Benchmarks and Performance Optimizations

Chapel Team, Cray Inc.
Chapel version 1.16
October 5, 2017
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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 Co forall Optimization
Bounded Remote Coforall: Background

Remote coforall was transformed by the compiler, from:

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

...roughly into:

```cpp
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)

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

now roughly converted to:

```latex
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

![Graphs showing performance improvements](images)
Bounded Remote Co forall: Stencil Impact

- Previously Chapel was 3-4x slower than reference

![Bar chart comparing Chapel (ugi) vs chapel (gn-mpi) vs Reference]

- 16 node Stencil PRK (order = 128k)

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Bounded Remote Coforall: Stencil Impact

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

![Bar chart showing performance comparison]

16 node Stencil PRK (order = 128k)
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

![Bar chart showing performance comparison between Chapel (ugni), chapel (gn-mpi), and Reference.](chart.png)

Legend:
- Chapel (ugni)
- chapel (gn-mpi)
- Reference

Y-axis: Rate (MFlop/s)

X-axis: Stencil PRK (order = 128k)
updateFluff: Stencil Impact

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

16 node Stencil PRK (order = 128k)
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

16 node Stencil PRK (order = 128k)

<table>
<thead>
<tr>
<th>Rate (MFlop/s)</th>
<th>Chapel (ugni)</th>
<th>chapel (gn-mpi)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>300000</td>
<td>700000</td>
<td>800000</td>
</tr>
<tr>
<td></td>
<td>200000</td>
<td>600000</td>
<td>700000</td>
</tr>
<tr>
<td></td>
<td>100000</td>
<td>500000</td>
<td>600000</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>400000</td>
<td>500000</td>
</tr>
</tbody>
</table>
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

![Bar chart showing performance comparison between Chapel (ugni), chapel (gn-mpi), and Reference for 16 node Stencil PRK (order = 128k).]
Array Locality Optimization
Local Array Fields: Background

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

16 node Stencil PRK (order = 128k)
PRK Summary
PRK: Summary

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

![Bar chart showing performance comparison](image-url)

16 node Stencil PRK (order = 128k)

- Chapel (ugi)
- chapel (gn-mpi)
- Reference

Rate (MFlop/s)

0 100000 200000 300000 400000 500000 600000 700000 800000

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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

16 node Stencil PRK (order = 128k)
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:
      ```csharp
     forall (i, j) in innerDom do
        in.localAccess[i, j];
      
      as something like:
      ```csharp
      ```
      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

![Chapel vs. SHMEM graph](image-url)
Serialization: Background

- **Temporary solution: use range literals**
  ```chapel
def myArray : [1..n] int;
```
- Avoids overhead because each array has its own local domain

---

**Chapel vs. SHMEM**

- **Nodes**: 1, 2, 4, 8, 16, 32, 64
- **Time (seconds)**: 0, 5, 10, 15, 20, 25

- **SHMEM**
- **CHPL-1.15-Global**
- **CHPL-1.15-Local**
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)

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

roughly converted into:

```c
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

**Chapel vs. SHMEM**

- Time (seconds)
- Nodes
- SHMEM
- CHPL-1.15-Global
- CHPL-1.16-Global
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
    
```c
   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
    
```c
   on Locales[numLocales-1] do body();    // did not decrement locale 0
  ```
  - Did not track remote tasks for non-blocking ons
    
```c
   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

```plaintext
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

![Chapel vs. SHMEM Graph](image_url)
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?

<table>
<thead>
<tr>
<th>Ada</th>
<th>C</th>
<th>Chapel</th>
<th>Clojure</th>
<th>C#</th>
<th>C++</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dart</td>
<td>Erlang</td>
<td>F#</td>
<td>Fortran</td>
<td>Go</td>
<td>Hack</td>
</tr>
<tr>
<td>Haskell</td>
<td>Java</td>
<td>JavaScript</td>
<td>Lisp</td>
<td>Lua</td>
<td></td>
</tr>
<tr>
<td>OCaml</td>
<td>Pascal</td>
<td>Perl</td>
<td>PHP</td>
<td>Python</td>
<td></td>
</tr>
<tr>
<td>Racket</td>
<td>Ruby</td>
<td>JRuby</td>
<td>Rust</td>
<td>Scala</td>
<td></td>
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<tr>
<td>Smalltalk</td>
<td>Swift</td>
<td>TypeScript</td>
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</tr>
</tbody>
</table>

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)

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.”

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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</tr>
</tbody>
</table>
Can sort results by execution time, code size, memory or CPU use:

<table>
<thead>
<tr>
<th>program source code, command-line and measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>\times source</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>1.0 C gcc #5</td>
</tr>
<tr>
<td>1.2 C++ g++ #5</td>
</tr>
<tr>
<td>1.7 Lisp SBCL #3</td>
</tr>
<tr>
<td>2.3 Chapel #2</td>
</tr>
<tr>
<td>3.3 Rust #2</td>
</tr>
<tr>
<td>5.6 C++ g++ #2</td>
</tr>
<tr>
<td>6.8 Chapel</td>
</tr>
<tr>
<td>8.0 Java #4</td>
</tr>
<tr>
<td>8.5 Haskell GHC</td>
</tr>
<tr>
<td>10 Java</td>
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<tr>
<td>10 Haskell GHC #4</td>
</tr>
<tr>
<td>11 C# .NET Core</td>
</tr>
<tr>
<td>11 Go</td>
</tr>
<tr>
<td>13 Go #2</td>
</tr>
<tr>
<td>13 Java #3</td>
</tr>
</tbody>
</table>

\[ \text{gz} == \text{code size metric} \]
\[ \text{strip comments and extra whitespace, then gzip} \]
Can also compare languages pair-wise:

### The Computer Language Benchmarks Game

**Chapel programs versus Go**

<table>
<thead>
<tr>
<th>source</th>
<th>secs</th>
<th>mem</th>
<th>gz</th>
<th>cpu</th>
<th>cpu load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapel</td>
<td>10.02</td>
<td>1,022,052</td>
<td>477</td>
<td>19.68</td>
<td>99% 72% 14% 12%</td>
</tr>
<tr>
<td>Go</td>
<td>29.51</td>
<td>352,804</td>
<td>798</td>
<td>61.51</td>
<td>77% 49% 43% 40%</td>
</tr>
</tbody>
</table>

**by benchmark task performance**

**regex-redux**

<table>
<thead>
<tr>
<th>source</th>
<th>secs</th>
<th>mem</th>
<th>gz</th>
<th>cpu</th>
<th>cpu load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapel</td>
<td>14.32</td>
<td>324,660</td>
<td>484</td>
<td>44.15</td>
<td>100% 58% 78% 75%</td>
</tr>
<tr>
<td>Go</td>
<td>34.77</td>
<td>269,068</td>
<td>654</td>
<td>132.04</td>
<td>95% 97% 95% 95%</td>
</tr>
</tbody>
</table>

**binary-trees**

<table>
<thead>
<tr>
<th>source</th>
<th>secs</th>
<th>mem</th>
<th>gz</th>
<th>cpu</th>
<th>cpu load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapel</td>
<td>11.38</td>
<td>46,056</td>
<td>728</td>
<td>45.18</td>
<td>100% 99% 99% 100%</td>
</tr>
<tr>
<td>Go</td>
<td>15.81</td>
<td>1,372</td>
<td>900</td>
<td>62.92</td>
<td>100% 100% 99% 99%</td>
</tr>
</tbody>
</table>
Can also browse program source code (but this requires actual thought):

```c
void get_affinity(int* is_smp, cpu_set_t* affinity1, cpu_set_t* affinity2)
{
    FILE* f;
    char buf[2048];
    pos = 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);
}
```

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

    coforall c in population do
        if c.haveMeetings(population, place, population);
        delete place;
}
```

**excerpt from 1210 gz Chapel #2 entry**

**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
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
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
  ● threading, 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

How many times slower?

program time / fastest program time

benchmarks game

09 May 2017 u64q

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

Relative performance, sorted by geometric mean

How many times slower?

Fortran improved mandelbrot, moved up 2 slots
C# improved several programs, moved up 1
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)

Compressed Code Size (normalized to smallest entry)

Execution Time (normalized to fastest entry)

smaller

faster

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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)

Compressed Code Size (normalized to smallest entry)

Execution Time (normalized to fastest entry)

smaller

faster
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

- close major SSCA2 leaks
- close RegEx leaks
- close DimensionalDist2D leaks
- close additional test 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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