Runtime and Third-Party Improvements

Chapel Team, Cray Inc.

Chapel version 1.13

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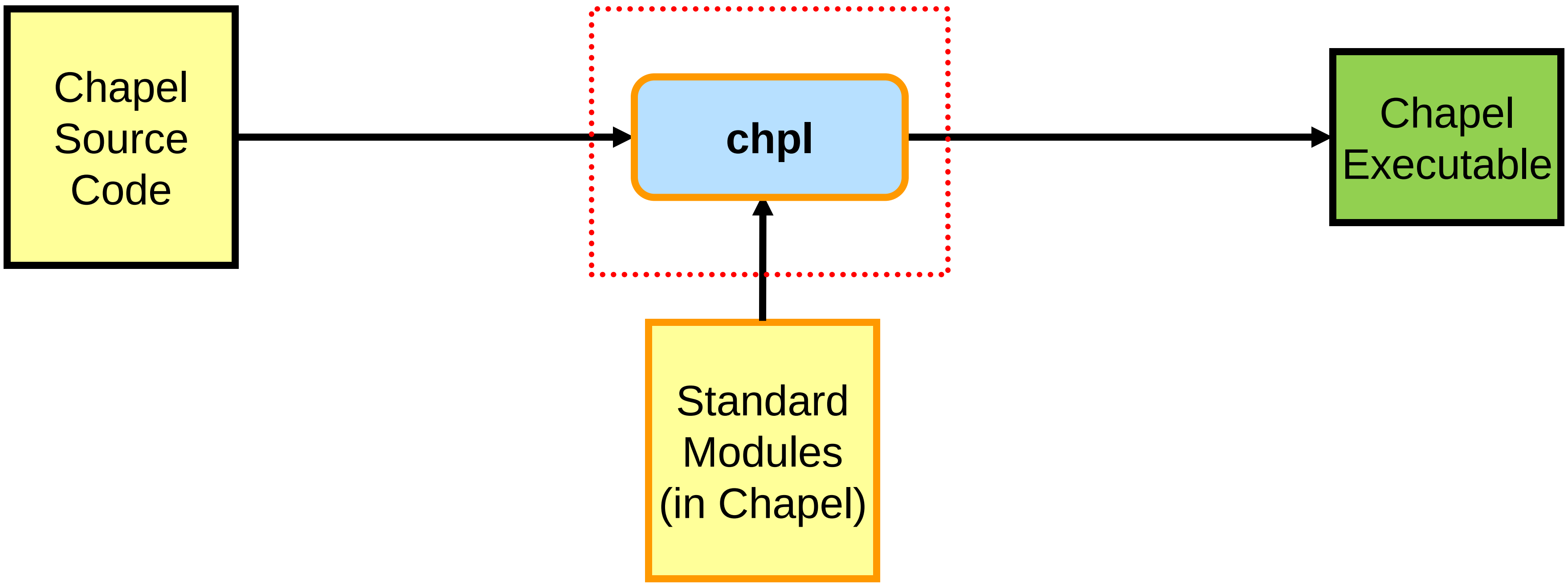
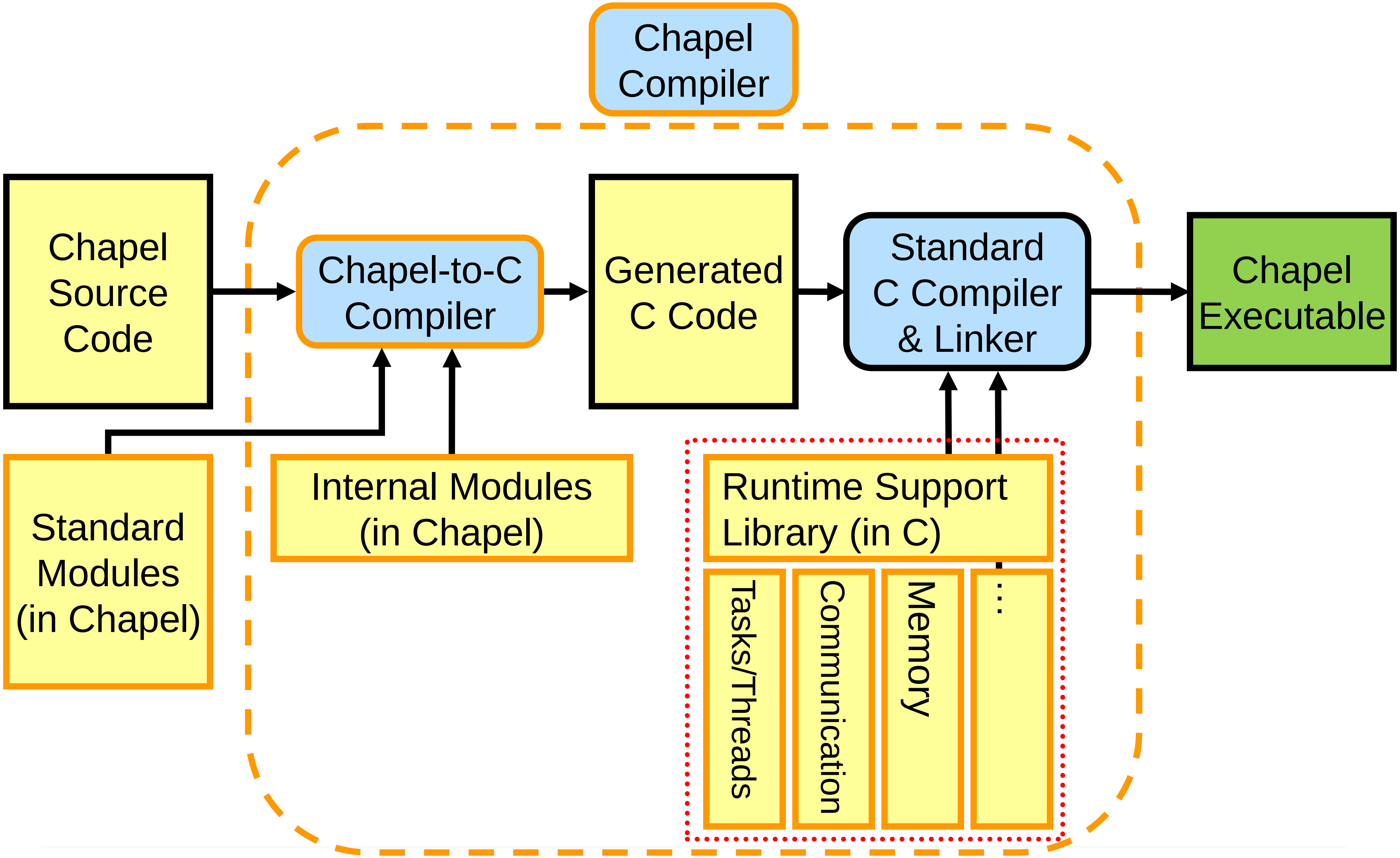
Outline

Runtime and Memory Layer Overview

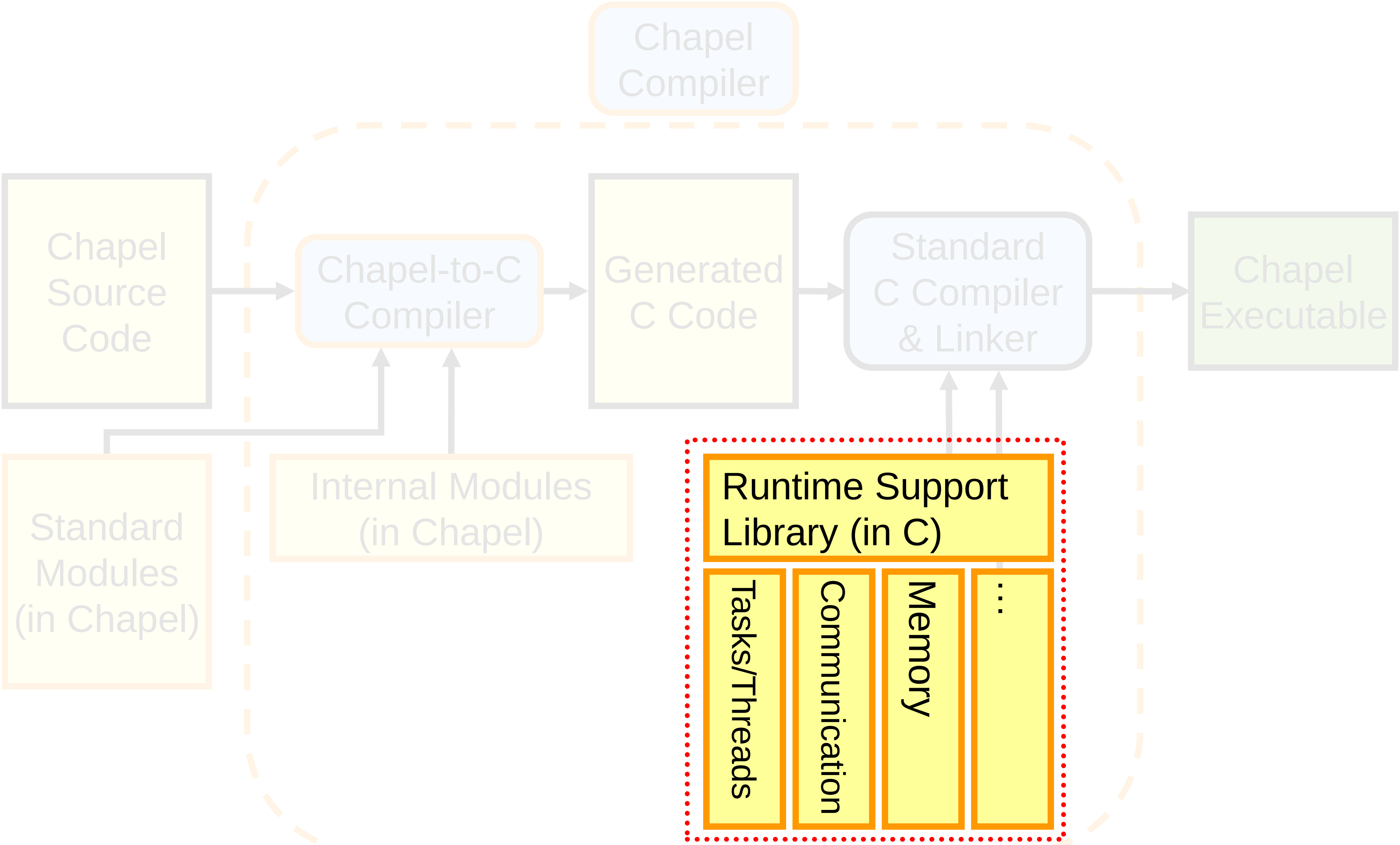
Compiling Chapel



Chapel Compilation Architecture



Chapel Compilation Architecture



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)

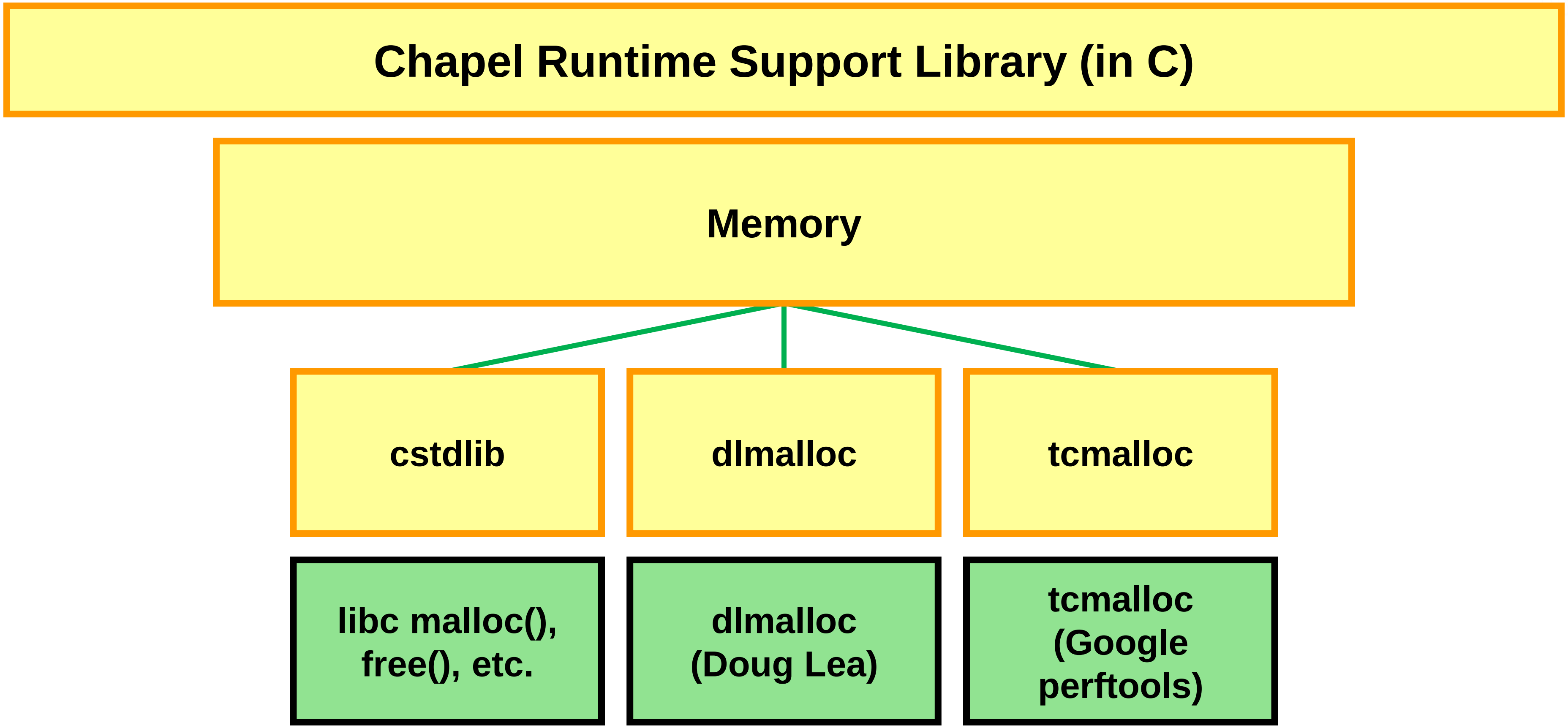
Chapel Runtime Organization

Chapel Runtime Support Library (in C)

Commu-nication	Tasking	Memory	Launch-ers	QIO	Timers	Standard

Standard and third-party libraries

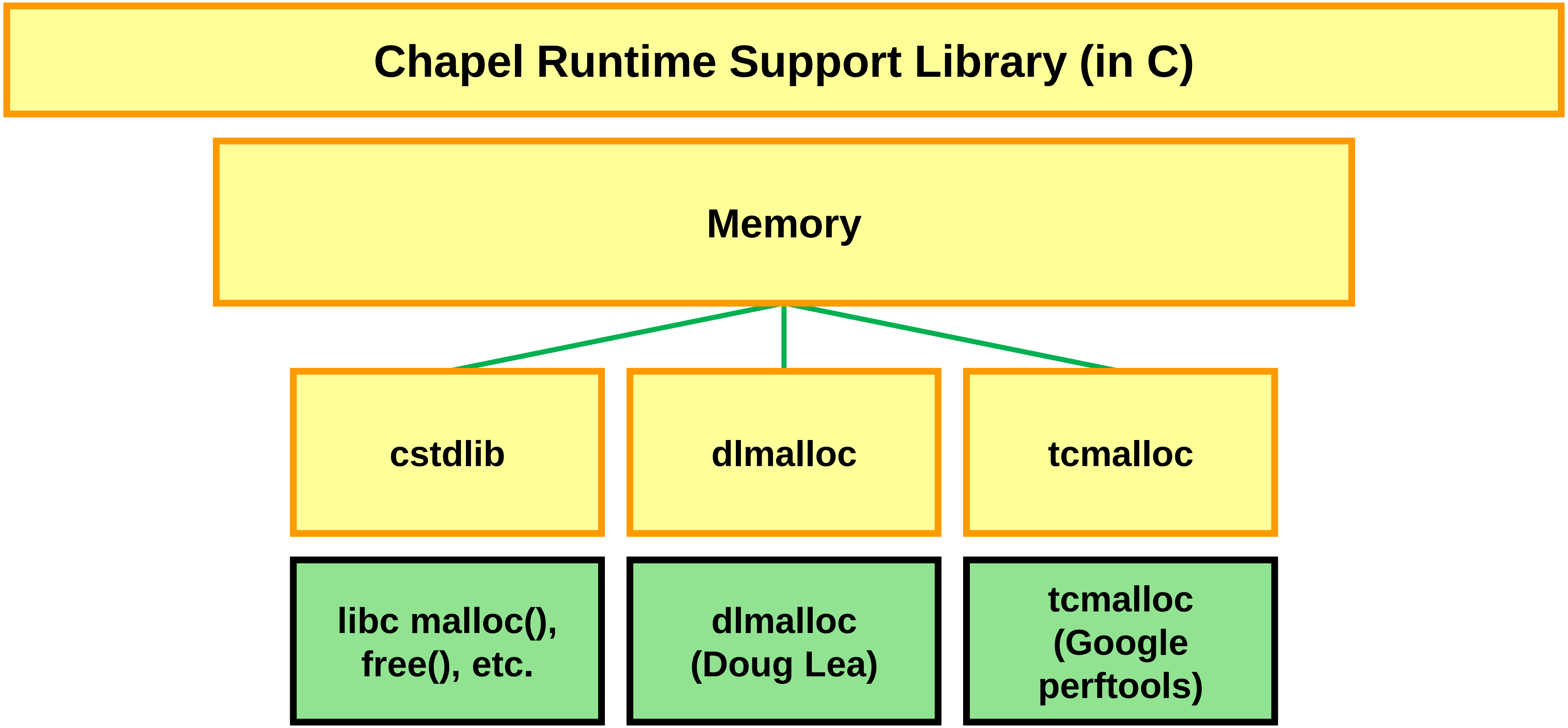
Runtime Memory Layer



Runtime Memory Layer

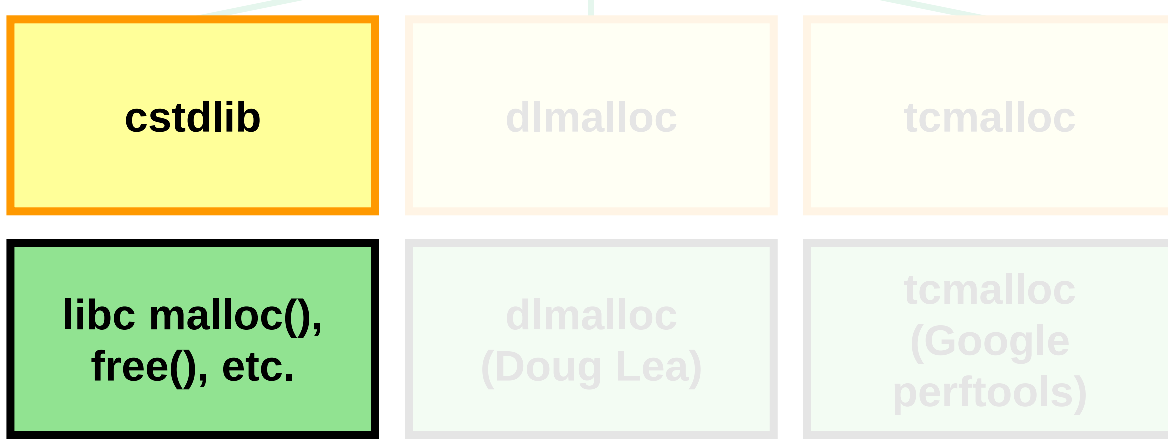
- **Supports dynamic memory management**
  - memory allocation, deallocation, and alignment
- **Ideally supports allocating out of a given memory region**
  - ugni and gasnet sometimes require a shared heap
  - in such cases, the communication layer:
    - grabs memory from the system
    - registers 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



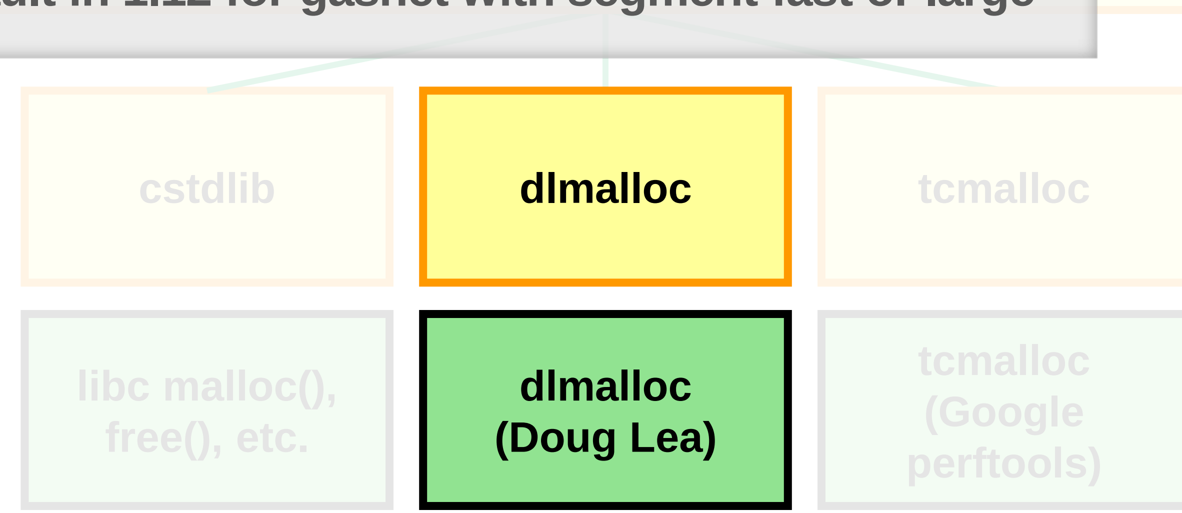
Runtime Memory Layer: cstdlib

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



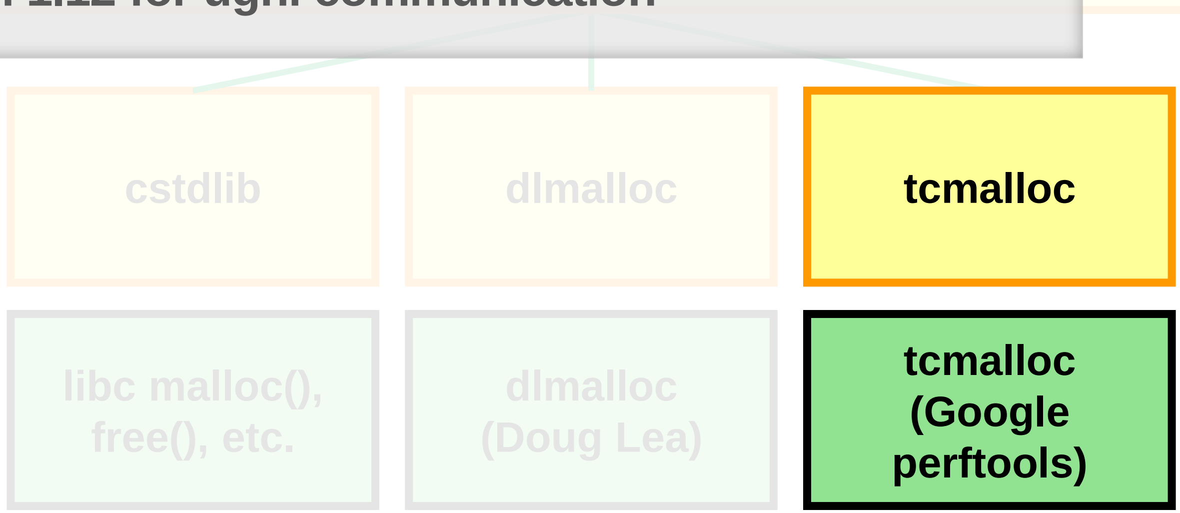
Runtime Memory Layer: dlmalloc

- **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**



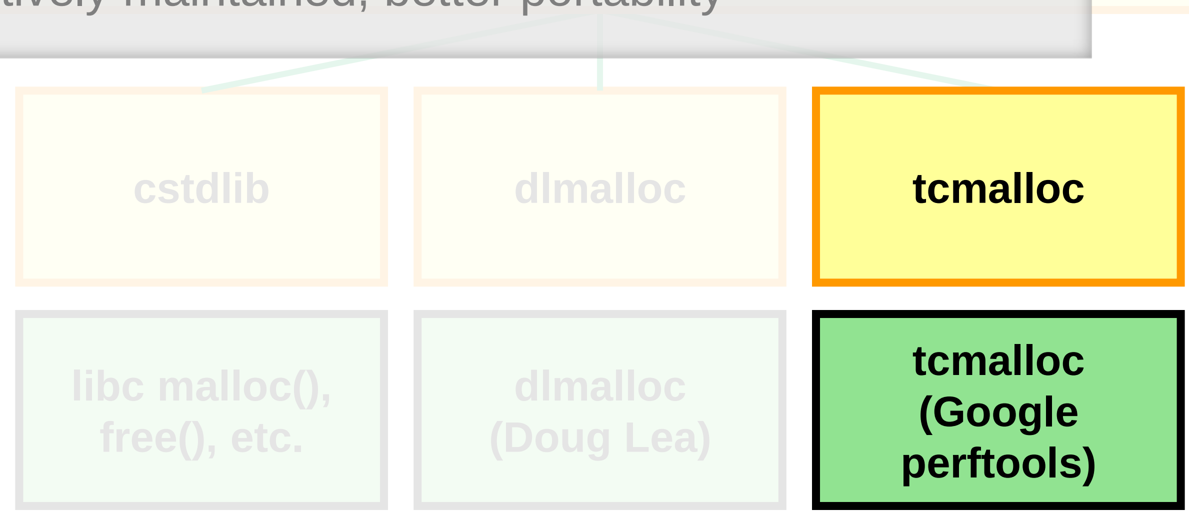
Runtime Memory Layer: tcmalloc

- **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



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**
  - https://github.com/jemalloc/jemalloc
- **Large number of notable users**
  - FreeBSD and NetBSD
  - Mozilla Firefox
  - Facebook
  - Android
  - Rust

Jemalloc: This Effort

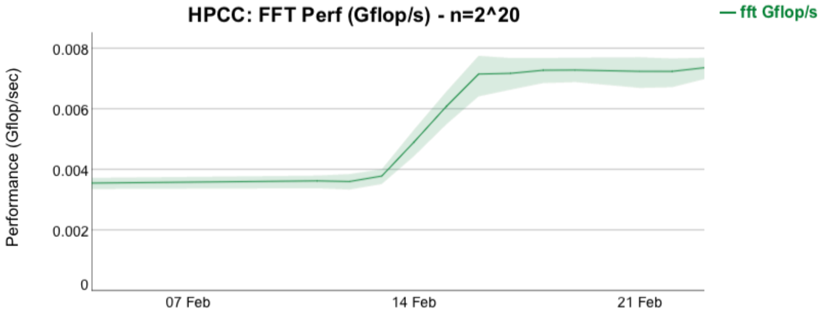
- **Added support for jemalloc**
  - initially just for configurations that did not require a shared heap
  - saw good performance, decided to add shared-heap support
    - using jemalloc's custom chunk allocator interface
  - implemented good_alloc_size() using extended API

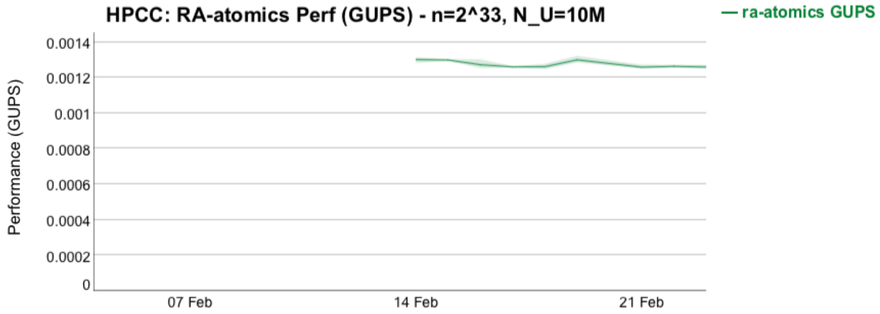
- **Switched our default allocator to jemalloc**
  - except for a few configurations:
    - gnu+darwin (build issues)
    - cygwin (build issues)
    - pgi (segfaults at execution time)

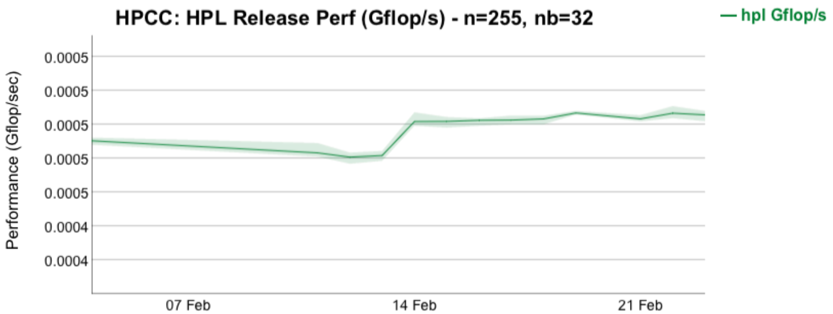
- **Removed dlmalloc and tcmalloc support**
  - jemalloc performs as well as tcmalloc and is as portable as dlmalloc

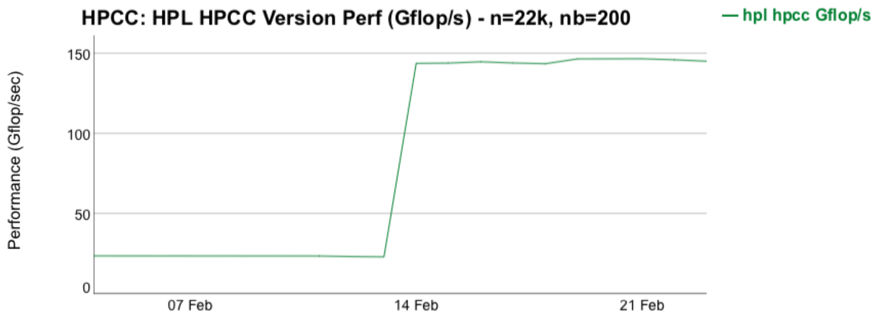
Jemalloc: Impact

- **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:



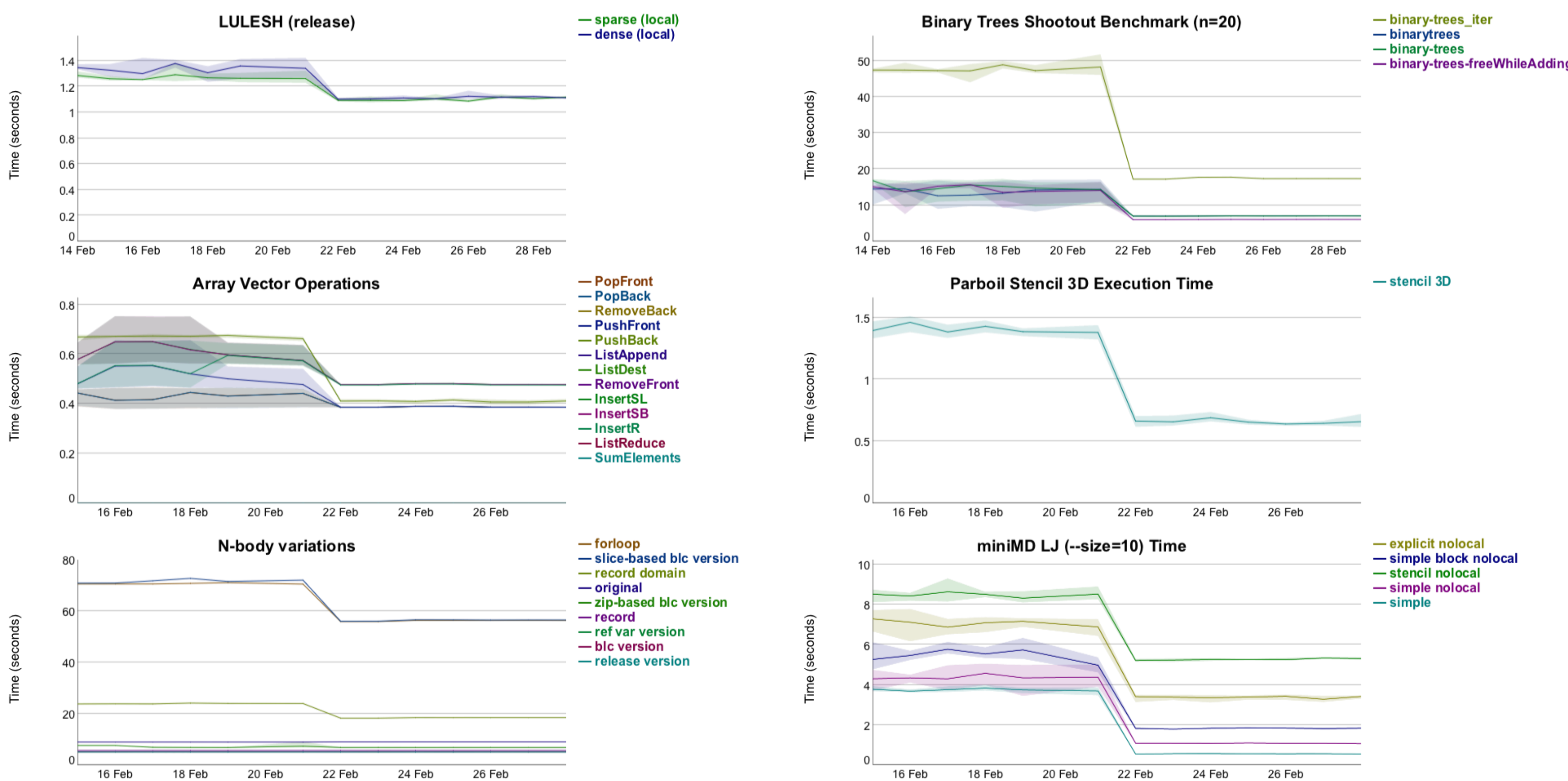






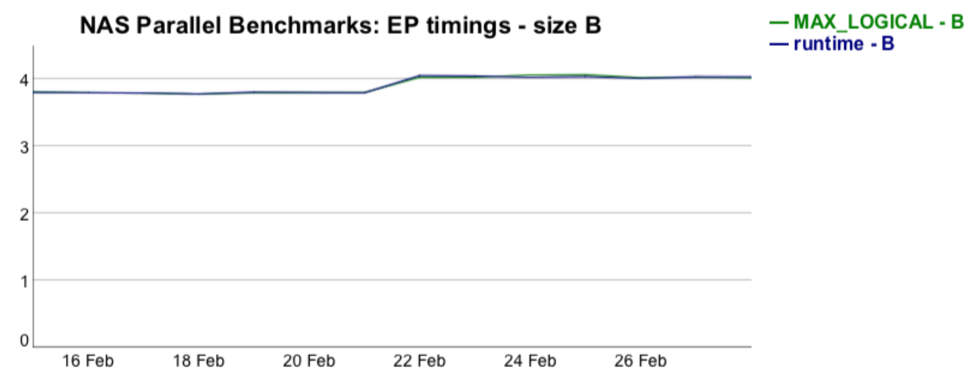
Jemalloc: Impact (continued)

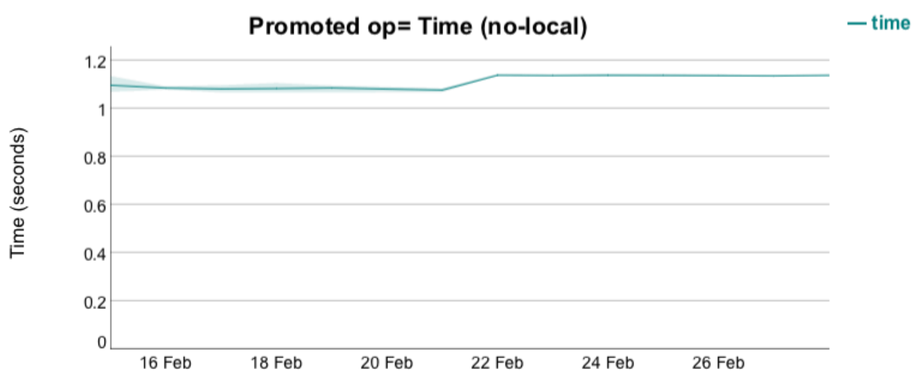
- **Excellent single-locale performance**
  - Substantial speedups from cstdlib to jemalloc switch:



Jemalloc: Impact (continued)

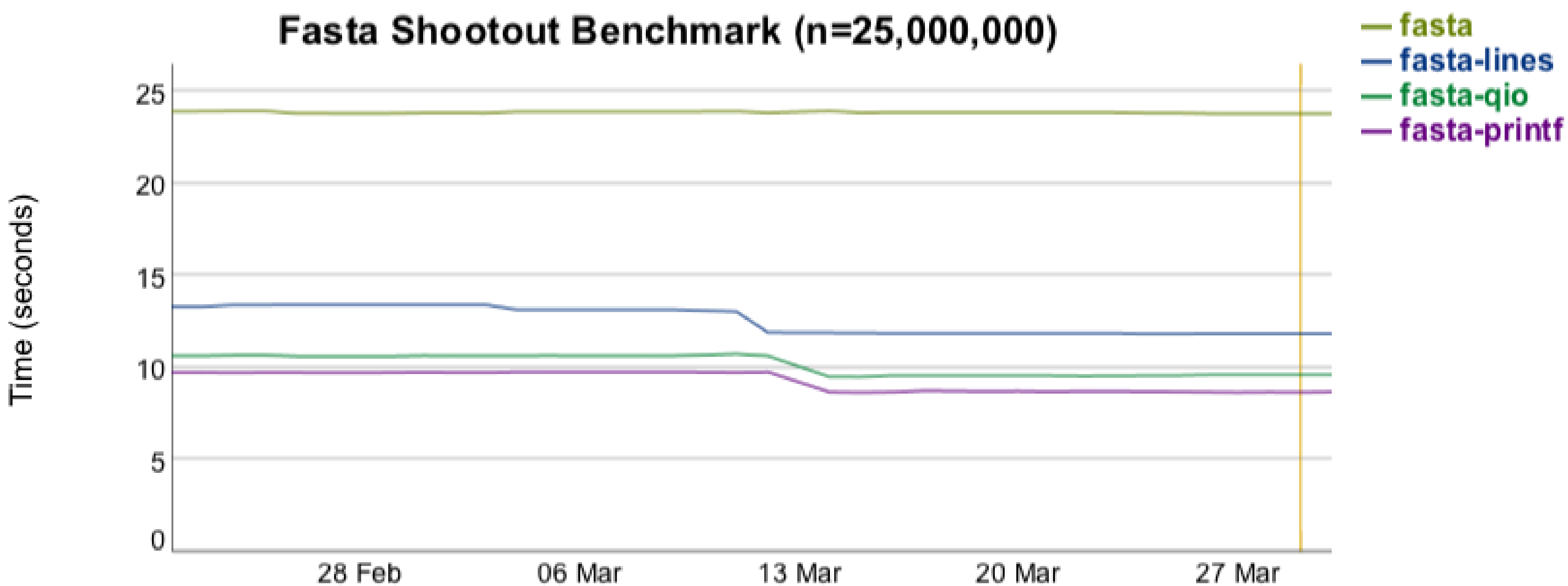
- **A few minor single-locale performance regressions**
  - only impacted tests that we aren't very invested in
    - i.e., benchmarks we haven't reviewed/optimized in-depth





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



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()

ugni Communication Layer Improvements

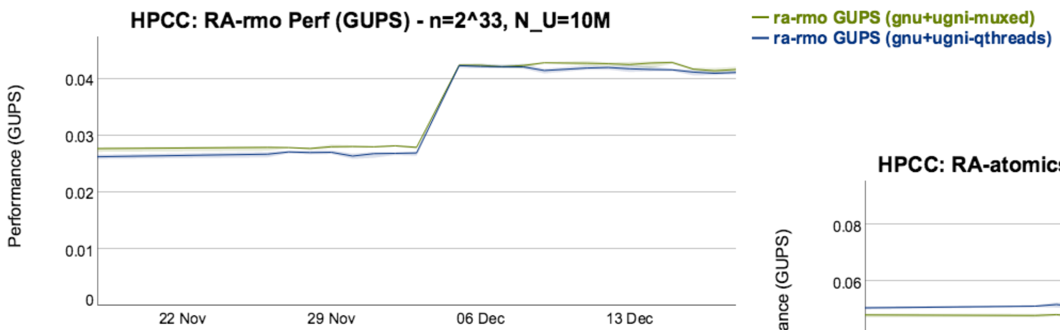
ugni Improvements: Background

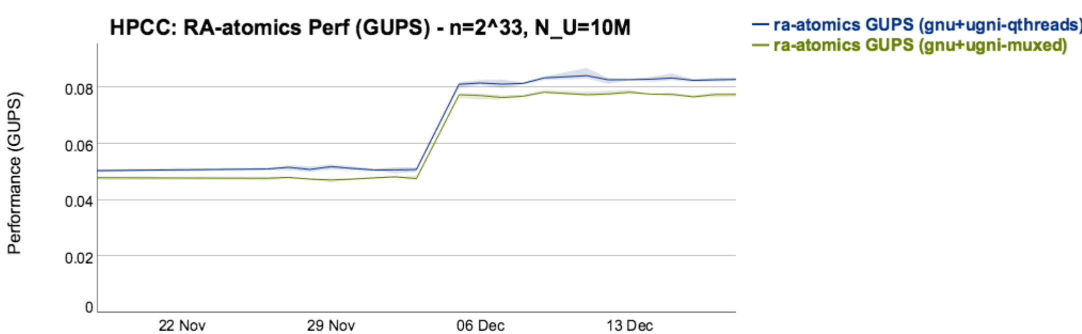
- **GNI memory registration wrecks NUMA affinity**
  - NIC needs virtual/physical mapping, so registration pins memory
    - NIC accepts virtual addrs from user code but references physical mem
  - GNI prefers pinning to NUMA domain 0 because it's closer to the NIC
  - Thus all or most memory ends up 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**





ugni 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()

ugni Improvements: Summary and Next Steps

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

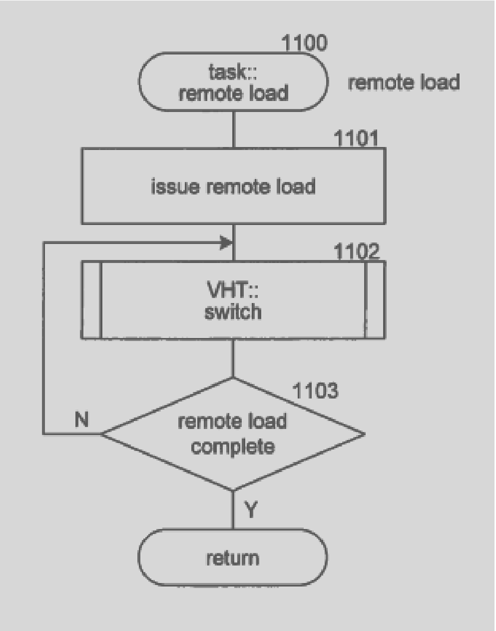
The Soft-threading Patent Has Been Granted

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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