Dynamic Registration Impact
  - Array Locality Optimization
- **ISx Benchmark Improvements**
  - Record Serialization
  - Task Counting Improvements
- **Computer Language Benchmarks Game Update**
- **Reductions in Memory Leaks**

PRK Case Study

PRK: Background

- **PRK: Parallel Research Kernels**
  - Compact set of parallel apps distilled from real benchmarks
  - 12 kernels, each testing a different parallel idiom
    - stencil, particle-in-cell, matrix transpose, sparse matrices, and more
  - Developed by Intel

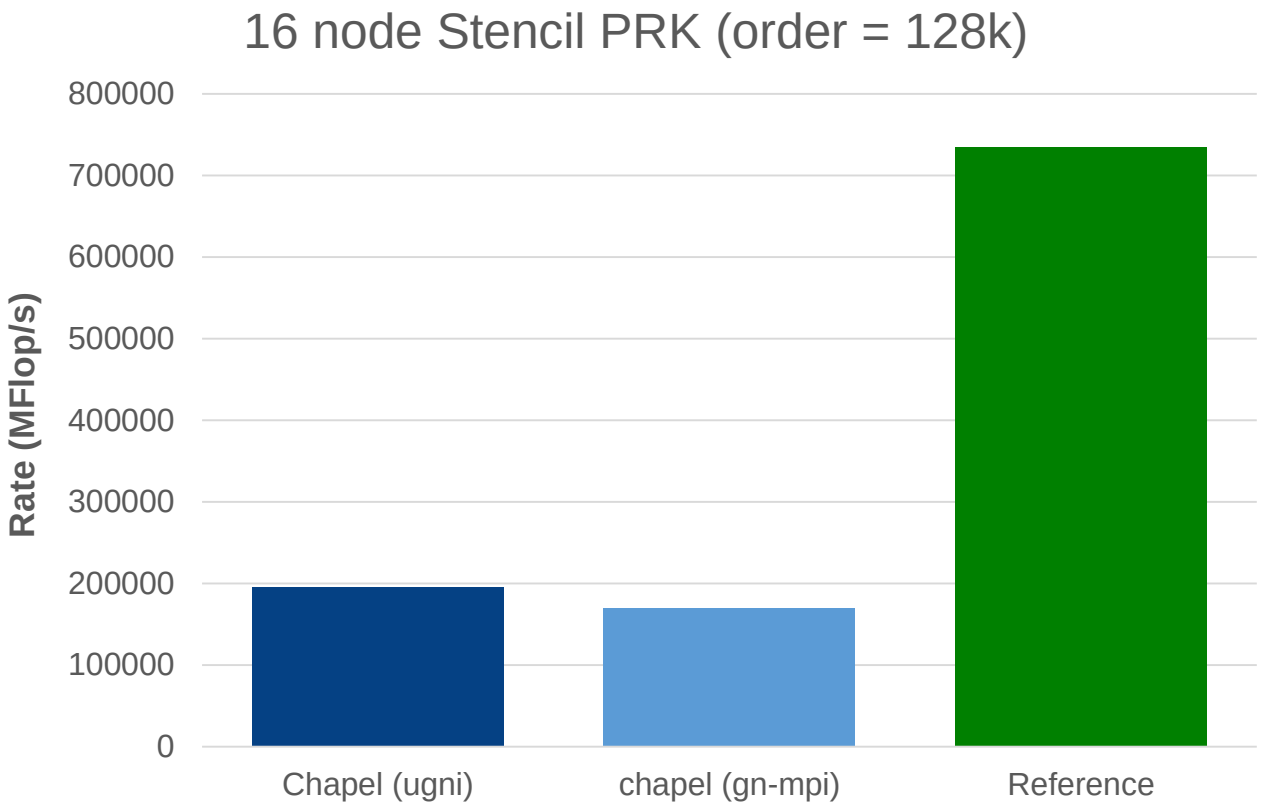
- **Focused on Stencil PRK for this release**
  - Added an “optimized” variant that sacrifices some elegance
    - used array localAccess instead of direct indexing

      `input.localAccess[i, j]` *// instead of input[i,j]*
    - used a local block to squash communication

      `forall` `(i,j)` **`in`** `innerDom` **`do local`** *// instead of **forall** (i, j) **in** innerDom*

PRK: Background

- **Optimized stencil still lagged behind reference in 1.15**
  - Chapel was 3-4x slower than reference OpenMP+MPI version



Bounded Coforall Optimization

Bounded Remote Coforall: Background

- **Remote coforalls were transformed by the compiler, from:**

```
coforall loc in Locales do on loc { body(); }
```

roughly into:

```
var endCount: atomic int;

for loc in Locales {
  endCount.add(1);                          // note: incrementing counter once per task
  executeOnNB(bodyWrapper, endCount);
}
endCount.waitFor(0);

proc bodyWrapper(endCount) {
  body();
  endCount.sub(1);
}
```

Bounded Remote Coforall: This Effort

- **Minimize end-count manipulation for "bounded" coforalls**
  - "bounded" coforalls have a known trip-count (range/domain/array)

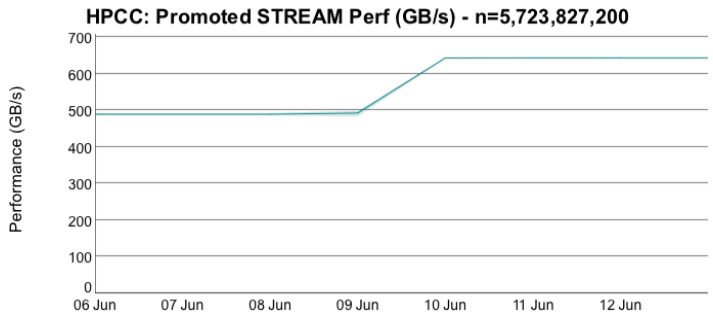
```
coforall loc in Locales do on loc { body(); }
```

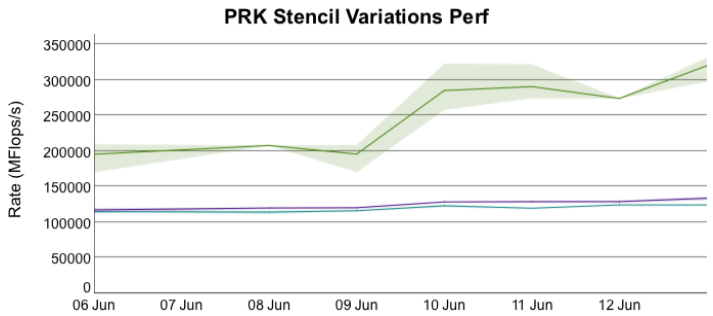
now roughly converted to:

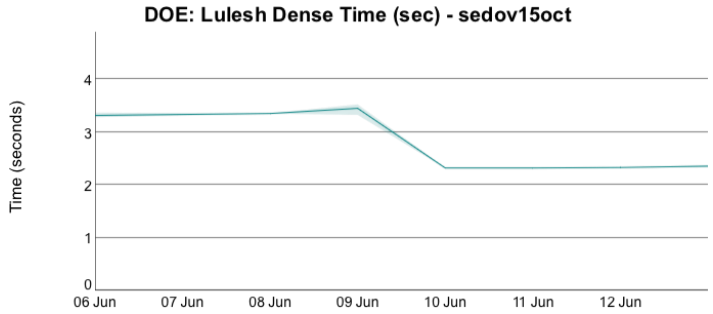
```
var tmpIter = Locales;
var numTasks = tmpIter.size
var endCount: atomic int;

endCount.add(numTasks);                    // single atomic op vs. op per task
for loc in tmpIter {
  executeOnNB(bodyWrapper, endCount);
}
endCount.waitFor(0);

proc bodyWrapper(endCount) { /* same as before */ }
```

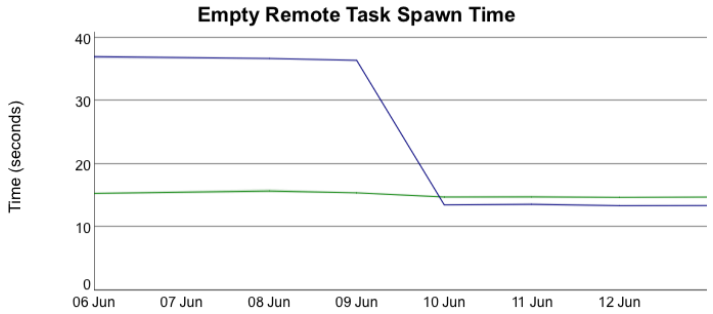
Bounded Remote Coforall: Impact

- Improved performance for several multi-locale benchmarks



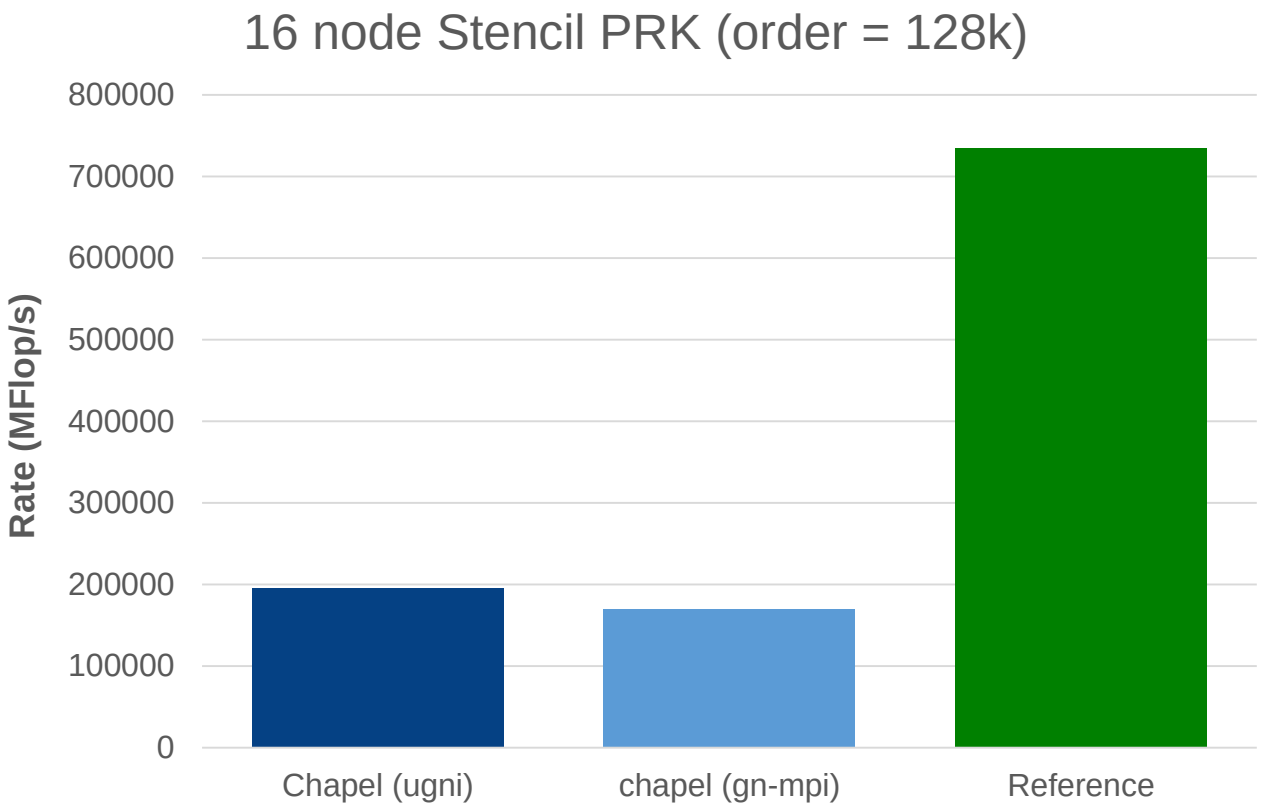






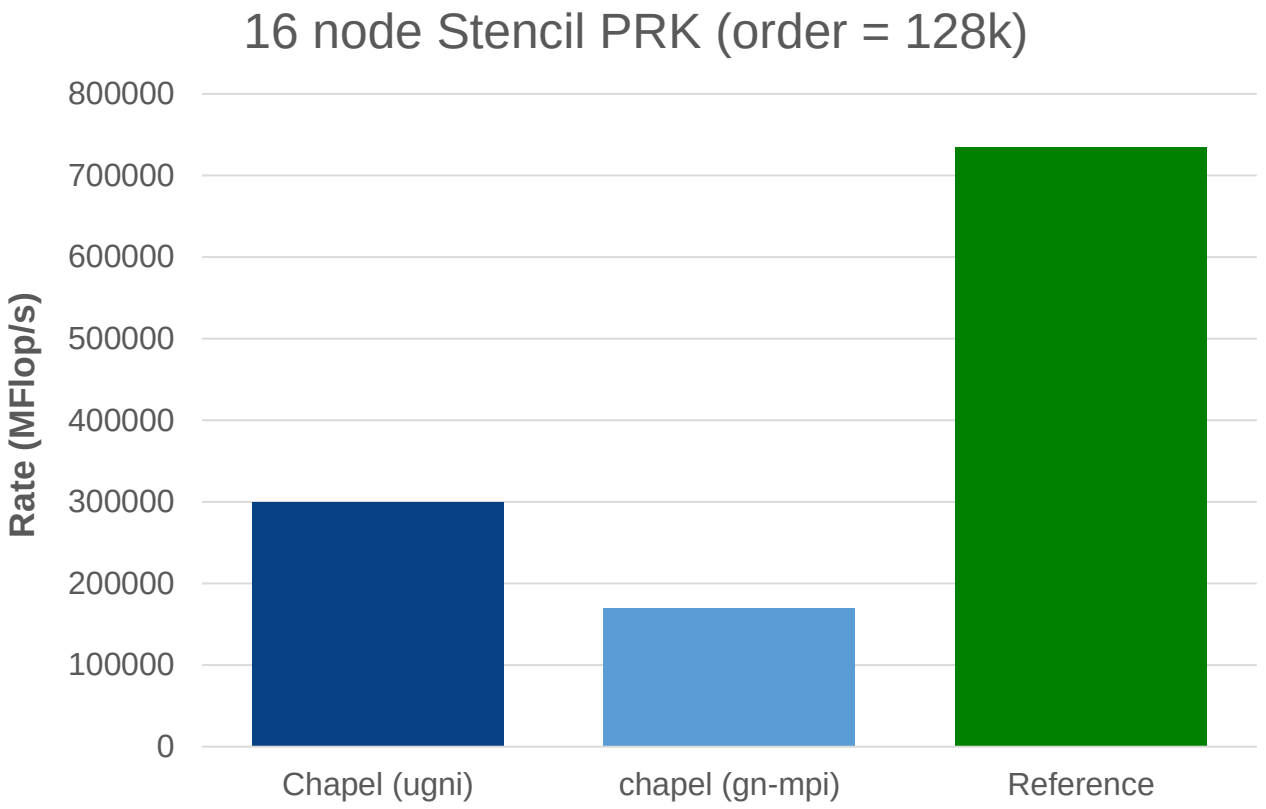
Bounded Remote Coforall: Stencil Impact

- **Previously Chapel was 3-4x slower than reference**



Bounded Remote Coforall: Stencil Impact

- **Previously Chapel was 3-4x slower than reference**
  - ugni version now ~1.5x faster than before

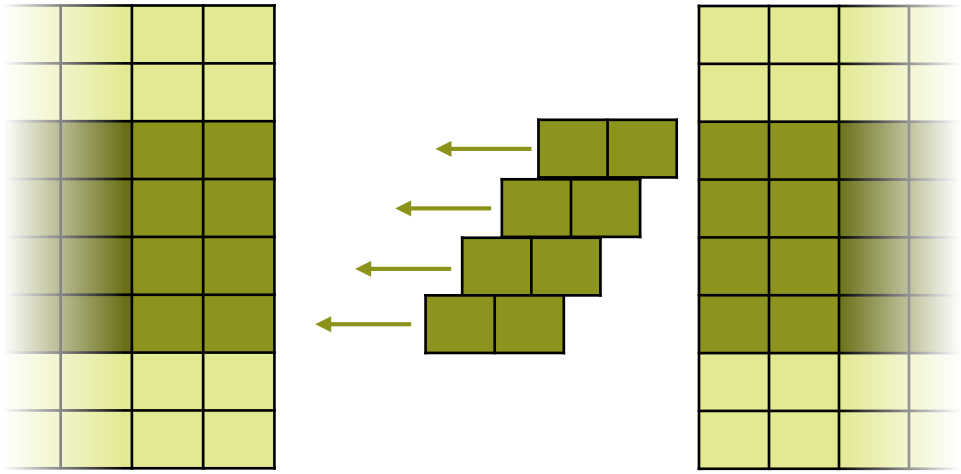


StencilDist updateFluff() Optimization

updateFluff: Background

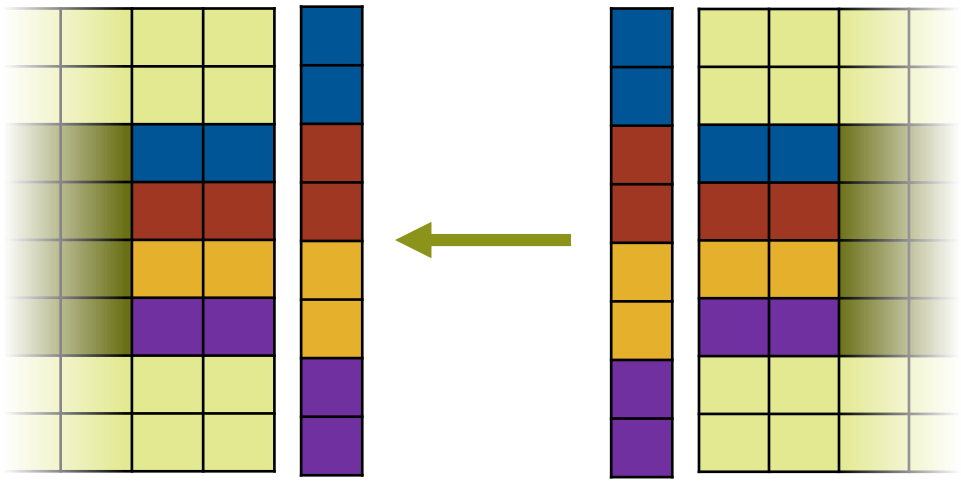
- **StencilDist: Block-like dist. for stencil computations**
  - Uses local cache of elements when read
  - 'updateFluff' method exchanges data with neighbors
  - Initially written for miniMD, now used by Stencil PRK and NPB MG

- **updateFluff naively exchanged elements**
  - Only bulk-transferred contiguous chunks at a time



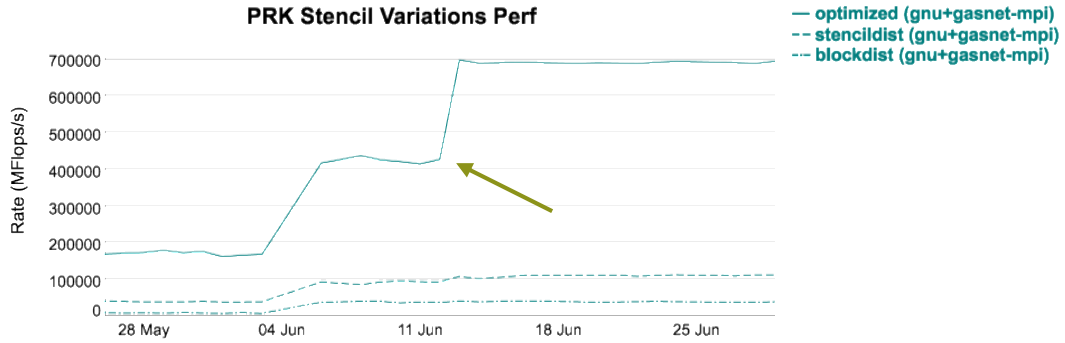
updateFluff: This Effort

- **Pack regions and perform one transfer**
  - Requires additional memory for buffers
  - Unpack on destination locale
  - Controlled by *'stencilDistAllowPackedUpdateFluff'* config param

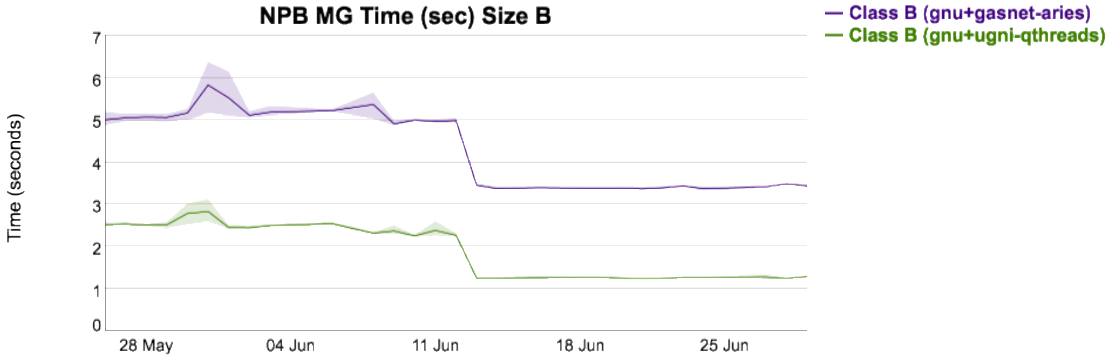


updateFluff: Impact

- Improved Stencil PRK under gasnet-mpi



- Also improved NPB MG



updateFluff: Status and Next Steps

Status:

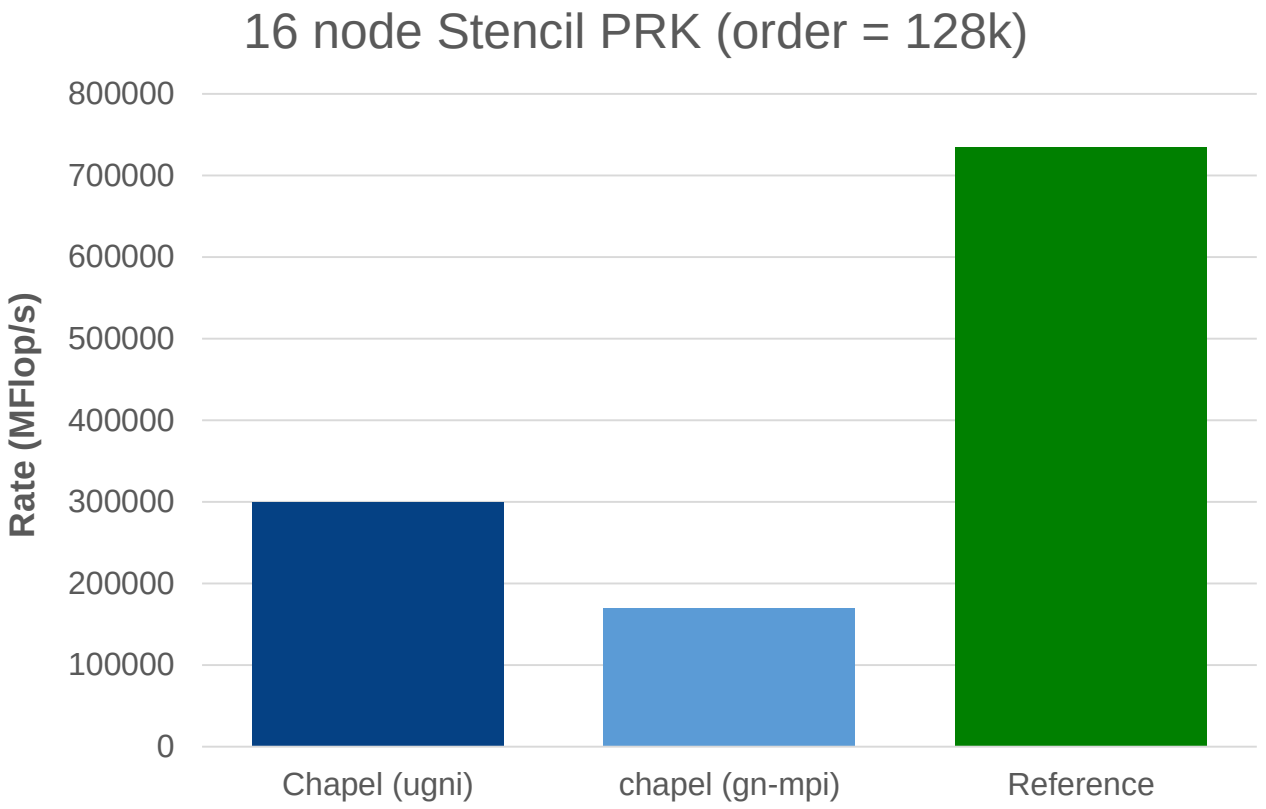
- Improved Stencil PRK and NPB MG performance
- Optimization enabled by default

Next Steps:

- Performance tuning
  - Not worth overhead for small numbers of elements
  - Find threshold that triggers the optimization

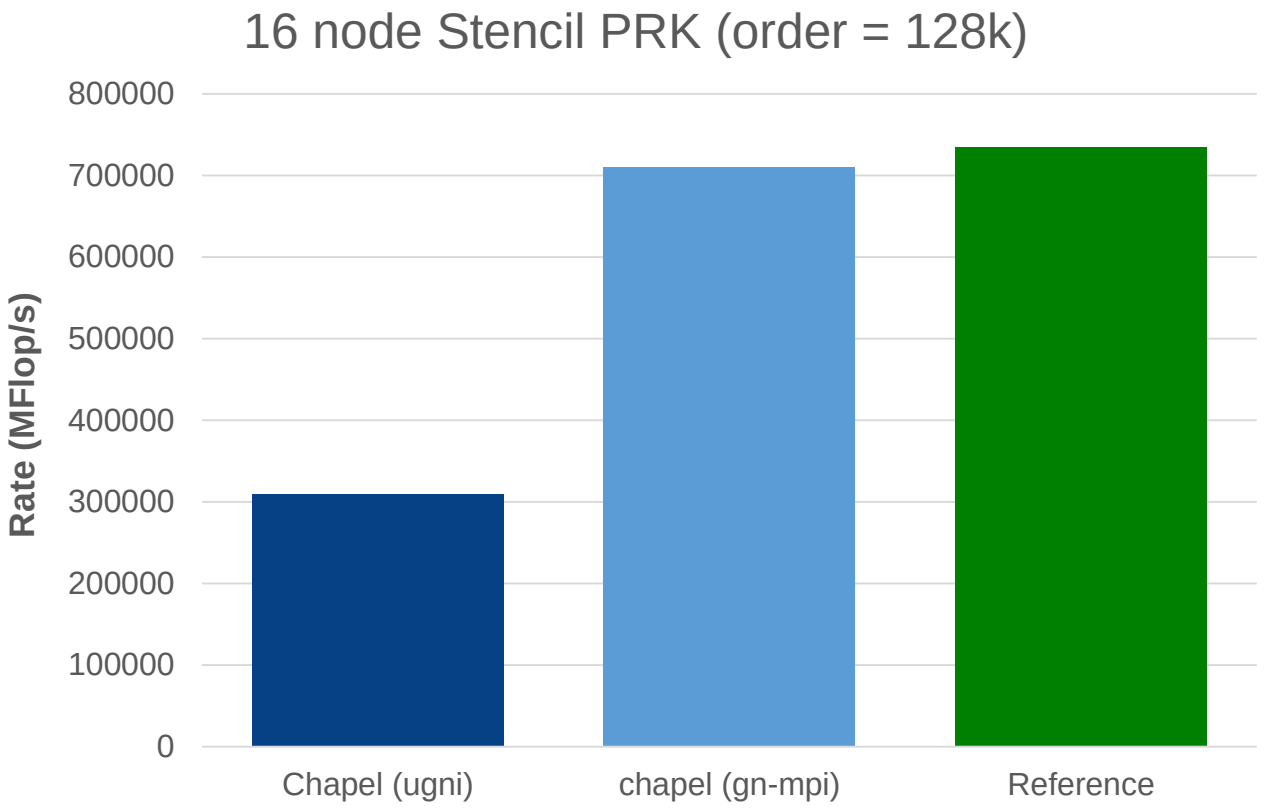
updateFluff: Stencil Impact

- **Previously Chapel was 2-4x slower than reference**



updateFluff: Stencil Impact

- **Previously Chapel was 2-4x slower than reference**
  - gn-mpi version is now on par with reference version (ugni still lagging)



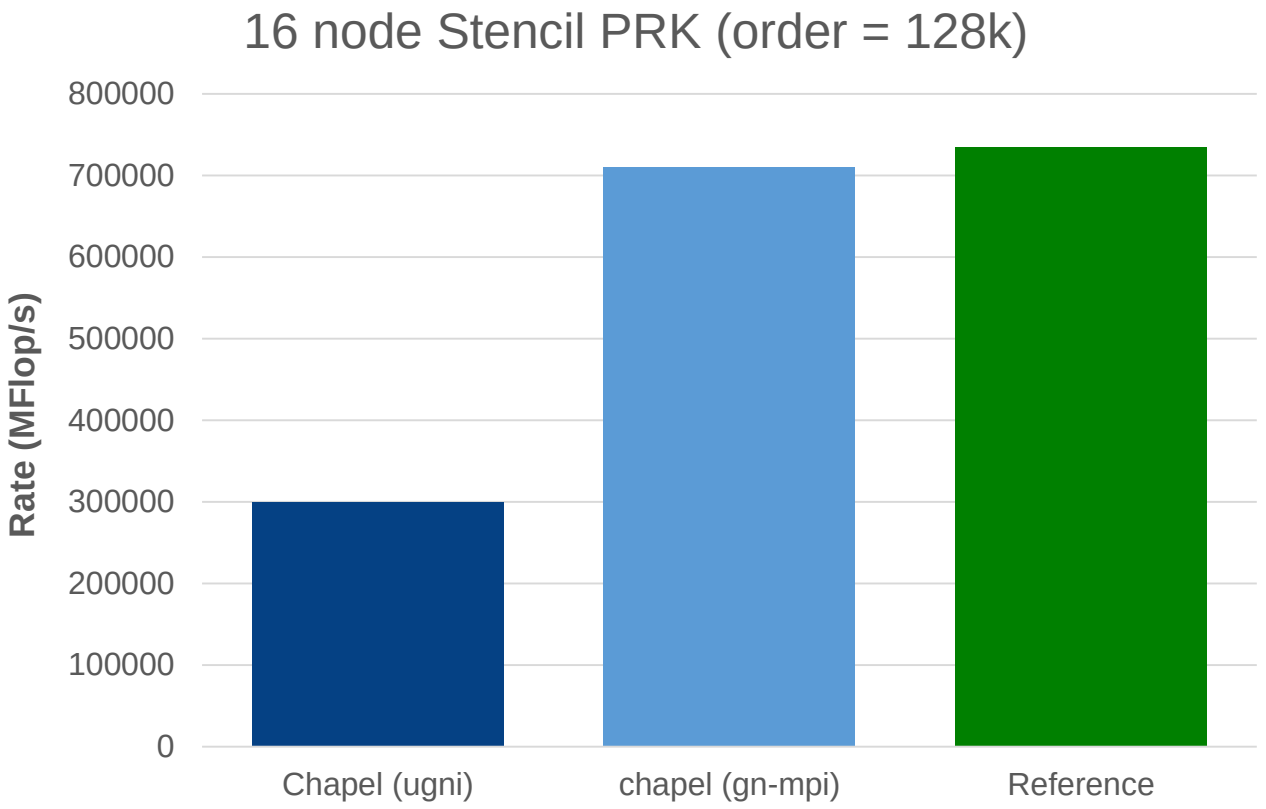
Dynamic Registration Impact

Dynamic Registration

- **Ugni performance was lagging behind gn-mpi**
  - Stencil PRK is sensitive to numa-affinity
- **Dynamic registration significantly improved performance**
  - Optimization detailed in runtime deck

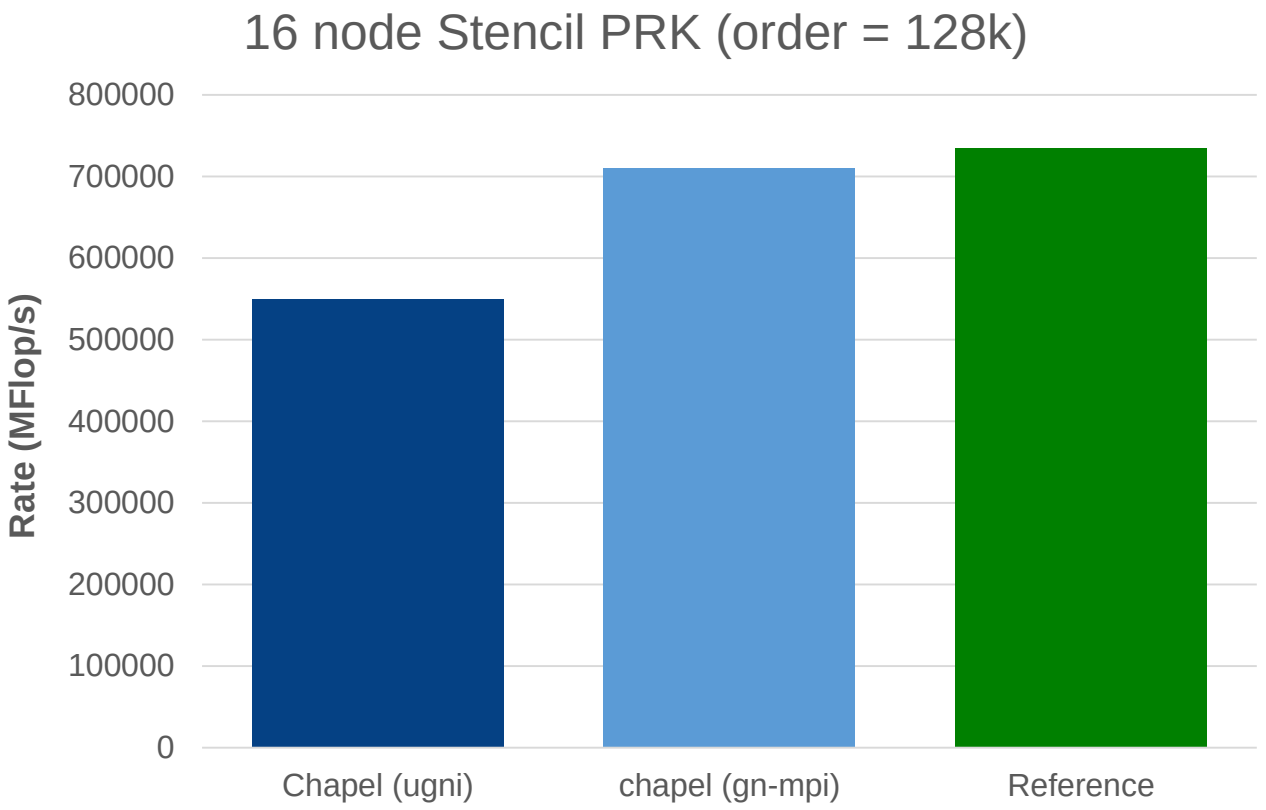
Dynamic Registration: Stencil Impact

- Previously ugni version was ~2.5x slower than reference



Dynamic Registration: Stencil Impact

- **Previously ugni version was ~2.5x slower than reference**
  - now 2x faster than before, though still behind reference and gn-mpi



Array Locality Optimization

Local Array Fields: Background

- **Optimized PRK used an inelegant local block**
  - Used to squash potential communication in array accesses

```
forall (i,j) in innerDom do local // instead of forall (i, j) in innerDom
```

- **"local field" pragma introduced in 1.11**
  - Marks a field as having the same locale as its parent
    - could be applied to classes, but not arrays

Local Array Fields: This Effort

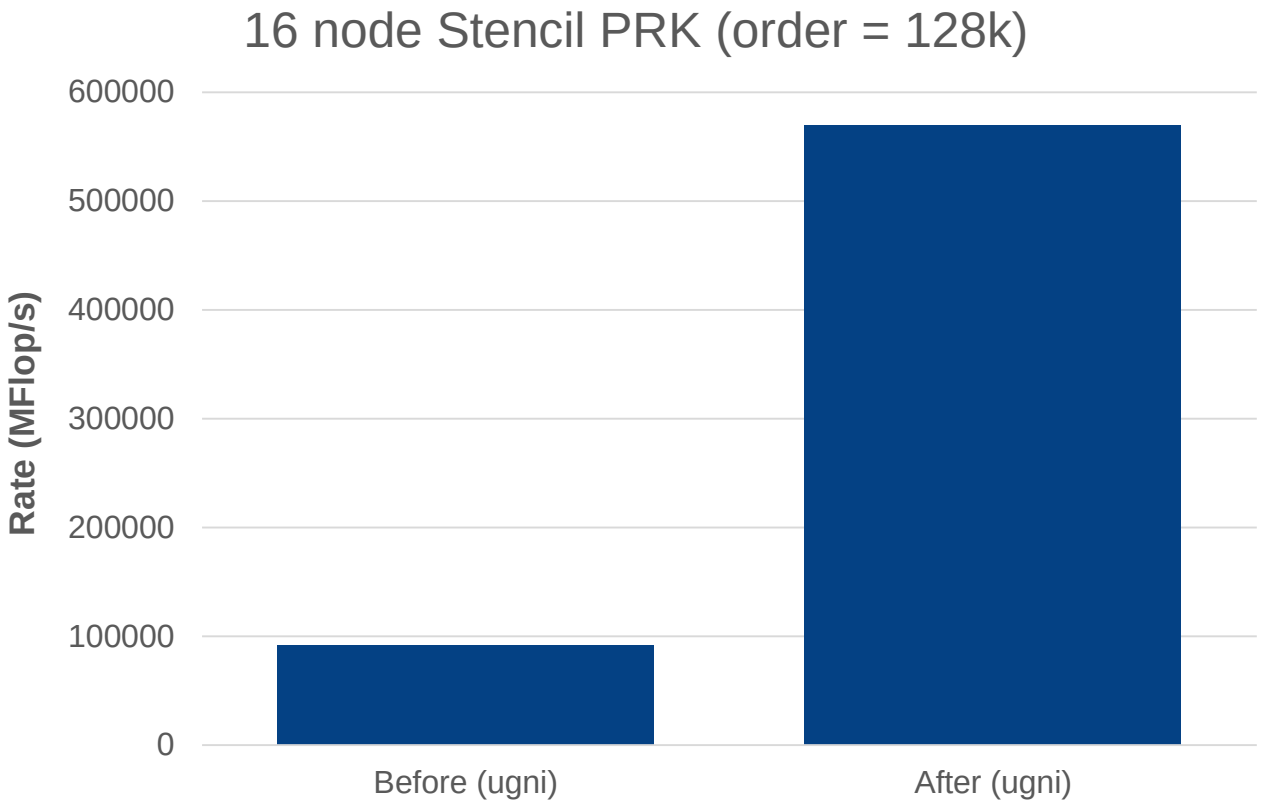
- Allow ‘local field’ pragma on arrays

```
class Wrapper {
  pragma "local field"
  var A : [1..10] int;
}
```

- Apply pragma in StencilDist, used by Stencil PRK
- Remove local block from optimized Stencil PRK

Local Array Fields: Impact

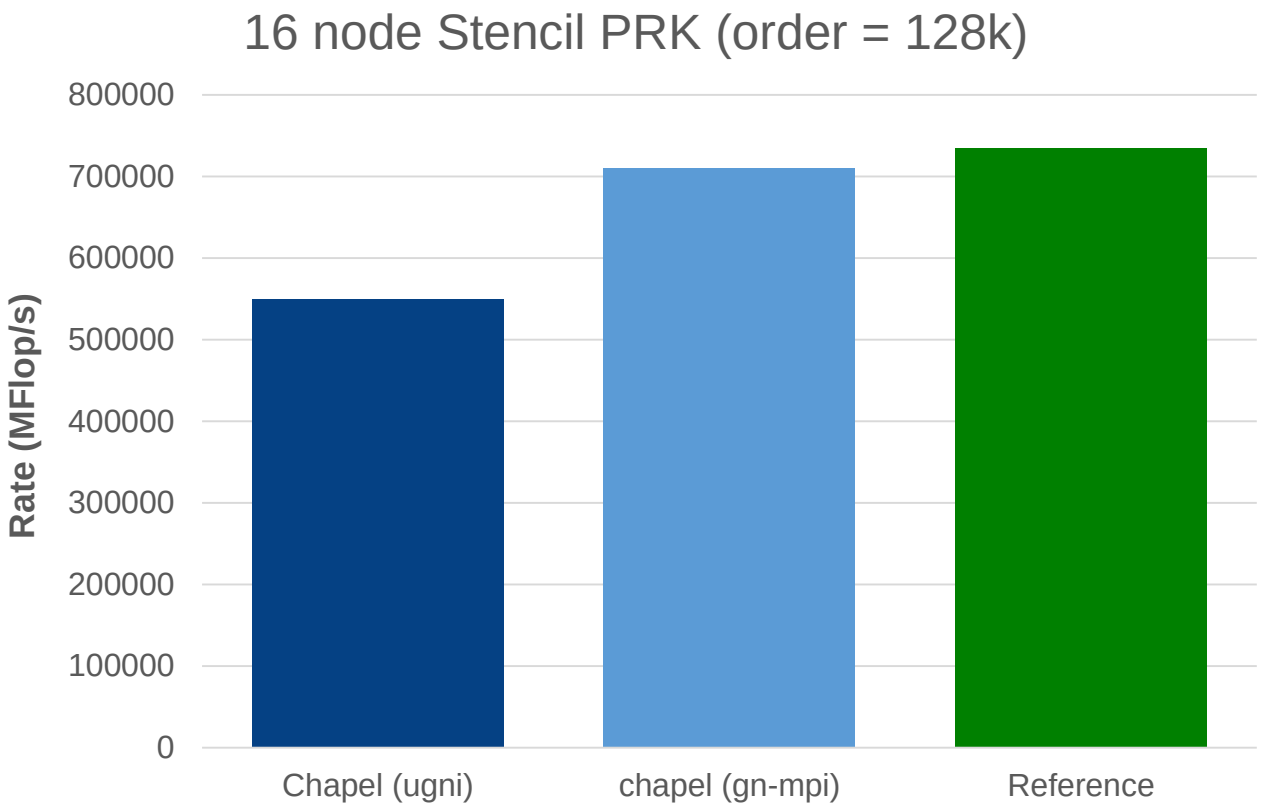
- **Performance without local block immensely improved**



PRK Summary

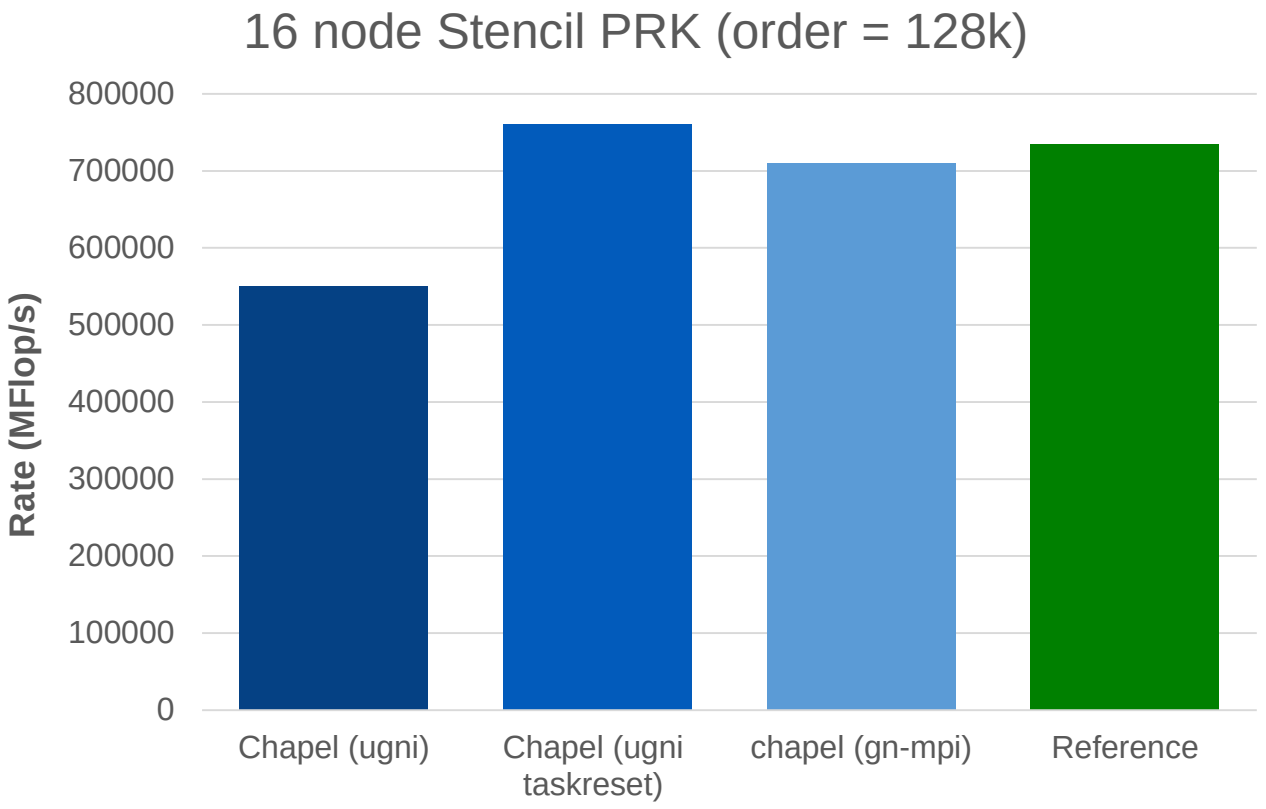
PRK: Summary

- **Optimized performance now mostly on par with reference**
  - Have removed some of the inelegant workarounds



PRK: Next Steps

- **Improve stencil performance for ugni comm layer**
  - Performance gap believed to be a result of poor task-affinity
    - experimental task-resetting work improves perf, but is not in 1.16



PRK: Next Steps

- **Reduce diff between elegant and optimized Stencil PRK**
  - use a local array view to avoid *localAccess* call
    - requires task-local variables. i.e. rewrite:

```
forall (i, j) in innerDom do
  in.localAccess[i, j];
```

as something like:

```
forall (i, j) in innerDom with (ref localIn=in.localView()) do
  localIn[i, j];
```

- **Continue to study PRKs**
  - Run PRK Stencil at larger scales
  - Explore additional PRKs

ISx Benchmark Improvements

ISx: Background

- **Scalable Integer Sort benchmark**
  - Developed at Intel, published at PGAS 2015
  - SPMD-style computation with barriers
  - Punctuated by all-to-all bucket-exchange pattern
  - References implemented in SHMEM and MPI
- **Chapel implementation introduced in 1.13 release**
  - Motivation: bucket-exchange is a common distributed pattern
- **Optimized version competes with the reference version**
  - But optimized version was slightly less elegant than we wanted

Record Serialization

Serialization: Background

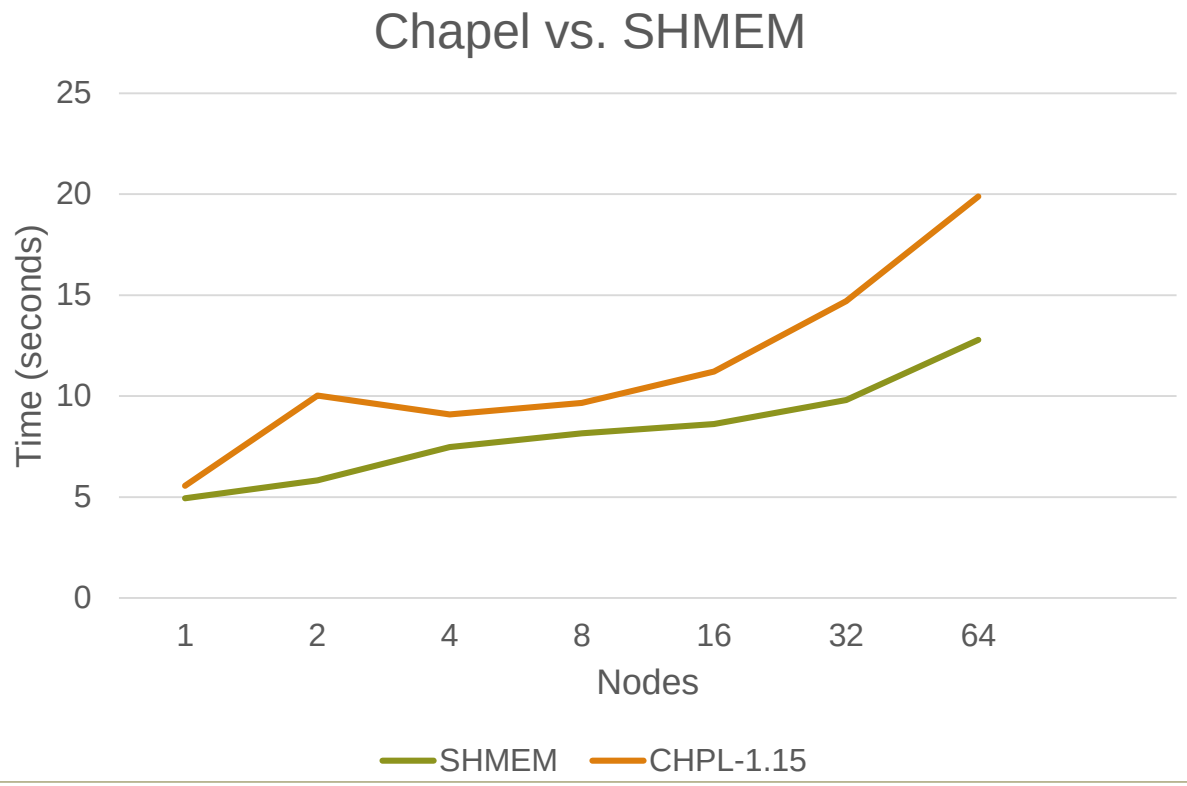
- **ISx declared task-local arrays over global const domain**

```
var myArray : [globalConstDom] int;
```

- **Domains must track their arrays**
  - If a domain is resized, related arrays must be resized as well
  - Uses on-statement to locale on which domain was created
  - Acquires a lock to update a list of arrays

Serialization: Background

- **Observed poor scaling in 1.15 compared to SHMEM**
  - All cores contending for lock on root locale
  - Note that the SHMEM version scales better than the MPI version

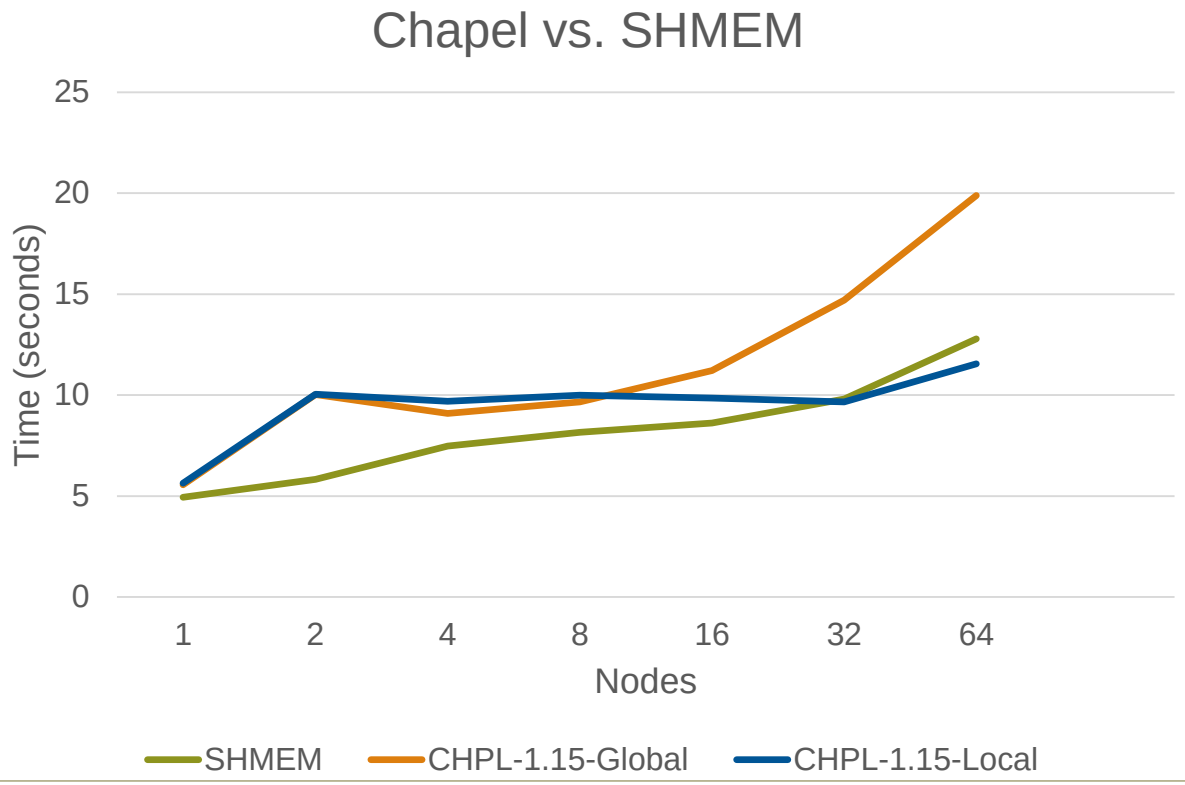


Serialization: Background

- **Temporary solution: use range literals**

```
var myArray : [1..n] int;
```

  - Avoids overhead because each array has its own local domain



Serialization: This Effort

- **Observation: global const domains can be replicated**
  - Their indices do not change, so they don't need to resize arrays
  - Locking restricted to intra-locale
- **Problem: existing replication performs shallow copies**
  - Domains implemented with records and classes
  - Need a way to replicate complex aggregate types
- **Solution: User-defined serialization across locales**

Serialization: This Effort

- **Implemented as methods on records:**
  - This method returns data necessary to recreate the record
    - Returns primitive type or record so it can be reclaimed later

```
proc myRecord.chpl__serialize() : X;
```

  - This type method accepts data and returns a record

```
proc type myRecord.chpl__deserialize(data : X) : myRecord;
```

- **Both methods required to trigger optimization**

Serialization: This Effort

- **Optimization triggers for local records**
  - If they can be remote value forwarded (sent as part of on-stmt)

```
const constR: R
 on Locales[1] {
  func(constR);
}
```

roughly converted into:

```
const constR: R;
var serialR = constR.chpl__serialize();
on Locales[1] /* serialR passed as part of arg bundle, no extra comm */ {
  const constR = R.chpl__deserialize(serialR);
  func(constR);
}
```

Serialization: This Effort

- **Optimization triggers for global const records**

```
const constR: R;
on Locales[1] {
  func(constR);
}
```

roughly converted into:

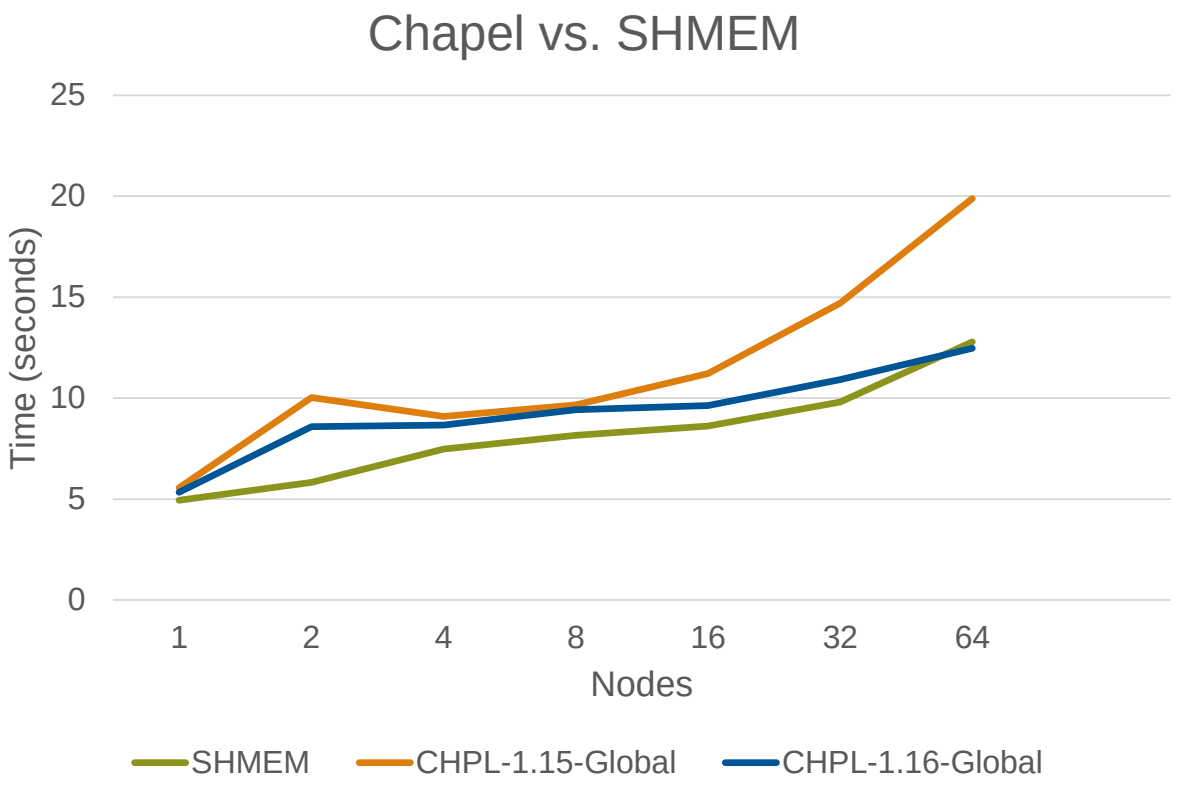
```
const constR: R;
bcastGlobal(constR); // serialize on loc 0, broadcast, deserialize on non-0 locs
on Locales[1] {
  func(constR); // locale-private copy, no communication required now
}
```

Serialization: This Effort

- **Implemented serialization for DefaultRectangular domains**
  - Very common and a good place to start
  - Can open to other domains as we gather experience
- **Also implemented serialization for strings**
  - Long-desired optimization
  - Unfortunately we lack distributed string benchmarks for comparison
  - Should still serve as a good stress-test for the optimization
- **Controlled by '--[no-]remote-serialization' flag**
  - Optimization is on by default

Serialization: Impact

- Can write ISx more elegantly without performance loss



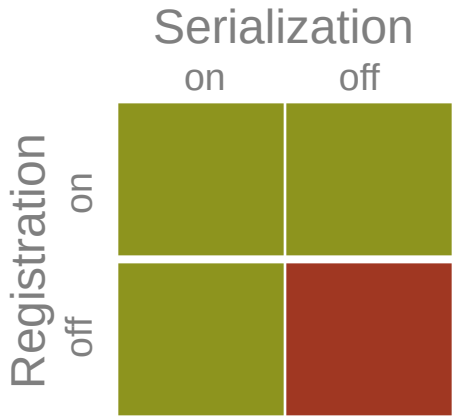
Serialization: Next Steps

- **Avoid serialization for local on-statements**
  - May add overhead depending on user's implementation
- **Standardize interface and semantics**
  - Current implementation mainly intended for internal use

Serialization - Supplemental

Serialization: Supplemental

- **Dynamic registration also helped the ISx scaling issue**
  - Unexpected result
  - "Resolves" scaling issue without serialization enabled
- **Hypothesis: Dynamic registration reduced lock contention**
  - Measured less time spent locking under dynamic registration
  - Something in dynamic registration code may be locking as well
    - This may offset tasks such that contention is less likely
- **Next Steps:**
  - Confirm hypothesis



Task Counting Improvements

Task Counting: Background

- **Running task count is used to determine forall parallelism**
  - Want to utilize all cores, without oversubscribing the system

```
forall i in 1..n do                 // should create here.maxTaskPar tasks
  forall j in 1..n do               // should not create any additional tasks
```

- **An inaccurate running task counter hurts performance**
  - Can result in too few or too many tasks being created

- **Task counting for tasks migrated via on-stmts was wrong**
  - Did not decrement local counter for moved tasks

```
on Locales[numLocales-1] do body();   // did not decrement locale 0
```

  - Did not track remote tasks for non-blocking ons

```
coforall loc in Locales do on Loc do
  // running task count was 0 for all non-0 locales
```

Task Counting: Background

- **Improper task-counting hurt ISx**

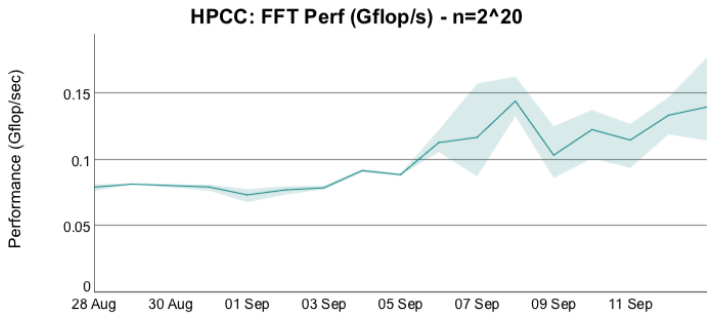
```
coforall loc in Locales do on Loc do
  coforall tid in 0..#perBucketMultiply {
    // task counter was numCores-1 instead of the true numCores
    ...
    // resulted in parallel init for some myKeys, which hurt affinity in later uses
    var myKeys: [0..#keysPerTask] keyType;
    ...
  }
```

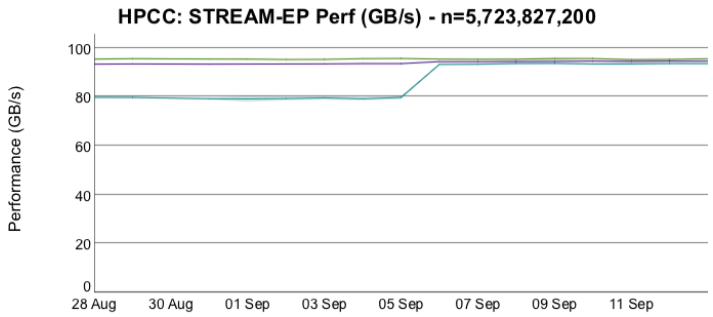
- **Required an ugly workaround to disable parallel array init**
  - *-schpl_defaultArrayInitMethod=ArrayInit.serialInit*

Task Counting: This Effort and Impact

- **This Effort: Improved accuracy of the running task counter**
  - Now correctly track running tasks for migrated tasks
  - Added a significant number of tests to lock-in behavior
    - inaccurate task-counting has been a longstanding and recurrent issue

- **Impact: Improved multi-locale performance**
  - Allows us to remove array initialization workaround for ISx

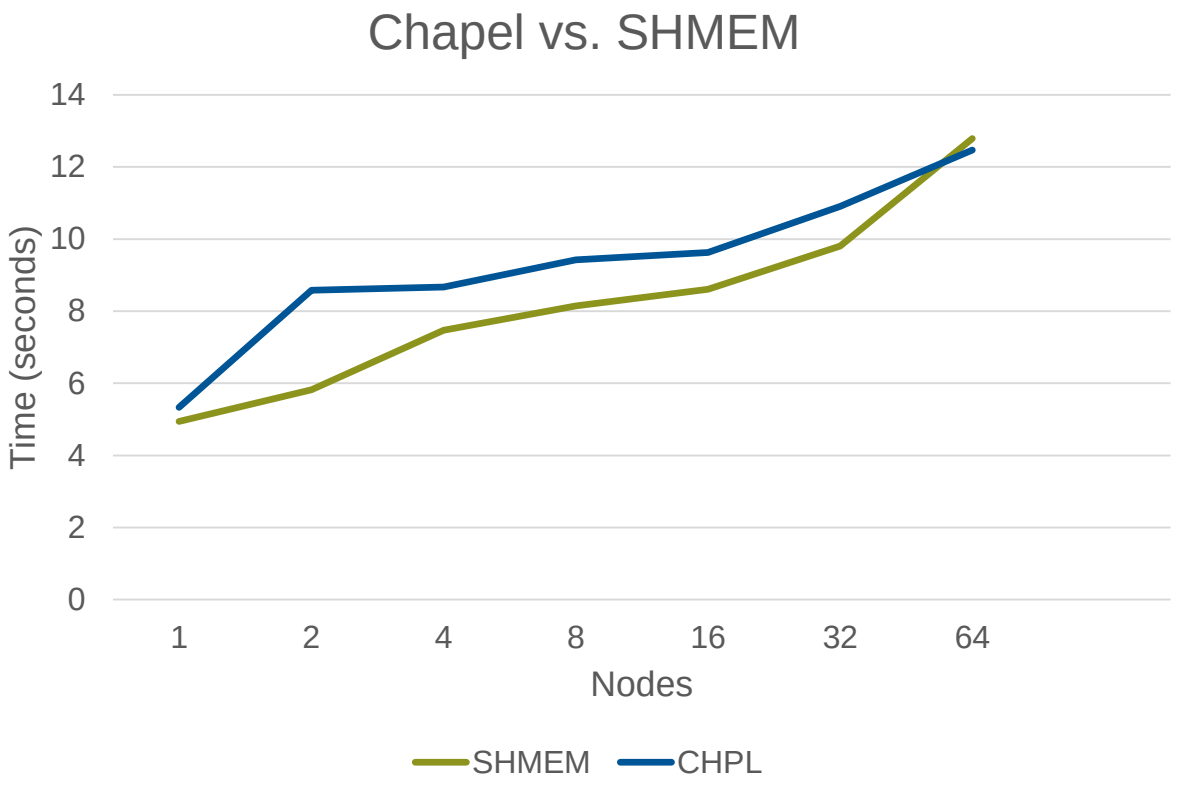




ISx Summary

ISx: Summary

- **ISx still performing on par with reference**
  - Previous inelegant workarounds have been removed



ISx: Next Steps

- **Improve ISx performance at smaller scales**
  - Performance slightly exceeds reference at 64 nodes
  - But is slightly behind at smaller node counts
- **Run ISx at even larger scales**
  - Identify and fix any scaling bottlenecks

Computer Language Benchmarks Game (CLBG) Update

CLBG: Background

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 Clojure C# C++

Dart Erlang F# Fortran Go Hack

Haskell Java JavaScript Lisp Lua

OCaml Pascal Perl PHP Python

Racket Ruby JRuby Rust Scala

Smalltalk Swift TypeScript

Website that supports cross-language game / comparisons

- 13 toy benchmark programs
- exercises key features like:
  - memory management
  - tasking and synchronization
  - vectorization
  - big integers
  - strings and regular expressions
- specific approach prescribed

Take results w/ grain of salt

- other programs may be different
  - not to mention other programmers
- specific to this platform / OS / …

That said, it's one of the only games in town…

CLBG: Background (Chapel's Approach)

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?

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Ada C Chapel Clojure C# C++

Dart Erlang F# Fortran Go Hack

Haskell Java JavaScript Lisp Lua

OCaml Pascal Perl PHP Python

Racket Ruby JRuby Rust Scala

Smalltalk Swift TypeScript

Chapel's approach to CLBG:

- want to know how we compare
- strive for entries that are elegant rather than heroic
  - e.g., "Want to learn how program x works? Check out the Chapel version."

CLBG: Background (Results)

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

The Computer Language Benchmarks Game

chameneos-redux

description

program source code, command-line and measurements

×	source	secs	mem	gz	cpu	cpu load
1.0	**C** gcc #5	**0.60**	820	2863	2.37	100% 100% 98% 100%
1.2	**C++** g++ #5	**0.70**	3,356	1994	2.65	100% 100% 91% 92%
1.7	**Lisp** SBCL #3	**1.01**	55,604	2907	3.93	97% 96% 99% 99%
2.3	**Chapel** #2	**1.39**	76,564	1210	5.43	99% 99% 98% 99%
3.3	**Rust** #2	**2.01**	56,936	2882	7.81	97% 98% 98% 98%
5.6	C++ g++ #2	3.40	1,880	2016	11.88	100% 51% 100% 100%
6.8	Chapel	4.09	66,584	1199	16.25	100% 100% 100% 100%
8.0	**Java** #4	**4.82**	37,132	1607	16.73	98% 98% 54% 99%
8.5	**Haskell** GHC	**5.15**	8,596	989	9.26	79% 100% 2% 2%
10	Java	6.13	53,760	1770	8.78	42% 45% 41% 16%
10	Haskell GHC #4	6.34	6,908	989	12.67	99% 100% 2% 1%
11	**C#** .NET Core	**6.59**	86,076	1400	22.96	99% 82% 78% 91%
11	**Go**	**6.90**	832	1167	24.19	100% 96% 56% 100%
13	Go #2	7.59	1,384	1408	27.65	91% 99% 99% 78%
13	Java #3	7.94	53,232	1267	26.86	54% 96% 98% 94%

The Computer Language Benchmarks Game

chameneos-redux

description

program source code, command-line and measurements

×	source	secs	mem	gz	cpu	cpu load
1.0	**Erlang**	58.90	28,668	**734**	131.19	62% 60% 51% 53%
1.0	**Erlang** HiPE	59.39	25,784	**734**	131.58	60% 56% 56% 54%
1.1	**Perl** #4	5 min	14,084	**785**	7 min	40% 40% 29% 28%
1.1	**Racket**	5 min	132,120	**791**	5 min	1% 0% 0% 100%
1.1	Racket #2	175.88	116,488	842	175.78	100% 1% 1% 0%
1.2	**Python 3** #2	236.84	7,908	**866**	5 min	24% 48% 27% 45%
1.3	**Ruby**	90.52	9,396	**920**	137.53	35% 35% 35% 34%
1.3	**Ruby** JRuby	48.78	628,968	**928**	112.15	65% 60% 49% 58%
1.3	**Go** #5	11.05	832	**957**	32.48	75% 74% 75% 73%
1.3	**Haskell** GHC #4	6.34	6,908	**989**	12.67	99% 100% 2% 1%
1.3	Haskell GHC	5.15	8,596	989	9.26	79% 100% 2% 2%
1.6	**OCaml** #3					32% 38% 37% 39%
1.6	Go					100% 96% 56% 100%
1.6	**Chapel**					0% 100% 100% 100%
1.6	Chapel #2					99% 99% 98% 99%

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

CLBG: Background (Pair-wise Comparisons)

Can also compare languages pair-wise:

The Computer Language Benchmarks Game

Chapel programs versus Go

all other Chapel programs & measurements

by benchmark task performance

regex-redux

source	secs	mem	gz	cpu	cpu load
Chapel	**10.02**	1,022,052	477	19.68	99% 72% 14% 12%
Go	29.51	352,804	798	61.51	77% 49% 43% 40%

binary-trees

source	secs	mem	gz	cpu	cpu load
Chapel	**14.32**	324,660	484	44.15	100% 58% 78% 75%
Go	34.77	269,068	654	132.04	95% 97% 95% 95%

fannkuch-redux

source	secs	mem	gz	cpu	cpu load
Chapel	**11.38**	46,056	728	45.18	100% 99% 99% 100%
Go	15.81	1,372	900	62.92	100% 100% 99% 99%

CLBG: Background (Browsing Programs)

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 #2 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 #5 entry

CLBG: This Effort

This Effort:

- No real focus on CLBG improvements this release cycle
  - most performance work focused on distributed memory benchmarks
- Some minor changes to released versions of CLBG programs:
  - added faster mandelbrot & chameneos versions to the examples directory
    - described in 1.15 release notes
    - had already been submitted to CLBG site

    `examples/benchmarks/shootout/mandelbrot-fast.chpl`

    `examples/benchmarks/shootout/chameneos-fast.chpl`
  - changed knucleotide to use the default parSafe mode
    - enabled by removal of locking from associative array accesses
    - minor elegance / code size improvement, no performance impact
    - not yet submitted to CLBG site

    `examples/benchmarks/shootout/knucleotide.chpl`

CLBG: Impact

Impact: Overall, no major changes

- Chapel execution times / ratios largely the same
- A few slips in rank / ratio, largely due to new entries being submitted
  - particularly for Rust, C#, F#, Java

8 / 13 programs in top-25 smallest:

- two #1 smallest:
  n-body
  thread-ring
- 2 others in the top-5 smallest:
  pidigits
  spectral-norm
- 1 other in the top-10 smallest:
  regex-redux
- 3 others in the top-25 smallest:
  chameneos-redux
  mandelbrot
  meteor-contest

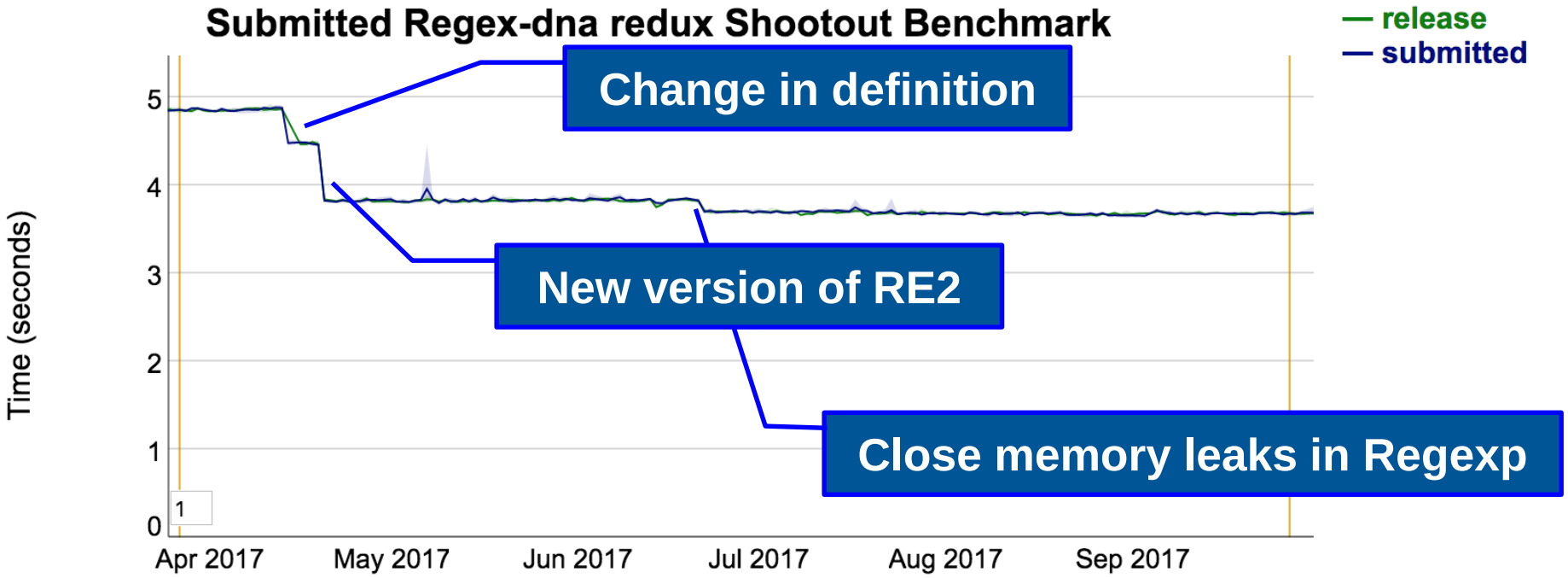
12 / 13 programs in top-25 fastest:

- one #1 fastest:
  pidigits
- 3 others in the top-5 fastest:
  chameneos-redux
  meteor-contest
  thread-ring
- 2 others in the top-10 fastest:
  fannkuch-redux
  fasta
- 6 others in the top-25 fastest:
  binary-trees
  k-nucleotide
  mandelbrot
  n-body
  regex-redux
  spectral-norm

CLBG: Impact (Regex-redux)

Impact: Regex-redux saw the most significant improvements

- primarily due to a new version of RE2
- to a lesser extent, due to closing memory leaks
- also changed its definition during this release cycle

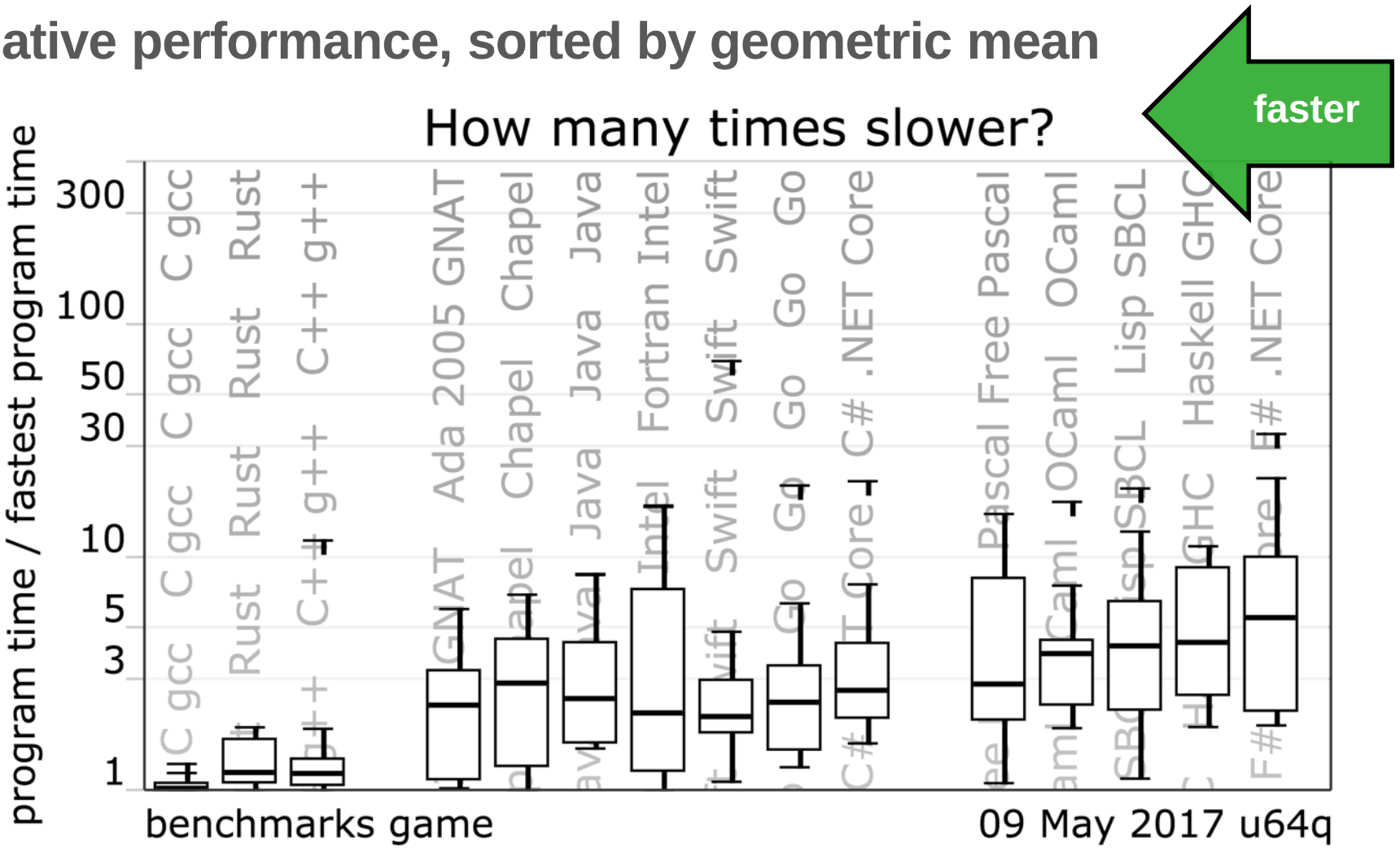


CLBG: Status (Notes on the following graphs)

- **Graphs that follow are taken from the CLBG website**
  - each column summarizes the fastest programs for a given language
  - threadring, chameneos-redux, meteor-contest are not included
  - sorted by geometric mean execution time, scaled to fastest entries
  - horizontal line indicates mean execution time
  - box indicates one standard deviation
  - whiskers indicate two standard deviations
  - additional whiskers indicate outliers

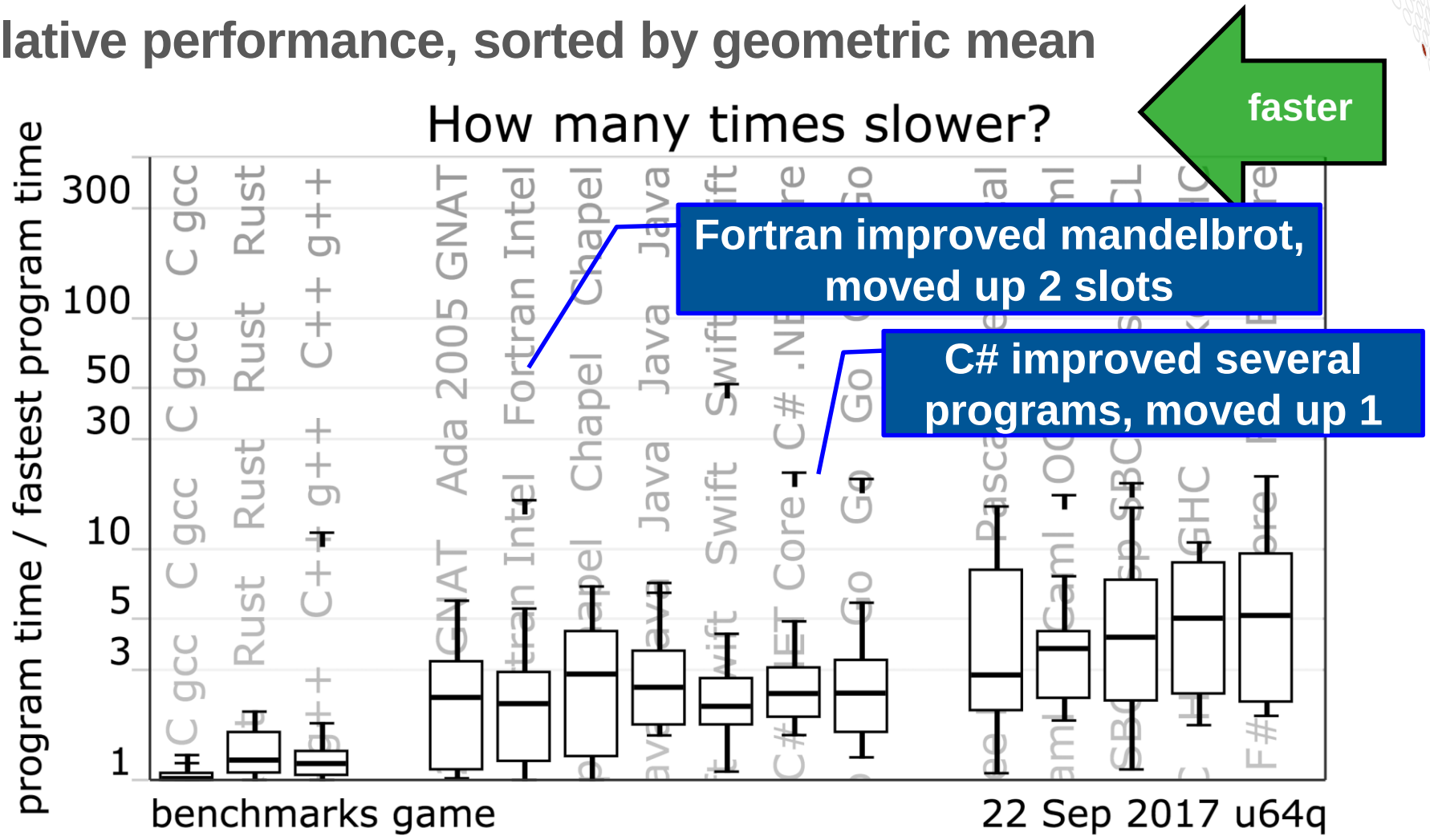
CLBG: Fast-faster-fastest graph (May 2017)

Relative performance, sorted by geometric mean



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

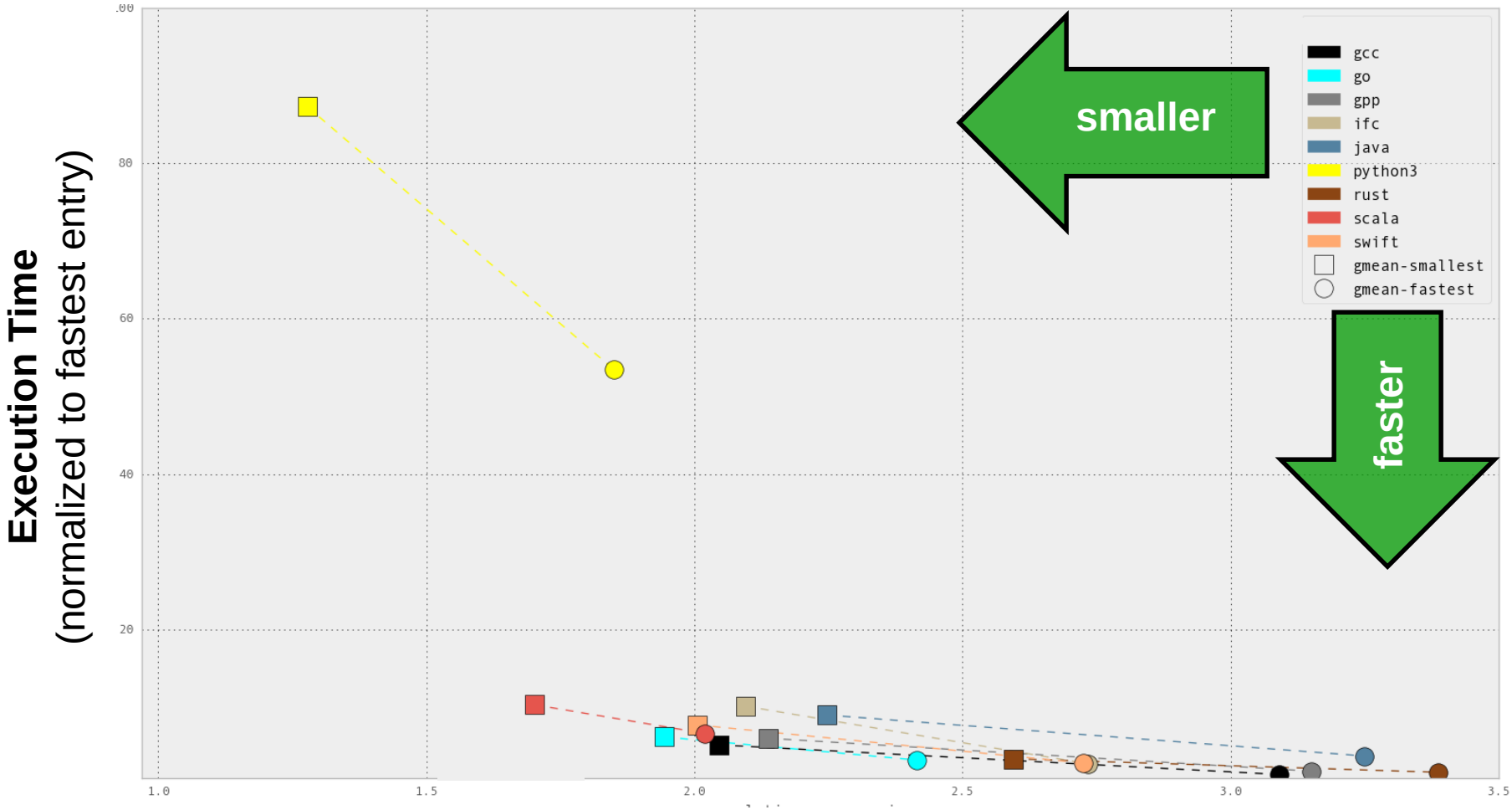
Relative performance, sorted by geometric mean



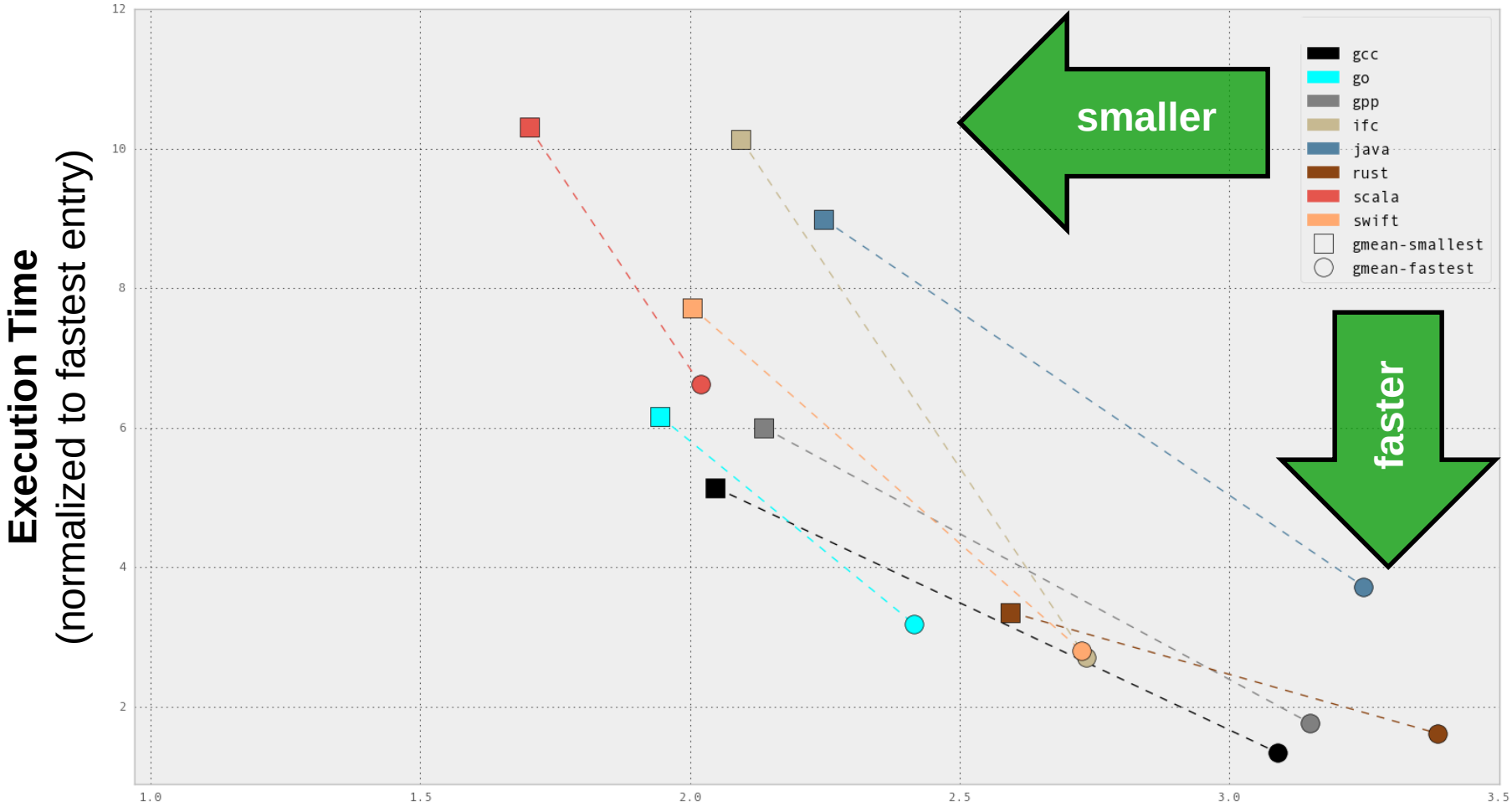
CLBG: Status (Notes on the following plots)

- **Graphs that follow are generated by us**
  - plot results taken from the CLBG site on Oct 18, 2017
  - all benchmarks are included (unlike the previous graphs)
    - rationale: Chapel cares about task-parallelism
  - x-axis shows normalized compressed code size (gz metric from site)
  - y-axis shows normalized execution time
  - each language represented by a pair of points:
    - geometric mean of fastest entries in each language shown via circle
    - geometric mean of smallest entries in each language shown via square
    - line connects the two points
    - if either point falls outside the graph, point and line are not shown (TODO)

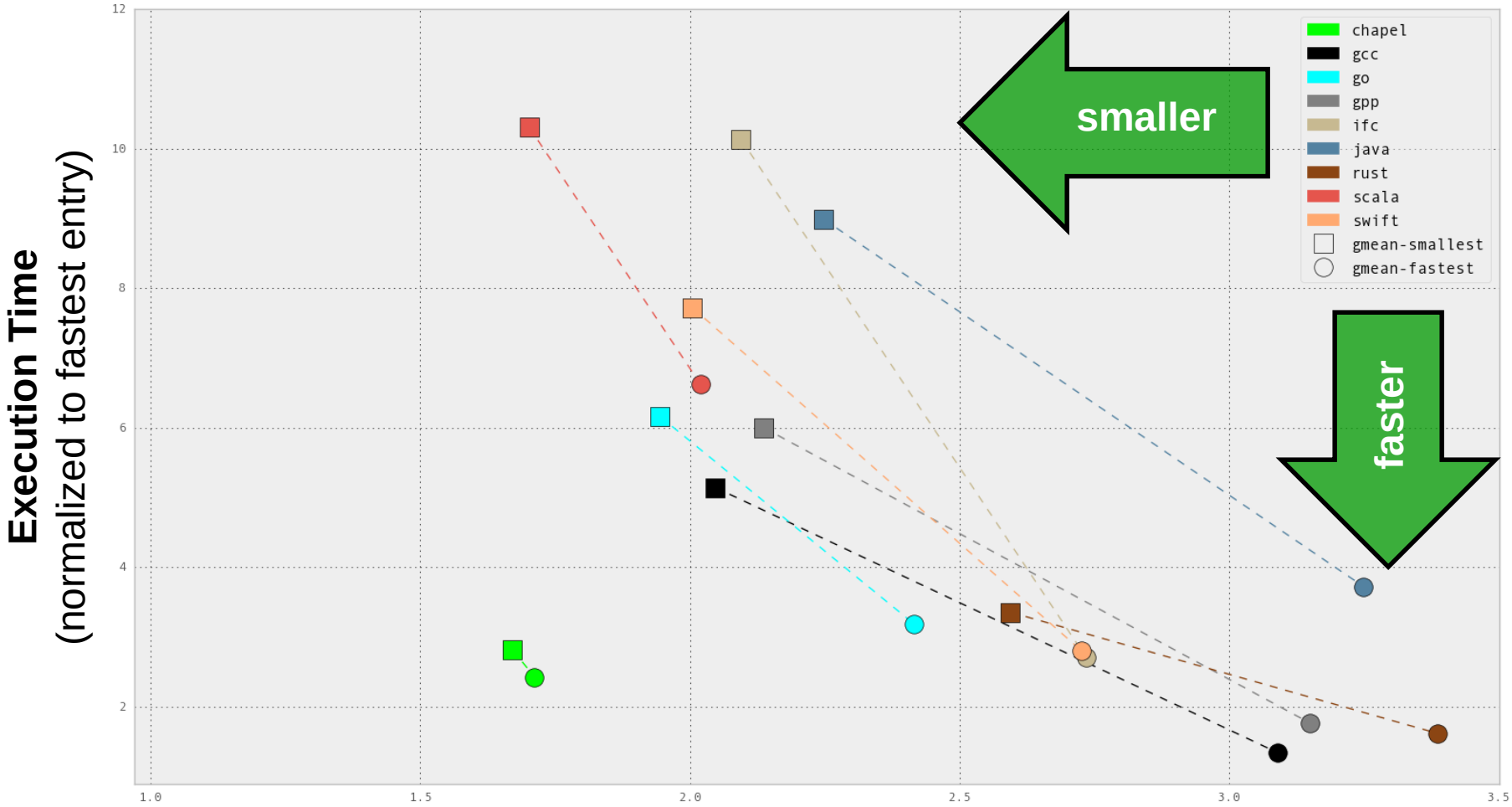
CLBG Language Cross-Language Summary
(May 2017 standings, languages of interest)



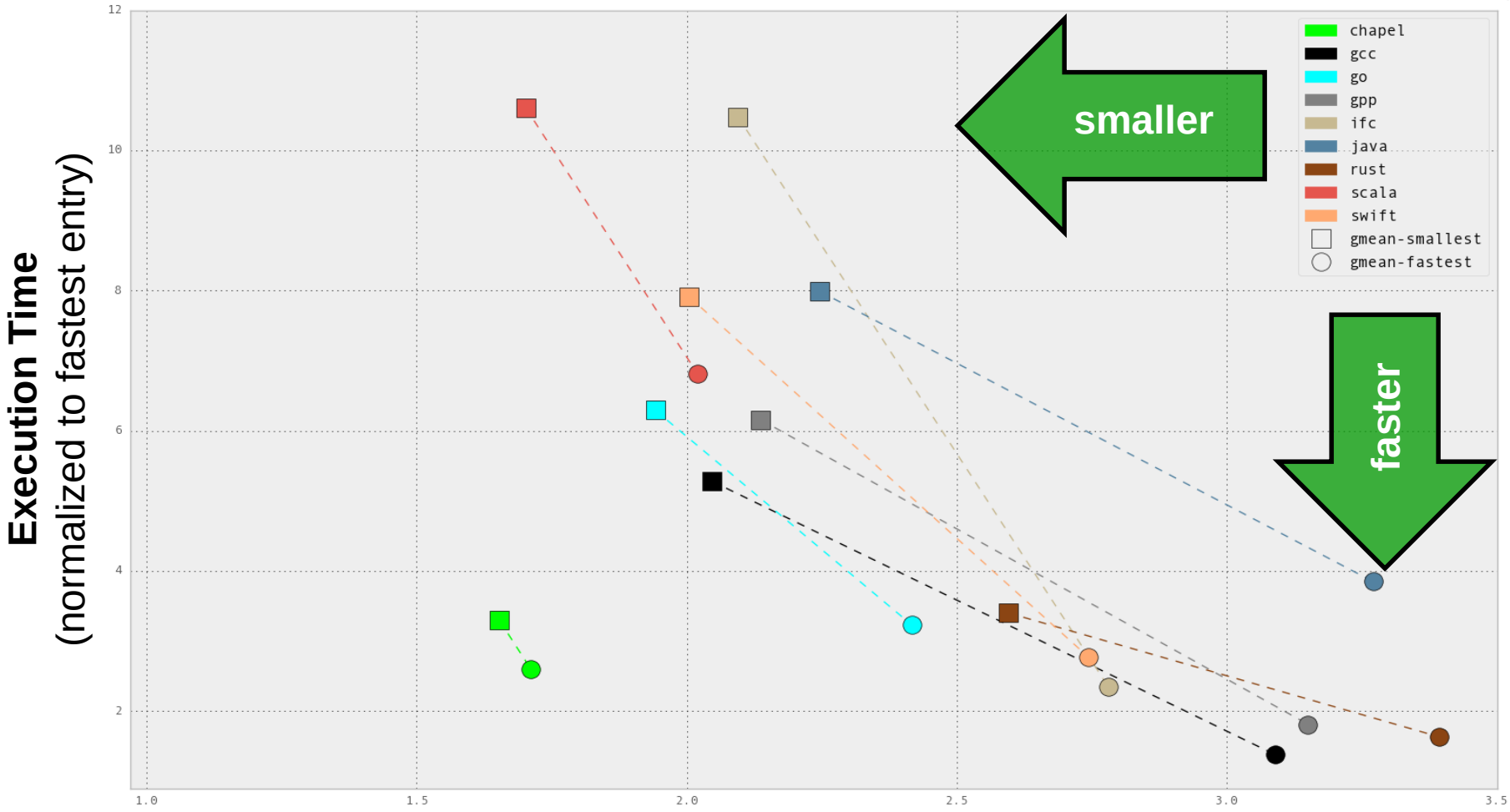
CLBG Language Cross-Language Summary
(May 2017 standings, without Python)



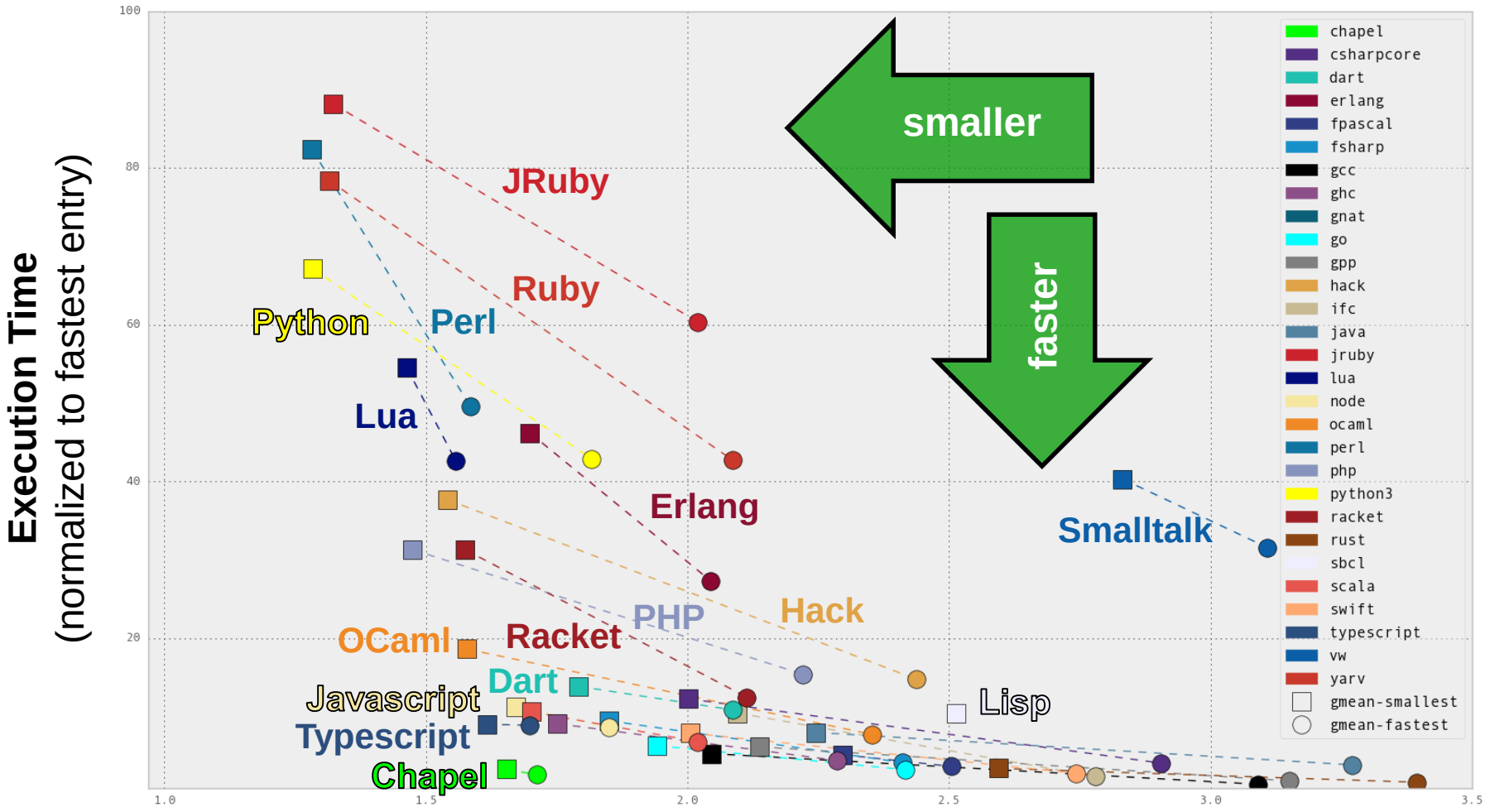
CLBG Language Cross-Language Summary
(May 2017 standings, with Chapel)



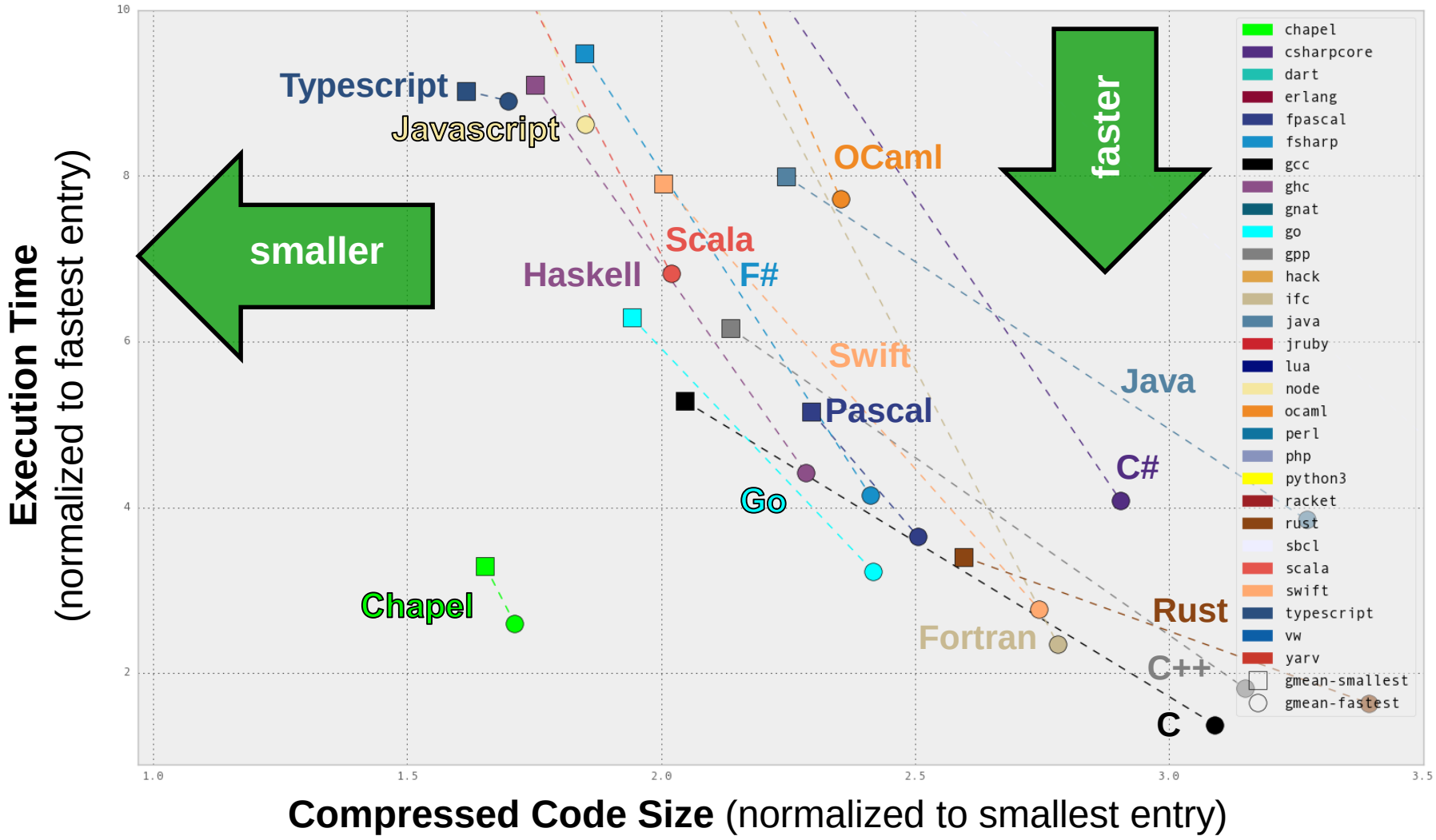
CLBG Language Cross-Language Summary
(Oct 2017 standings, with Chapel)



CLBG Language Cross-Language Summary
(Oct 2017 standings, all languages)



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



Reductions in Memory Leaks

Memory Leaks: Background

Background:

- Past few releases have closed major sources of leaks
  - Leaking of record fields due to missing destructor calls
  - Leaking of arrays due to bad memory management
- Postulated that most remaining leaks were in user-level code
  - e.g., tests that allocate without deleting:

```
var myC = new C();     // test invocation of initializer
// program fails to delete myC so leaks it…
```

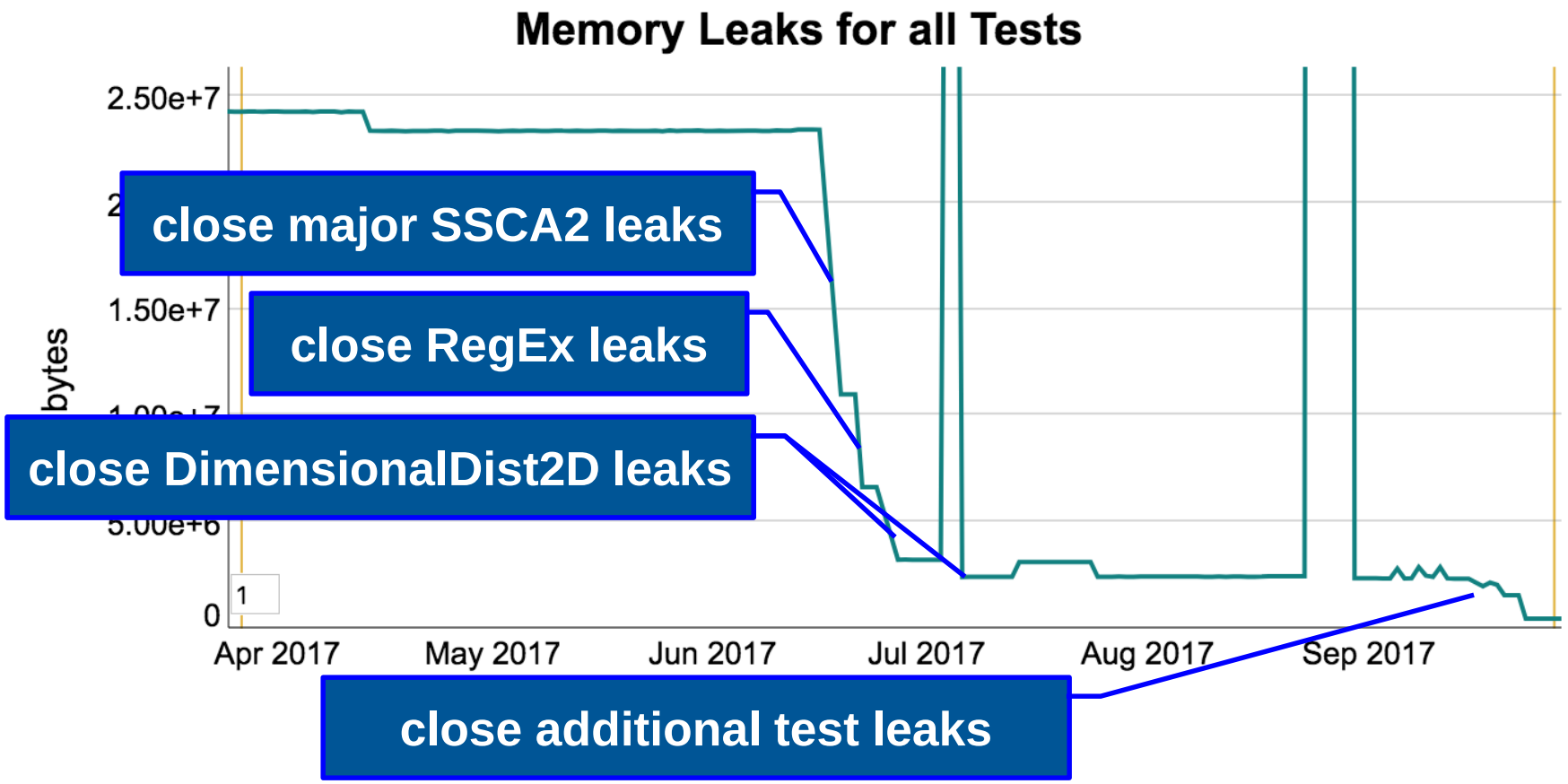
Memory Leaks: This Effort

This Effort: Continued to close memory leaks

- closed many significant test-based leaks:
  - SSCA2
  - AMR
  - Graph500
  - vertex coloring
  - bulk comm stencil tests
  - fock
  - NAS EP
  - label propagation
  - lsms
- also closed a few leaks in our library modules:
  - string leaks in Regex.subn(), qio_regexp_replace()
  - DimensionalDist2D leaks

Memory Leaks: Impact

Impact: 50x reduction in memory leaks



Memory Leaks: Next Steps

Next Steps:

- Close remaining leaks
  - Still believe user code is responsible for most remaining leaks
  - However, likely to be some remaining library-based leaks as well
- Tighten up nightly testing to prevent new leaks from being introduced

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