Benchmarks and Performance Optimizations

Chapel version 1.20

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@ChapelLanguage

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CRAY CHAPEL

Outline

- Unordered Copy Improvements
- Unordered Compiler Optimization
- Task Placement Improvements
- InfiniBand Improvements
- Performance Portability
- RandomStream Optimization
- Memory Pressure
- Memory Leaks

Unordered Copy Improvements

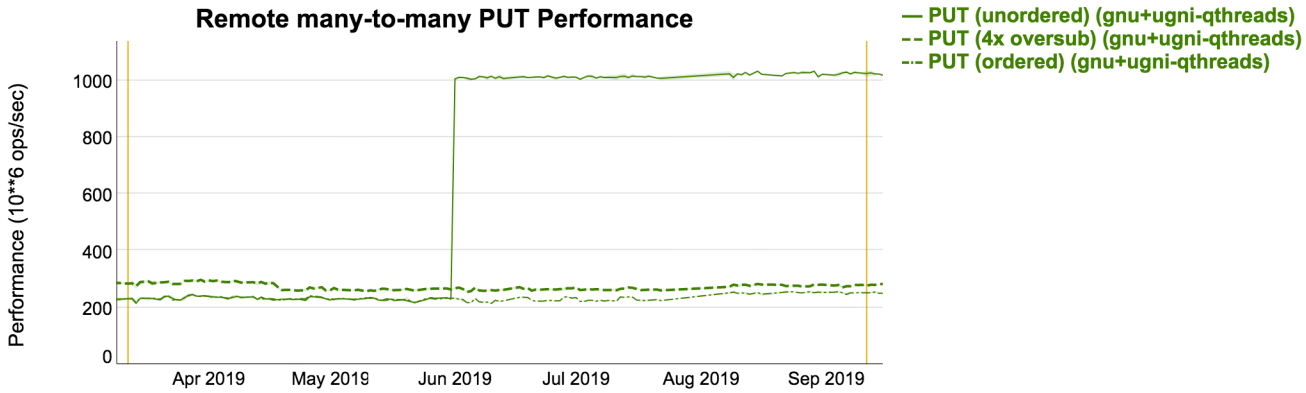
Unordered Copy: Background

- 'unorderedCopy(dst, src)' was added in 1.19
  - Provides faster remote copies when sequential-consistency is not required

- Initial implementation had some limitations
  - Only optimized when source was remote (network GET)
  - Source had to be a 'var' ('const' / 'param' not supported)
  - Did not work for promoted calls
  - Only supported numeric types

Unordered Copy: This Effort

- Optimized performance when destination is remote (network PUT)
  - 4.5x faster than ordered PUTs



Unordered Copy: This Effort

- Extended support to 'param' and 'const' sources:

```
forall i in 1..n do
  unorderedCopy(A[i], 1);   // 1 is a ‘param’ value
forall i in 1..n do
  unorderedCopy(A[i], i);   // i is a ‘const’ variable
```

- Fixed support for promoted calls:

```
unorderedCopy(A, 1);
unorderedCopy(A, B);
```

- Extended support to Boolean types:

```
unorderedCopy(done, true);
```


Unordered Copy: Impact, Next Steps

Impact:

- unorderedCopy is now more usable and performant

Next Steps:

- Extend unorderedCopy to all plain old data (POD) types
  - Tune performance for larger POD types
- Optimize for all comm layers
  - Currently only optimized for comm=ugni

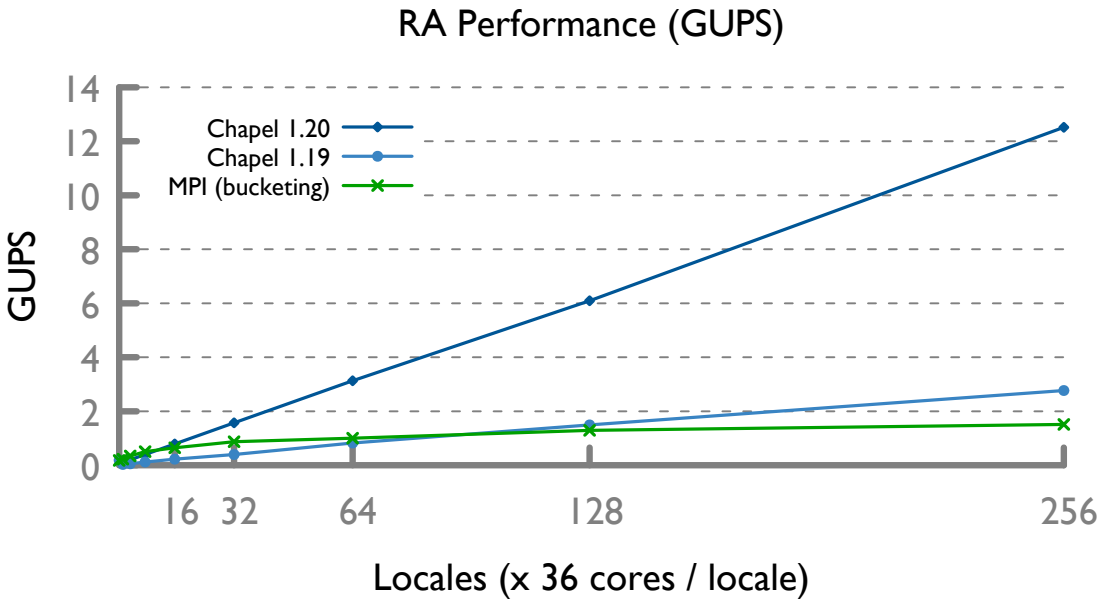
Unordered Compiler Optimization

Unordered Optimization: Background

- Unordered operations provide a significant performance speedup
  - But they are an advanced feature that break the memory consistency model
- Many Chapel idioms should be amenable to unordered operations
  - Chapel semantics make these types of transformations possible
    - e.g., most synchronization-free forall loops
- 1.19 included a prototype optimization to automatically use unordered ops
  - Implemented towards end of release cycle, so left "off" by default

Unordered Optimization: This Effort

- Improved the optimization to support more distributions
- Enabled the unordered compiler optimization by default



Unordered Optimization: Impact, Next Steps

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Impact:

- Many programs benefit from unordered operations with no source changes

Next Steps:

- Extend optimization to handle promoted expressions
- Expand how many statements can be optimized
  - Currently, only the last statement of a forall loop is optimized

Task Placement Improvements

Task Placement: Background

- Chapel relies on first touch to get correct NUMA affinity
  - First store to a memory page gives it affinity with the CPU's NUMA domain
- Computations with tasking patterns that match initialization get proper affinity
  - i.e., tasks will operate on memory local to their NUMA domain

```
var A, B, C: [1..m] real;                  // Parallel initialization

forall (a, b, c) in zip(A, B, C) do        // Same affinity as initialization, good performance
  a = b + alpha * c;
```


Task Placement: Background

- Improper affinity severely hurts memory bandwidth-driven benchmarks
  - Previously a simple round-robin assignment of tasks to threads was used
    - Only worked well if loops used all threads with no intervening tasks

```
var A, B, C: [1..m] real;                  // Parallel initialization

forall (a, b, c) in zip(A, B, C) do        // Same affinity as initialization, good performance
  a = b + alpha * c;

coforall 1..here.maxTaskPar/2 { }          // Interleaved tasks skew round-robin assignment

forall (a, b, c) in zip(A, B, C) do        // Tasks offset from initialization affinity, poor performance
  a = b + alpha * c;
```

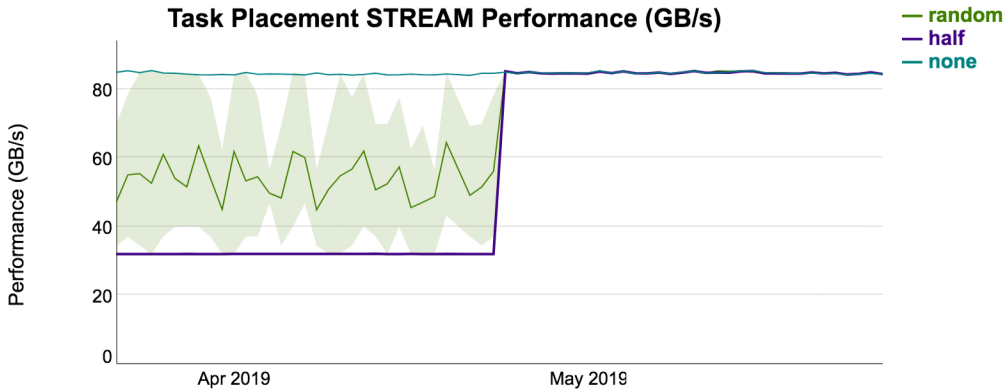

Task Placement: This Effort, Impact

This Effort: Implemented a task resetting policy

- When a parallel loop uses all threads, reset task placement

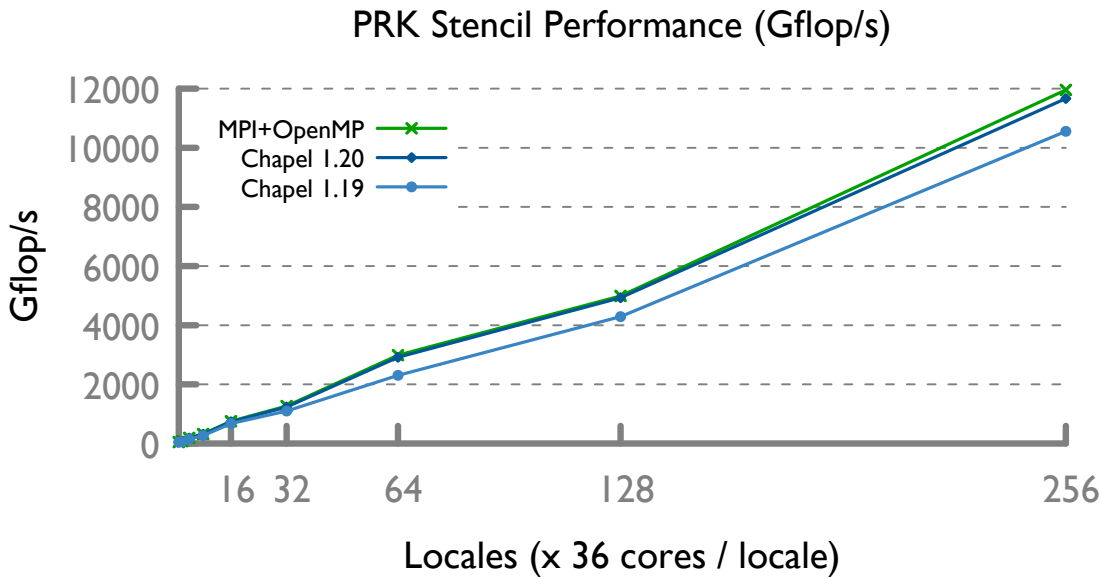
Impact: Improved performance for cases where interleaving tasks are created

- Up to a 2x improvement for Stream variation that created additional tasks



Task Placement: Performance Impact

- Improved performance for cases where interleaving tasks are created
  - 10% improvement for PRK Stencil



Task Placement: Next Steps

- Consider running with a process per NUMA domain
  - First touch is not always enough

```
var A, B, C: [1..m] real;          // parallel first touch

for (a, b, c) in zip(A, B, C) do   // serial computation, 1/2 ops on wrong NUMA domain
  a = b + alpha * c;

forall i in 1..m by -1 do.         // different parallel iteration, all ops on wrong NUMA domain
  A[i] = B[i] + alpha * C[i];
```

- Tradeoffs between performance and ease-of-use
  - Current locale-per-node mapping is easy to reason about
    - Intuitive transition from single- to multi-locale programs

InfiniBand Improvements

InfiniBand: Background

- To date, we have mostly focused on performance for Cray systems with ugni
  - Intent was to ensure we have the right language features/semantics first
    - Then expand capabilities to other networks

- Recently there have been several requests for better InfiniBand performance

InfiniBand: This Effort

- Added nightly InfiniBand performance testing
  - Results are available at: https://chapel-lang.org/perf/16-node-cs/
  - Tracking GASNet InfiniBand for segment large (default) and segment fast
    - Segment large does dynamic registration, fast does static
    - NUMA affinity is better with segment large
    - Communication performance is better with segment fast

config	Stream	PRK-Stencil	ISx	RA-rmo	RA-on
gn-ibv-large	~1500 GB/s	~780 GFlops/s	~55 s	0.0011 GUPS	0.0010 GUPS
gn-ibv-fast	~650 GB/s	~340 GFLops/s	~16 s	0.0021 GUPS	0.0010 GUPS

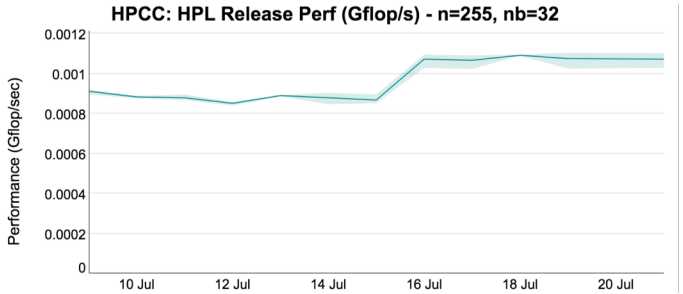
InfiniBand: This Effort, Impact

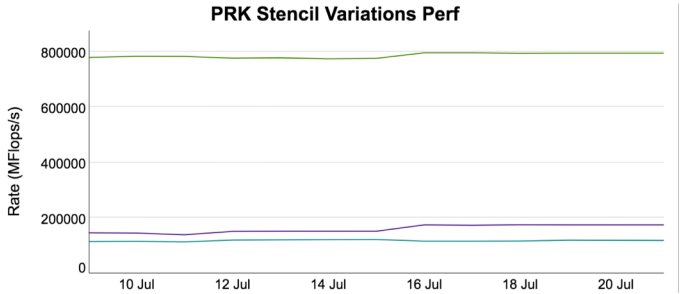
This Effort: Identified interference from the progress thread (on-stmt handler)

- Switched from an active to a blocking progress thread

Impact: Improved performance for compute-bound benchmarks

- Slightly increased latency for processing incoming on-stmts





InfiniBand: Next Steps

- Collaborate with the GASNet team and improve InfiniBand performance
  - Map to GASNet-EX remote atomics
  - Use multiple endpoints as they come online (better comm concurrency)
  - Explore better dynamic registration options to improve NUMA affinity

- Run reference benchmarks to figure out what InfiniBand is capable of
  - Use benchmarks where Chapel lags to guide further optimization

Performance Portability

Performance Portability: Background, Effort

Background: We want Chapel to perform well on all systems

- Performance on Cray networks is best and we have started to tune InfiniBand
- Little effort has been put into tuning Ethernet so far

This Effort: Ran core benchmarks on several networks to compare performance

- Cray Aries (ugni)
- FDR InfiniBand (gasnet-ibv segment large)
- Gigabit Ethernet (gasnet-udp segment everything)

Performance Portability: Status

- Core benchmarks on a Cray-XC and Cray-CS
  - Similar per-node hardware: dual 18-core Broadwell CPUs and 128 GB RAM

config	Stream	PRK-Stencil	ISx	RA-rmo	RA-on
ugni (Aries)	~1500 GB/s	~780 GFlops/s	~9 s	0.1150 GUPS	0.0100 GUPS
gn-ibv-large (56 Gb FDR)	~1500 GB/s	~780 GFlops/s	~55 s	0.0011 GUPS	0.0010 GUPS
gn-udp (1 Gb E)	~1500 GB/s	~450 GFlops/s	~800 s	0.0003 GUPS	0.0004 GUPS

Performance Portability: Next Steps

- Add nightly Ethernet performance testing and tune performance
- Run reference benchmarks for Ethernet and InfiniBand
- Explore optimizations that will benefit high-latency networks
  - Cray networks have extremely low latency, especially for small transfers
  - Other networks will likely require some sort of aggregation

RandomStream Optimization

RandomStream: Background, This Effort

Background:

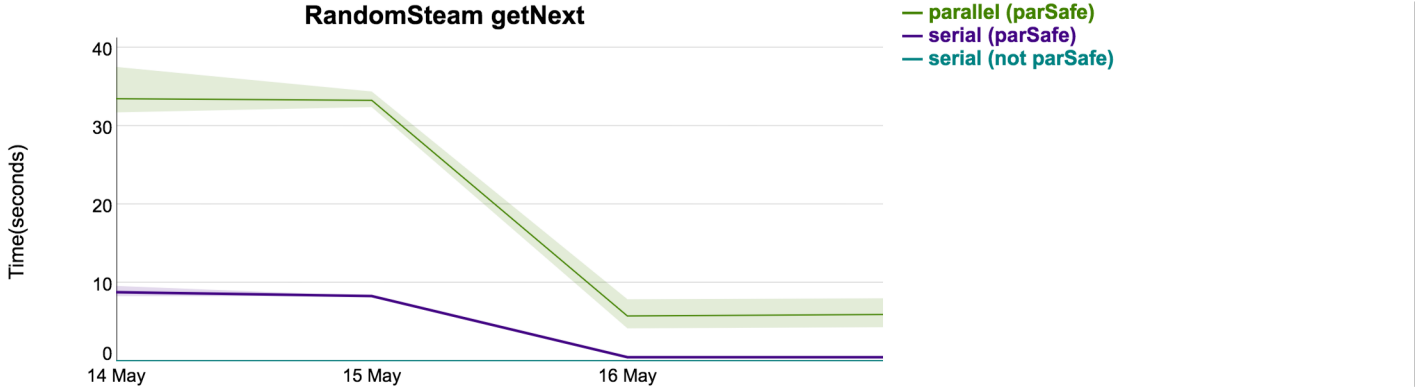
- RandomStream() library routine is parallel-safe by default
- Previously, a sync was used as a lock to provide parallel safety
  - Sync variables are heavyweight
  - ~200x overhead when parallel safety is not required

This Effort:

- Created an optimized test-and-test-and-set spinlock
- Replaced RandomStream sync lock with optimized spinlock
- Used spinlock to optimize other parallel-safe data structures

RandomStream: Impact

- Significantly faster RandomStream()
  - Only 25% overhead for parallel safety when generating real(64) values



RandomStream: Next Steps

- Reduce overhead for sync variables
  - Minimize cost for uncontended accesses
- Create a lock/mutex library
  - Include spinlock and more sophisticated/scalable locks

Memory Pressure Improvements

Memory Pressure: Background

- By default, Chapel task stacks are 8MB
  - Chosen as a "safe" default to help avoid stack overflows
- Normally, only pages that are used are backed by physical memory
- On networks that require registration, full 8MB is backed by physical memory
  - This limits the number of tasks that can exist/run concurrently

Memory Pressure: Background

- Creating many tasks with no user-induced yield could also exhaust memory
  - Tasks should run to completion before another is started
  - However, the following no-op program used to run out of memory under ugni

```
coforall 1..100_000 do on Locales[1] { }
```

- This would happen because:
  - Locale 0 enqueues tasks on Locale 1
  - Tasks created on Locale 1 yield during implicit comm that signals completion
  - Yielded tasks are moved to the end of a task queue
  - Task scheduler round-robins through all tasks, whether new or yielded

Memory Pressure: Effort, Next Steps

This Effort:

- Avoid yielding until a task has performed a non-trivial amount of comm
  - Reduces memory pressure from short tasks

Next Steps:

- Consider more sophisticated task queueing strategies
- Explore ways to reduce stack size to increase number of concurrent tasks
  - e.g., compiler analysis to determine maximum stack size

Memory Leak Improvements

Memory Leaks: Background, This Effort

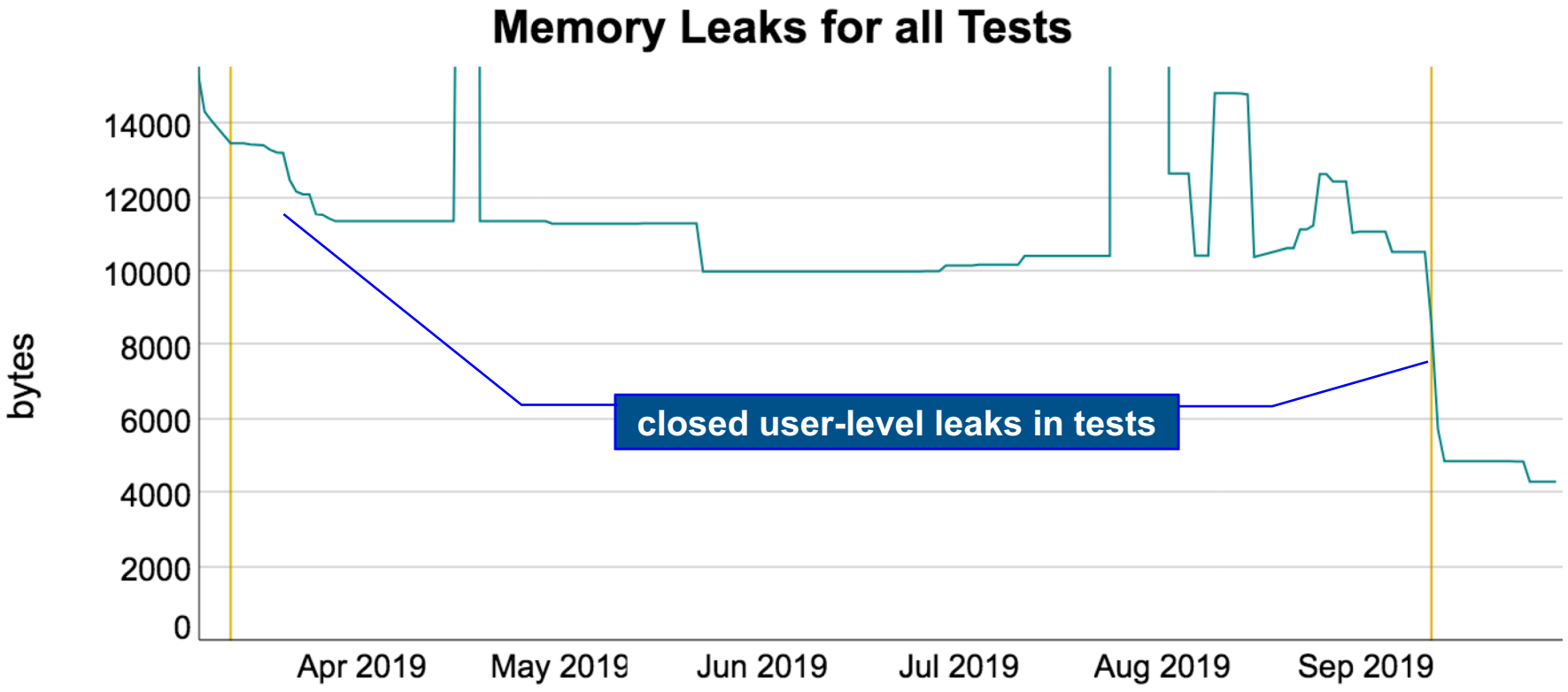
Background:

- Historically, Chapel testing resulted in a large number of memory leaks
- Recent releases have driven this number sharply downward

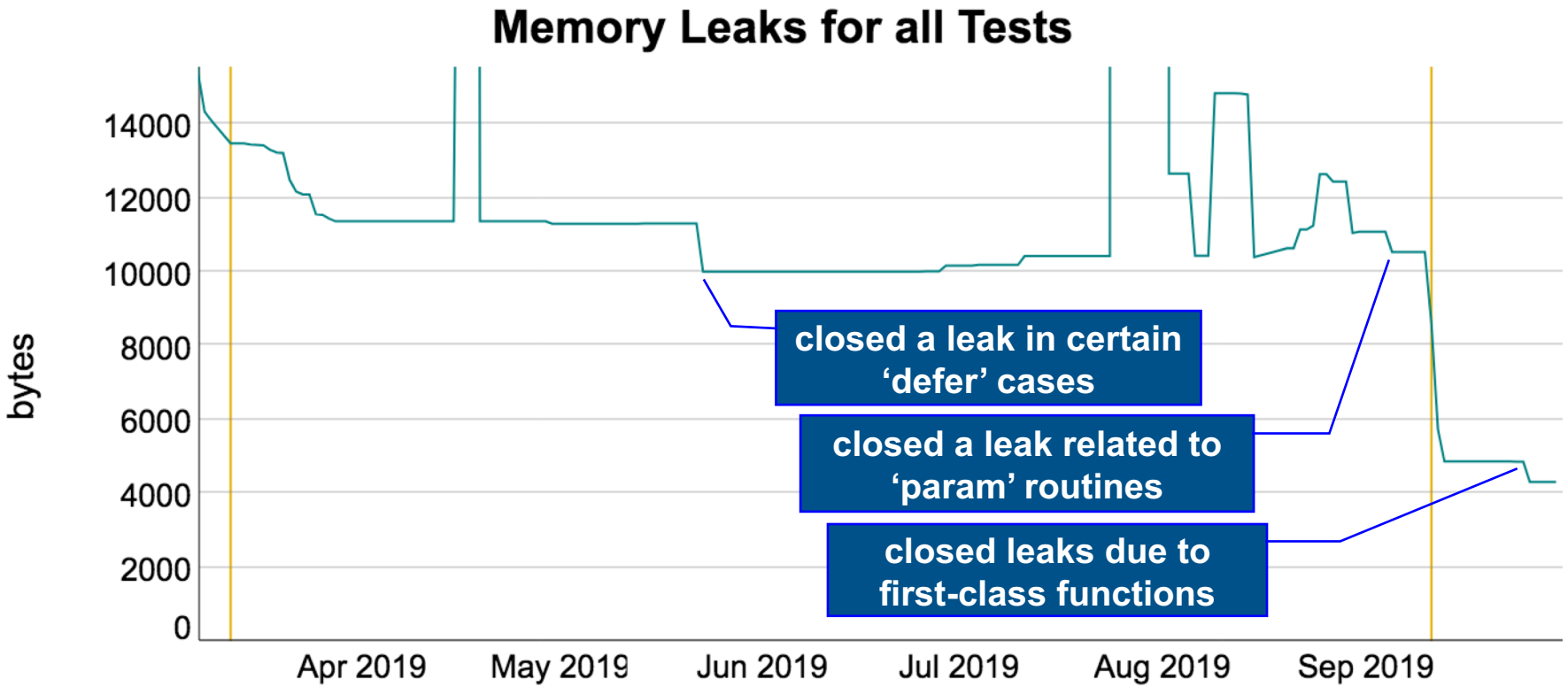
This Effort:

- Memory leaks were not a significant priority for this release
- However, additional progress was made, most notably:
  - Closing leaks in tests themselves
  - Closing leaks caused by defer statements
  - Just after the release, closed leaks due to first-class functions

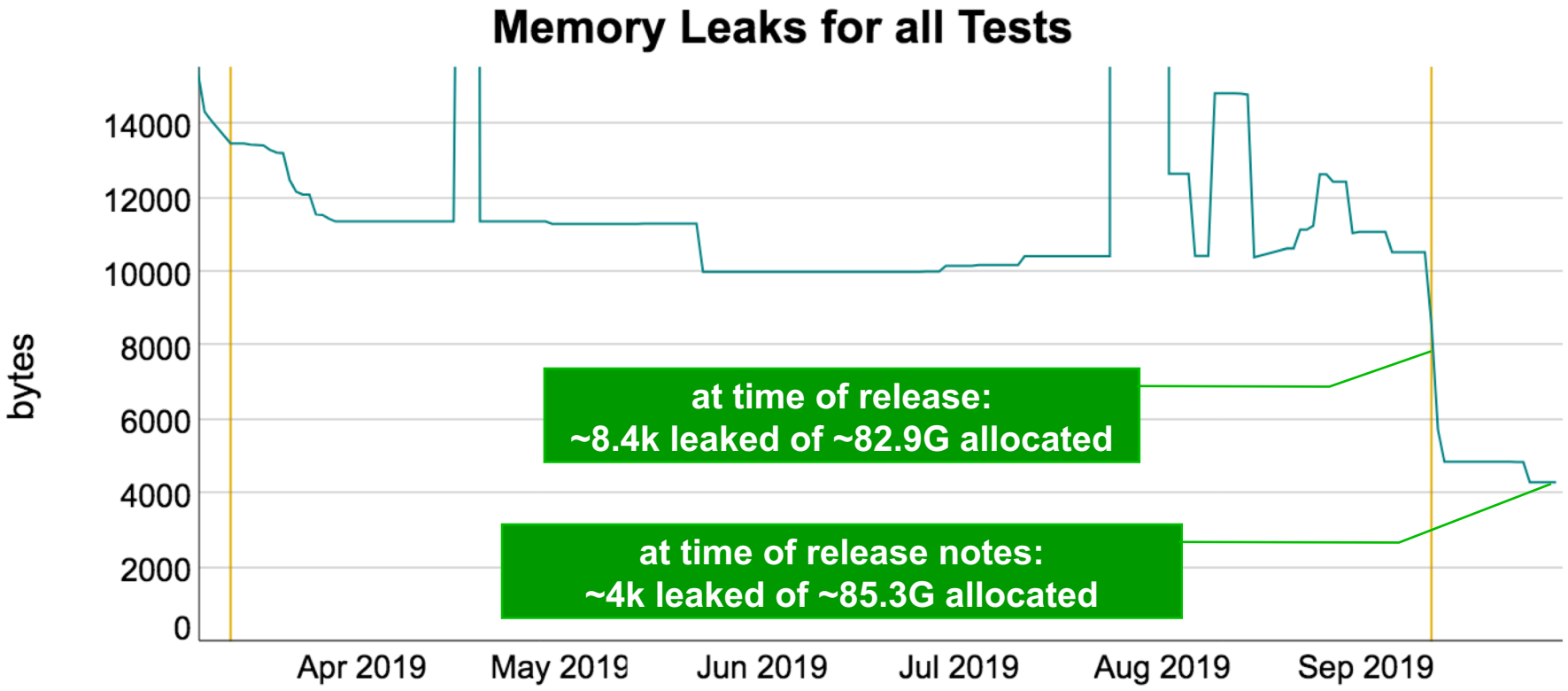
Memory Leaks: This Effort, Impact (major fixes)



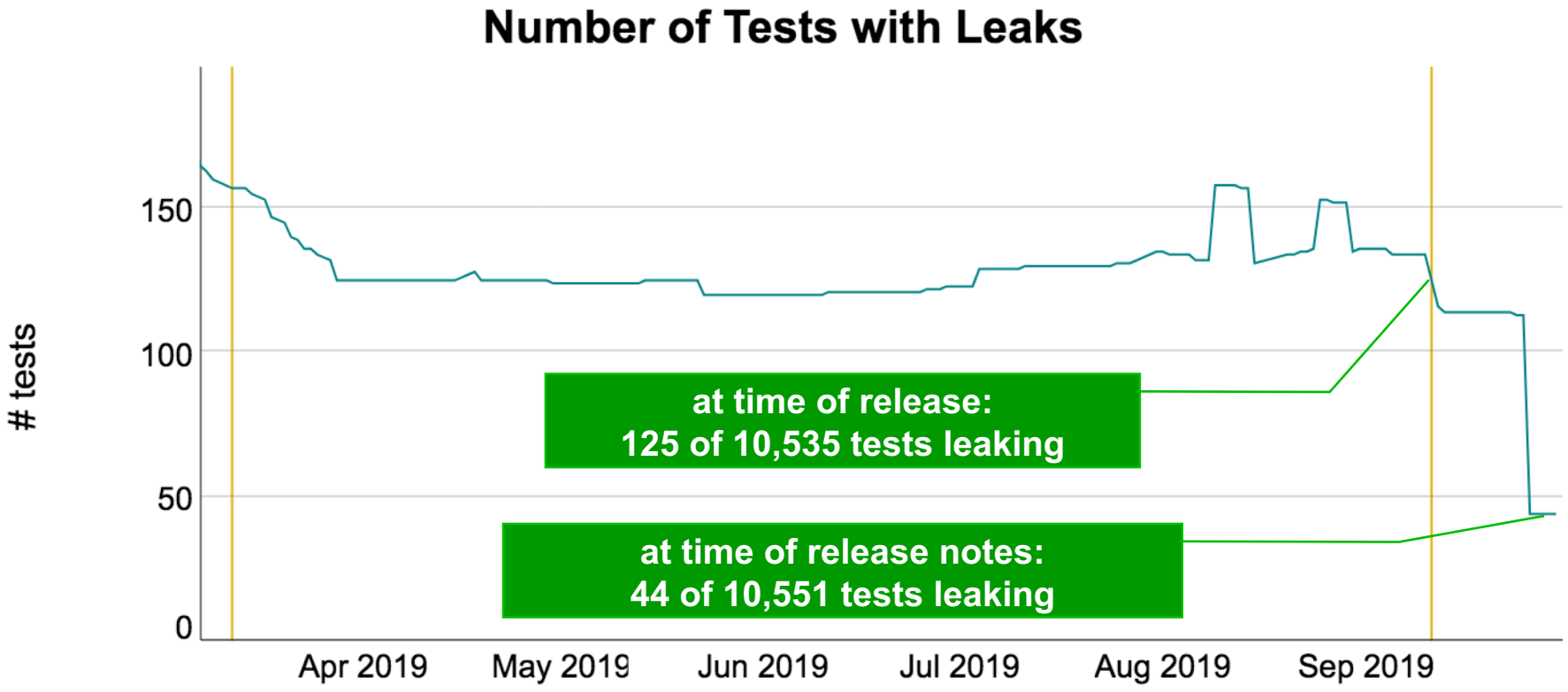
Memory Leaks: This Effort, Impact (major fixes)



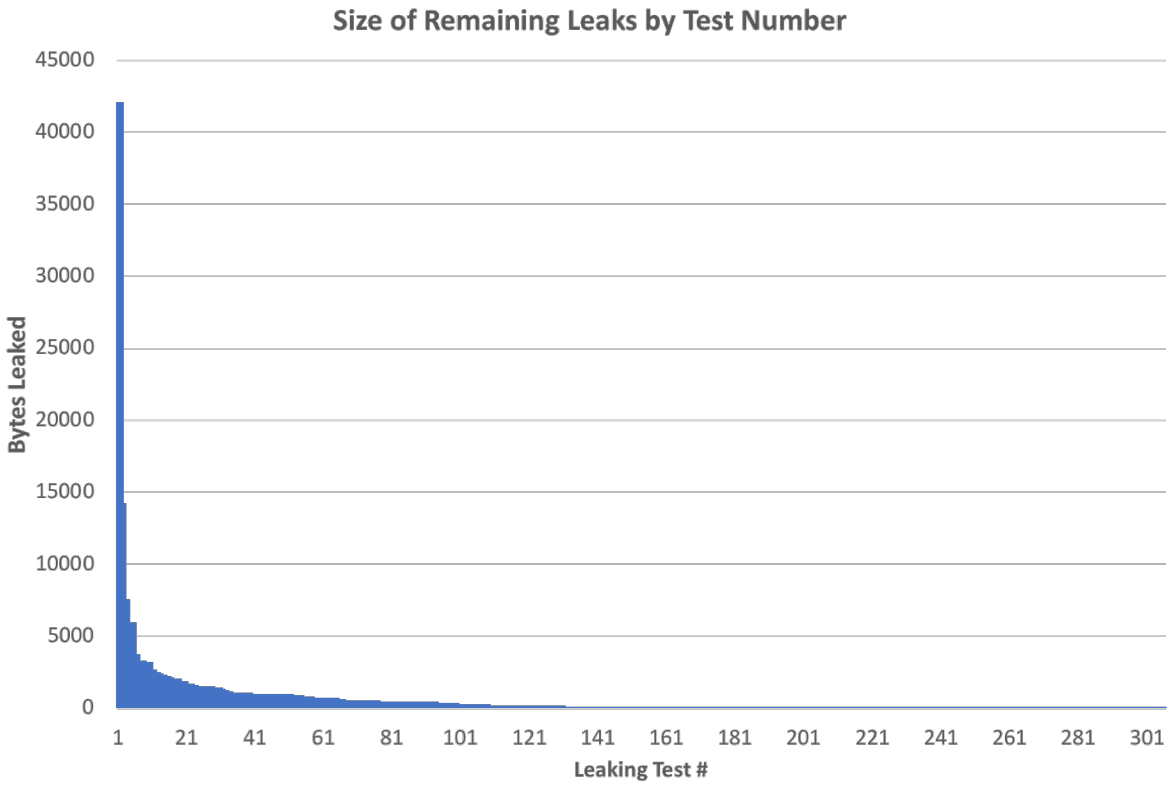
Memory Leaks: Status (amount of memory)



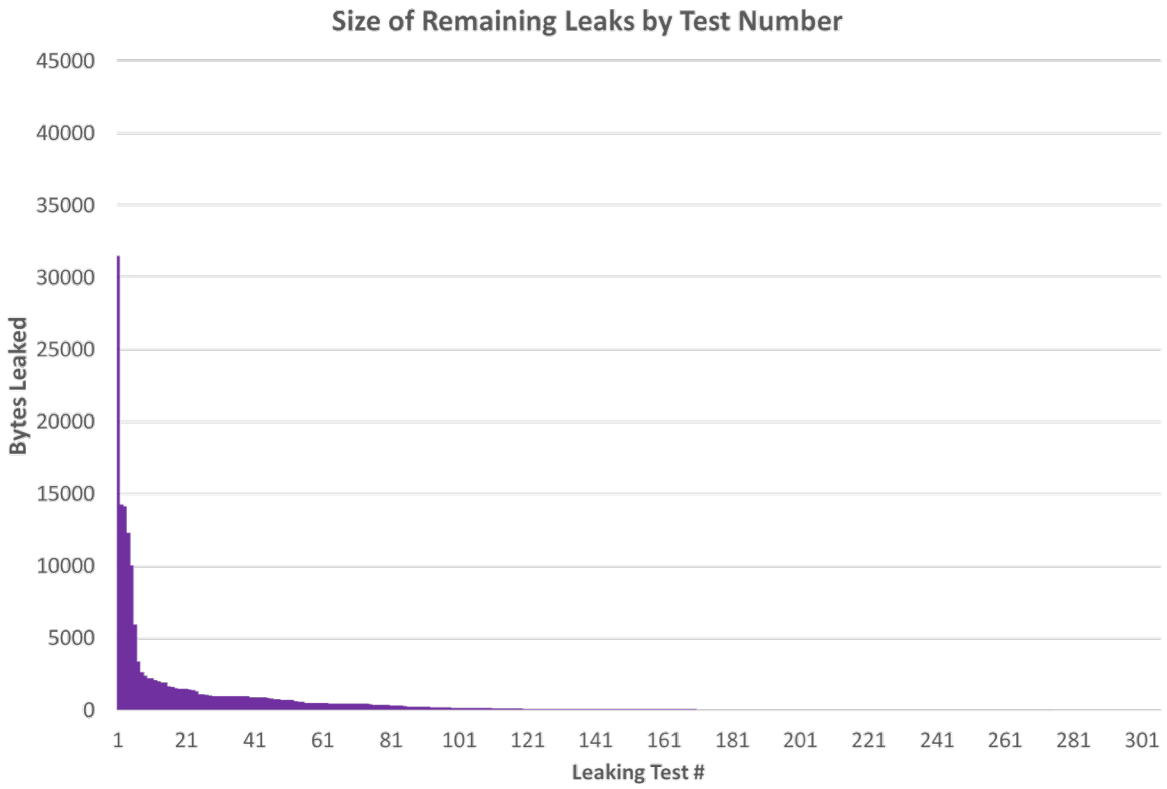
Memory Leaks: Status (number of tests)



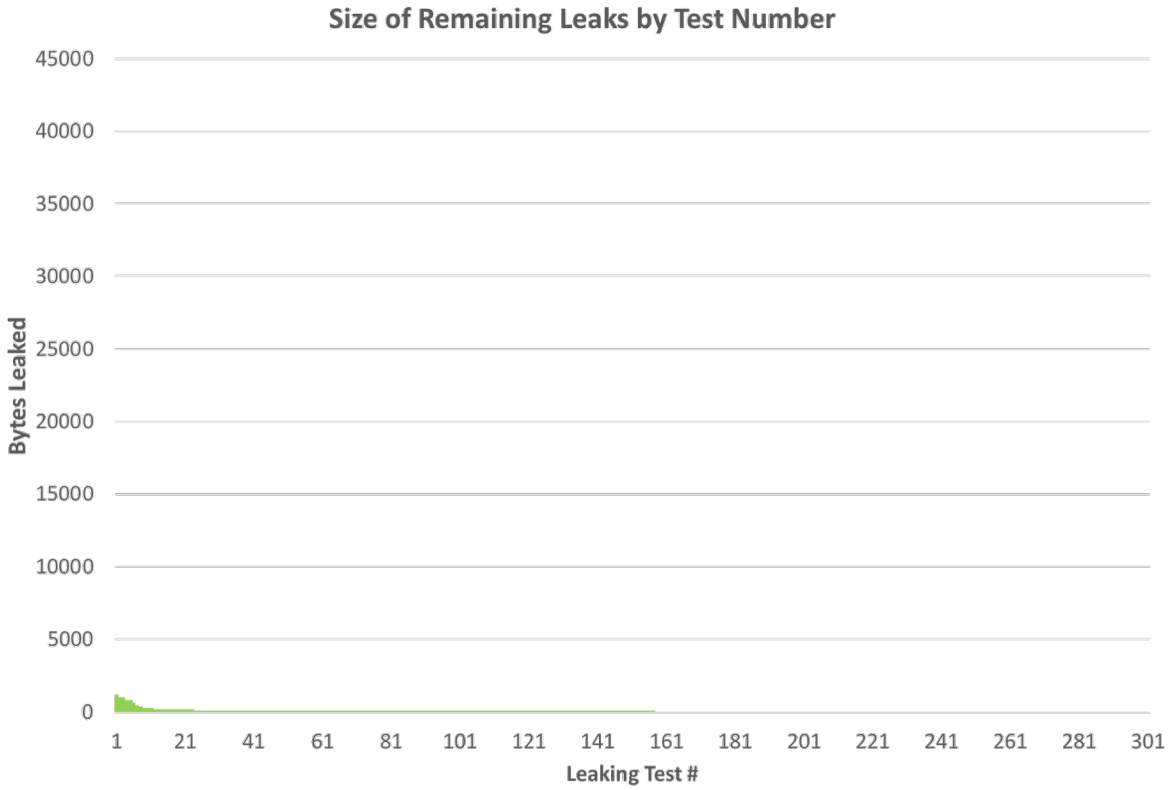
Memory Leaks: Remaining Leaks (as of 1.17)



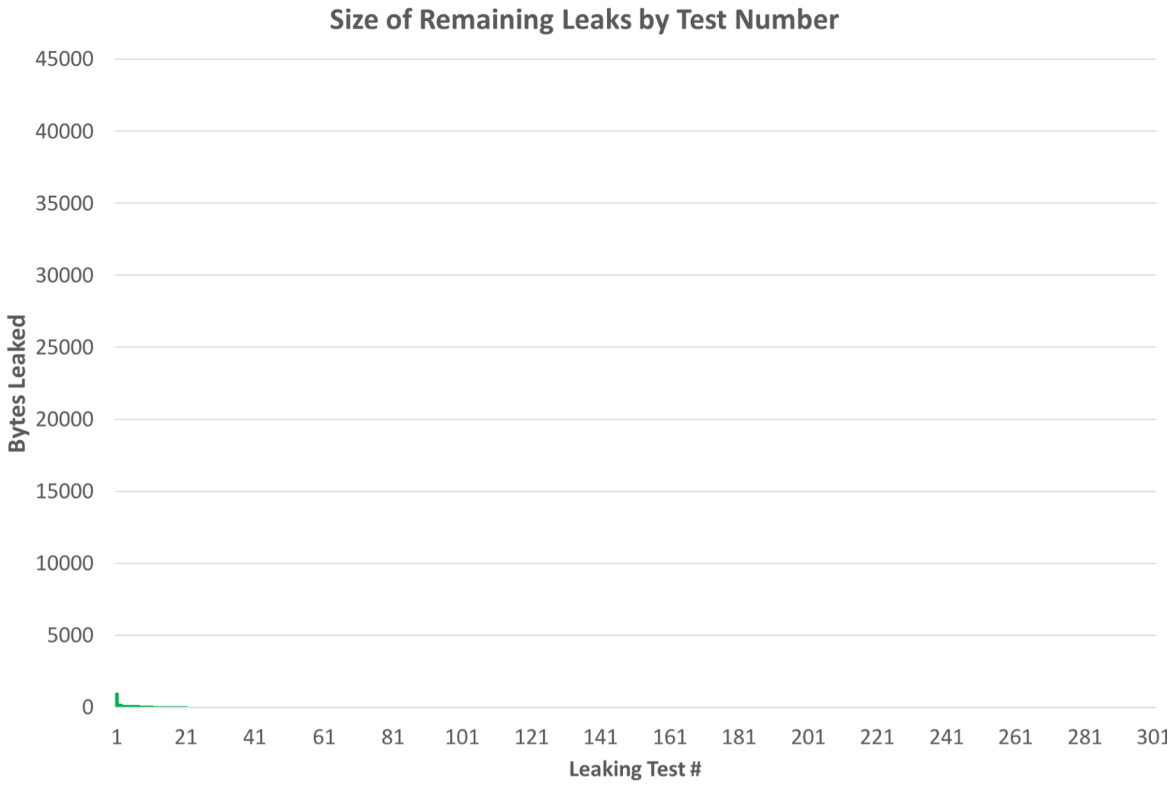
Memory Leaks: Remaining Leaks (as of 1.18)



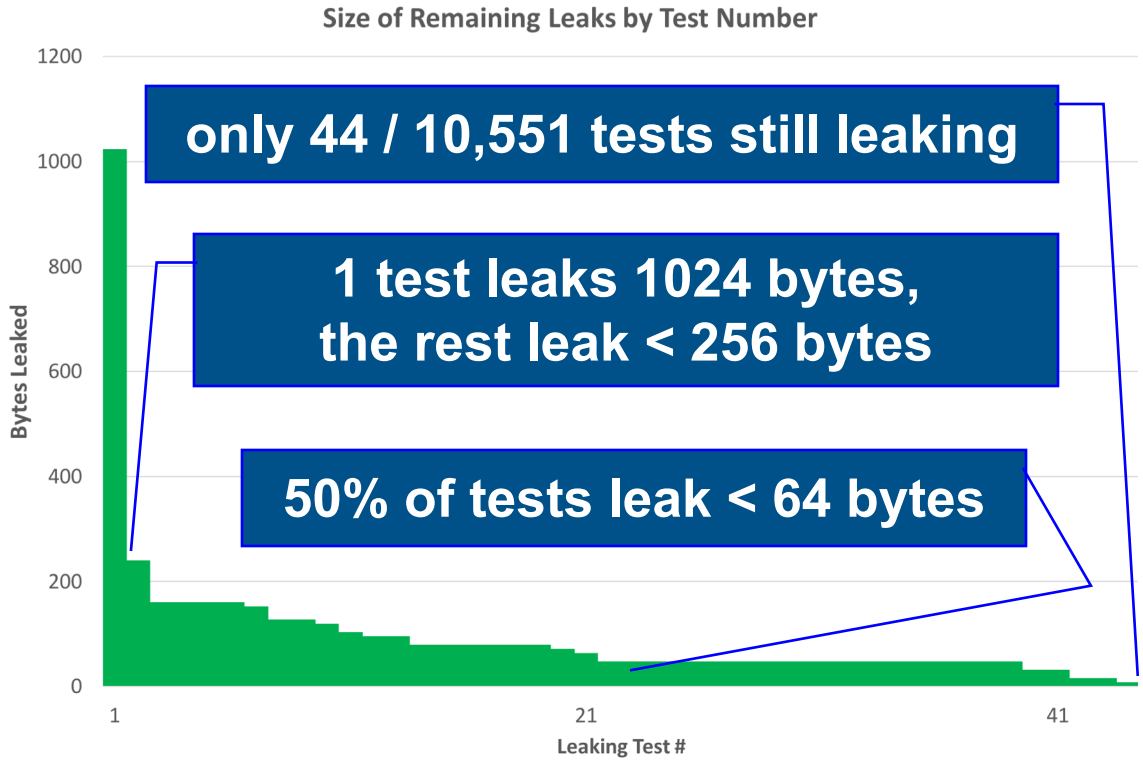
Memory Leaks: Remaining Leaks (as of 1.19)



Memory Leaks: Remaining Leaks (as of 1.20)



Memory Leaks: Remaining Leaks (as of 1.20)



Memory Leaks: Next Steps

- Close remaining leaks:
  - A few cases of leaks in error-handling
  - A few cases of leaking for certain domain map patterns
  - A few other corner cases
- Turn nightly leaks testing into a correctness, rather than performance, check
- Check status of leaks for multi-locale runs, LLVM back-end

For More Information

For a more complete list of related changes in the 1.20 release, refer to the 'Performance Improvements' and 'Memory Improvements' sections in the CHANGES.md file

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