Runtime and Third-Party Improvements

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Chapel version 1.13
April 7, 2016
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Outline

- Runtime and Memory Layer Overview
- Jemalloc Memory Layer
- ugni Communication Layer Improvements
- Soft-threading Patent Granted
- Other Third-Party Changes
Runtime and Memory Layer Overview
Compiling Chapel

Chapel Source Code → chpl → Chapel Executable

Standard Modules (in Chapel)
Chapel Compilation Architecture

Chapel Source Code → Chapel-to-C Compiler → Generated C Code → Standard C Compiler & Linker → Chapel Executable

- Standard Modules (in Chapel)
- Internal Modules (in Chapel)
- Runtime Support Library (in C)
  - Tasks/Threads
  - Communication
  - Memory
  - ...
Chapel Compilation Architecture

Chapel Source Code → Chapel-to-C Compiler → Generated C Code → Standard C Compiler & Linker → Chapel Executable

- Standard Modules (in Chapel)
- Internal Modules (in Chapel)

Runtime Support Library (in C):
- Tasks/Threads
- Communication
- Memory
- ...
Chapel Runtime

- Lowest level of Chapel software stack
- Supports language concepts and program activities
- Relies on system and third-party services
- Written in C

Composed of layers
- A misnomer – these are not layers in the sense of being stacked
- More like posts, in that they work together to support a shared load
- Standardized interfaces
- Interchangeable implementations

Env. vars. select configuration when building the runtime
- Also select between configurations when compiling a Chapel program
  - (must have already been built ahead of time)
Chapel Runtime Organization

Chapel Runtime Support Library (in C)

- Communication
- Tasking
- Memory
- Launchers
- QIO
- Timers
- Standard

Standard and third-party libraries
Runtime Memory Layer

Chapel Runtime Support Library (in C)

Memory

cstdlib

dmalloc

tcmalloc

libc malloc(), free(), etc.
dmalloc (Doug Lea)
tmalloc (Google perftools)
Runtime Memory Layer

● **Supports dynamic memory management**
  - memory allocation, deallocation, and alignment

● **Ideally supports allocating out of a given memory region**
  - ugni and gasnet sometimes require a shared heap
  - in such cases, the communication layer:
    - grabs memory from the system
    - registers it with the NIC
    - hands it over to the memory layer
  - and the memory layer:
    - must fulfill allocations from that memory segment
      (instead of grabbing memory from the system)
Runtime Memory Layer

Chapel Runtime Support Library (in C)

Memory

- cstdlib
- dlmalloc
- tcmalloc

libc malloc(), free(), etc.
dlmalloc (Doug Lea)
tcmalloc (Google perftools)
Runtime Memory Layer: cstdlib

- **System allocator:**
  - portable
  - relatively poor multi-threaded performance
  - no shared-heap support
- **the default in 1.12 when a shared heap was not required**
Runtime Memory Layer: dmalloc

- Doug Lea’s `dlmalloc` allocator:
  - relatively portable
  - poor multi-threaded performance
  - shared-heap support

- the default in 1.12 for gasnet with segment fast or large

`cstdlib`

`libc`

`malloc`(), `free`, etc.

Chapel Runtime Support Library (in C)

Memory

Runtime Memory Layer:

- `dlmalloc`
  - `dlmalloc` (Doug Lea)
  - relatively portable
  - poor multi-threaded performance
  - shared-heap support

- the default in 1.12 for gasnet with segment fast or large

`cstdlib`

`tcmalloc`

`libc malloc()`, `free()`, etc.

`tcmalloc`

(tcmalloc (Google perftools))
Runtime Memory Layer: tcmalloc

- **Google Perftool’s tcmalloc allocator:**
  - not as portable as we’d like (gnu, clang, intel only)
  - excellent multi-threaded performance
  - shared-heap support

- default in 1.12 for ugni communication
Runtime Memory Layer: tcmalloc

- Tried to make tcmalloc our preferred allocator for 1.10
  - experienced sporadic segfaults with Qthreads
- Decided to pursue jemalloc instead
  - reputed to have good multi-threaded performance
  - actively maintained, better portability

- cstdlib
- dlmalloc
- libc malloc(), free(), etc.
- dlmalloc (Doug Lea)
- tcmalloc
  - tcmalloc (Google perftools)
Jemalloc Memory Layer
Jemalloc: Overview

- **General purpose malloc implementation**
  - “scalable concurrency support”
  - “emphasizes fragmentation avoidance”
  - also supports an extended API
    - good alloc size, sized deallocation, etc.

- **Actively maintained on GitHub**

- **Large number of notable users**
  - FreeBSD and NetBSD
  - Mozilla Firefox
  - Facebook
  - Android
  - Rust
Jemalloc: This Effort

● **Added support for jemalloc**
  ● initially just for configurations that did not require a shared heap
  ● saw good performance, decided to add shared-heap support
    ● using jemalloc’s custom chunk allocator interface
  ● implemented good_alloc_size() using extended API

● **Switched our default allocator to jemalloc**
  ● except for a few configurations:
    ● gnu+darwin (build issues)
    ● cygwin (build issues)
    ● pgi (segfaults at execution time)

● **Removed dlmalloc and tcmalloc support**
  ● jemalloc performs as well as tcmalloc and is as portable as dlmalloc
Jemalloc: Impact

- Excellent multi-locale performance
  - No performance regressions from tcmalloc to jemalloc switch
    - this is great news, as tcmalloc provided excellent performance
  - Substantial performance improvements from dlmalloc to jemalloc switch:
Jemalloc: Impact (continued)

- Excellent single-locale performance
- Substantial speedups from cstdlib to jemalloc switch:
Jemalloc: Impact (continued)

- A few minor single-locale performance regressions
  - only impacted tests that we aren’t very invested in
  - i.e., benchmarks we haven’t reviewed/optimized in-depth

![Graph showing NAS Parallel Benchmarks: EP timings - size B and Promoted op= Time (no-local)]
Jemalloc: Impact (continued)

- Implementing `good_alloc_size()` also improved perf.
  - `good_alloc_size()` lets you reduce slack for strings, vectors, etc.
  - see Facebook’s [vector documentation](#) for more information
  - we currently use `good_alloc_size()` for strings

![Fasta Shootout Benchmark (n=25,000,000)](image)
Jemalloc: Summary and Next Steps

Summary:

- Added support for jemalloc
- Switched to jemalloc as our default allocator for most configurations
  - overall result was a dramatic performance improvement
  - likely resulted in much less memory fragmentation as well

Next Steps:

- Look into fixing support for darwin+gnu, cygwin, and pgi
- Use more of the extended API (sized_deallocation(), etc.)
- Use good_alloc_size() for array-as-vector
- Consider overriding malloc to call into jemalloc
  - possible performance benefits for third-party code that calls malloc()
ugi Communication Layer Improvements
GNI memory registration wrecks NUMA affinity
- NIC needs virtual/physical mapping, so registration pins memory
  - NIC accepts virtual addrs from user code but references physical mem
- GNI prefers pinning to NUMA domain 0 because it’s closer to the NIC
- Thus all or most memory ends up there; user first-touch has no effect
- Touch-before-registering forces locality, but we can’t leverage that yet

Workaround: don’t register user memory
- Permit user first-touch to have its usual effect

Register minimal internal memory
- GNI RDMA communication requires registration
- Includes management data, trampoline buffers, etc.
- Implies: reworking many internal data structures
  - these were previously allocated from the (registered) heap

This is a stopgap, not a principled solution
ugni Improvements: Status and Impact (1)

● Reworked ugni communication layer internals
  ● Streamlined resource management
    ● GNI RDMA comm. domains (represent Gemini/Aries FMA descriptors)
  ● Reorganized internal data structures and procedures
    ● request buffers and completion handling for remote on-stmts
    ● completion handling for nonblocking GET/PUT

● Result: improved remote memory access performance
ugi Improvements: Status and Impact (2)

- **Implemented minimal registered memory**
  - Register communicable internal data structures
  - Register trampoline buffers for communicating user data
  - Don’t register anything else
  - Add logic to bounce transfers through trampolines, etc.

- **Results without hugepages:**
  - Much-improved NUMA-related performance
    - Cray XC multi-node: stream-ep ~2X faster than with hugepages
    - on par with HPCC MPI+OpenMP reference version
  - Hurt comm-intensive benchmark performance in some cases
    - sometimes dramatic: have seen ~50X slower for RA-rmo
  - Beneficial side effect: without hugepages, ‘Spawn’ works with ugni
    - GNI kernel driver has issues duplicating registered memory in fork()
Summary:

- Support for minimal registered memory is complete
- Related work greatly improved remote memory access performance
- Users can optionally run without hugepages
  - remember: this is only a stopgap, or for specific use cases
- Principled solution for performance is to use the numa locale model
  - first-touch currently depends on luck: how tasks are assigned to threads
  - numa locale model won’t depend on first-touch
  - numa locale model improvements didn’t make it into 1.13 release
    - (see “Ongoing Efforts” deck for more information)

Next Steps:

- Investigate performance surprises due to minimal registered memory
Soft-threading Patent Granted
The Soft-threading Patent Has Been Granted

**Background:** Intellectual property in Cray runtime layers
- Enables fine-grained compute/communicate overlap in ugni+muxed

**This Effort:** Patent 9,201,689 at uspto.gov

Software emulation of massive hardware threading for tolerating remote memory references

**Impact:** Cray runtime layer IP no longer secret

**Next Steps:** Lightweight comp & comm overlap in other layers?
- Need to evaluate effectiveness of lightweight switching in Qthreads
- If effective, may be able to retire muxed tasking
Other Third-Party Changes
Other Third-Party Changes

- Turned on optimizations when compiling ‘re2’ optimized
- Enabled ‘re2’ for Cray and PGI compilers
- Upgraded GASNet to version 1.26.0
- Upgraded hwloc to version 1.11.2
  - also cherry-picked a /proc/mounts buffer overflow fix from their master
- Upgraded LLVM to version 3.7
- Made several third-party directories more Git-friendly
  - stopped embedding version numbers in subdirectory names
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