Benchmarks and Performance Optimizations

Chapel Team, Cray Inc.

Chapel version 1.17

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Safe Harbor Statement

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Outline

- **Ugni Improvements**
  - Extend and Register the Heap Dynamically
  - Nonblocking Active Message Responses
  - Comm Domain Limit
  - Avoid 'Bus Error' Messages
  - Scalability Improvements
- **ISx Improvements**
  - Scalable Barrier
  - Park the Main Process
  - Reduce Progress Thread Interference
- **Meltown and Spectre Impact**
- **Reductions in Memory Leaks**
- **Other Performance Optimizations**

Ugni Improvements

Extend and Register the Heap Dynamically

Dynamic Heap: Background and Effort

Background: NIC-registered heap had unfortunate limitations

- Performance
  - Poor NUMA memory affinity, because registration pins to NUMA node 0
  - Up-front heap creation and registration increased program startup cost

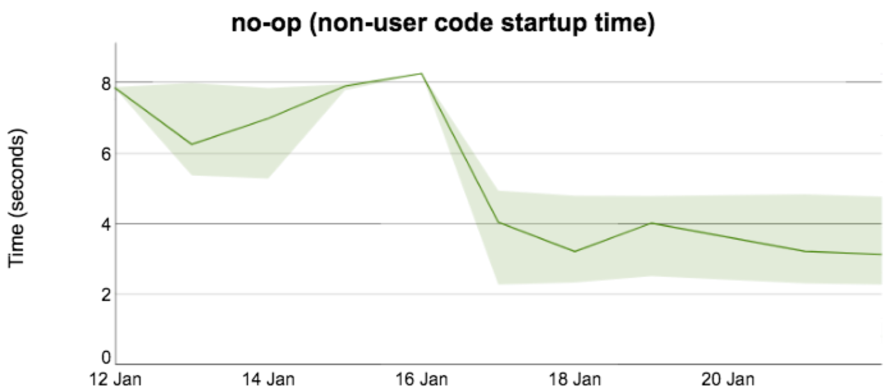
- Ease of use
  - Fixed-size heap cannot be extended if not large enough
  - Pushed default to err toward too-large
  - If default nevertheless too small, computing a better size was impractical

This Effort: Extend and register heap dynamically

- Reuses infrastructure added in 1.16 for dynamic registration of arrays

Dynamic Heap: Positive Impact

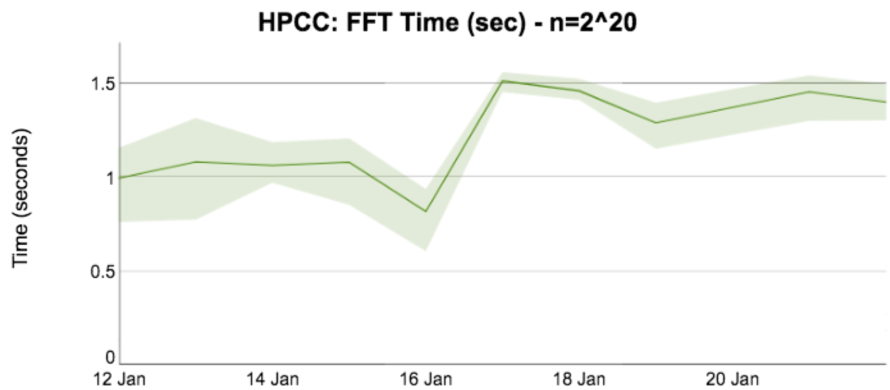
- Faster startup

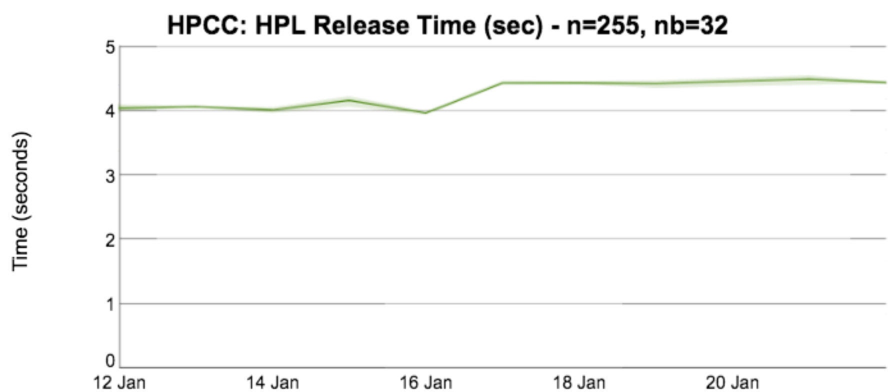


- Better non-array NUMA affinity (don't have a specific test)
- Improved usability: no need to estimate max heap size

Dynamic Heap: Negative Impact

- Two performance regressions, not yet understood





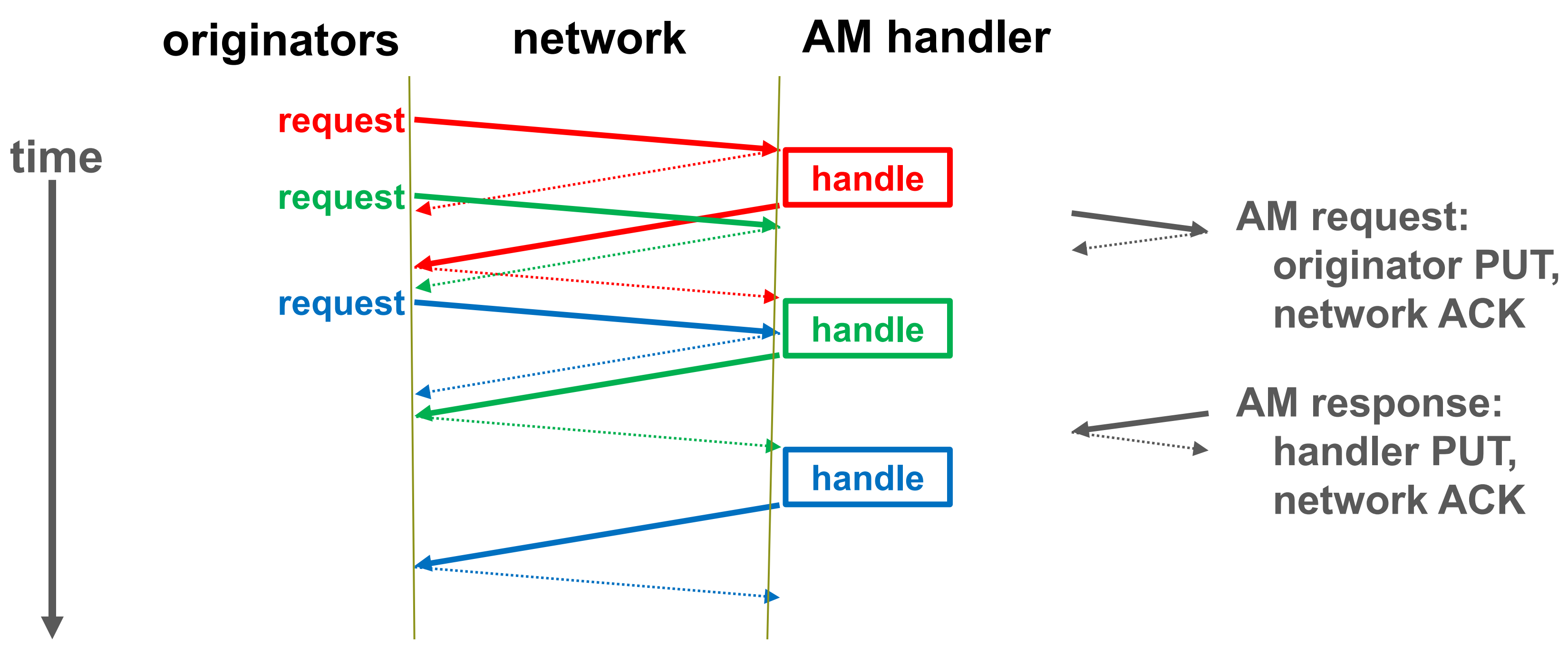
Dynamic Heap: Next Steps

- **Look into FFT and HPL performance regressions**
- **Could/should we do this in other configs with registration?**
  - Explore options for gasnet-aries

Nonblocking Active Message Responses

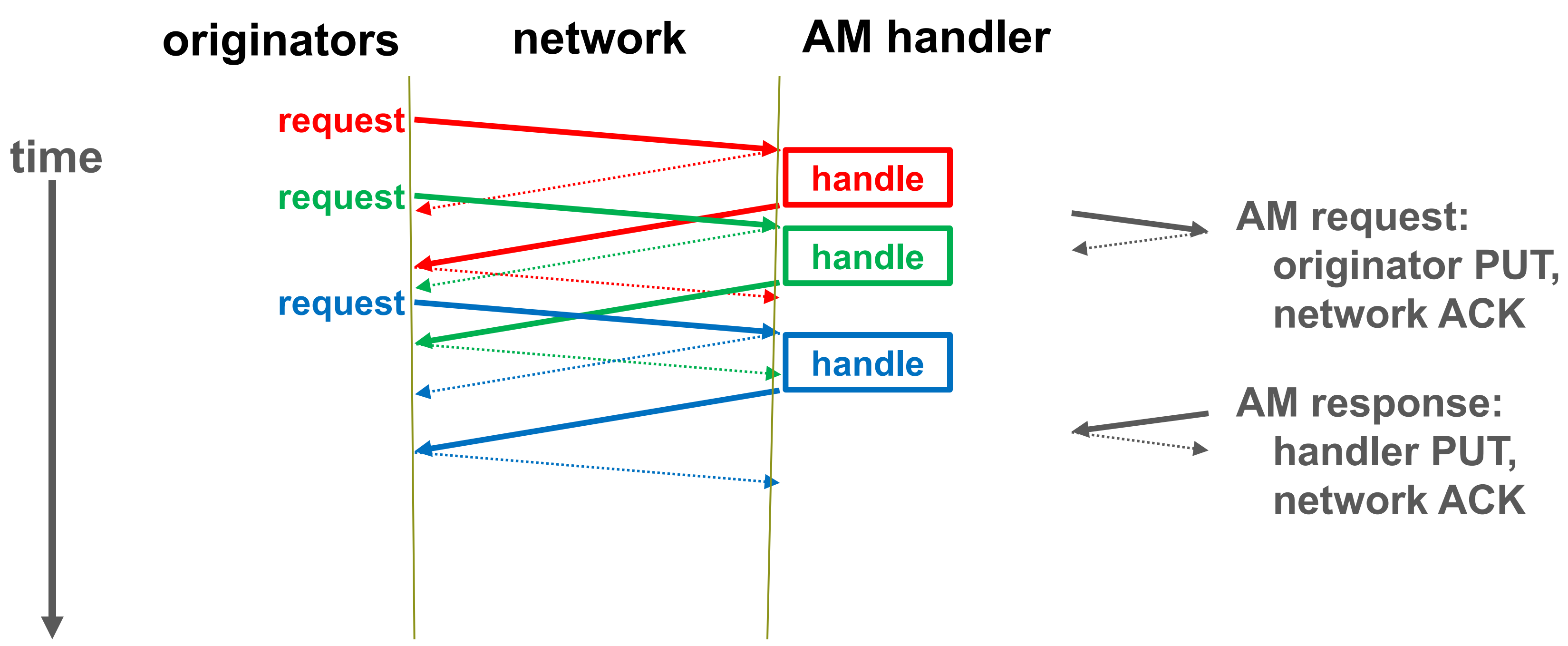
AM Responses: Background

- **Active Message handlers slowed by response overhead**
  - Waited for network to acknowledge completion responses
  - Added 1-2 microseconds (i.e., 1 network round trip) per AM



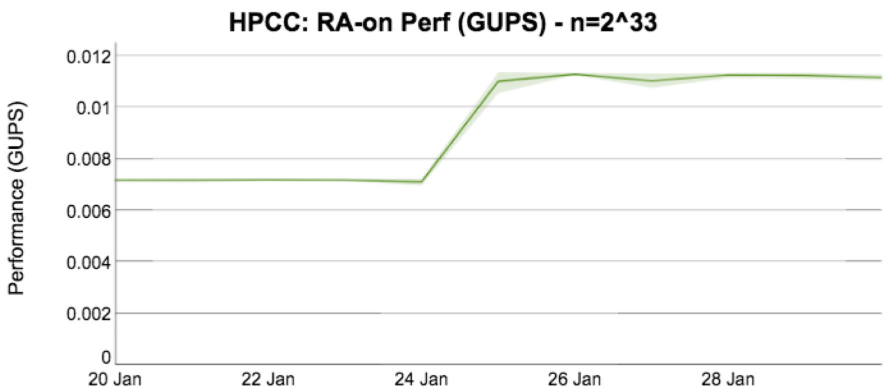
AM Responses: This Effort

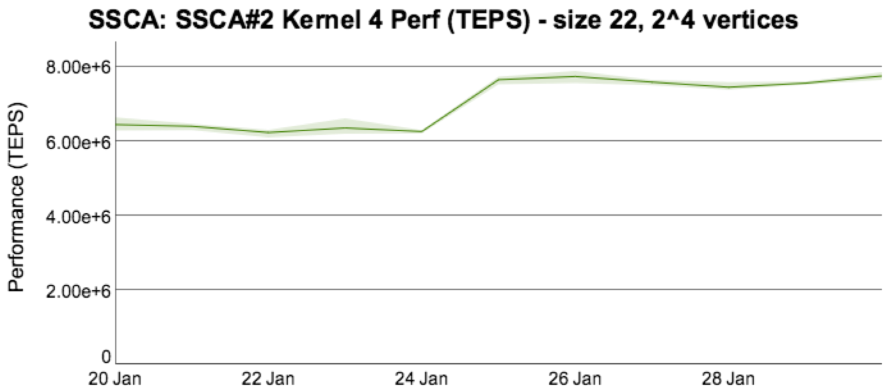
- **Use nonblocking PUTs for AM responses**
  - Begin handling next request as soon as previous response is sent
  - Don't wait for response ACKs, just consume them as they arrive



AM Responses: Impact

- Performance improvements for AM heavy benchmarks





Comm Domain Limit

Comm Domain Limit

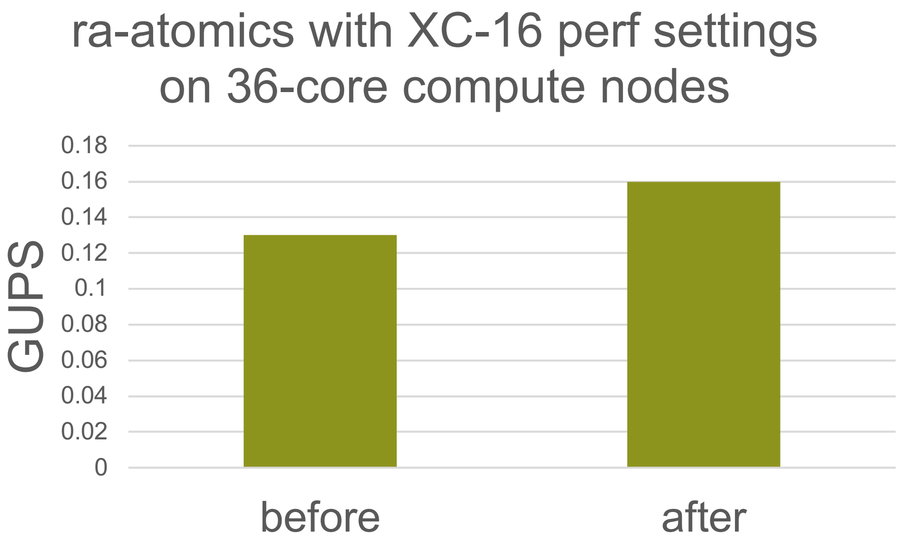
Background: Limited to at most 30 GNI comm domains on XC

- Legacy code from Gemini; Aries hardware limit is 128

This Effort: Raise limit on XC to 120 comm domains

- Can now make effective use of more than 30 cores

Impact:



Avoid ‘Bus Error’ Messages

Avoid 'Bus Error' Messages

Background: Running out of memory caused 'Bus Error' halt

- Result of SIGBUS signal if page allocation failed when first touched
- Side effect of allocation technique that improved NUMA locality

This Effort: Emit usual "out of memory" message instead

- Only for SIGBUS due to touching new memory, not others

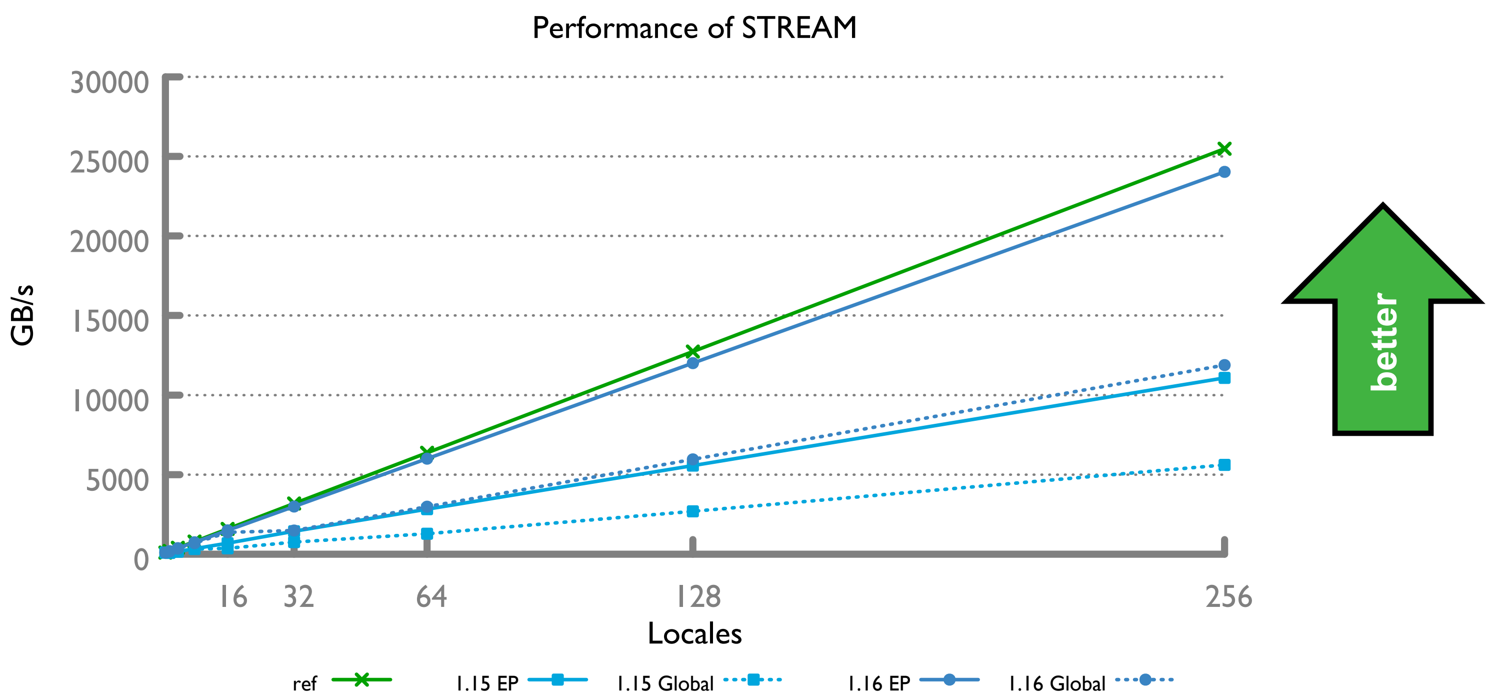
Impact: Improved ease-of-use

- Removes an awkward special case and associated documentation

Scalability Improvements

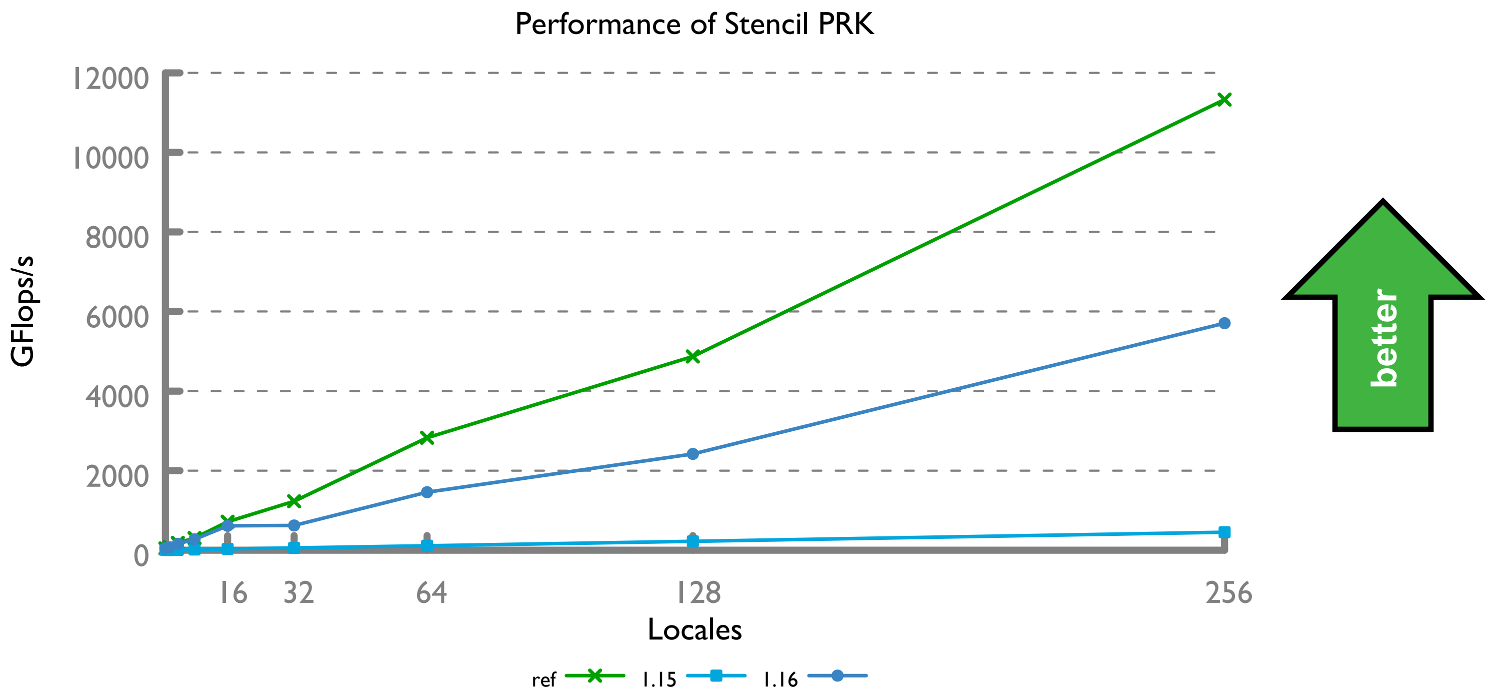
Scalability: Background

- **1.16 had significant performance improvements**
  - But there were a few ugni performance mysteries
    - Stream Global scalability was worse than Stream EP



Scalability: Background

- **1.16 had significant performance improvements**
  - But there were a few ugni performance mysteries
    - PRK Stencil scalability lagged behind reference (but gn-mpi on par with ref)



Scalability: Background

- **Remote task spawning included in Global Stream timers**
  - EP spawns to all locales before starting timers

Stream EP

```
coforall loc in Locales do on loc {
  var A, B, C: [1..m] elemType;
  initVectors(B, C);

  startTimer();

  forall (a, b, c) in zip(A, B, C) do
    a = b + alpha * c;

  stopTimer();
}
```

Global Stream

```
const ProblemSpace = {1..m} dmapped …;
var A, B, C: [ProblemSpace] elemType;
initVectors(B, C);

startTimer();

forall (a, b, c) in zip(A, B, C) do
  a = b + alpha * c;

stopTimer();
```

- **Remote task spawning included in PRK Stencil as well**

Scalability: Background

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

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

roughly into:

```
var endCount: atomic int;

endCount.add(Locales.size);
for loc in Locales {
  executeOnNB(loc, bodyWrapper, endCount);




}
endCount.waitFor(0);

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

Scalability: Background

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

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

roughly into:

```
var endCount: atomic int;

endCount.add(Locales.size);
for loc in Locales {
  // inlining the call to executeOnNB(loc, bodyWrapper, endCount):
  chpl_comm_initiate_remote_fork(loc, ACK, …);
  while(!received(ACK)) {
    chpl_task_yield(); // problem – yielded before all remote tasks started
  }
}
endCount.waitFor(0);

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

Scalability: This Effort

- **Avoid yielding when doing NB remote forks under ugni**

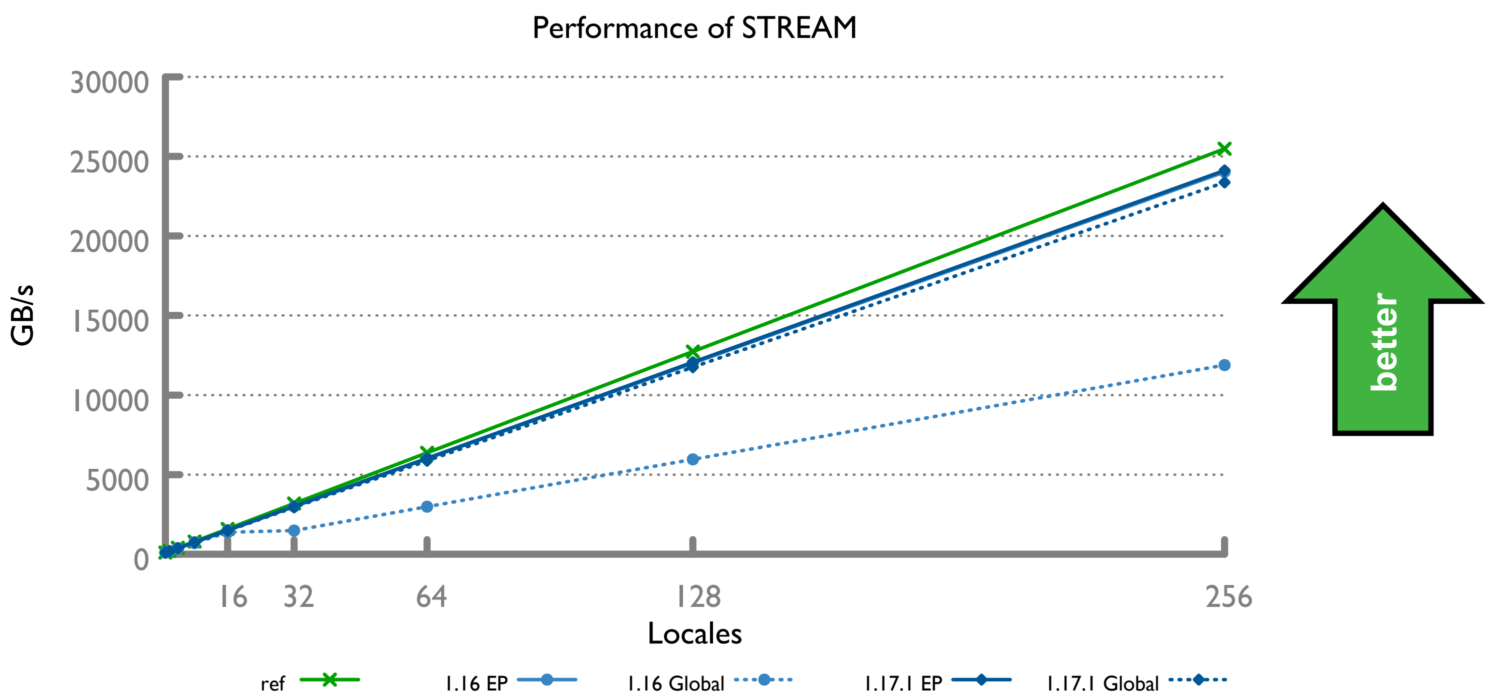
```
coforall loc in Locales do on loc { body(); }
```

now roughly transformed into:

```
var endCount: atomic int;

endCount.add(Locales.size);
for loc in Locales {

  chpl_comm_initiate_remote_fork(loc, ACK, …);
  while(!received(ACK)) {} // network round trip wait before next iteration


}
endCount.waitFor(0);

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

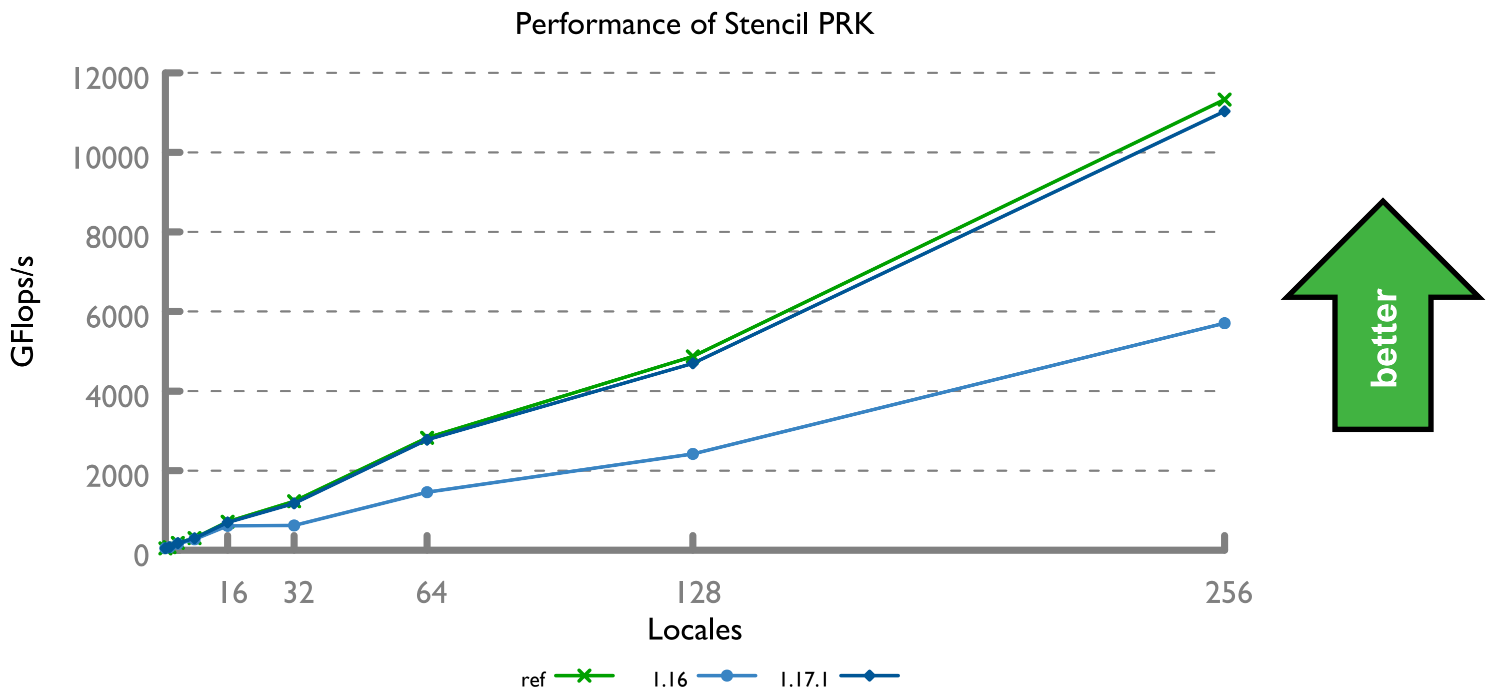
Scalability: Impact

- **Significantly improved scalability under ugni**
  - Stream Global scaling close to Stream EP up to 256 nodes



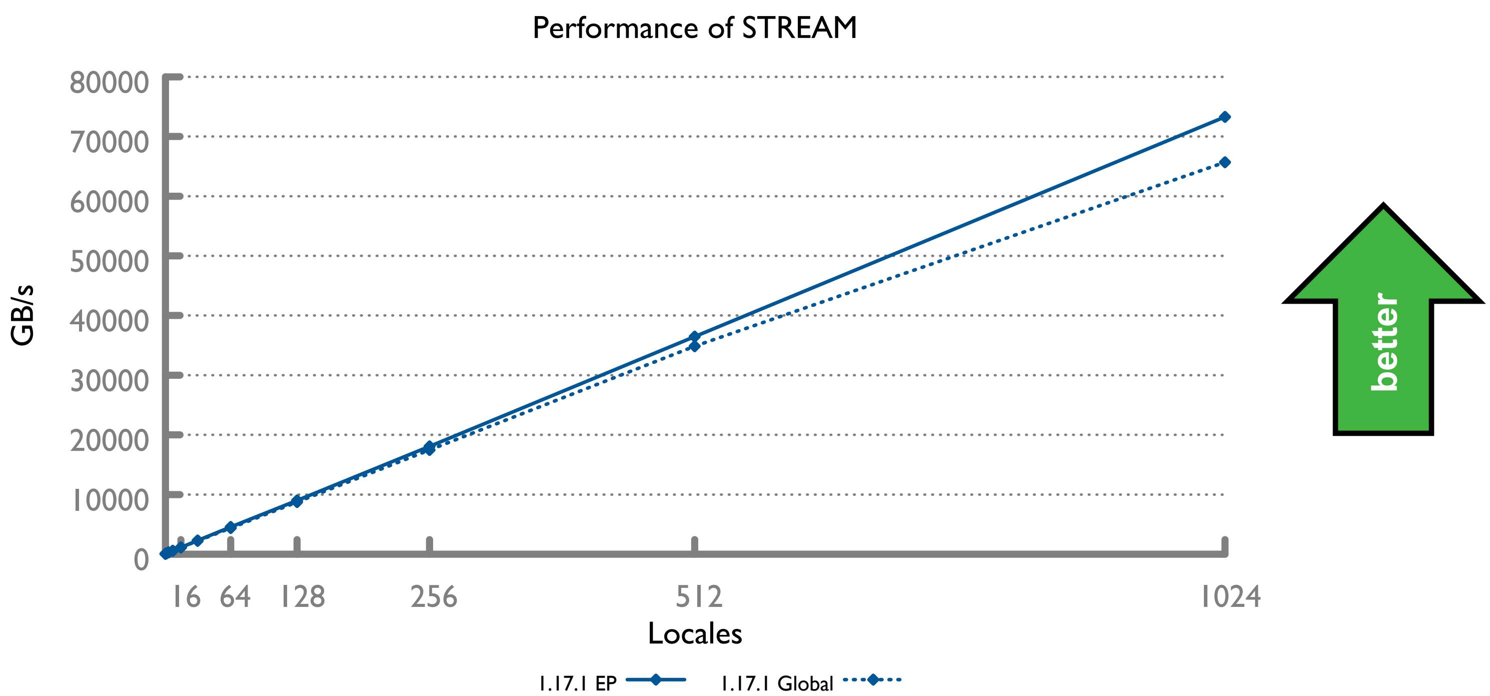
Scalability: Impact

- **Significantly improved scalability under ugni**
  - PRK Stencil performance is on par with reference up to 256 nodes



Scalability: Next Steps

- **Scalability is good for up to 256 locales**
  - At higher scales (1024 shown below), scalability starts to suffer



Scalability: Next Steps

- **Same interface is used to create 1 task or 1 million tasks**
  - Great for code reuse, but has scalability bottlenecks
    - task spawning is serialized

```
endCount.add(Locales.size);
for loc in Locales {
  chpl_comm_initiate_remote_fork(loc, ACK, …);
  while(!received(ACK)) {}          // network round trip wait before next iteration
}
endCount.waitFor(0);
```

- **Introduce a bulk spawning interface**
  - Amenable to many optimizations
    - Initiate multiple tasks at once, instead of one at a time
    - Use an “end count” mechanism optimized for the network
    - Do tree-based spawning instead of a 1-to-all spawning

ISx Improvements

ISx: Background

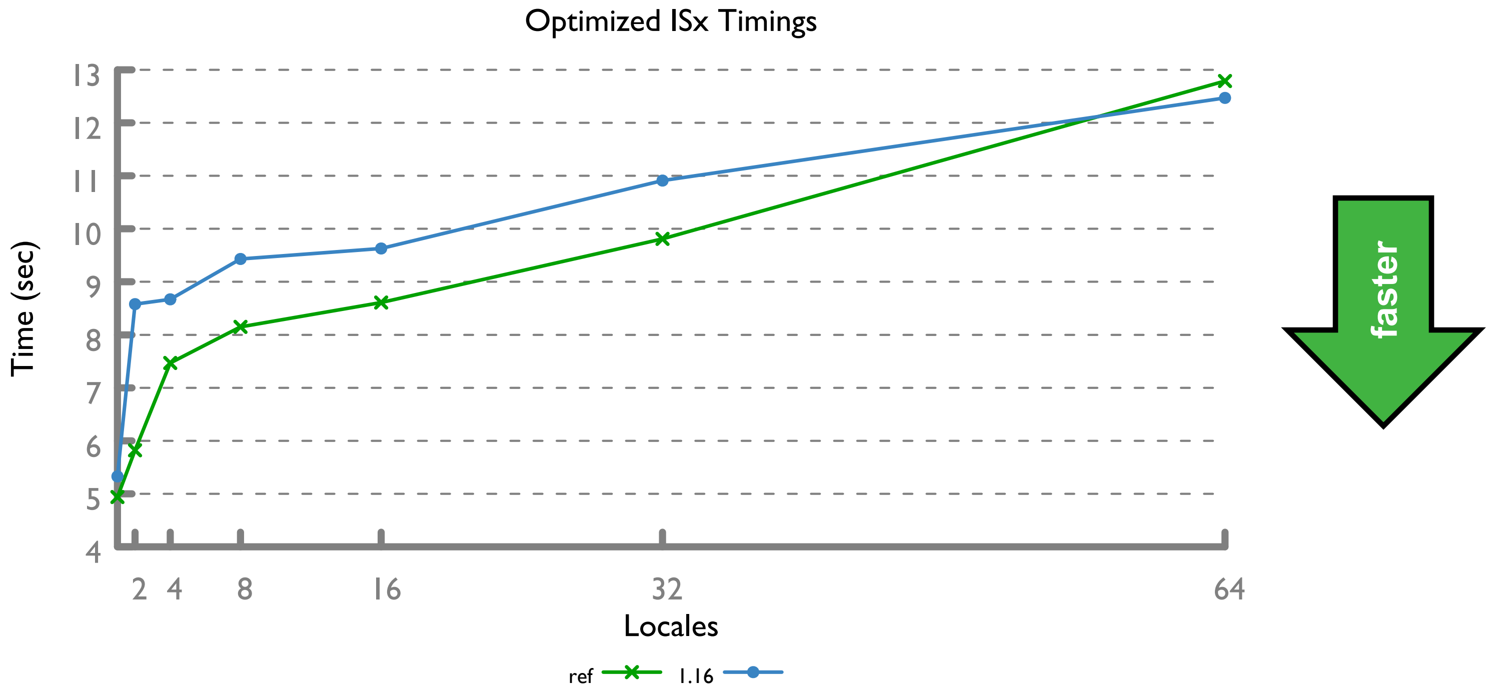
- **Scalable Integer Sort benchmark**
  - Developed at Intel, published at PGAS 2015
  - SPMD-style computation with barriers
  - Punctuated by all-to-all bucket-exchange pattern
  - References implemented in SHMEM and MPI

- **Chapel implementation introduced in 1.13 release**
  - Motivation: bucket-exchange is a common distributed pattern

Scalable Barrier

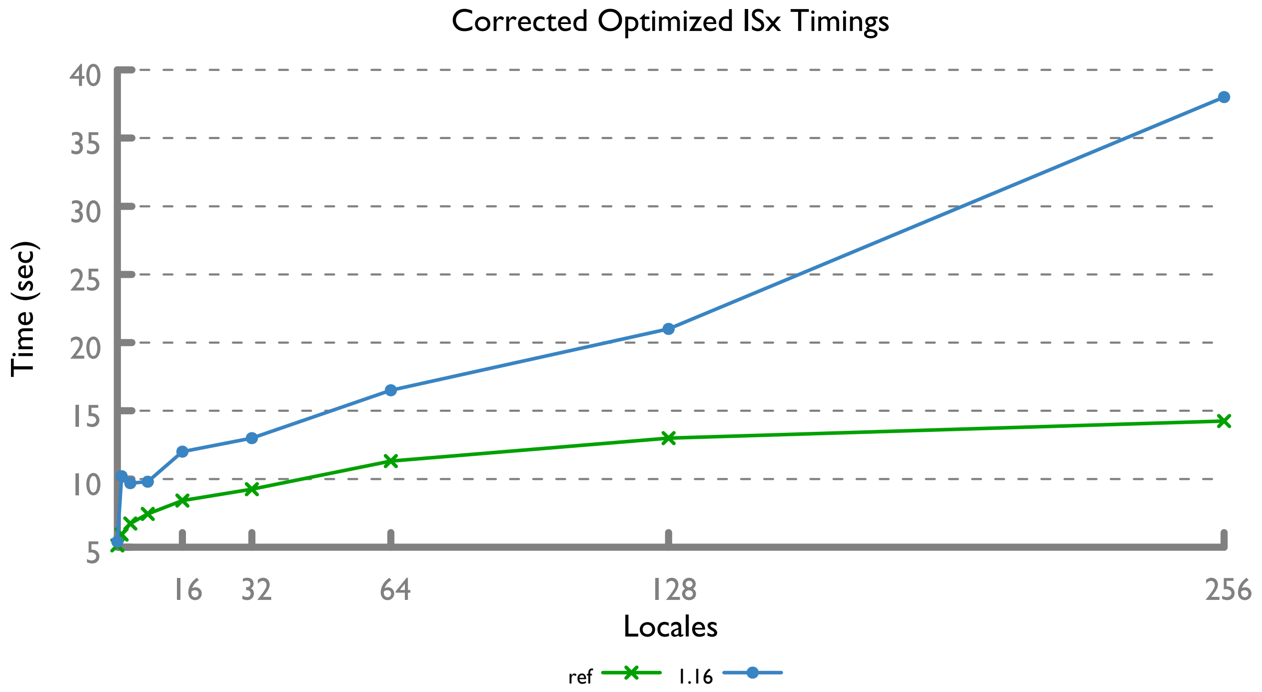
Scalable Barrier: Background

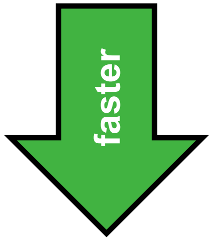
- **Previously reported ISx scalability on par with reference**
  - Believed we were mostly done looking at ISx



Scalable Barrier: Background

- **Unfortunately we discovered some issues**
  - Found a bug in our port that reported min, rather than avg, timings
  - At larger scales performance drops drastically
  - A bug fix for dynamic registration further hurt performance





Scalable Barrier: Background

- **Identified barrier implementation as scalability limiter**
  - Barrier used a single atomic variable on one locale
    - all remote locales did active messages back to that locale
  - 36-cores on 256 locales results in ~10,000 tasks on barrier locale
    - huge bottleneck, and default size task-stacks led to OOMs

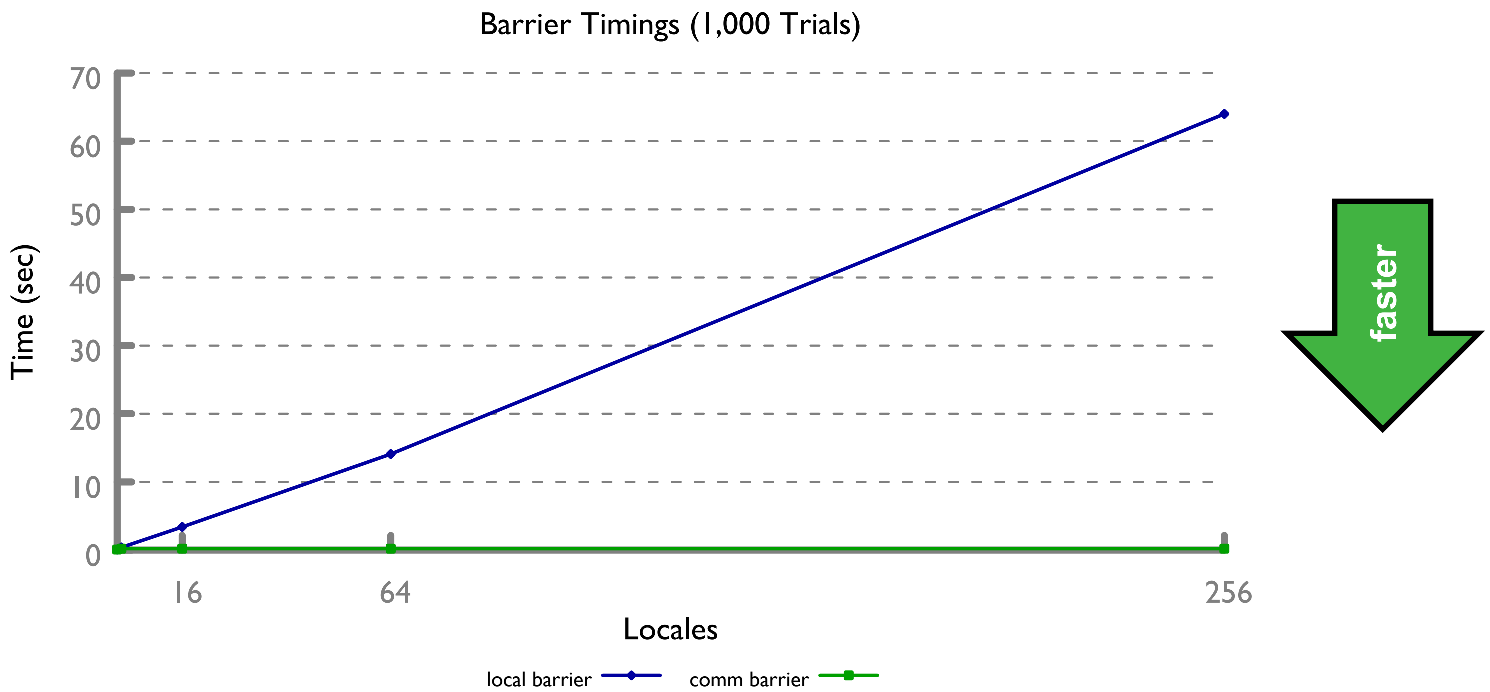
Scalable Barrier: This Effort

- **Added a scalable allLocalesBarrier**
  - A singleton global barrier that must be called from all locales
    - optionally, with multiple tasks on each locale
  - Similar to `shmem_barrier_all()` or `MPI_Barrier(MPI_COMM_WORLD)`

```
use AllLocalesBarriers;

coforall loc in Locales do on loc {
  allLocalesBarrier.barrier();
  writeln("After barrier");
}

allLocalesBarrier.reset(4);
coforall loc in Locales do on loc do
  coforall tid in 1..4 do
    allLocalesBarrier.barrier();
```

Scalable Barrier: Impact

- **allLocalesBarrier offers significantly better scalability**
  - Over 2,000 times faster at 256 locales (and scaling better)
  - No on-stmts, so no single-node bottleneck or massive task creation



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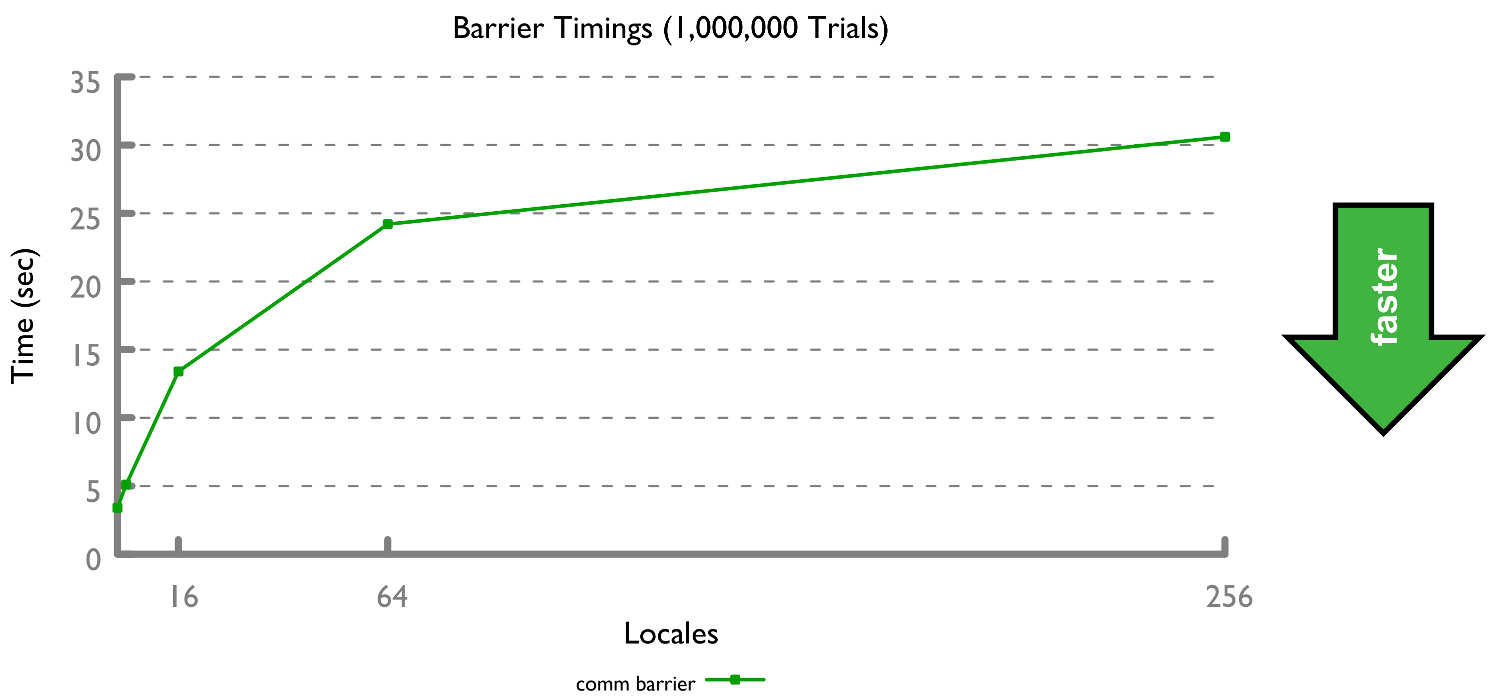
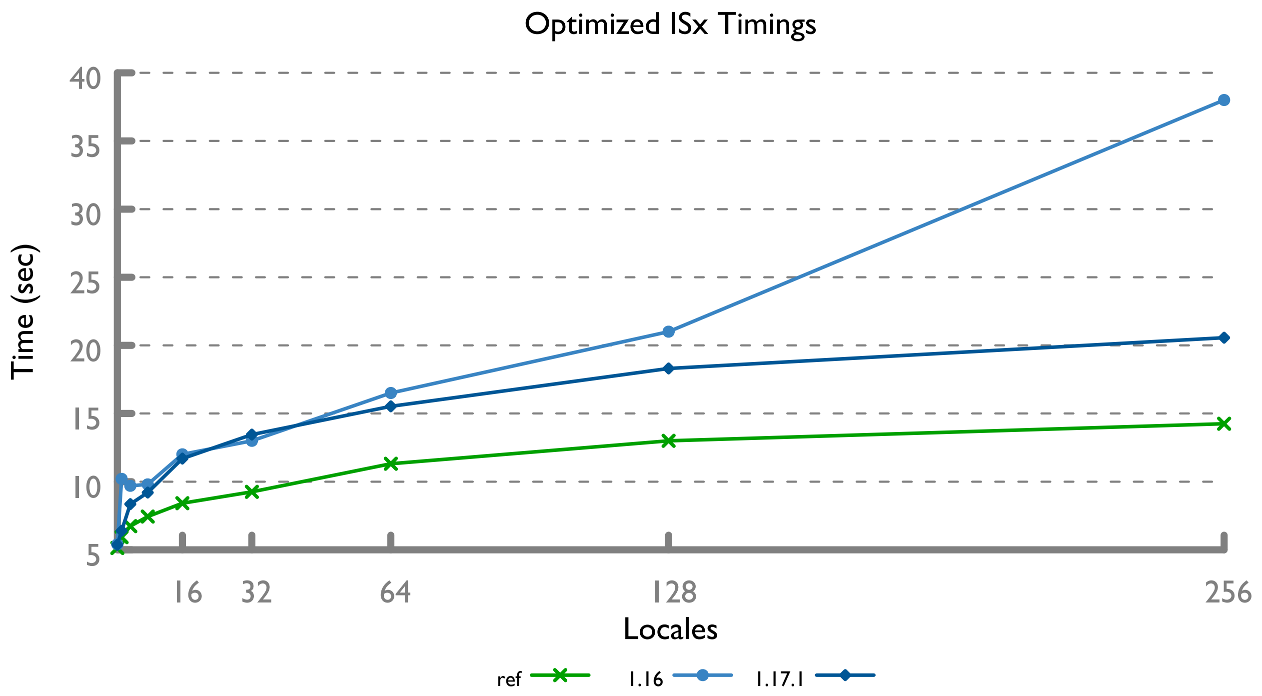
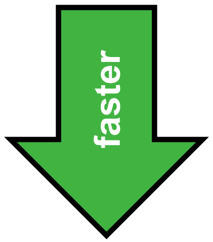


Scalable Barrier: Impact

- **Significantly improved scalability of ISx**
  - Raw performance still behind reference, but scaling well
  - No longer any on-stmts in ISx





Scalable Barrier: Next Steps

- **allLocalesBarrier has some limitations**
  - All locales must participate
  - A singleton barrier, only one instance exists
- **Add more usable barrier implementations**
  - Ability to barrier between a subset or team of locales
  - Ability to create multiple barriers
    - e.g.

```
var teamABarrier  = new LocalesBarrier(Locales[0..5]);
var teamBBarrier  = new LocalesBarrier(Locales[6..10]);
var allLocBarrier = new LocalesBarrier(Locales);
```

Park the Main Process

Main Process: Background and Effort

Background: allLocalesBarrier hooks into chpl_comm_barrier()

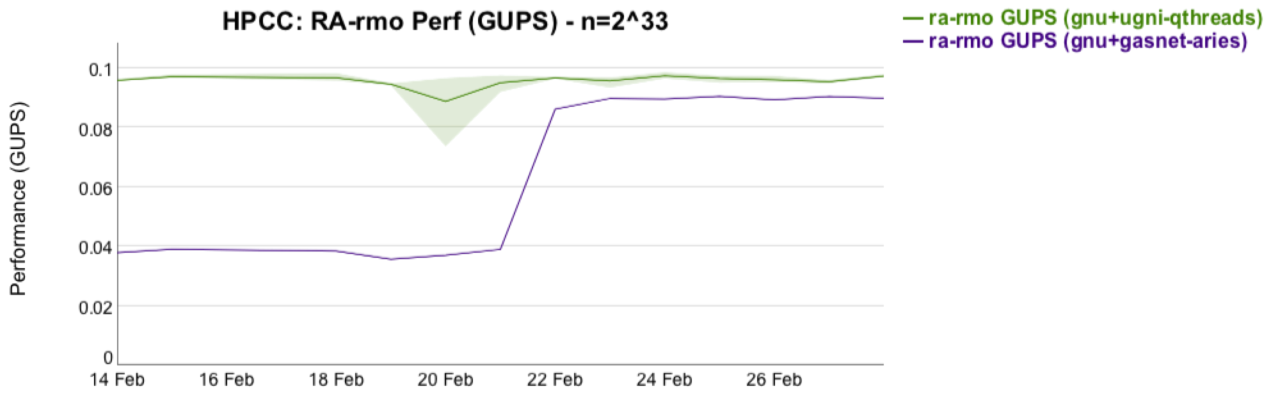
- Optimized for the network and comm layer
  - tree-based put barrier under ugni, dissemination barrier under gasnet-aries
- chpl_comm_barrier() was previously tied up by runtime
  - Main process on non-0 locales waited for locale 0 to shutdown

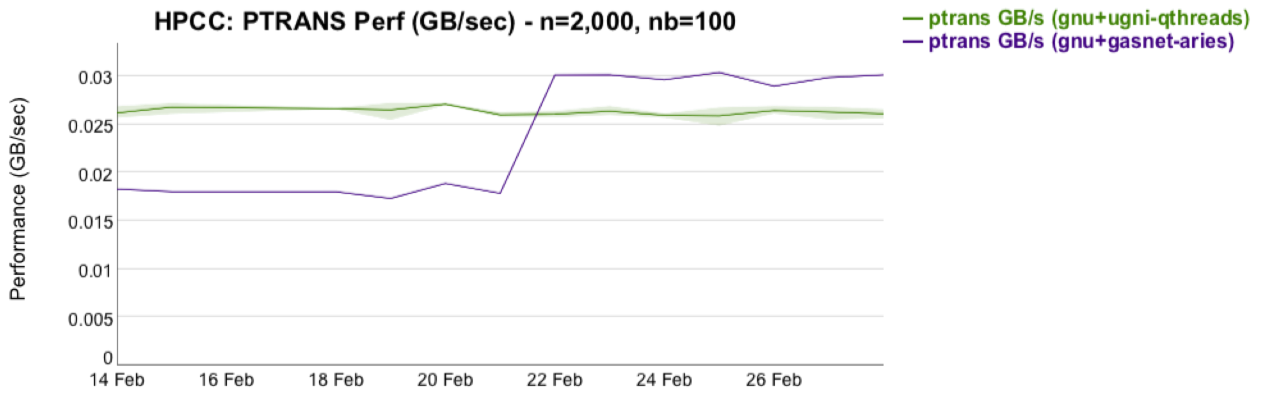
This Effort: Park the main process on a condition variable

- Signaled during shutdown by an active message from locale 0
- Frees up chpl_comm_barrier() for use in user-code

Main Process: Impact

- Parking main process improved gasnet-aries performance





Reduce Progress Thread Interference

Progress Thread Interference: Background

- **For multi-locale programs we start a "progress thread"**
  - Separate pthread that processes active messages (on-stmts)
  - Actively checked for messages, yielding if none found

```
while (run_progress_thread) {
  if (new_am()) process_am();
  else sched_yield();
}
```

- **Even with no on-stmts, progress thread interfered**
  - Context switch between progress thread and thread hosting chpl tasks
  - Resulted in wide variations for tasks doing identical operations:

```
input-step: 0.91 avg (0.81 min .. 1.28 max)
```

Progress Thread Interference: This Effort

- **Added an experimental blocking progress thread**
  - ugni only, enabled with CHPL_RT_COMM_UGNI_BLOCKING_CQ=y

```
while (run_progress_thread) {
  am = block_for_am(); // kernel mediated, blocking call
  process_am(am);
}
```

- **Enabled for ISx, but not by default for 1.17**
  - Improves ISx and benchmarks with few active messages
  - But slightly increase latency of active messages
    - mostly impacts microbenchmarks, but wanted more time to investigate

- **Enabled by default for 1.17.1**
  - See Spectre/Meltdown slides for more information

Progress Thread Interference: Impact

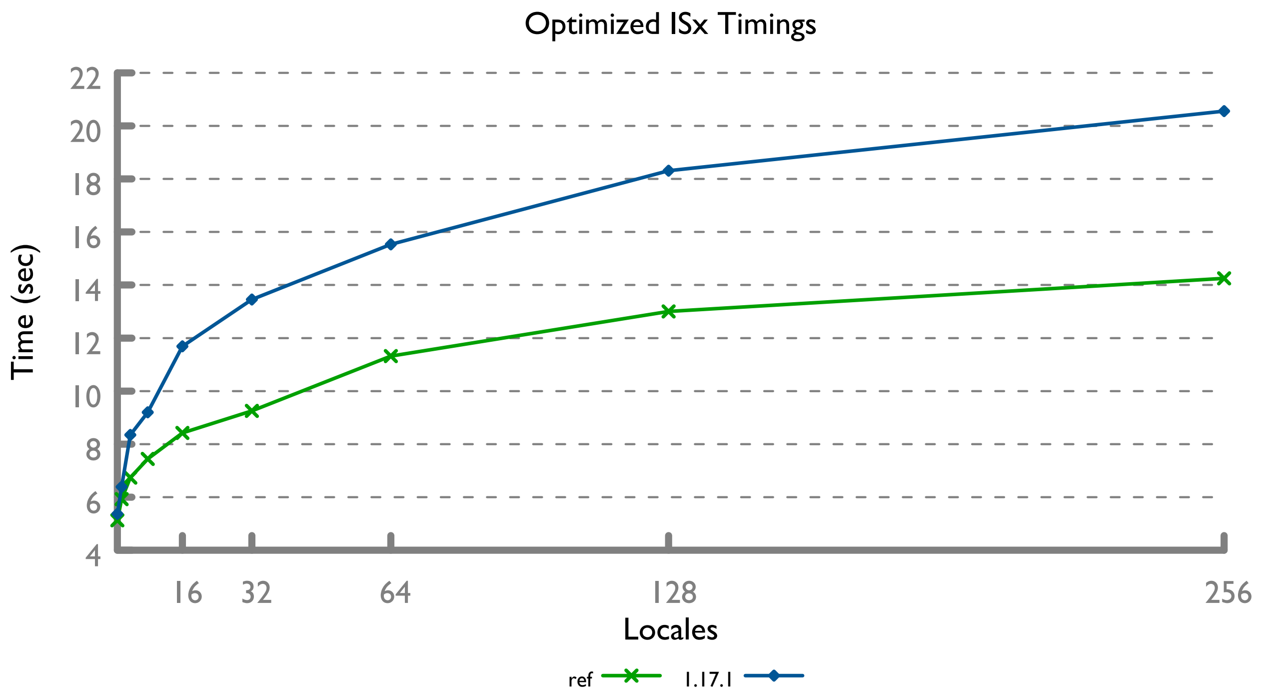
- **Reduced variability for ISx steps**

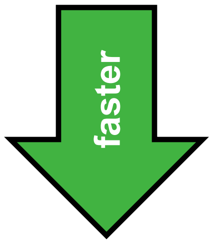
```
input-step: 0.91 avg (0.81 min .. 1.28 max)

input-step: 0.89 avg (0.81 min .. 0.95 max)
```

- **Remaining variability due to dynamic array registration**
  - Kernel fault-in times for large allocations tend to vary

ISx: Summary

- **ISx scalability on par with reference**
  - (raw performance is still ~25% behind, but scaling well)





ISx: Next Steps

- **Continue to improve ISx performance**
  - Avoid dynamic registration for arrays
    - new dynamic heap extension can amortize cost of allocation/registration
    - dynamic array registration helps with parallel first-touch
    - but ISx runs in an SPMD manner, arrays initialized serially
  - Eliminate any extra communication compared to reference
  - Investigate using RDMA (BTE) for large puts/gets
    - currently only use FMA, but BTE should be better for large transfers

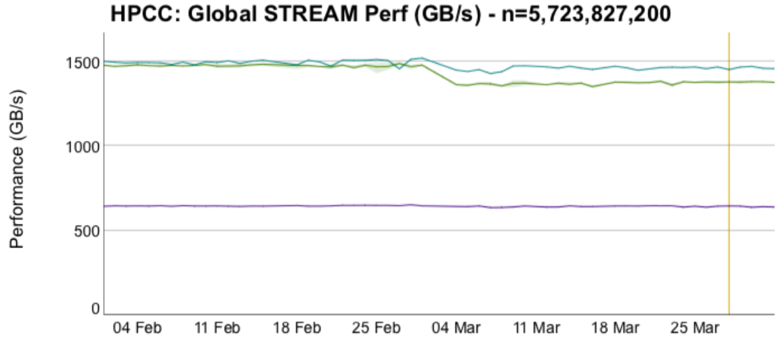
Meltdown and Spectre Impact

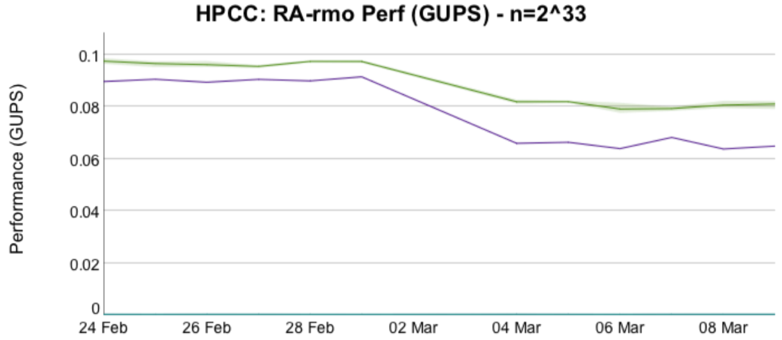
Meltdown and Spectre: Background

- **Meltdown and Spectre exploit security vulnerabilities**
  - Patches to mitigate exploits were expected to hurt performance
  - We had hoped that the impact on HPC/Chapel would be limited
    - overhead expected to be for I/O, system calls, etc. -- not HPC kernels

Meltdown and Spectre: Background

- **Unfortunately patches hurt multi-locale performance**
  - In some cases, performance regressions were significant
    - ~10% hit for stream-global, ~30% hit for ra-rmo
    - surprising, since stream is just memory bandwidth, RA just NIC operations





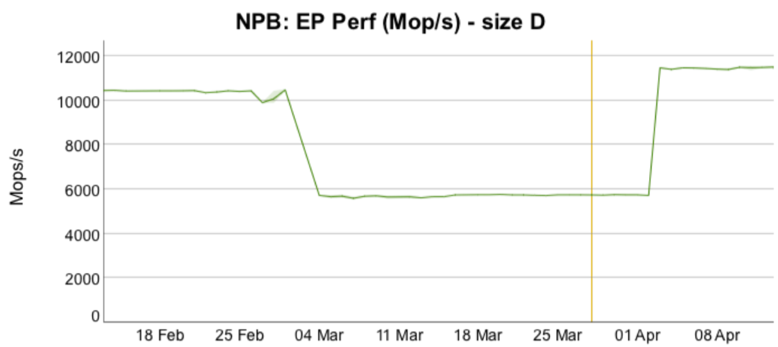
- **Discovered overhead is from progress thread interference**
  - Patches increased cost of context switches
  - Task running on core shared with progress thread slowed down

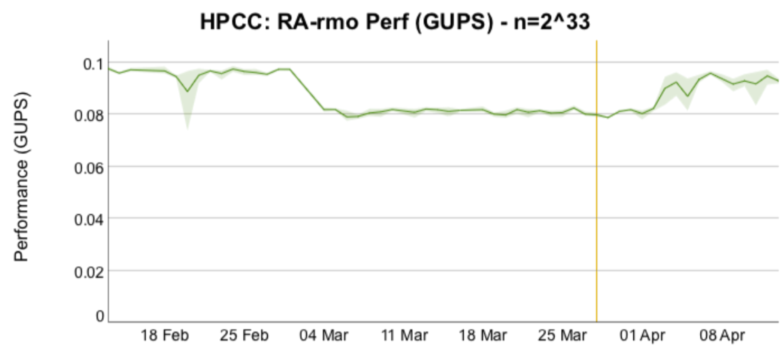
Meltdown and Spectre: This Effort

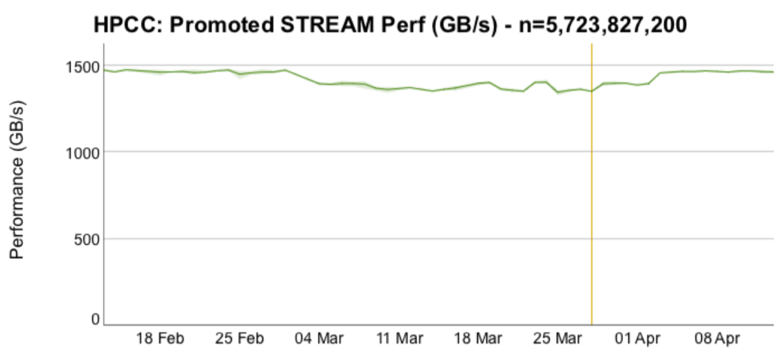
- **Reduce interference from the progress thread**
  - Fortunately, ISx investigation had us looking at this recently
  - Previously added an option to use a blocking progress thread
    - Now we just enable that functionality by default
    - Not resolved in time for 1.17 release, but is included in 1.17.1

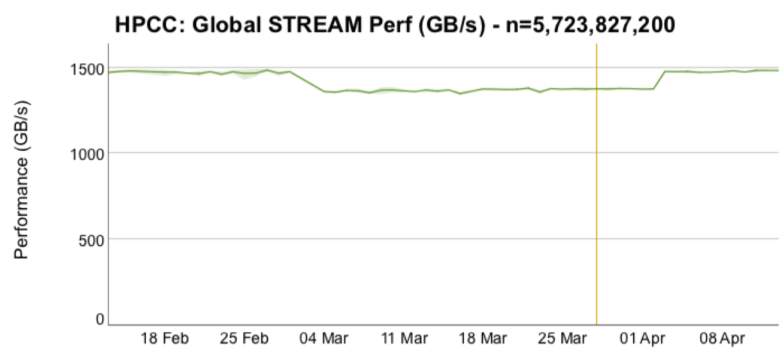
Meltdown and Spectre: Impact

- **Restored performance to pre-patch levels**
  - In some cases performance is better than before



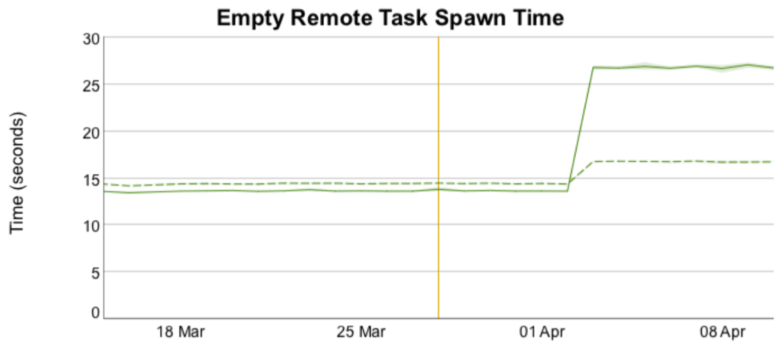


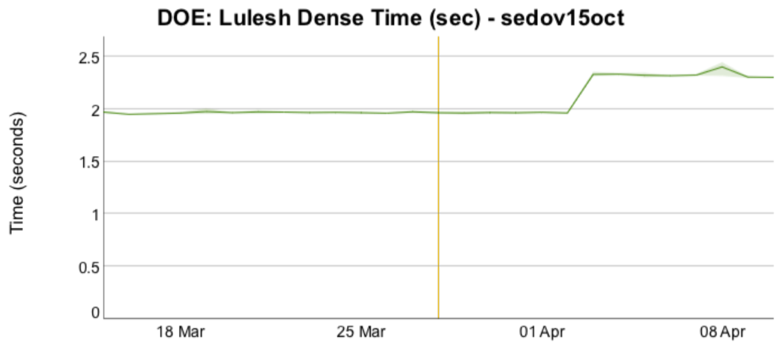




Meltdown and Spectre: Impact

- **Caused some performance regressions**
  - Using a blocking progress thread slightly increases on-stmt latency





Meltdown and Spectre: Next Steps

- **Reduce progress thread interference for GASNet**
  - Will need to work with the GASNet team on a strategy

Reductions in Memory Leaks

Memory Leaks

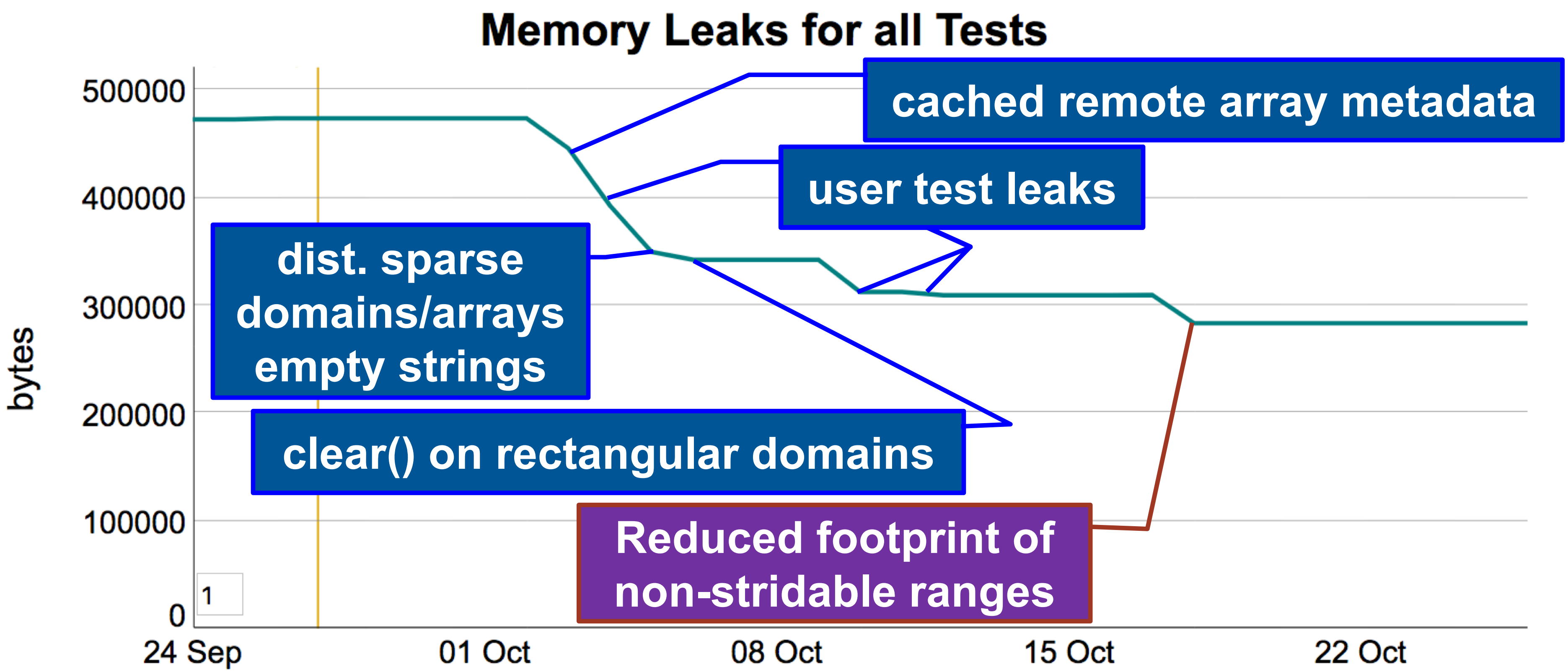
Background:

- Historically, Chapel testing has leaked a large amount of memory
- Chapel 1.15 and 1.16 closed major sources of large-scale leaks
- Remaining cases considered less concerning, but still undesirable

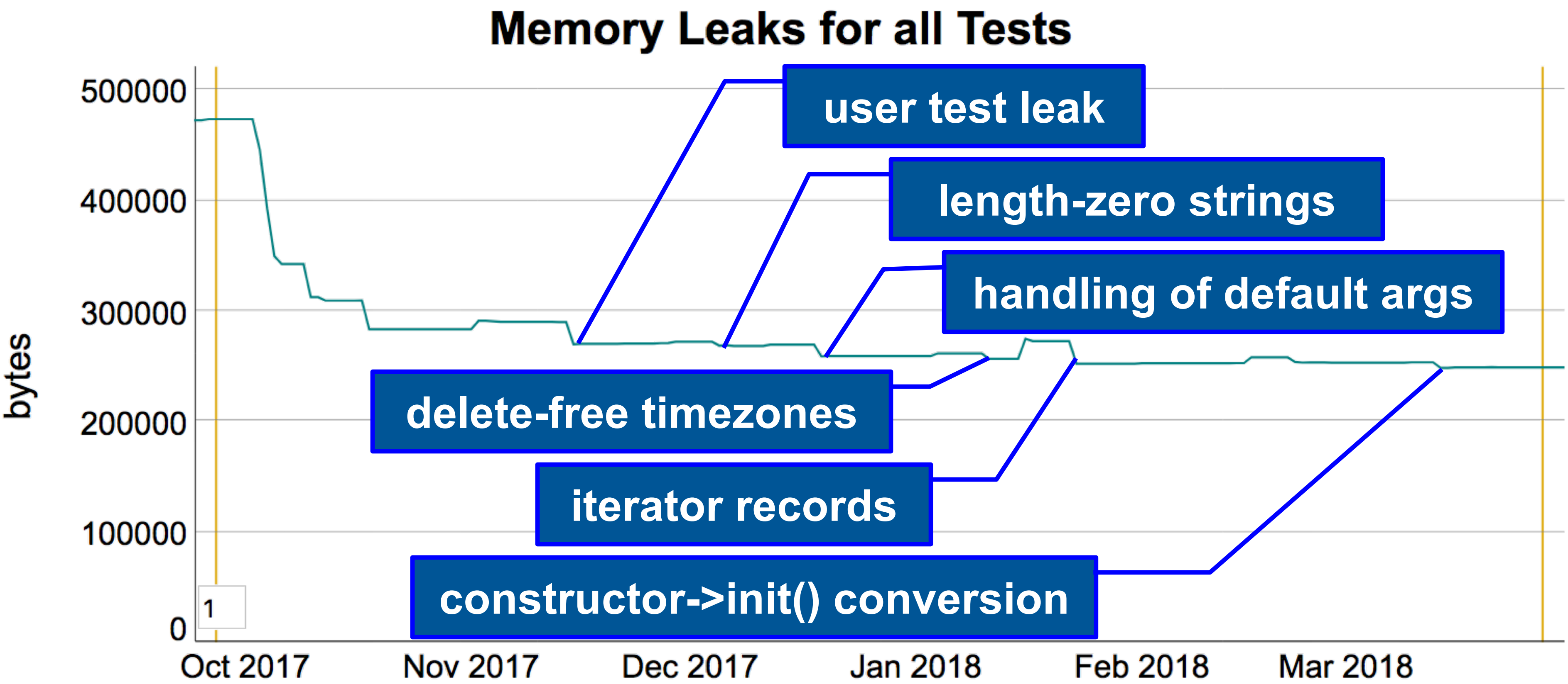
This Effort:

- Closed a number of additional sources of minor leaks:
  - distributed sparse domains and arrays
  - local caches of remote array metadata
  - iterator records
  - timezones in ‘DateTime’ module (using \`Shared\`)
  - rectangular arrays whose domains had been ‘clear()’ed
  - temporary strings allocated in IO routines / zero-length strings
  - user-level leaks in test programs
- Also, reduced the memory footprint of non-stridable ranges

Memory Leaks: This Effort (October 2017)

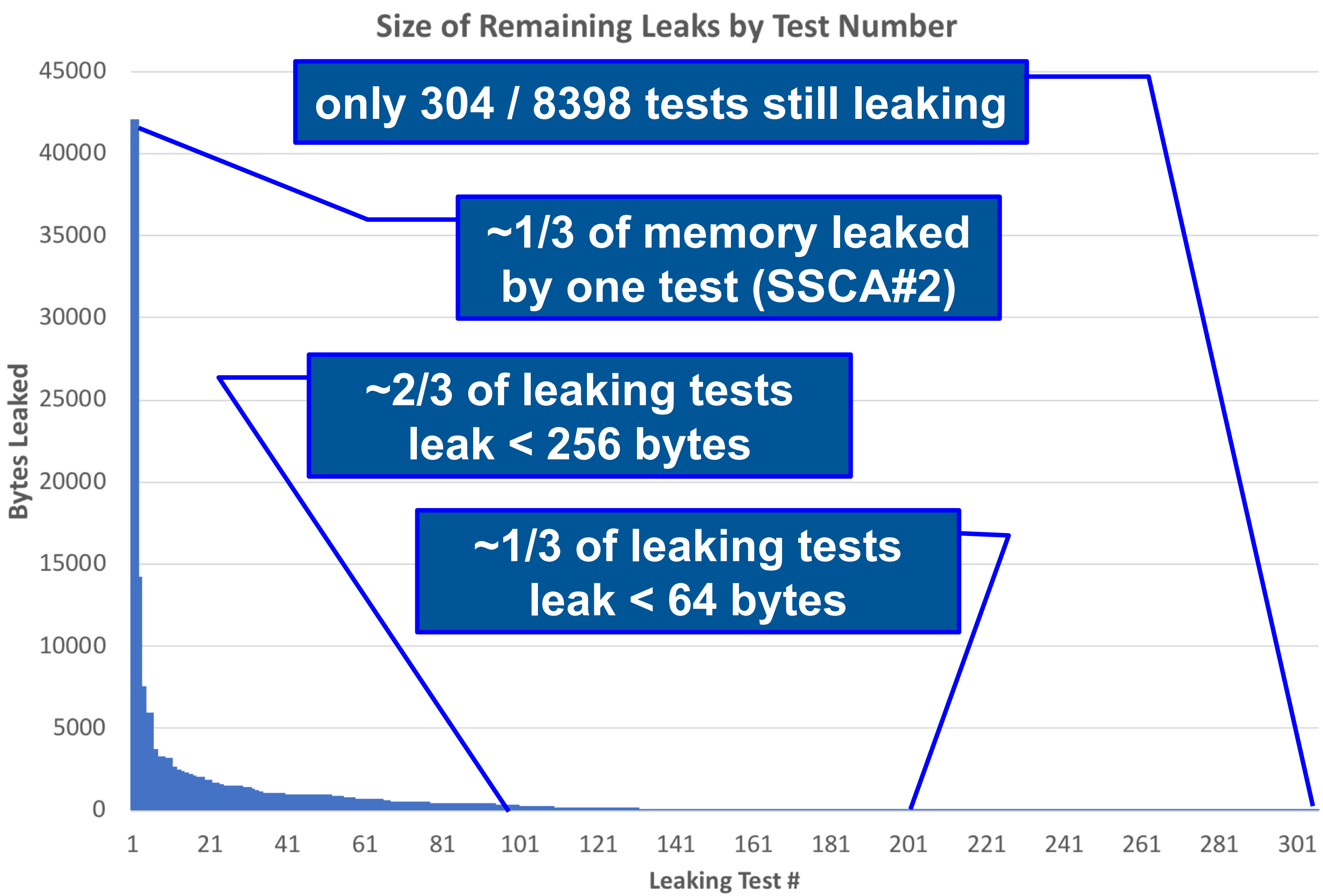


Memory Leaks: This Effort (1.17 release cycle)



Impact: reduced leaks in nightly testing by ~50%

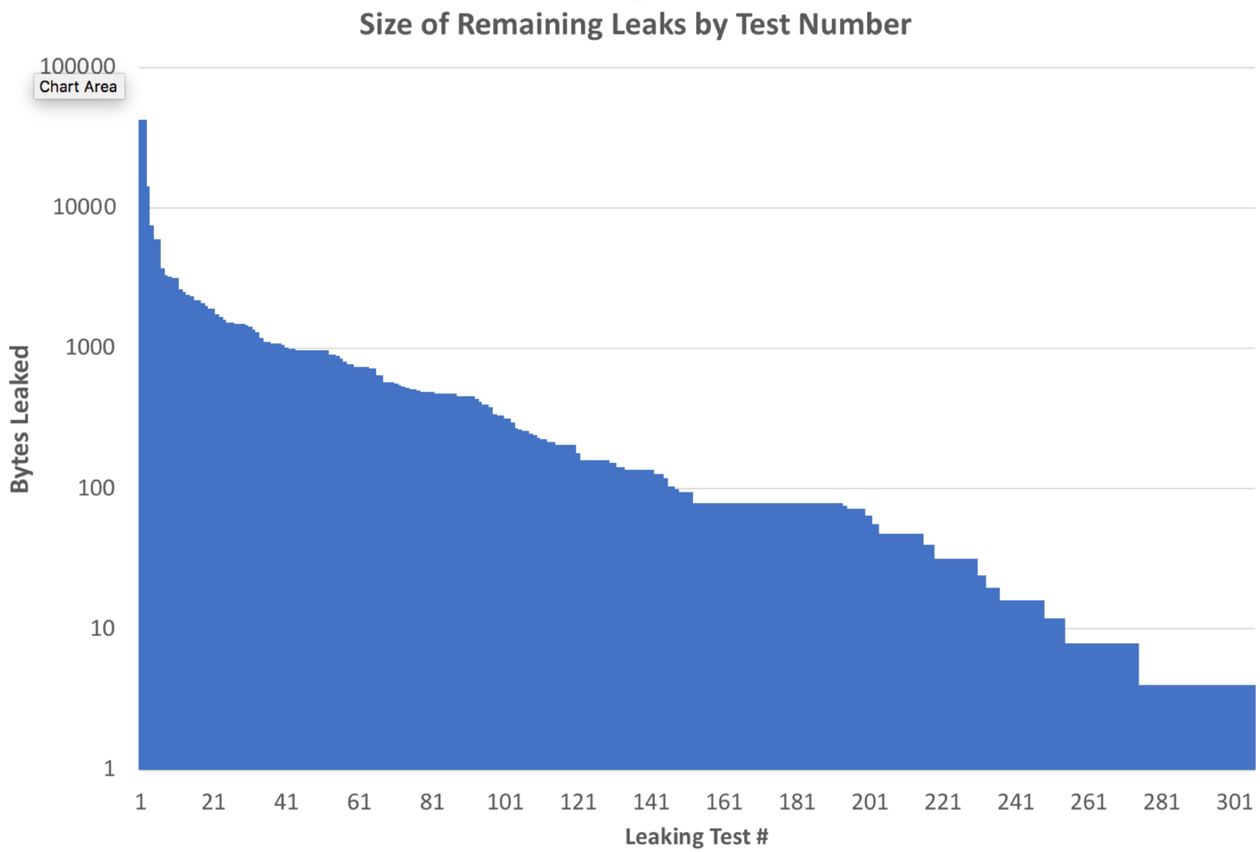
Memory Leaks: Remaining Leaks (as of April 10)



Memory Leaks: Next Steps

Next Steps:

- Continue working through remaining leaks as a background task



Other Performance Optimizations

Other Performance Optimizations

- Improved remote value forwarding optimization for types with initializers

- Reduced wide-pointer overhead for domains and distributions

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