OPENFABRICS ALLIANCE

13th ANNUAL WORKSHOP 2017

Performance of a Task-Parallel PGAS Programming Model using OpenSHMEM and UCX

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Outline

- **State of Multi-Threading in OpenSHMEM**
- AsyncSHMEM Overview
- API Extensions
- Runtime Implementations
- Performance Evaluation
- Discussion of Contributions & Future Directions

OpenSHMEM Threading Group

Concerned with enabling safe use of OpenSHMEM in a multi-threaded environment.

- OpenSHMEM today is not thread-safe

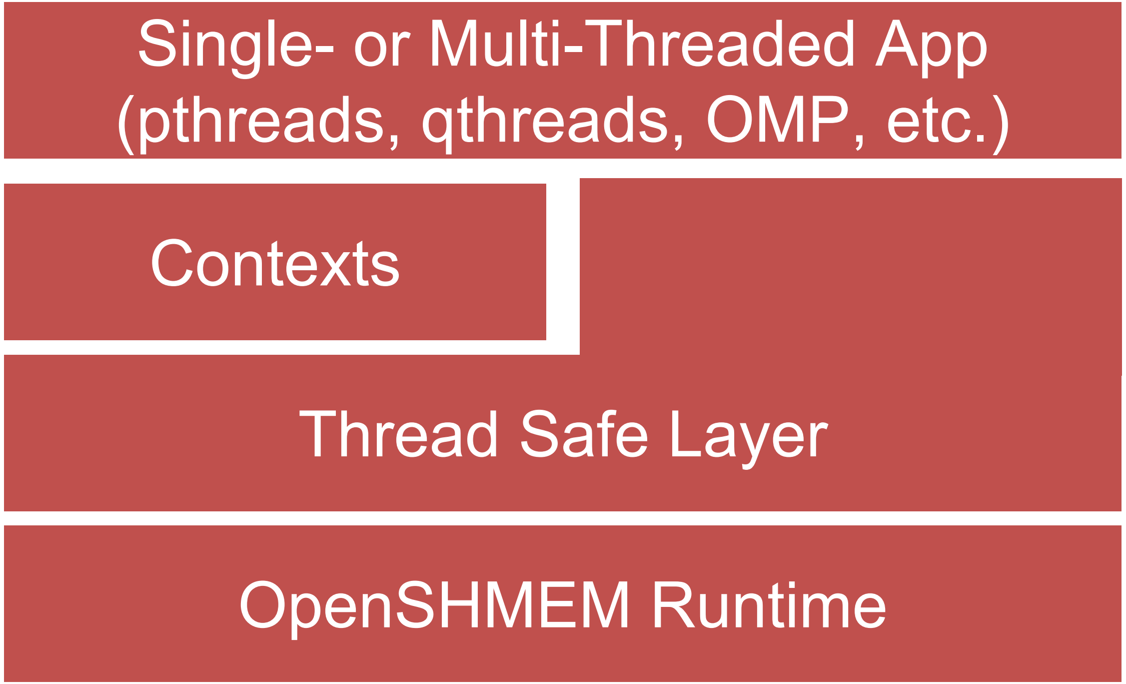
Bottom-up approach to the general problem of thread safety.

Likely outcome: MPI-like thread safety with OpenSHMEM contexts

```
for (t = 0; t < nthreads; t++) {
  shmem_ctx_create(0, ctxs + t);
}

#pragma omp parallel
{
  ...
  shmem_ctx_putmem(...,
        ctxs[omp_get_thread_num()]);
  ...
}
```

OpenSHMEM Threading Group



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AsyncSHMEM Overview

AsyncSHMEM targets the same problems as the OpenSHMEM threading group.

Look at the problem top-down: how can we make multi-threaded runtimes more OpenSHMEM-aware to improve their use together (productivity and performance).

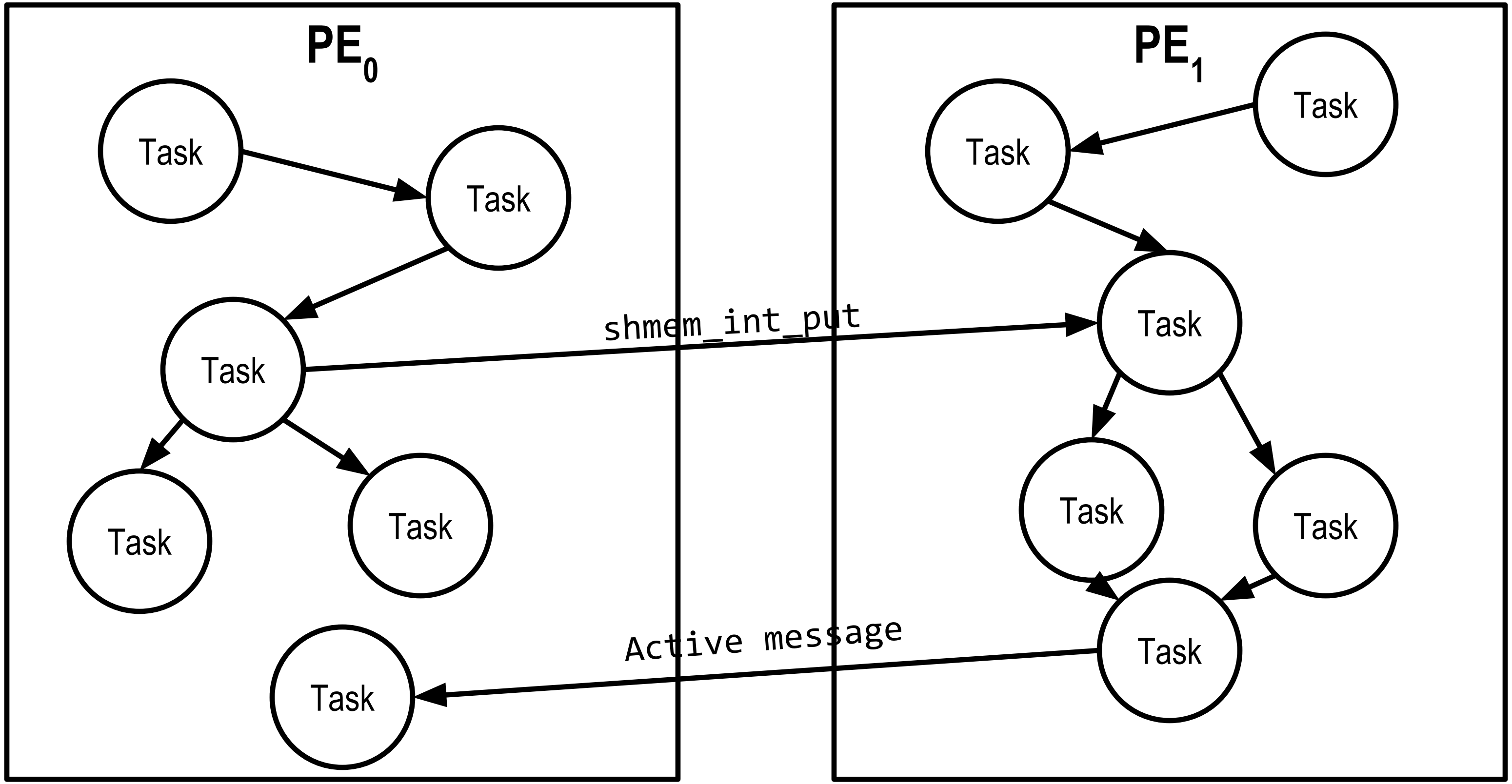
Encourage asynchrony to protect against variability/latencies in future HPC systems.

AsyncSHMEM Goals and Deliverables

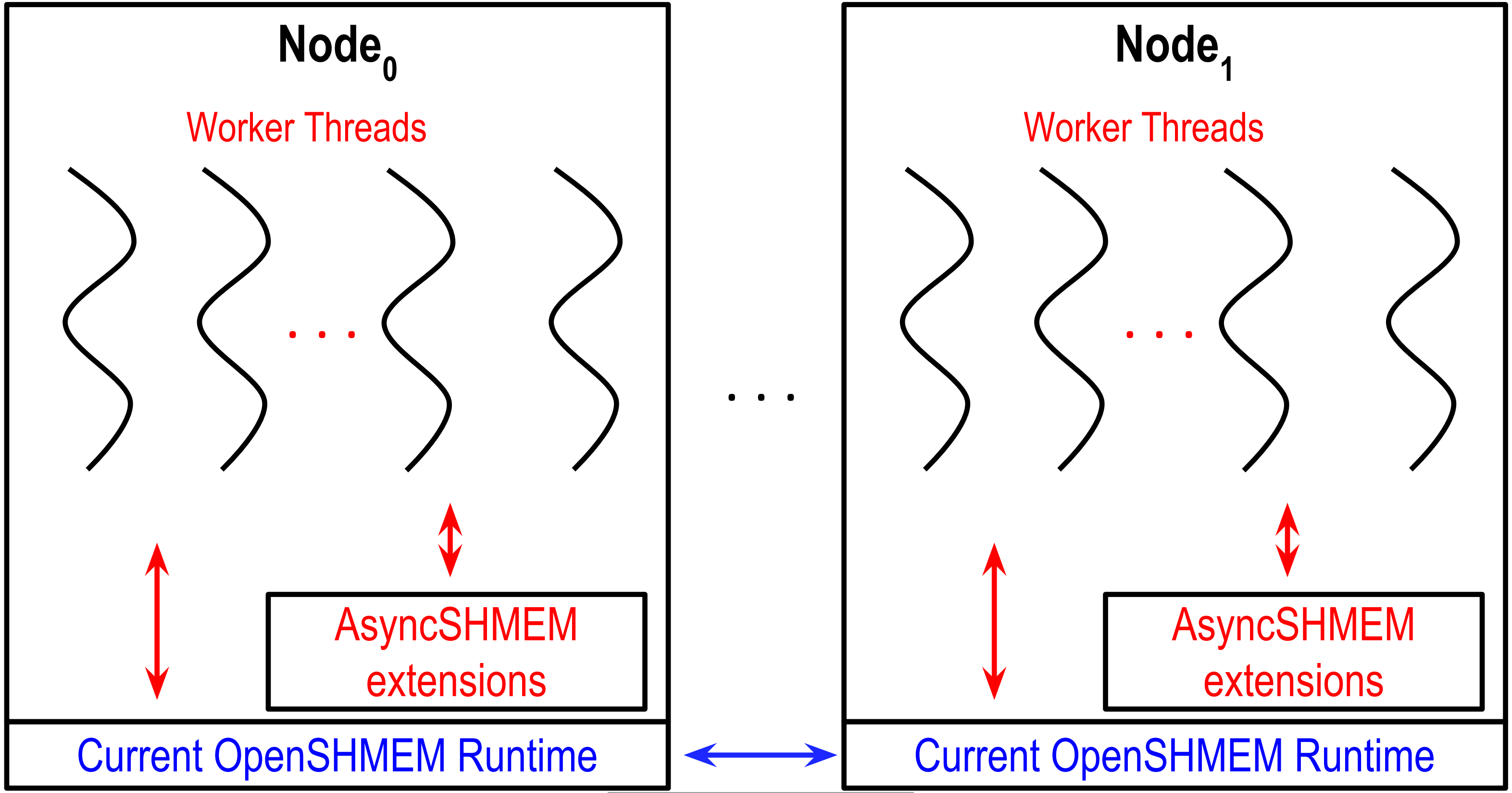
- Explore new APIs at the boundary between OpenSHMEM and tasking APIs
- Develop runtimes to support these extensions and existing APIs:

1. *Offload Runtime* works with current runtimes, does not rely on thread safety of OpenSHMEM implementation, more opportunities for exploiting asynchrony, especially for new applications (implemented)
2. *Contexts-Based Runtime* looks ahead to contexts, uses them under the cover to drive the network from multiple threads while minimizing lock contention (in-progress)

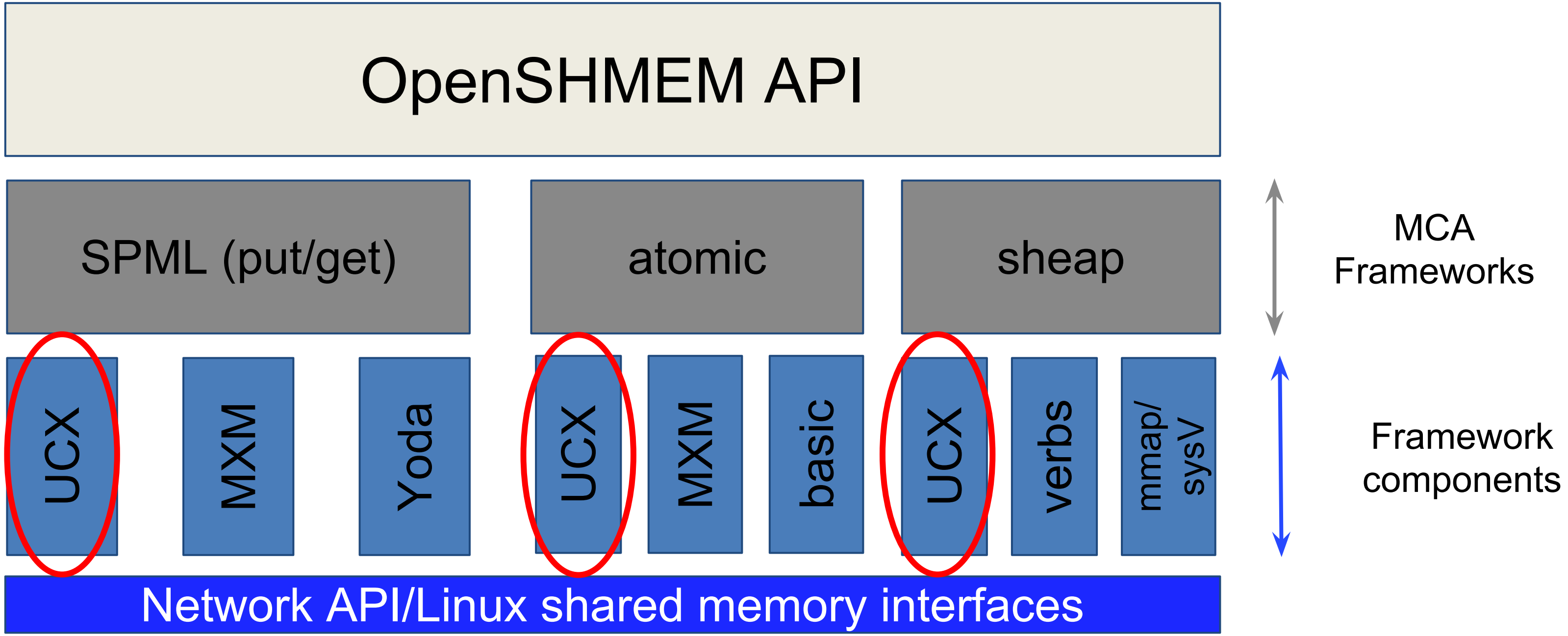
AsyncSHMEM Execution Model



AsyncSHMEM Under the Covers



Open MPI/OSHMEM Runtime



UCX components used in this study

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Creating an asynchronous task --- shmem_task()

```
void shmem_task(void (*body)(void *), void *data);
```

Creates an asynchronous task defined by body (like “begin” construct in Chapel)

```
void foo(void *data) {// Body of child task
    . . .
}

void entrypoint(void *args) { // Body of root task
    shmem_task(foo, NULL);
}

int main(int argc, char** argv) {
    shmem_worker_init(entrypoint, NULL);
}
```

Join synchronization for parallel tasks --- shmem_task_scope

```
void shmem_task_scope_begin();
void shmem_task_scope_end();
```

Starts and ends a task synchronization scope. Like Chapel's "sync" construct, shmem_task_scope_end() waits on *all* tasks created in scope before returning control to the calling task. Task scopes may be nested.

```
void foo(void *data) {
    shmem_task(bar, NULL);
}

void entrypoint(void *args) {
    shmem_task_scope_begin();
    {
        shmem_task(foo, NULL);
        shmem_task(baz, NULL);
    }
    shmem_task_scope_end(); // Wait for tasks foo, bar, baz
}
```

Futures and Promises

```
void shmem_satisfy_promise(shmem_promise_t *promise, void *data);
```

Store a value into a single-assignment promise.

```
void shmem_task_await(shmem_future_t *future, void (*body)(void *data), void *data);
```

Create an asynchronous task whose execution is predicated on the satisfaction of the specified future.

```
void producer(void *data) {
    shmem_satisfy_promise((shmem_promise_t *)data, NULL);
}

void consumer(void *data) {
    // Only starts executing after producer satisfies the promise
}

shmem_task_await(shmem_future_for_promise(promise), consumer, NULL);
```

Communication-Driven Tasks --- shmem_task_when()

```
void shmem_int_task_when(int *ivar, int cond, int value,
        void (*body)(void *), void *data);
```

Create an asynchronous task when the specified condition is satisfied on the specified location in the symmetric heap. Analogous to shmem_int_wait_until, except that this call never blocks.

Communication-driven tasks allow remote communication to trigger asynchronous task creation on a PE.

Analogous to existing shmem_wait APIs, but these APIs do not block, and also offer single- and multi-condition variants.

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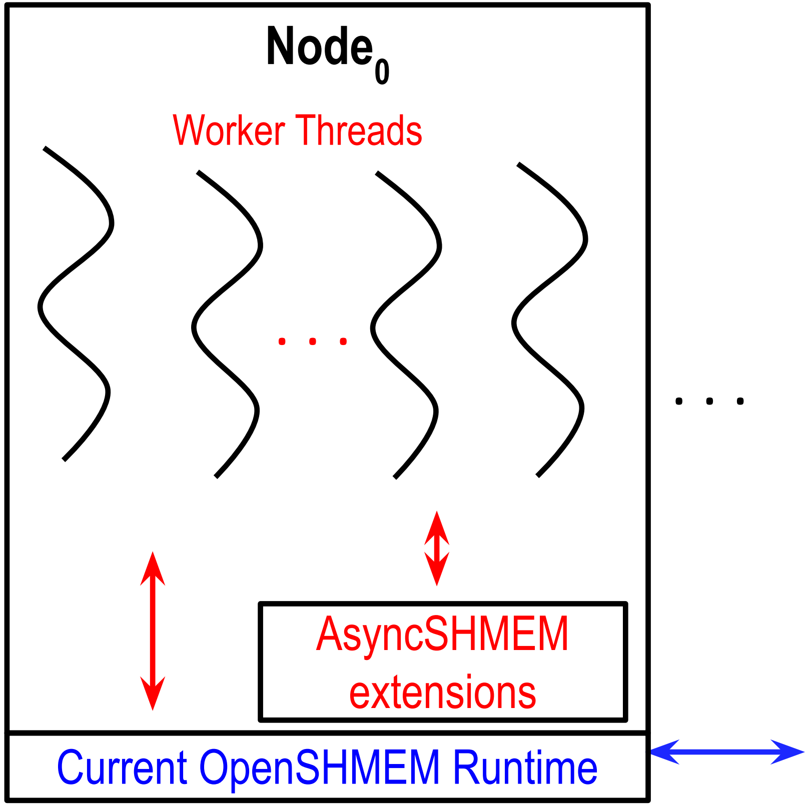
AsyncSHMEM Under the Covers (Recap)

Two implementations of the AsyncSHMEM API:

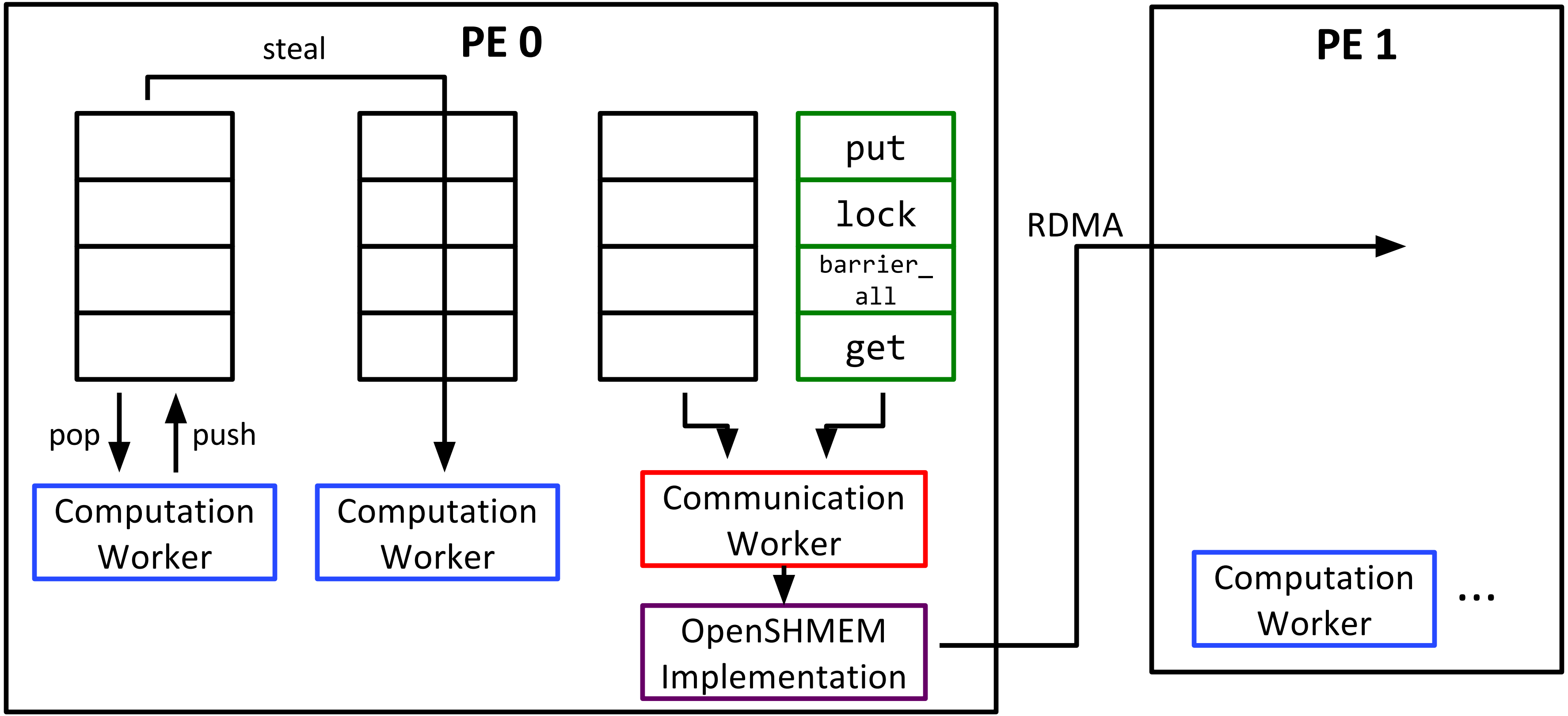
- **Offload** runtime
- **Contexts** runtime

Both fundamentally based on the same system design: work-stealing, multi-threaded runtime paired with an OpenSHMEM implementation.

- In this case, OpenMPI's OSHMEM over UCX



Offload Runtime

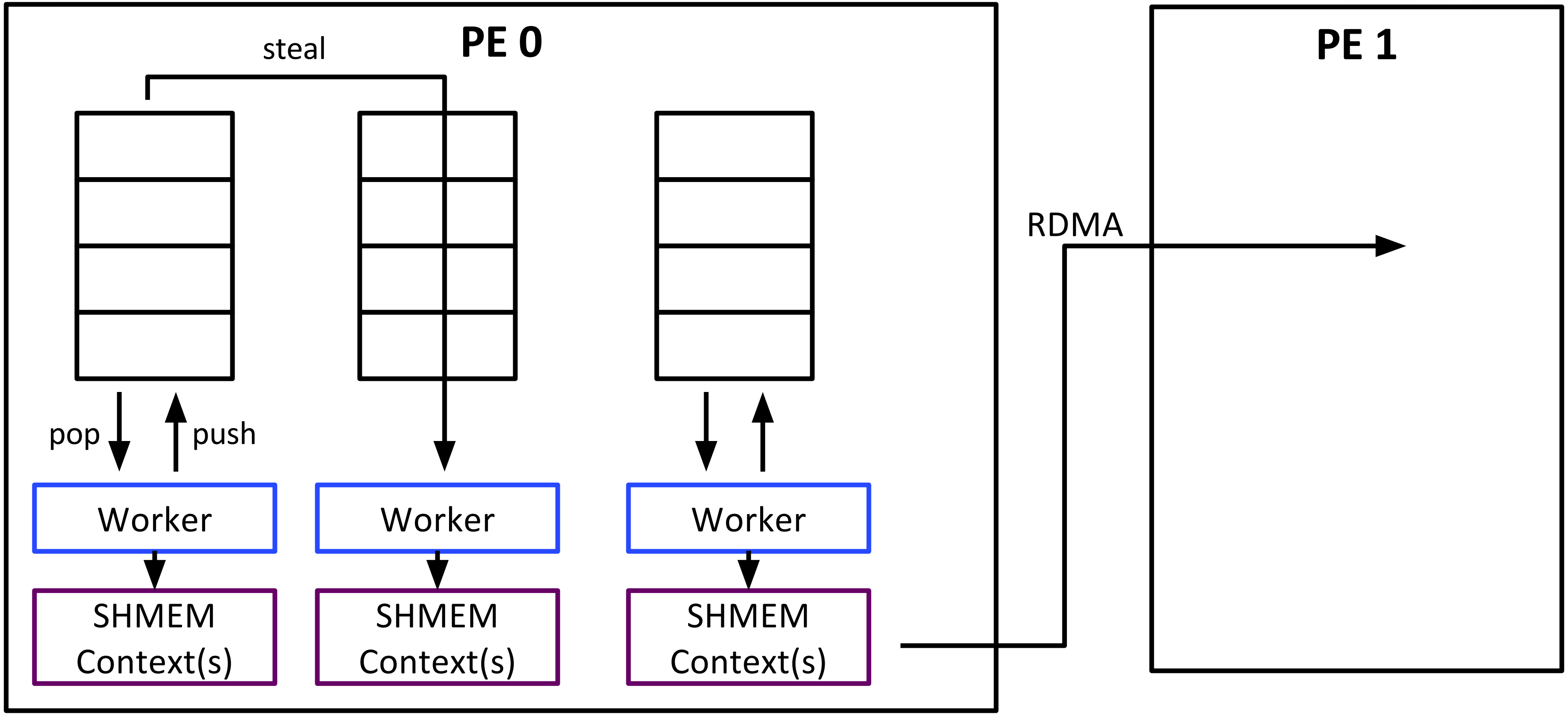


Offload Runtime (cond'td)

Example lifetime of a shmem_int_put in the offload runtime:

1. Arguments to the shmem_int_put call are wrapped in a task, placed at the communication worker.
2. Calling task is suspended, current worker thread picks up another task.
3. Communication worker eventually picks up shmem_int_put task and performs the shmem_int_put call.
4. Suspended task is re-inserted into work-stealing runtime.

Contexts Runtime (In-Progress)



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Application Benchmarks

Extensions to OpenSHMEM are in part being validated through application benchmarks.

Application focus to date:

- ISx – Distributed integer sort (dataset = up to 2 billion keys per node)
- UTS – Unbalanced tree search (dataset = T1XXL)
- G500 - Distributed breadth first search (dataset = up to 2^27 vertices)

Evaluation shown today performed on LANL Hickok and Rice DAVINCI systems using OpenMPI's OpenSHMEM implementation over UCX and the AsyncSHMEM Offload runtime.

Experimental Setup

Two clusters were used for these experiments (will also show non-UCX tests on Titan):

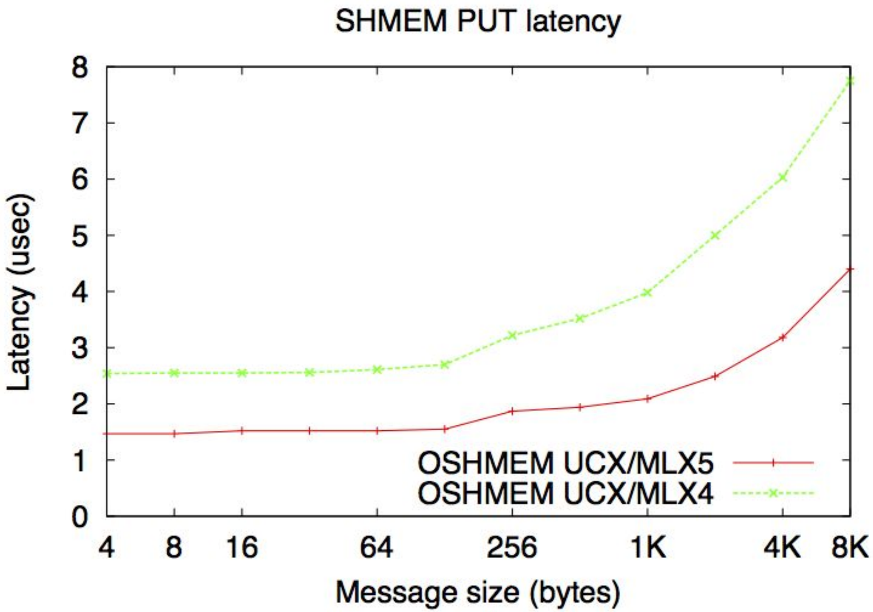
DAVINCI cluster at Rice

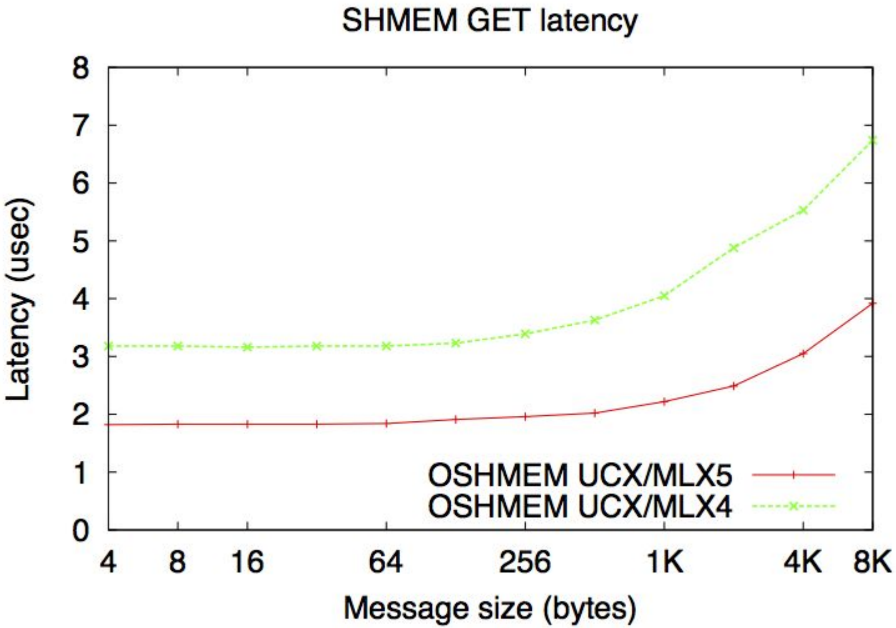
- Dual socket 2.8 GHz Westmere with 6 cores/socket
- Mellanox ConnectX3 QDR, PCI-e gen2
- RHEL 6.5/OFED 2.2-1

Hickok network technology testbed at LANL

- Dual socket 2.1 GHz Broadwell with 8 cores/socket
- Mellanox ConnectX5 EDR, PCI-e gen3
- 5 36-port EDR switches cabled in fat tree
- RHEL 7.2/MOFED 4.0.1-0

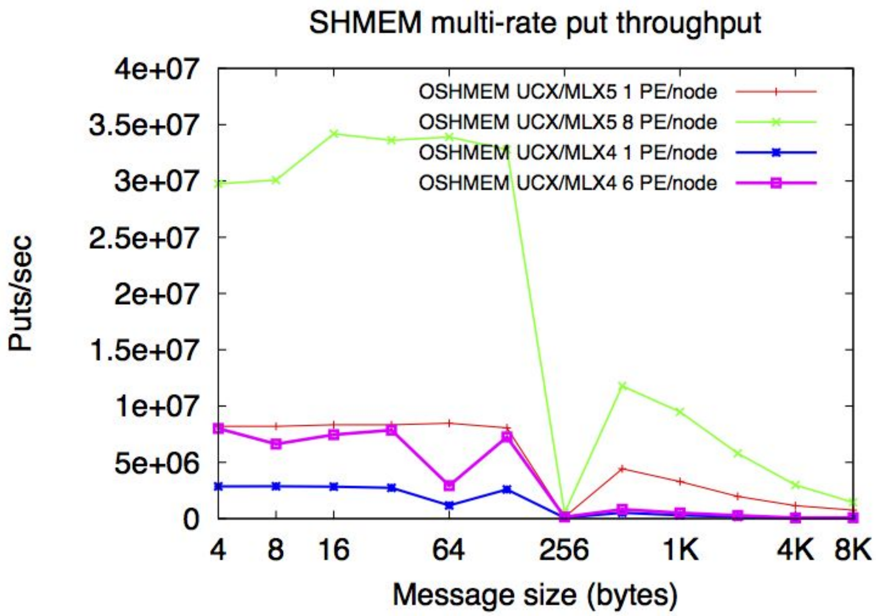
OSU OpenSHMEM micro-benchmark results

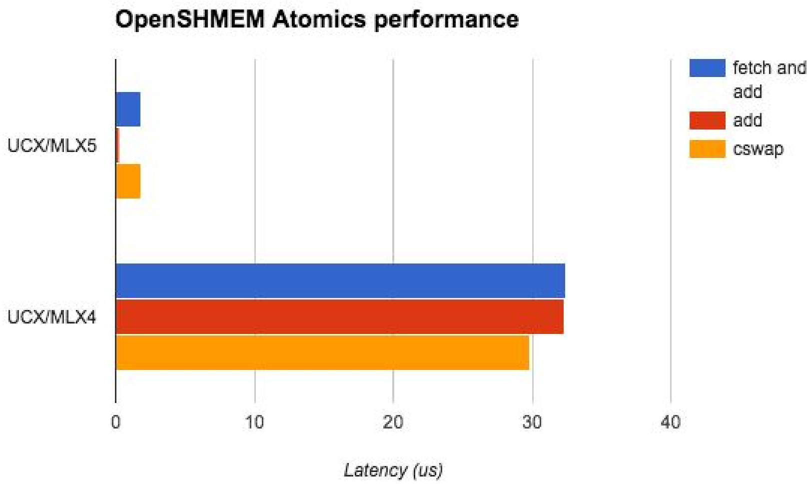




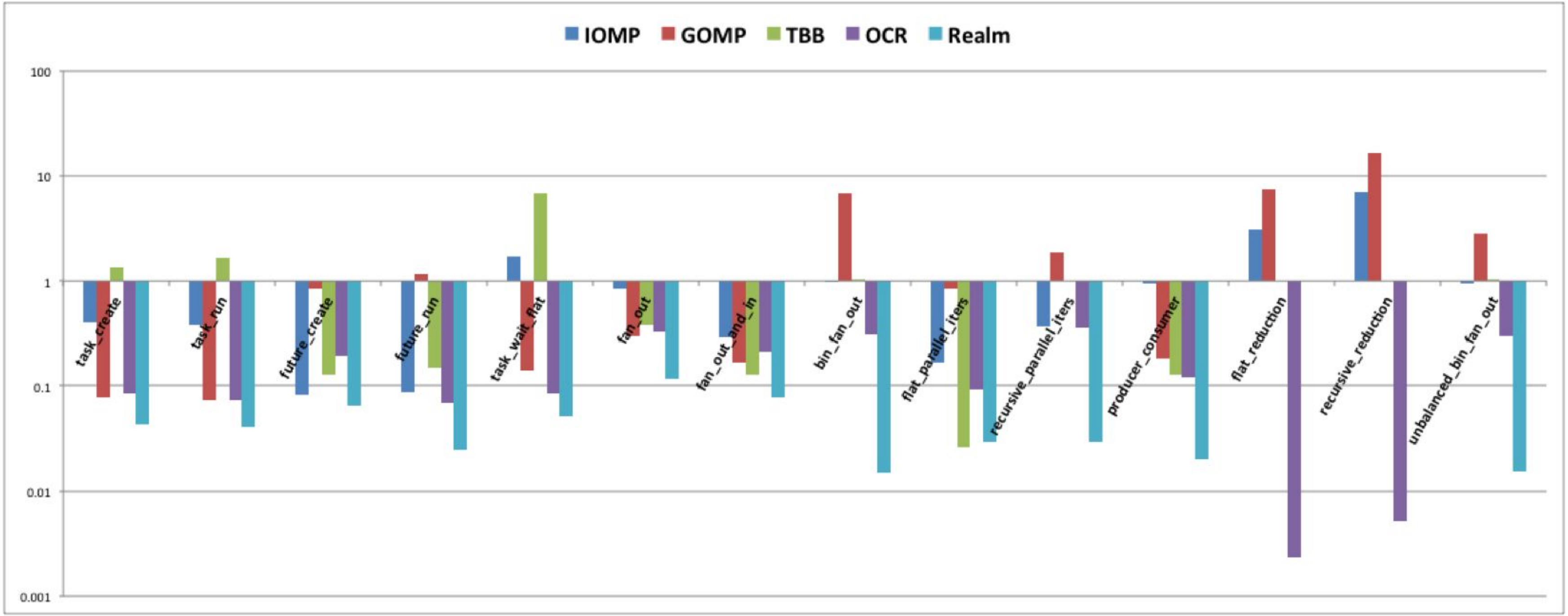
UCX_TLS=dc_mlx5,sm or UCX_TLS=rc,sm

OSU OpenSHMEM micro-benchmark results

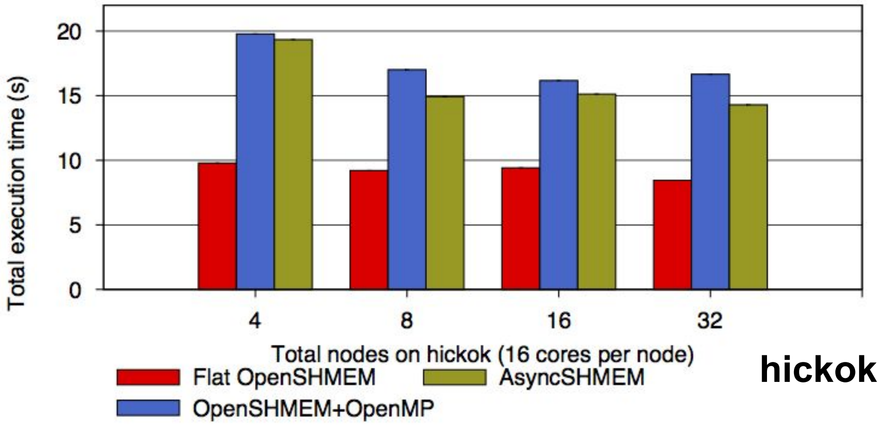




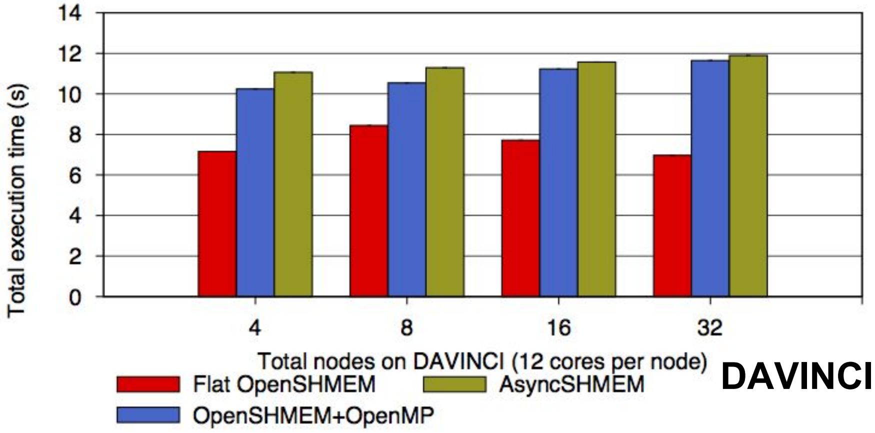
Habanero Tasking Micro-Benchmarks



ISx

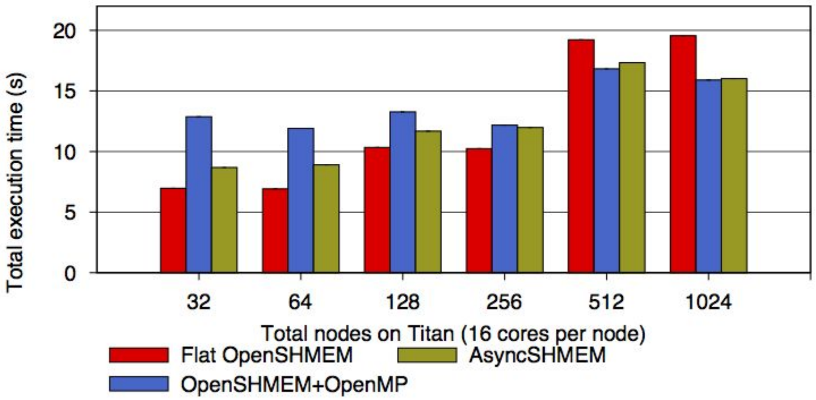


hickok



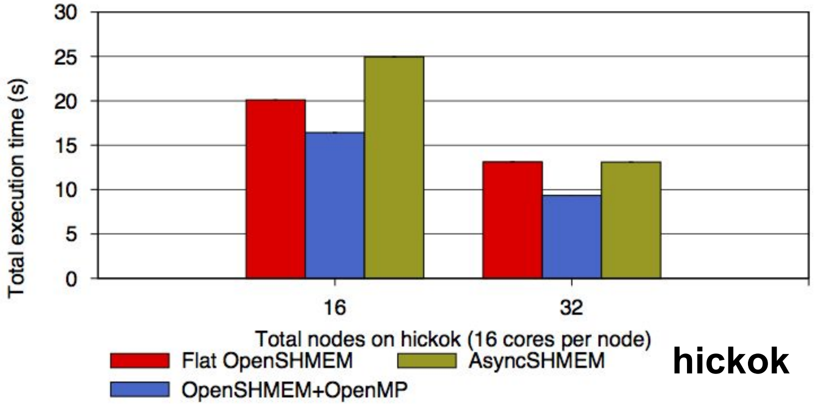
DAVINCI

Low overheads of tasking layer yields improvement on hickok, hybrid parallelism improves performance at large scales.

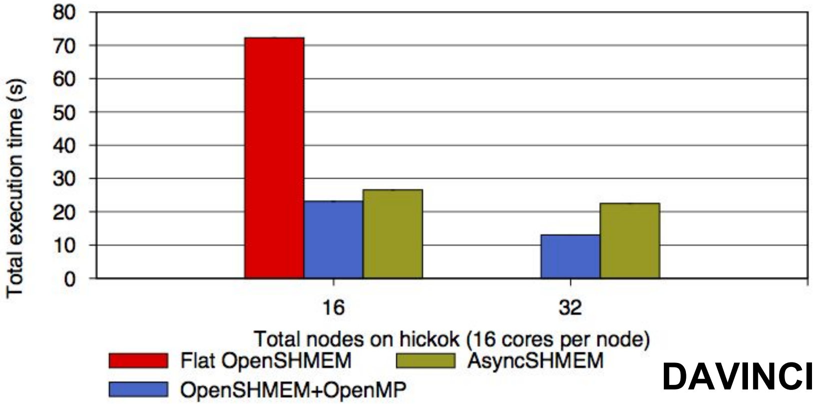


Titan scaling results

UTS



hickok



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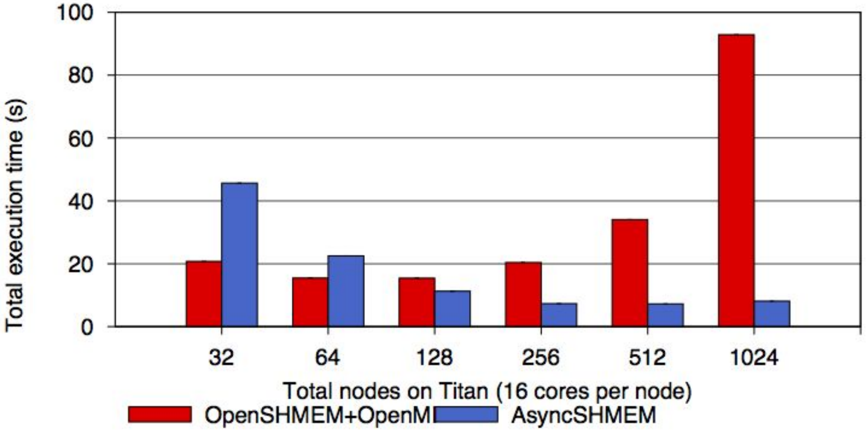
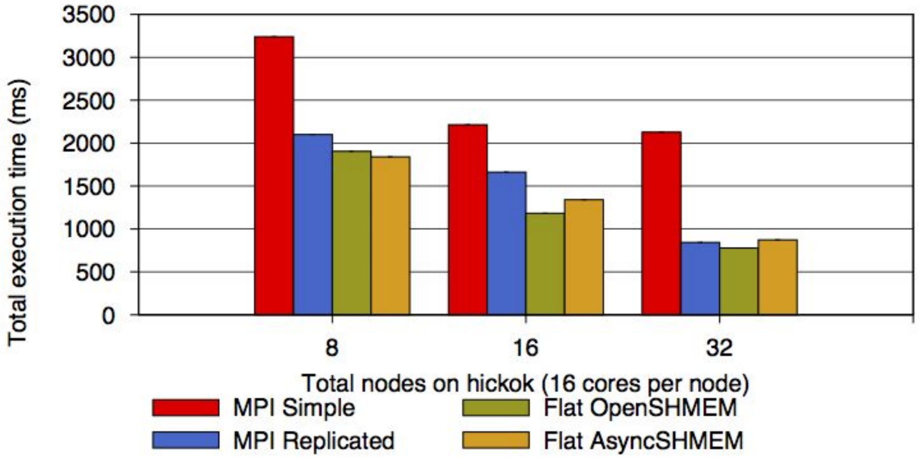
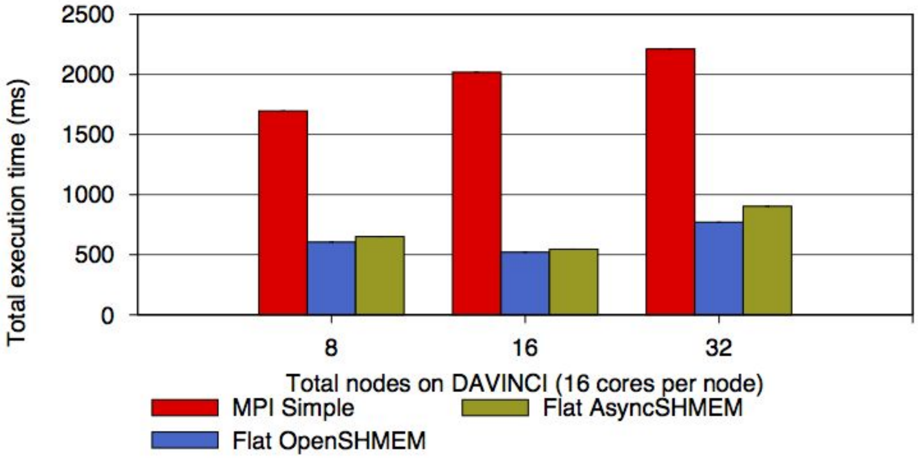


Titan scaling results

G500



hickok



DAVINCI

Similar scaling results to 1024 nodes on Titan.

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Contributions

Key contributions:

1. Exploration of OpenSHMEM and task-parallel runtimes, tying parallelism and communication together and proposing extensions at the boundary of the two.
2. Two implementations of these extensions.

API extensions for parallelism motivated by Habanero model, with the addition of APIs that connect OpenSHMEM communication with task-parallel execution.

Ongoing Work

Runtime integration with Contexts in collaboration with Jim Dinan, Kayla Seager at Intel.

Continue to iterate on existing benchmarks.

Exploration of algorithmic opportunities opened up by contexts.

New application development (Fast Multipole Method).

Acknowledgements

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University

Backup

Summary of New APIs

Environment

- shmem_worker_init
- shmem_my_worker
- shmem_n_workers

Fork-join tasks

- shmem_task
- shmem_parallel_for
- shmem_task_scope_begin
- shmem_task_scope_end

Futures and promises

- shmem_satisfy_promise
- shmem_future_wait
- shmem_task_future
- shmem_task_await

Communication-driven tasks

- shmem_int_task_when
- shmem_int_task_when_any

Environment APIs --- Hello World Example

```
void shmem_worker_init(void (*entrypoint)(void *), void *data);
```

Initializes *both* the OpenSHMEM (using shmem_init and shmem_finalize) and work-stealing runtimes. entrypoint is the root task of the PE. The number of worker threads created is configurable by environment variable.

```
int shmem_my_worker();
```

Returns a unique ID for the calling thread.

```
int shmem_n_workers();
```

Returns the number of threads in the thread pool for the calling PE.

```
void entrypoint(void *args) {
    printf(“This is thread %d, PE %d\n”, shmem_my_worker(), shmem_my_pe());
}

int main(int argc, char** argv) {
    shmem_worker_init(entrypoint, NULL);
}
```

Creating a range of parallel tasks --- shmem_parallel_for()

```
void shmem_parallel_for(int lower_bound, int upper_bound,
        void (*body)(int, void *), void *data);
```

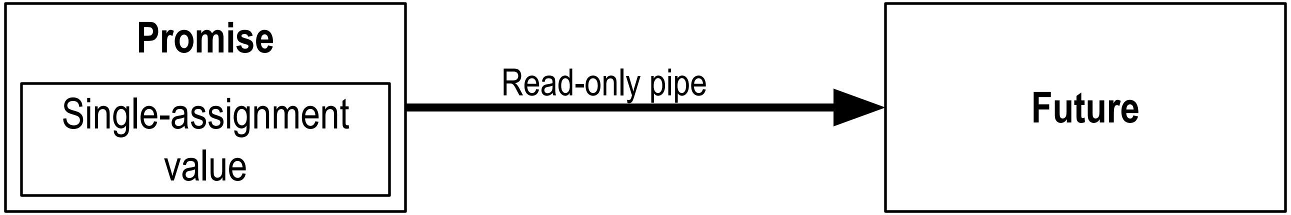
Efficiently creates a batch of tasks, one for each integer in the range [lower_bound, upper_bound). There is no implicit synchronization at the end of a call to shmem_parallel_for.

```
void foo(int iter, void *data) {
    printf("Hello from parallel iteration %d\n", iter);
}

void entrypoint(void *args) { // Create 100 tasks with indices 0..99
    shmem_parallel_for(0, 100, foo, NULL);
}

int main(int argc, char** argv) {
    shmem_worker_init(entrypoint, NULL);
}
```

Futures and Promises

```
shmem_promise_t *shmem_create_promise();
shmem_future_t *shmem_future_for_promise(shmem_promise_t *promise);
```

Create promise and future objects (akin to std::future and std::promise in C++).




```
void entrypoint(void *args) {
    shmem_promise_t *promise = shmem_create_promise();
    shmem_future_t *future = shmem_future_for_promise(promise);
}
```

Futures and Promises

```
void shmem_satisfy_promise(shmem_promise_t *promise, void *data);
```

Store a value into a single-assignment promise.

```
void *shmem_future_wait(shmem_future_t *future);
```

Wait for a future to be satisfied, and return its value.

```
void producer(void *data) {
    shmem_satisfy_promise((shmem_promise_t *)data, NULL);
}

void consumer(void *data) {
    void *result = shmem_future_wait((shmem_future_t *)data);
}

shmem_task(producer, promise);
shmem_task(consumer, shmem_future_for_promise(promise));
```

Communication-Driven Tasks --- Example

PE 0

```
void load_balancer(void *data) {
  // Load balancing logic here,
  // based on updated info from
  // remote PE
  ...
  // Re-register load balancer to
  // handle new updates from PE 1
  shmem_int_task_when(...);
}

shmem_int_task_when(remote_pe_load,
    SHMEM_CMP_NE, *remote_pe_load,
    load_balancer, NULL);
...
```

PE 1

```
// Called periodically to update PE
// 0 with info for distributed work
// stealing
shmem_int_put(remote_pe_load,
    local_pe_load, 1, 0);
```