Benchmarks and Performance Optimizations

Chapel versions 1.21 / 1.22
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Outline

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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

Mismatched Stream Performance

Performance (GB/s)

1.20 to 1.21
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 Time

Locales (x 36 cores / locale)

Time (sec)
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

```plaintext
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: 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

```chapel
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

Number of Multilocation Tests with Leaks

- Started tracking in the most recent release cycle

zooming in…
Memory Leaks: Multi-locale Leaks (zoomed)

Number of Multilocal Tests with Leaks

- Closed multilocal-specific string/bytes leaks for 1.22
- Closed leaks in Sparse Block and Hashed distributions
- Closed leaks in user code

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Memory Leaks: Multi-locale Leaks (zoomed)

Number of Multilocal Tests with Leaks

- Closed a leak in variables initialized with loops
- Closed a leak in Private distribution
- Closed leaks in multi-locale string/bytes interoperability
Memory Leaks: Multi-locale Leaks (volume)

- At time of release: ~440K leaked of ~37G allocated
- At time of release notes: no leaks in ~37G allocated
MemoryLeaks: Single-localeLeaks

very active release cycle in terms of memory changes

- Compiler changes
  - Split initialization
  - Copy elision
  - Early deinitialization
- Test changes
  - Start tracking mason
Memory Leaks: Single-locale Leaks

Accidental introduction of a leak in a test, will not affect any user code

Number of tests with leaks reduced from 125 to 34 release-over-release
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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