Benchmarks and Performance Optimizations

Chapel versions 1.21 / 1.22

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Outline

- [Array Optimizations]
  - Distributed Array/Domain Creation
  - Fast-Follower Improvements
  - Parallelize PrivateDist Scan
  - Resize Arrays In-Place
- Runtime Improvements
  - InfiniBand Improvements
  - Misaligned GET Improvements
  - Remote Cache Improvements
  - Serial I/O Optimization
- Unordered Operations
  - Unordered Copy Improvements
  - Automatic Unordered Copy
- Memory Leak Improvements

Array Optimizations

Distributed Array/Domain Creation

Array/Domain Creation: Background, This Effort

Background:

- Typically, array/domain creation is not part of a benchmark's timed region
  - However, use cases like Arkouda create many arrays/domains on the fly
- Creation involves a lot of all-to-all communication
  - Previously, this was fine-grained and had significant overhead at scale

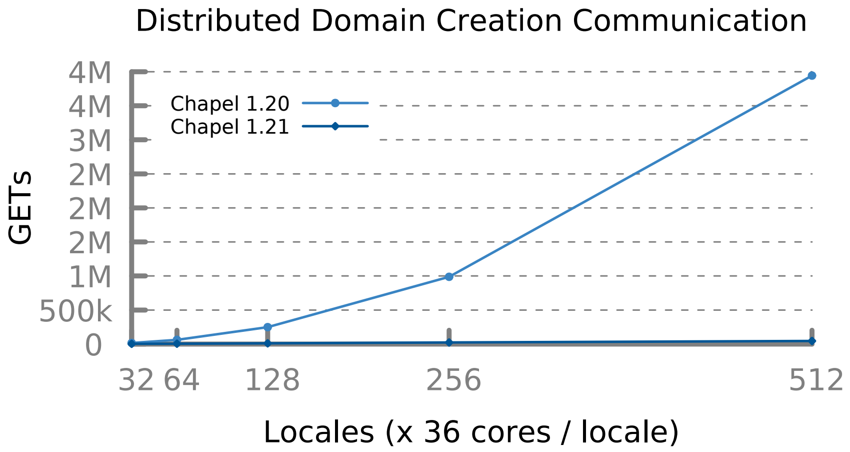
This Effort:

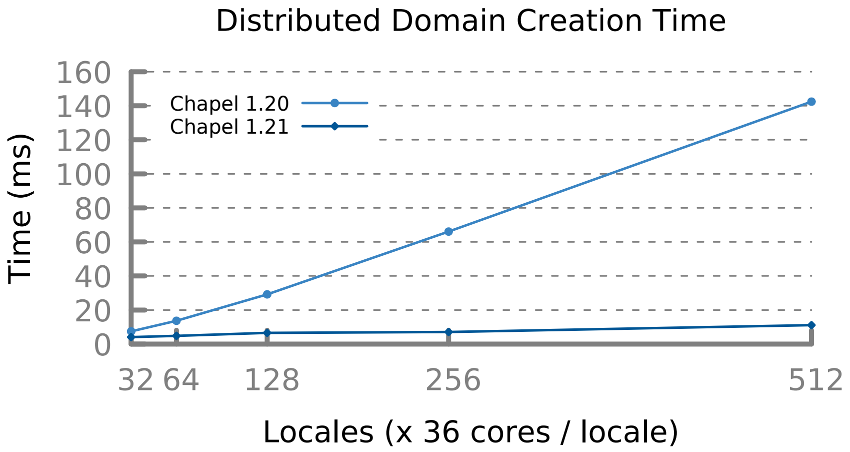
- Use bulk communication distributed during domain and array creation

```
var dom = {1..n} dmapped Block({1..n});    // domain creation
var arr: [dom] real;                       // array creation
```

Domain Creation: Impact

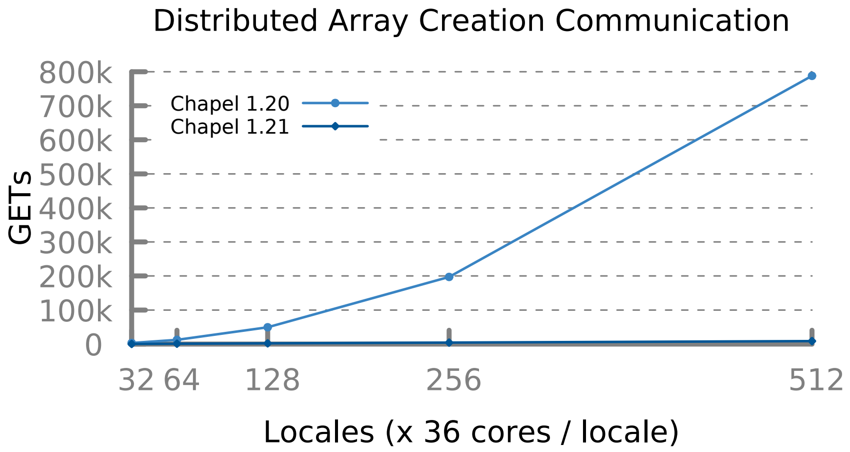
- Significantly faster and more scalable distributed domain creation
  - At 512 locales: 85x fewer GETs, 10x faster

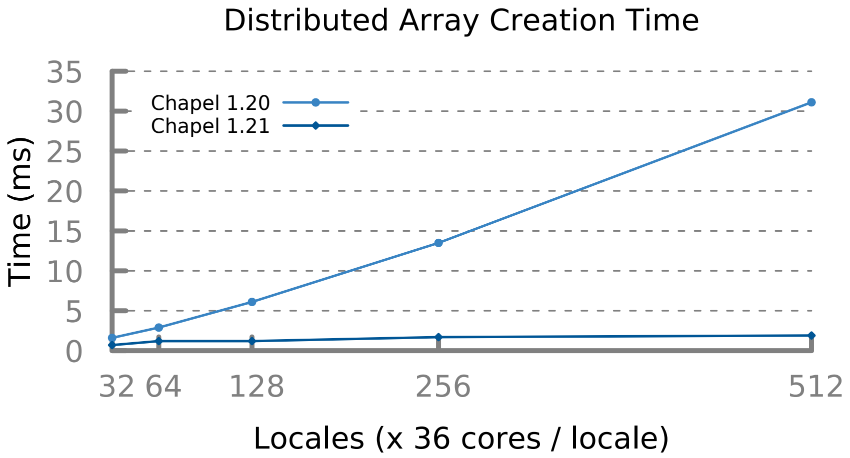




Array Creation: Impact

- Significantly faster and more scalable distributed array creation
  - At 512 locales: 90x fewer GETs, 15x faster





Fast-Follower Improvements

Fast-Follower: Background, This Effort

Background: "Fast Followers" optimize iteration over aligned distributed arrays

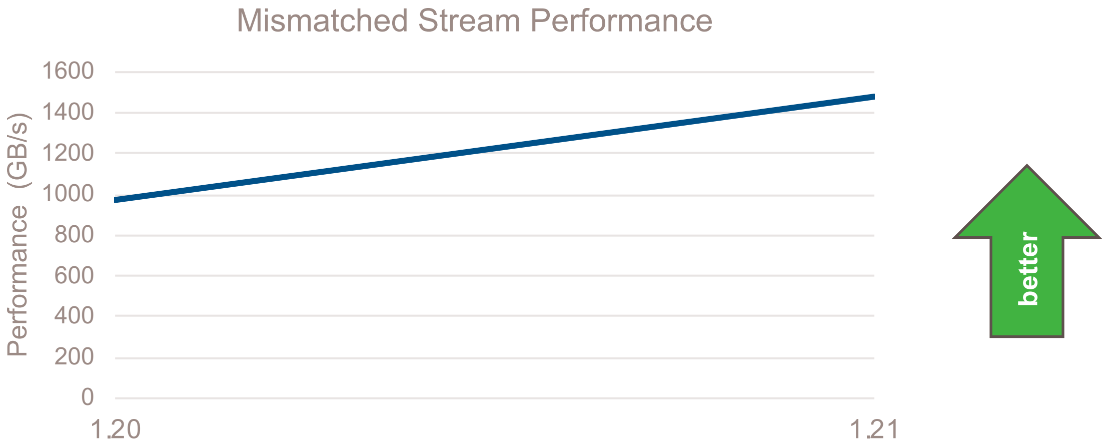
- Can skip locality checks when arrays have the same distribution/alignment
- Previously, arrays had to have identical domains and element types

```
var A, B = newBlockArr({1..n}, real);
var    C = newBlockArr({1..n}, int);
A = B + 3.0 * C; // not optimized, different types, not identical domains
```

This Effort: Enable optimization for equivalent domains and any element type

Fast-Follower: Impact

- Fast followers now trigger in more cases
  - 1.5x improvement for Stream with different element types



Parallelize PrivateDist Scan

PrivateDist Scan: Background, This Effort

Background: PrivateDist provides replicated values across all locales

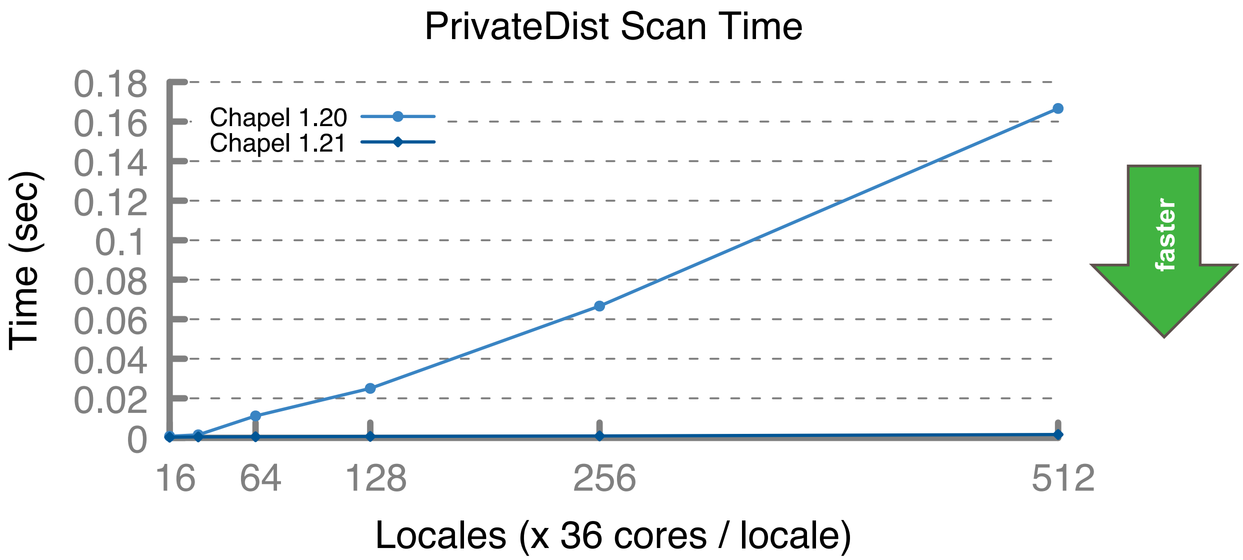
- Scans over PrivateDist arrays were serialized
- Resulted in poor scalability and a compile-time serialization warning

This Effort: Parallelized scans over PrivateDist arrays

- Eliminated serialization warning

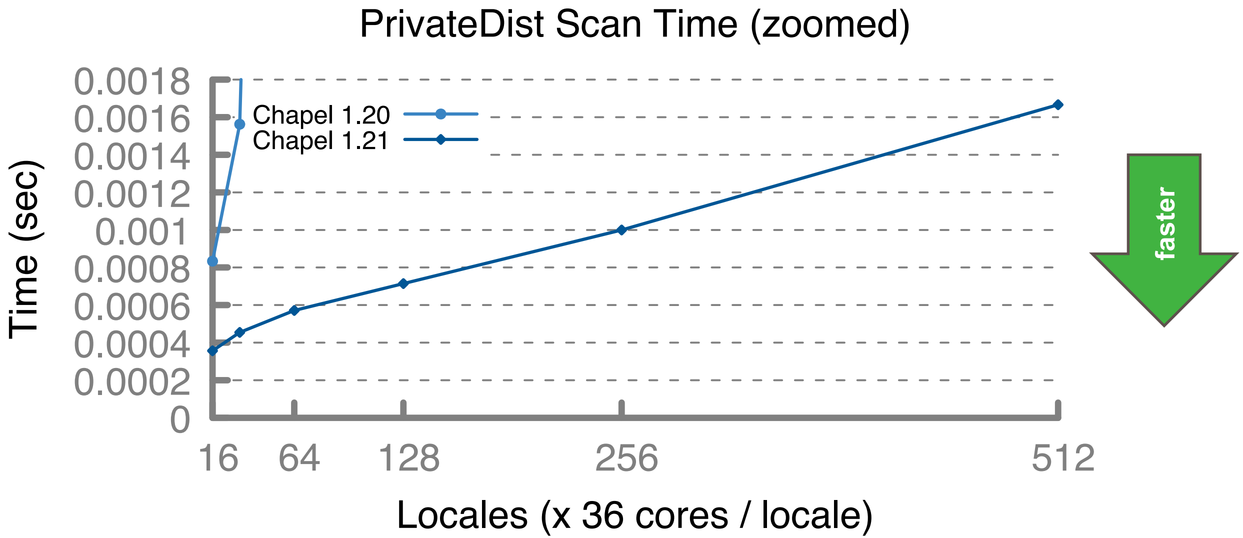
PrivateDist Scan: Impact

- Significantly improved scan performance and scalability
  - 100x speedup at 512 nodes



PrivateDist Scan: Impact

- Significantly improved scan performance and scalability
  - 100x speedup at 512 nodes



Resize Arrays In-Place

Resize-in-Place: Background

- Chapel reallocates arrays based on indices, not memory layout

```
var D = {1..3};
var A: [D] int = [1, 2, 3];
D = {0..4};
writeln(A);    // prints "0, 1, 2, 3, 0", not "1, 2, 3, 0, 0"
```

- For this reason, rectangular arrays have traditionally been resized by:
  1. allocating a new array
  2. copying over elements within the intersection of D_{old} and D_{new}
  3. ensuring that any new elements are default-initialized

Resize-in-Place: This Effort

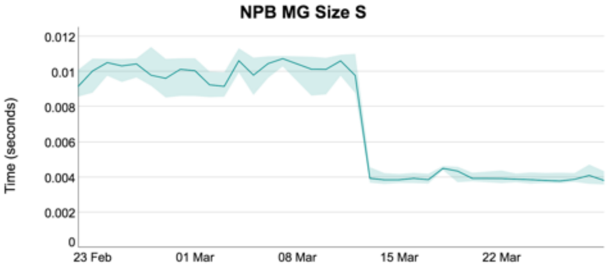
- However, some array resizings are amenable to being done in-place
  - Notably, 1D array resizings in which the low bound and stride don't change:

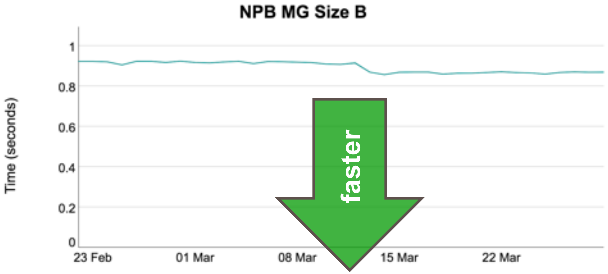
```
var D = {1..3};
var A: [D] int = [1, 2, 3];
D = {1..5};   // D's prefix & stride are identical, so we need not move the array
writeln(A);   // prints "1, 2, 3, 0, 0"
```

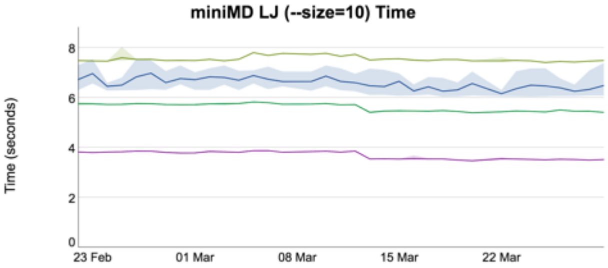
- As a result, such cases are now handled by:
  1. calling realloc() on the array's buffer
  2. ensuring that any new elements are default-initialized
- Note: realloc() can't always resize in place; but when it can, there's a benefit

Resize-in-Place: Impact

- CLBG reverse-complement improved by ~7.7% on UMA compute nodes
  - No significant impact on NUMA compute nodes
    - (challenging to do anything smart w.r.t. NUMA locality when resizing)
- Also resulted in improvements for a few other benchmarks:







Resize-in-Place: Status and Next Steps

Status:

- A minor improvement, yet one that does no harm and is nice when it helps

Next Steps:

- As motivating examples arise:
  - extend realloc-in-place to other cases (e.g., multidimensional arrays)
  - tune implementation further for NUMA compute nodes

Runtime Improvements

InfiniBand Improvements

InfiniBand: Background, This Effort

Background: Started running InfiniBand performance testing last release

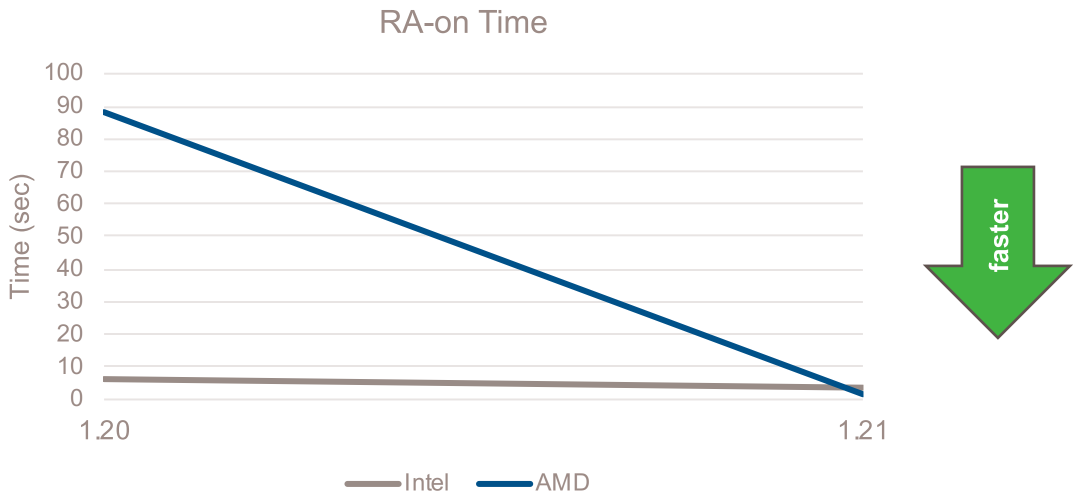
- Nightly configuration runs on machine with Intel processors
- Ran some experiments on AMD EPYC processors
  - Saw significant performance degradations for ‘on’-heavy workloads

This Effort: Optimized on-statements for InfiniBand

- Serialized calls to on-statement handlers to reduce contention

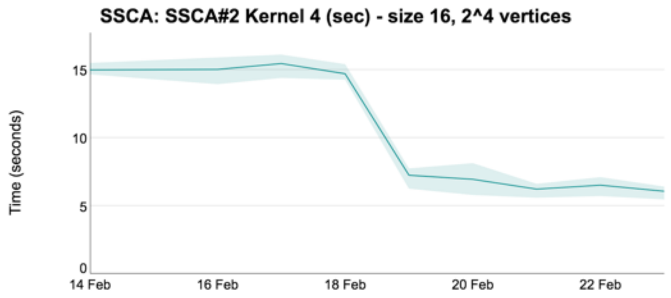
InfiniBand: Impact

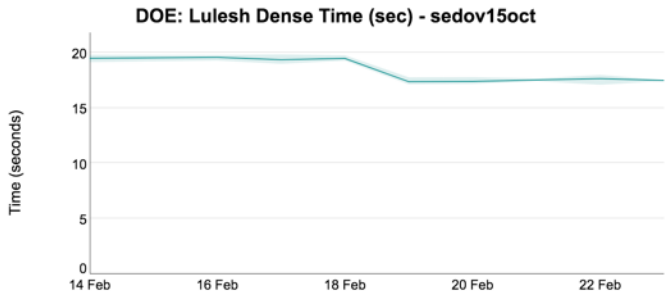
- Significantly improved on-statement performance
  - For RA-on using 48-core Intel Cascade Lake and AMD Rome processors
    - 2x speedup on Intel, 55x speedup on AMD



InfiniBand: Impact, Next Steps

Impact: Improvements for other on-statement-heavy benchmarks





Next Steps: Better understand root cause of original degradation

- Unknown why performance was more impacted on AMD processors

Misaligned GET Improvements

Misaligned GET: Background, This Effort

Background: GETs on the Aries NIC must be 4-byte aligned

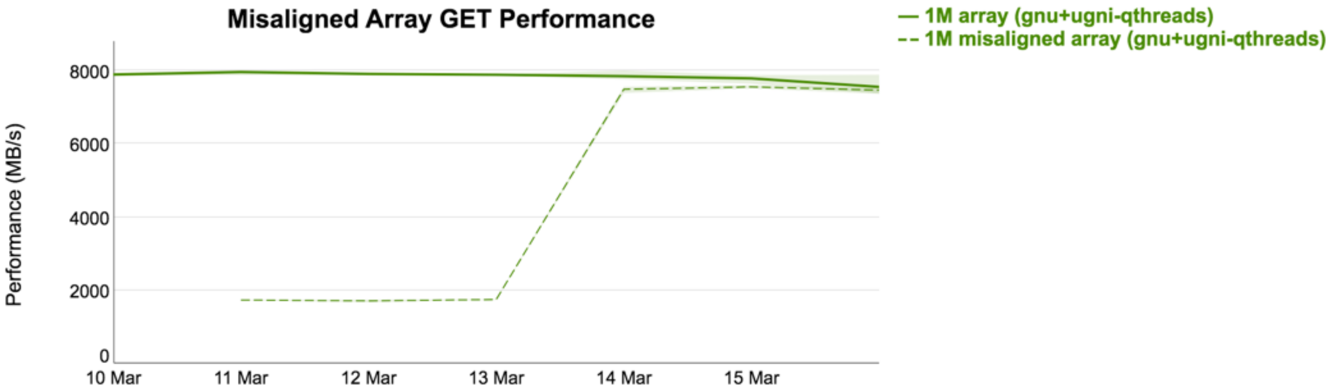
- When not aligned, perform GET to bounce buffer, copy to target buffer
- Previously, this code path was not well-tested
  - Most Chapel benchmarks use 8-byte int(64)/real(64)
  - Arkouda uses uint(8)/bool arrays, which exposed several bugs

This Effort: Improve misaligned GETs

- Fixed correctness issues and added additional tests
- Optimized large misaligned GETs
  - Use 0-copy GET for aligned interior; only bounce misaligned head/tail

Misaligned GET: Impact

- Improved performance for large misaligned GETs
  - 4x improvement for transfers larger than 1MB



Remote Cache Improvements

Remote Cache: Background

- Chapel has a cache for remote data that can be enabled with --cache-remote
  - Can provide significant speedups for suboptimal communication patterns
  - Supports read-ahead and write-behind, can eliminate repeated communication

```
var A, B:[1..n] int;
on Locales[1] do
  for i in 1..n do
    B[i] = A[i];

//  A[i] normally 8-byte GET, done in 1024-byte chunks with cache read-ahead
// B[i] normally 8-byte PUT, done in 1024-byte chunks with cache write-behind
// Normally repeated GETs for array metadata, only 1 GET with cache
```

Remote Cache: Background

- Can provide large speedups for real workloads, especially on slower networks
  - 3x speedup for MiniMD on Aries, 100x on FDR InfiniBand
  - 20x speedup for PTRANS on Aries, 500x on FDR InfiniBand

- Previously, there were several issues that prevented it from being recommended
  - Large performance regressions for some workloads
  - Hangs or crashes under comm=ugni
  - Not regularly tested

Remote Cache: This Effort

- Addressed --cache-remote correctness issues
  - Fixed several hangs and crashes under ugni
  - Fixed support for unorderedCopy
  - Fixed support for guard pages
- Eliminated known performance overheads
  - Bypass cache for large transfers
- Added nightly testing across all communication implementations

Remote Cache: Status, Next Steps

Status: --cache-remote is stable enough to recommend to users

- Can provide substantial improvements for suboptimal communication patterns

Next Steps: Explore enabling --cache-remote by default

- Want to explore synthetic benchmarks to better tune
- Need to evaluate performance and memory overhead at scale

Serial I/O Optimization

Serial I/O: Background, This Effort

Background: Chapel I/O is parallel-safe by default

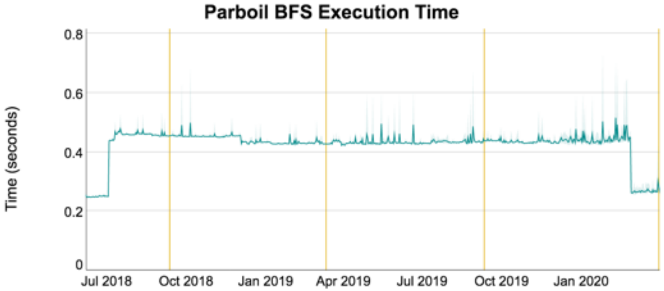
- 1.18 changed I/O to use a sync lock to improve parallel performance
- However, this hurt the performance of serial I/O

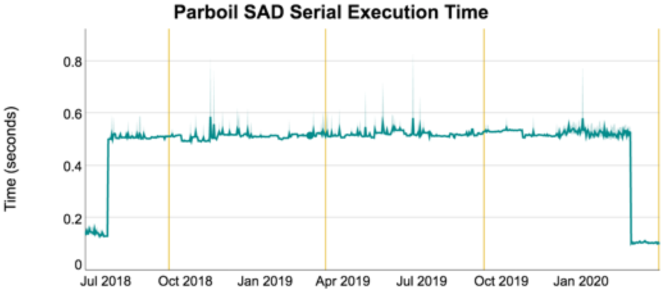
This Effort: Switched to an optimized atomic spinlock for I/O

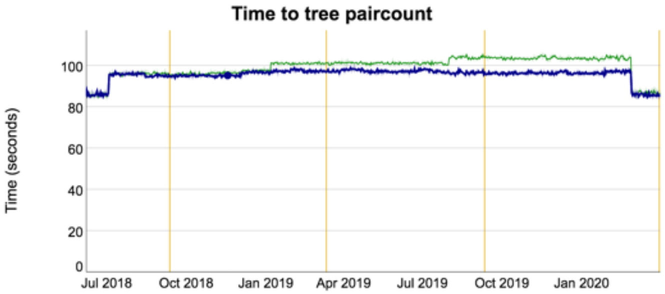
- Has minimal serial overhead while maintaining good parallel performance

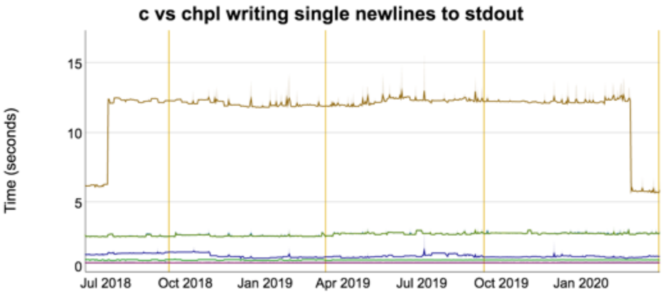
Serial I/O: Impact

- Resolved previous serial I/O regressions









Unordered Operations

Unordered Copy Improvements

Unordered Copy: Background, This Effort

Background: 'unorderedCopy(dst, src)' is a faster, non-sequential consistent copy

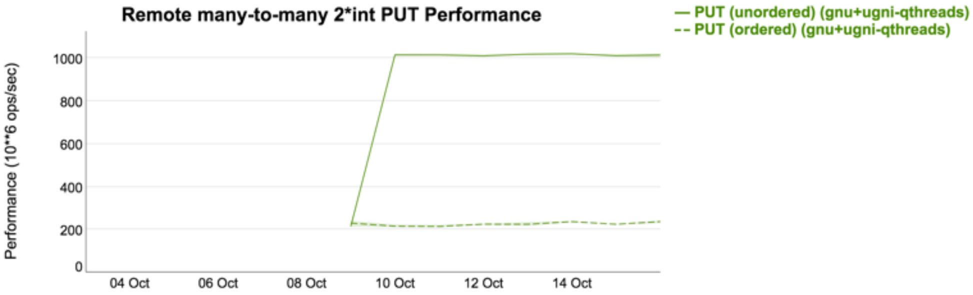
- Previously, it was only implemented for numeric and bool types

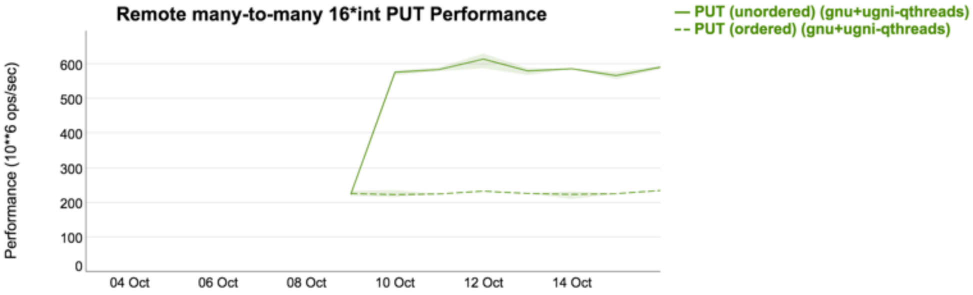
This Effort: Extended support to all trivially copyable types

- numeric/bool
- numeric/bool tuples
- numeric/bool records with no copy-init, deinit, or assignment overload

Unordered Copy: Impact

- Faster copies for trivially copyable types
  - 4.5x speedup for 2*int tuple, 2.5x for 16*int





Automatic Unordered Copy

Auto Unordered Copy: Background, This Effort

Background: Unordered operations provide a significant performance speedup

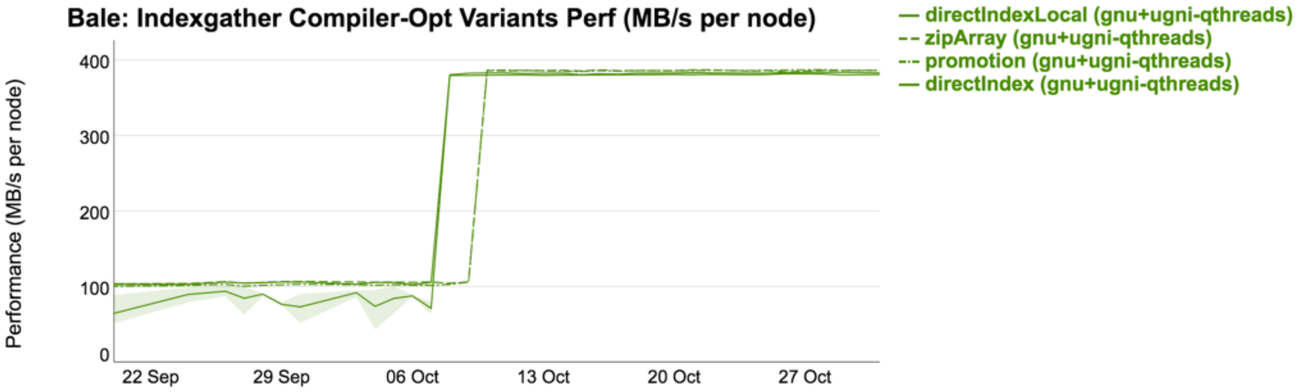
- But they are an advanced feature that break the memory consistency model
- 1.20 enabled an optimization to automatically use unordered ops
  - Triggered for array indexing (e.g. 'A[i]'), but not other iteration idioms

This Effort: Extended compiler optimization

- Handles promotion, zippered iteration, direct array iteration

Auto Unordered Copy: Impact

- More idioms can be optimized by compiler
  - Bale indexgather variants automatically optimized



Memory Leak Improvements

Memory Leaks: Background, This Effort

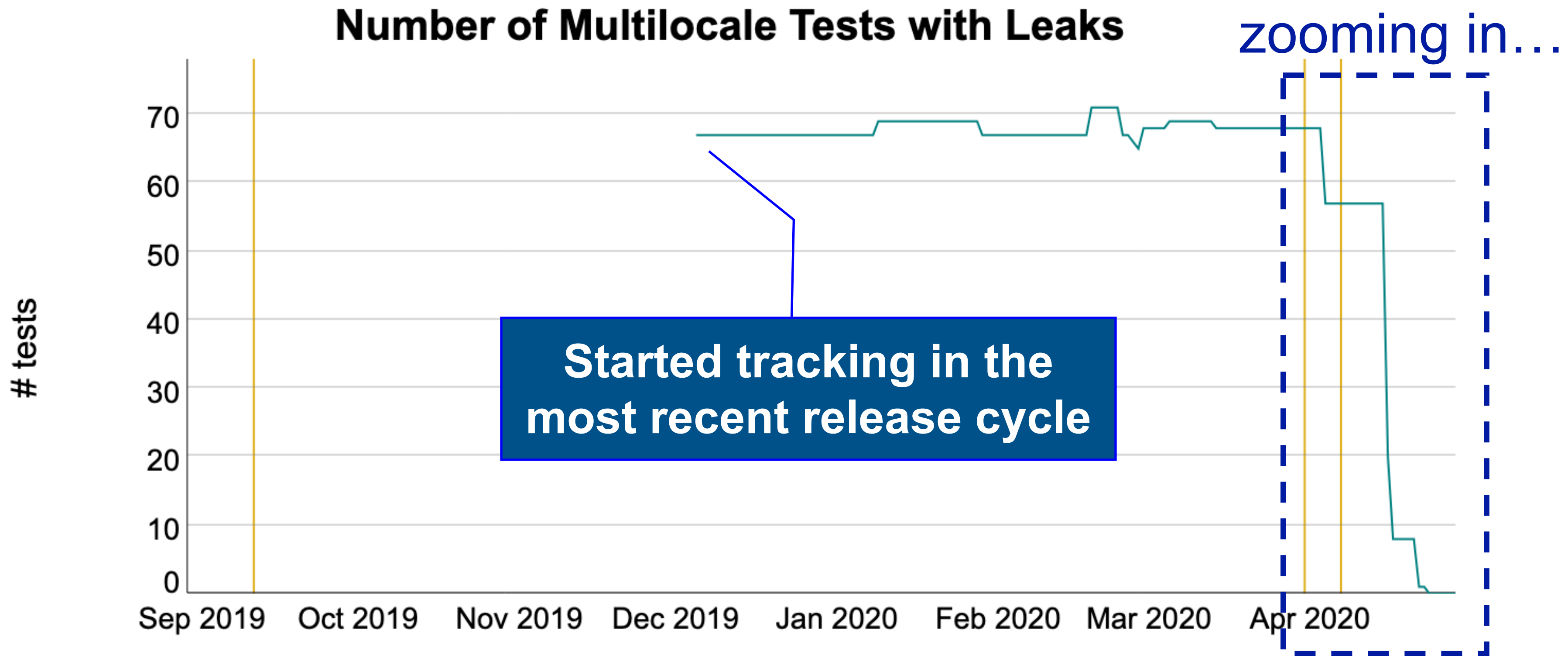
Background:

- Recent releases closed many major memory leaks
  - However, we monitored only single-locale leaks
- A few important configurations were not tested for memory leaks
  - e.g. multi-locale, LLVM backend

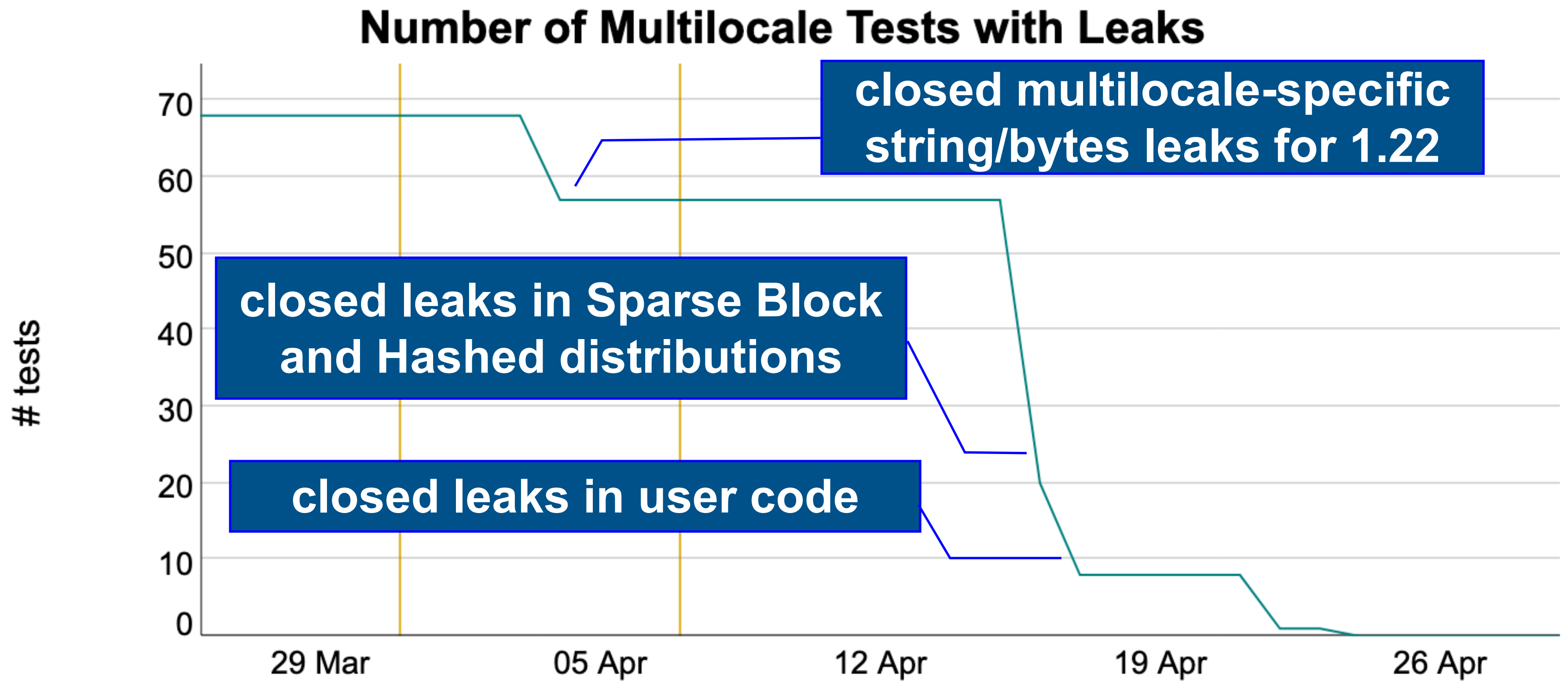
This Effort:

- Track and close multi-locale leaks
  - Different set of leaks that we do not catch in single-locale runs
- Verified that there are no leaks specific to using LLVM back-end
- Reduction in single-locale leaks

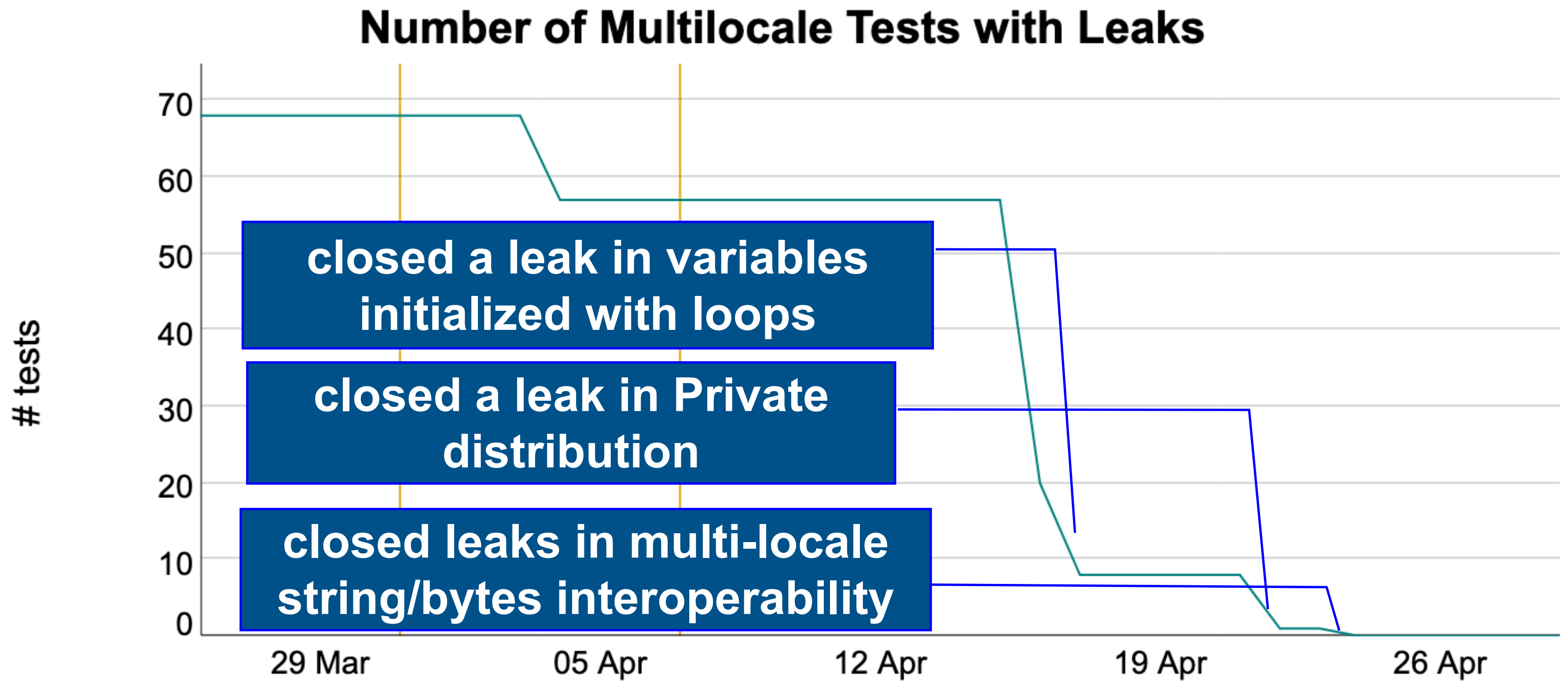
Memory Leaks: Multi-locale Leaks



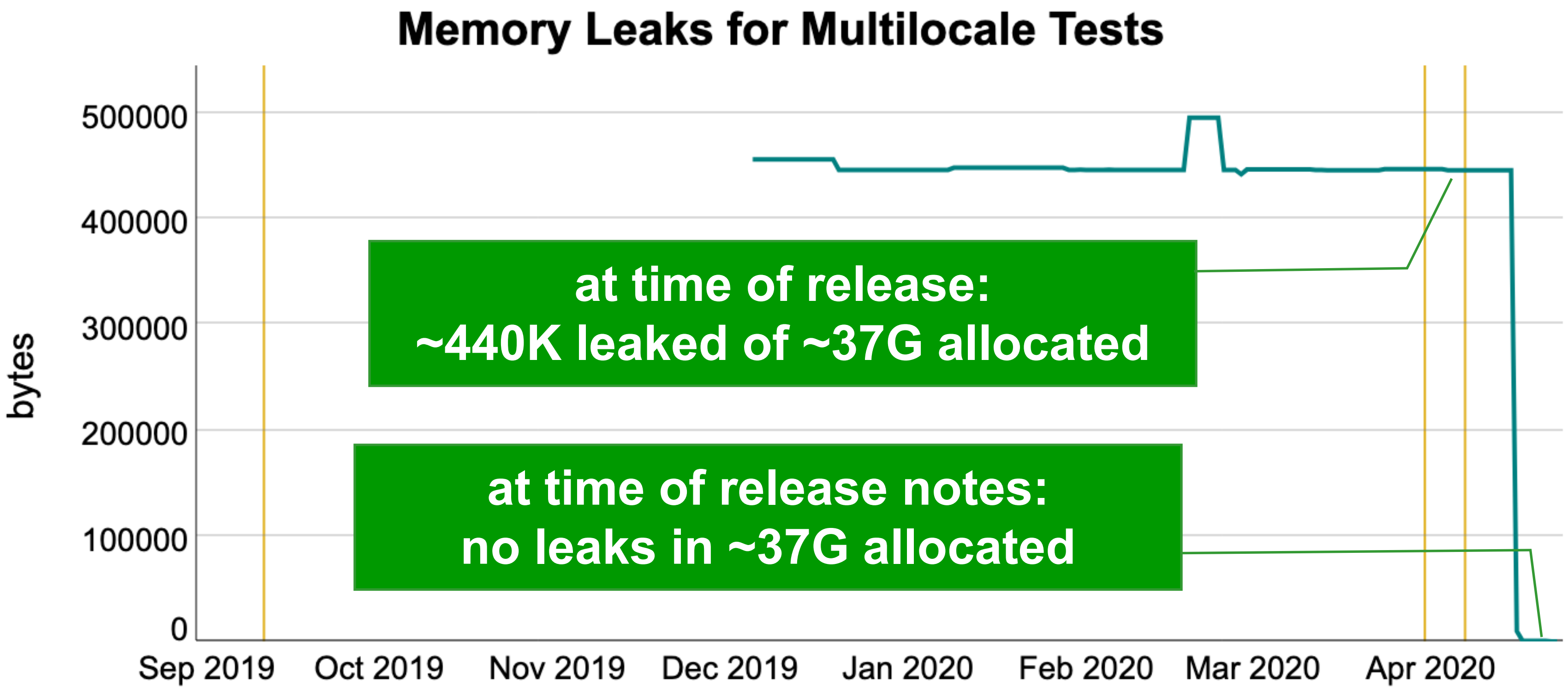
Memory Leaks: Multi-locale Leaks (zoomed)



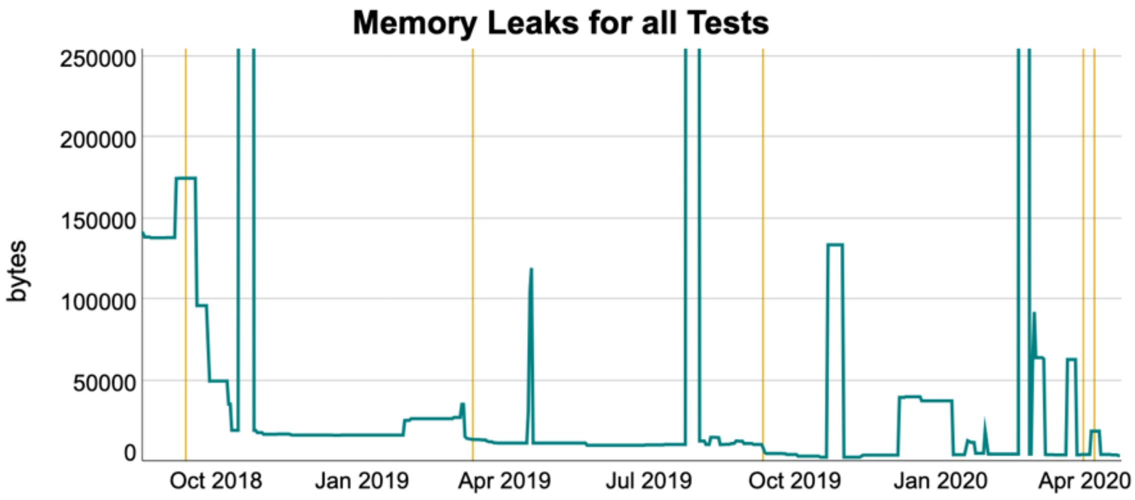
Memory Leaks: Multi-locale Leaks (zoomed)



Memory Leaks: Multi-locale Leaks (volume)



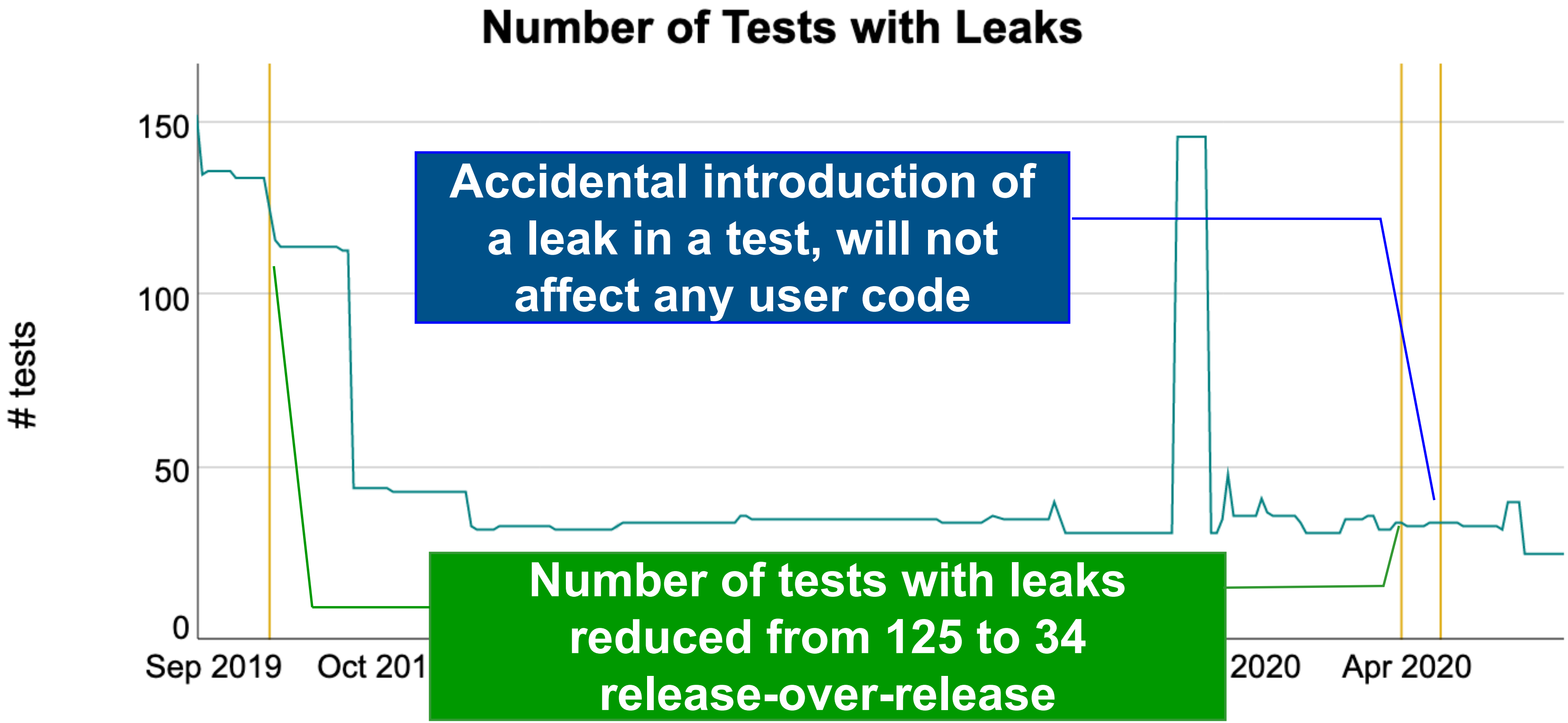
Memory Leaks: Single-locale Leaks



very active release cycle in terms of memory changes

- Compiler changes
  - Split initialization
  - Copy elision
  - Early deinitizalization
- Test changes
  - Start tracking mason

Memory Leaks: Single-locale Leaks



Memory Leaks: Impact, Next Steps

Impact:

- Closed all known multi-locale memory leaks
- Reduced single-locale memory leaks
- Confirmed that there is no additional leak when using LLVM backend

Next Steps:

- Eliminate remaining single-locale leaks
- Make new leaks a correctness error

For More Information

For a more complete list of related changes in the 1.21 and 1.22 releases, refer to the 'Performance Improvements' and 'Memory Improvements' sections in the CHANGES.md file

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