Benchmarks and Performance Optimizations

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Outline

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

```java
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:

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

• Extended support to Boolean types:

```c
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

**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

```chapel
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;
```
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

```latex
var A, B, C: [1..m] real; 

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

coforall 1..here.maxTaskPar/2 { } 

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

// Parallel initialization

// Same affinity as initialization, good performance

// Interleaved tasks skew round-robin assignment

// Tasks offset from initialization affinity, poor performance
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
Consider running with a process per NUMA domain

First touch is not always enough

```plaintext
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/](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

<table>
<thead>
<tr>
<th>config</th>
<th>Stream</th>
<th>PRK-Stencil</th>
<th>ISx</th>
<th>RA-rmo</th>
<th>RA-on</th>
</tr>
</thead>
<tbody>
<tr>
<td>gn-ibv-large</td>
<td>~1500 GB/s</td>
<td>~780 GFlops/s</td>
<td>~55 s</td>
<td>0.0011 GUPS</td>
<td>0.0010 GUPS</td>
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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

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<th>RA-on</th>
</tr>
</thead>
<tbody>
<tr>
<td>ugni (Aries)</td>
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<tr>
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<td>~800 s</td>
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<td>0.0004 GUPS</td>
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</table>
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
    \[ \text{coforall~1..100_000~do~on~Locales[1]~\{}~\{} \]

• 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 for all Tests

<table>
<thead>
<tr>
<th>bytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>14000</td>
</tr>
<tr>
<td>12000</td>
</tr>
<tr>
<td>10000</td>
</tr>
<tr>
<td>8000</td>
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<td>4000</td>
</tr>
<tr>
<td>2000</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

closed user-level leaks in tests

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Memory Leaks: This Effort, Impact (major fixes)

- Closed a leak in certain 'defer' cases.
- Closed a leak related to 'param' routines.
- Closed leaks due to first-class functions.
Memory Leaks: Status (amount of memory)

at time of release:
~8.4k leaked of ~82.9G allocated

at time of release notes:
~4k leaked of ~85.3G allocated
Memory Leaks: Status (number of tests)

Number of Tests with Leaks

at time of release: 125 of 10,535 tests leaking

at time of release notes: 44 of 10,551 tests leaking
Memory Leaks: Remaining Leaks (as of 1.17)

Size of Remaining Leaks by Test Number

Bytes Leaked

1 21 41 61 81 101 121 141 161 181 201 221 241 261 281 301

Leaking Test #
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)

only 44 / 10,551 tests still leaking

1 test leaks 1024 bytes, the rest leak < 256 bytes

50% of tests leak < 64 bytes
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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