Performance Optimizations

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Outline

- Task Spawning Case Study
- Qthreads Hybrid Waiting
- Stack-Allocate Argument Bundles
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- Other Performance Optimizations
Task Spawning Case Study
LCALS: Background

- **LCALS: Livermore Compiler Analysis Loop Suite**
  - Loop kernels designed to measure compiler performance
  - Developed by LLNL
  - [https://codesign.llnl.gov/LCALS.php](https://codesign.llnl.gov/LCALS.php)

- 30 kernels total (11 have parallel variants)

- Each kernel is run for three sizes (Short, Medium, Long)

- Ported LCALS to Chapel in the 1.12 timeframe
  - first released with Chapel 1.13
  - used to identify performance bottlenecks
  - current port is a pretty direct transliteration
LCALS: Background

- Serial performance on par with the reference since 1.14
- Result of several array optimizations

Serial Chapel vs g++

Normalized time – serial reference is 1.0

- g++
- Chapel serial
LCALS: Background

- Parallel variants still lagged behind the reference in 1.14
  - between 1.5X and 8X slower for long problem size

![Parallel Chapel vs OMP](chart)

- Normalized time – parallel reference is 1.0

- **g++ OMP**
- **Chapel parallel**
LCALS: Background

- Discovered that most of the time is spent spawning tasks
  - conceptually, kernels perform a simple parallel idiom in a trial-loop
  - e.g. code for the MULADDSUB kernel

```chapel
for 0..#num_samples {
  forall i in 0..#len {
    out1[i] = in1[i] * in2[i];
    out2[i] = in1[i] + in2[i];
    out3[i] = in1[i] - in2[i];
  }
}
```

```c++
for (s=0; s<num_samples; ++s) {
  #pragma omp parallel for
  for (i=0; i<len; i++) {
    out1[i] = in1[i] * in2[i];
    out2[i] = in1[i] + in2[i];
    out3[i] = in1[i] - in2[i];
  }
}
```
LCALS: Background

- Discovered that most of the time is spent spawning tasks
  - conceptually, kernels perform a simple parallel idiom in a trial-loop
  - e.g. code for the MULADDSUB kernel
  - exacerbated for the “short” problem size

```c
// Modest num trials, modest trip count
for 0..#12000 {
    forall i in 0..#44217 {
        ...
    }
}

// Huge num trials, tiny trip count
for 0..#15000000 {
    forall i in 0..#171 {
        ...
    }
}
```
Task Spawning: Background

- Decided to focus on improving task spawning speed
  - created a no-op task-spawn micro-benchmark to investigate
  - Chapel, OpenMP, and native qthreads variants

```chapel
for 1..trials do
  forall 1..cores do;
```

```openmp
for (i=0; i<trials; i++)
  #pragma omp parallel for
  for (j=0; cores; j++) {
    ...
  }
```

```qthreads
for (i=0; i<trials; i++) {
  qthread_incr(&endCount, cores)
  for (j=0; j<cores; j++)
    qthread_fork(decEndCount, ...);

  while (endCount != 0) qthread_yield();
}
```
Task Spawning: Background

- **Results of task spawning micro-benchmark with 1.14:**
  - Performance wasn’t too far off for lower core-count machines
    - Run on an 8-core (16 HT) Nehalem node, with gcc 6.3
    - Chapel within 80% of OpenMP, qthreads within 10%
  - Performance was further off of OpenMP for high core-count machines
    - Run on a 28-core (56 HT) Broadwell node, with gcc 6.3
    - Chapel was ~6x slower than OpenMP, qthreads was ~5x slower
Task Spawning: Background

- **Task spawning performance goals for this release:**
  - determine if qthreads can be competitive with OpenMP
    - if not, need to explore other tasking layer options
  - minimize tasking overhead that Chapel introduces
    - minimize overhead introduced by the compiler, modules, runtime shim
Qthreads Hybrid Waiting
Hybrid Waiting: Background

● **Idle workers have 2 mechanisms to wait for work**
  ● set at qthreads configure time:
    ● spinwait (busy-waiting -- continuous spinloop)
    ● condwait (sleep -- uses a pthread condwait)

● **Our default wait-policy was condwait**
  ● chosen while investigating qthreads as our default over fifo
    ● spin-waiting killed performance of single/low-threaded codes
    ● condwait hurt performance of some highly-parallel code
      ● but not dramatically, investigation done on an 8-core machine

● **Determined that pure condwait hurts task-spawn speed**
  ● significant penalty on high core-count machines
  ● needed to implement a new waiting mechanism
Hybrid Waiting: This Effort

- **Implemented a hybrid spin/condwait scheme**
  - conceptually simple
    - spin for some amount of time before giving up and sleeping
  - difficult part was choosing spin duration

- **Current strategy: spin 300,000 times before sleeping**
  - opted for a spincount-based strategy (instead of a time-based)
    - low overhead, easy to implement
  - experiments showed 100k-300k provided best task-spawn perf
  - went with the upper bound, since Chapel is a parallel language
    - also happens to match GNU OpenMP spincount policy
  - on Crays, default is bumped to 3,000,000
    - applications that warrant a Cray are likely to be very parallel
Hybrid Waiting: Impact

- Resulted in significant performance improvements
  - particularly for single-locale programs
Hybrid Waiting: Impact

- Resulted in significant performance improvements
- Some nice multi-locale improvements as well
- Bumping spincount on Crays further improved fft/hpl (not shown here)
Hybrid Waiting: Impact

- Some minor regressions
  - for short-lived minimally-parallel benchmarks
  - acceptable in light of improvements on highly-parallel benchmarks
Hybrid Waiting: Status and Next Steps

Status:
- Hybrid spin/condwait scheme implemented
  - contributed upstream
- Significantly improved speed of task-spawning
  - without seriously hurting serial applications

Next Steps:
- Add a friendlier user-facing policy mechanism
  - e.g. WAIT_POLICY={active, passive} vs. SPINCOUNT=30000
- Implement spin-wait policy across qthreads schedulers
  - currently nemesis (flat) only, need to expand to distrib (numa)
- Explore time-based spinning strategies
  - may offer a more “portable” balance across architecture
  - Intel’s OpenMP runtime uses a time-based strategy
Hybrid Waiting: Task Spawning Impact

- Previously Chapel and qthreads lagged behind OpenMP
Hybrid Waiting: Task Spawning Impact

- Hybrid waiting significantly closes the gap with OpenMP
  - 3x faster: Chapel within ~80% of OpenMP, qthreads within 10%
  - next step is to reduce Chapel’s overhead

![28-core Task Spawn Times (normalized to OpenMP)]
Stack-Allocate Argument Bundles
Stack Arg Bundles: Background

- **on/begin/cobegin/coforall** create argument bundles
  - on-statement and task bodies are outlined
  - runtime calls outlined function in new task or on remote locale
  - argument bundles store variables to be passed to the outlined function

- Generated code heap-allocated argument bundles
  - adding overhead to tasks, on-statements

- Heap allocation was redundant
  - fifo allocated a task descriptor and could store arguments there
  - qthreads already had the ability to copy arguments into new task
  - comm layers needed to copy bundle in some cases
    - caller could free argument bundle immediately
    - but comm/tasking could delay call to outlined function & use of bundle
Stack Arg Bundles: This Effort

- Adjust compiler to stack-allocate argument bundles

- Further minimize copying within the runtime
  - runtime often needs to add information to argument bundle
    - e.g. which function to run on remote locale
  - this should be contiguous in memory with argument bundle
    - e.g. to send in one network message
  - solution: include a struct for runtime information in the bundles…
    … to completely avoid heap-allocating or copying in many cases

- Adjust runtime to work with stack-allocated arg bundles
  - including all tasking and communication layers
    - fifo, qthreads, muxed, ugni, gasnet
  - while there, minimized heap allocation calls in tasking & comms
Stack Arg Bundles: Impact

- Resulted in single-locale speedups
- and a decrease in the total amount of memory allocated
Stack Arg Bundles: Impact

- 10-15% improvement for multi-locale RA-on
  - RA-on creates many on statements
  - stack-allocating reduced on statement overhead

![Graph showing performance improvements over time](image-url)
Stack Arg Bundles: Next Steps

Next Steps:

- Remove other unnecessary heap allocation in generated code
- Consider a heap-to-stack compiler optimization
Stack Arg Bundles: Task Spawning Impact

- Chapel was within ~80% of OpenMP
Stack Arg Bundles: Task Spawning Impact

- Stack allocating arg bundles reduces Chapel’s overhead
- now within 60% of OpenMP

28-core Task Spawn Times (normalized to OpenMP)

- Chapel
- Qthreads
- GNU OpenMP
Bounded Coforall Optimization
Bounded Coforall: Background

- Coforallls are transformed by the compiler, from:

```plaintext
coforall i in 1..10 { body(); }
```

roughly into:

```plaintext
var endCount: atomic int;
for i in 1..10 {
    endCount.add(1);
    spawnTask(bodyWrapper, endCount);
}
endCount.waitFor(0);

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

// note: incrementing once per task
Bounded Coforall: This Effort

- **Minimize end-count manipulation for “bounded” coforalls**
- “bounded” coforalls have a known trip-count (range/domain/array)

```c
coforall i in 1..10 { body(); }
```

now roughly converted to:

```c
var tmpIter = 1..10;
var numTasks = tmpIter.size
var endCount: atomic int;

endCount.add(numTasks);  // single atomic op vs. op per task
for i in tmpIter {
    spawnTask(bodyWrapper, endCount);
}
endCount.waitFor(0);

proc bodyWrapper(endCount) { /* same as before */ }
```
Bounded Coforall: Impact

- Improved performance for many single-locale benchmarks
- No known regressions

**Graphs:**

- **LULESH (release):**
  - Improved performance for many single-locale benchmarks
  - No known regressions

- **LCALS (raw_omp, short):**
  - Improved performance for many single-locale benchmarks
  - No known regressions

- **Empty Task Spawn Timings (500,000 x maxTaskPar):**
  - Improved performance for many single-locale benchmarks
  - No known regressions

- **Empty Serialized Task Spawn Timings (500,000 x maxTaskPar):**
  - Improved performance for many single-locale benchmarks
  - No known regressions
Bounded Coforall: Status and Next Steps

**Status:**
- optimized coforall over types with a known trip-count
  - currently ranges/domains/arrays
  - only done for “local” coforall currently

**Next Steps:**
- Implement optimization for “remote” coforall
  ```chapel
cforall i in 1..10 do on Locales[i] { body(); }
  ```
- Add support for “bulk” spawning to our runtime interface
  - single runtime call to spawn all tasks instead of call per task
  - would further minimize overhead introduced by Chapel
- Add support for “bulk” spawning to qthreads
  - likely that this would permit qthreads optimizations
Bounded Coforall: Task Spawning Impact

- Chapel was within ~60% of OpenMP
Bounded Coforall: Task Spawning Impact

- Coforall optimization further reduces Chapel’s overhead
  - now within 30% of OpenMP

![28-core Task Spawn Times (normalized to OpenMP)]
Task Spawning Summary
Task Spawning: Summary

- Task spawning investigation led to several optimizations
  - implemented a hybrid spin/condwait scheme in qthreads
  - moved argument bundles from the heap to the stack
  - minimized task counting overhead of bounded coforalls

- Optimizations had a significant impact
  - large performance improvements for many benchmarks
    - LCALS, MiniMD, Lulesh, SSCA2, and many others
  - task spawning is around 4 times faster now
Task Spawning: Performance Impact

- **1.14 task spawning performance**
  - over 5x slower than GNU OpenMP
Task Spawning: Performance Impact

1.15 task spawning performance
- within 30% of GNU OpenMP for 28-core machine
- within 5% for 8-core machine (not shown here)

28-core Task Spawn Times
(normalized to OpenMP)
Task Spawning: LCALS Performance Impact

1.14 LCALS performance

Parallel Chapel vs g++/OMP

Normalized time – parallel reference is 1.0

Normalized Time

Normalized Time

g++ OMP
Chapel parallel
Task Spawning: LCALS Performance Impact

- **1.15 LCALS performance**
  - ~3-4x speedup: on par or very close to reference for most kernels

![Parallel Chapel vs g++/OMP](image)

- Normalized time – parallel reference is 1.0

*Normalized time*
Task Spawning: Next Steps

● **Continue to optimize task spawning**
  ● minimize Chapel’s overhead
    ● add a bulk spawning interface to the runtime shim
  ● further optimize qthreads
    ● add a bulk spawning interface
  ● explore alternatives to qthreads?
    ● Argobots, Intel’s OpenMP runtime, OCR
  ● explore different task joining mechanisms
    ● alternatives to our current atomic “end count”

● **Add additional task-spawning benchmarks**
  ● add a stream-like variant
  ● add nested parallelism variants
Other Performance Optimizations
Other Performance Optimizations

- Optimized iteration over 1D strided arrays
- Improved loop invariant code motion optimization
- Improved remote-value-forwarding optimization
- Improved performance of casting strings to numeric types
- Optimized `<~>` to avoid unnecessary reference counting
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