Argobots: Lightweight Threading/Tasking Framework

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https://collab.cels.anl.gov/display/ARGOBOTS

Charm++ Workshop 2015

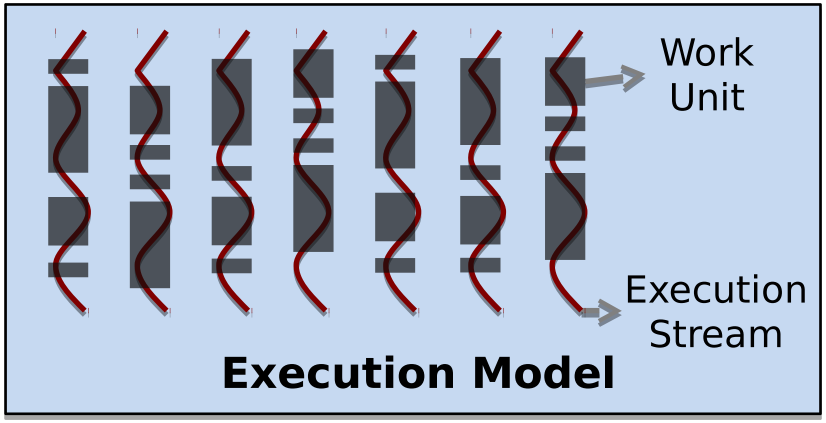
Motivation: extreme scale computing

- Massive on-node parallelism
  - Need for supporting fine-grained asynchronous work units
  - Lightweight threading and tasking methods
- Need for interoperability among multiple programming models in a single application
  - Different runtime strategies
  - Domain Specific Language
  - Better productivity and performance

- Part of the Argo project

Argobots

- Lightweight Low-level Threading/Tasking Framework
- Massive parallelism
  - Execution Streams guarantee progress
  - Work Units execute to completion
- Offers low-level abstraction of threads and tasks



Outline

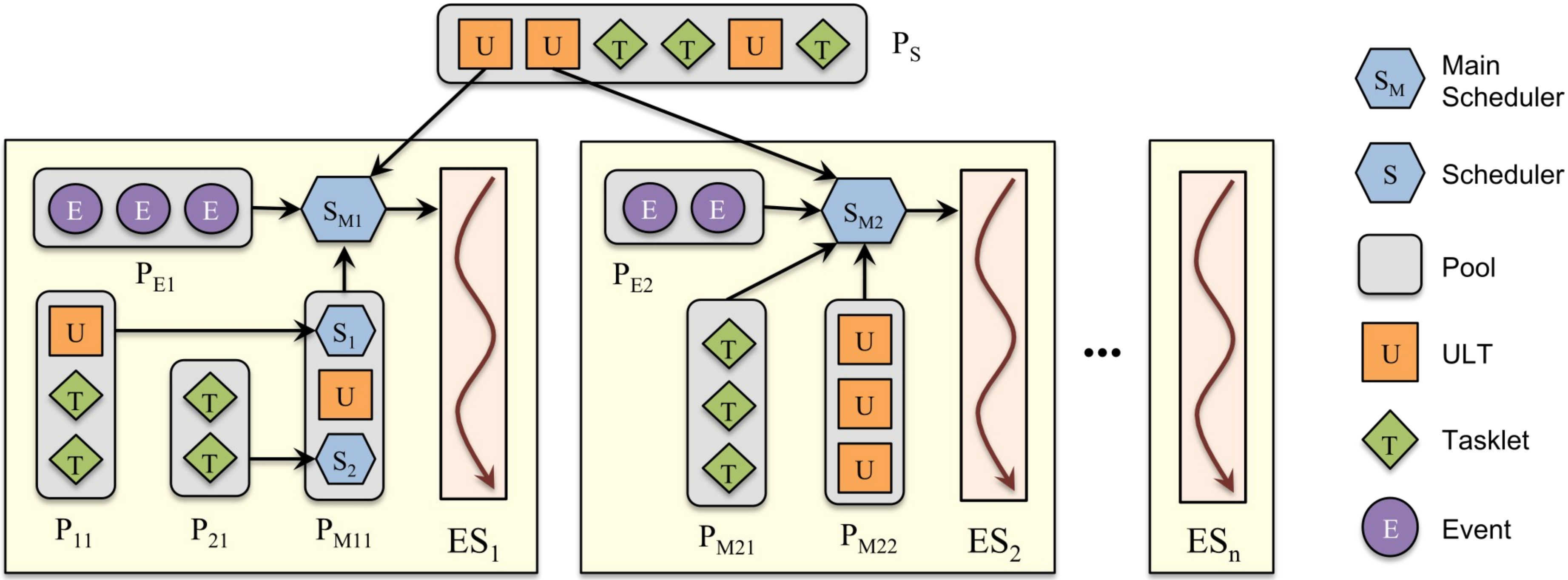
- Execution model
- Interface
- Evaluation
- Programming models

Execution Model

Semantic

- Execution Stream (ES)
  - Responsible for the execution of work units
  - Corresponds to one hardware resource
  - No preemption between work units
- Work Unit
  - Associated with function call and executes to completion
  - Two types
    - User Level Thread (ULT): has its own stack
      - Can yield and synchronize
    - Tasklet: no stack

Design

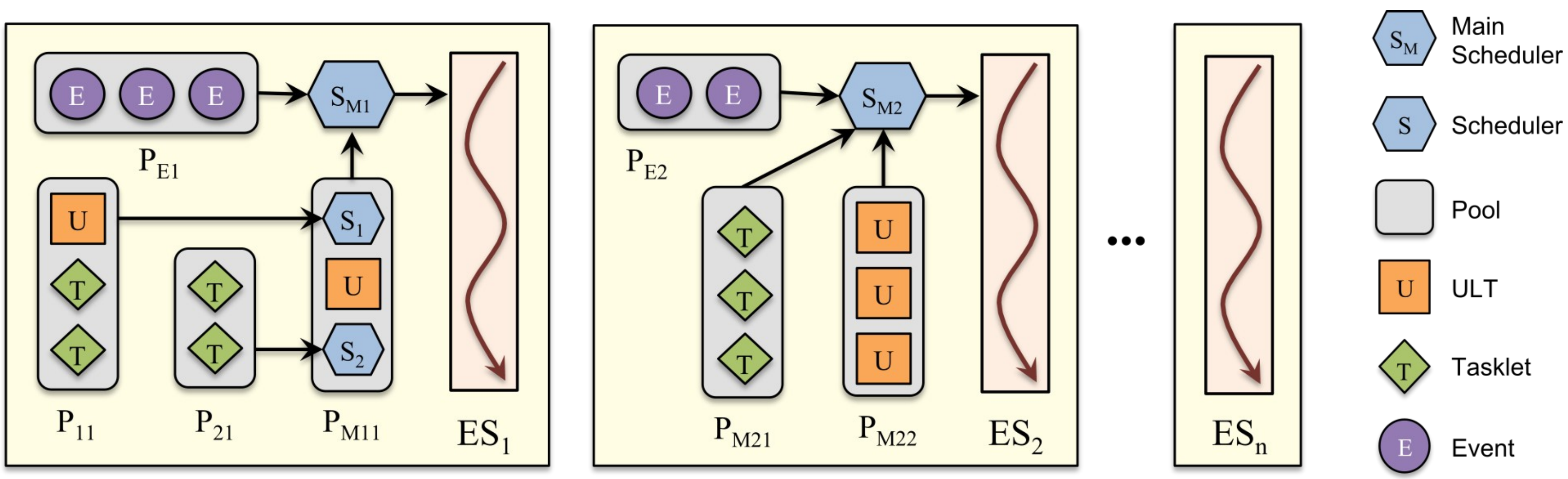


- Pools: set of ready work units
  - Private or Shared
- Schedulers
  - Different strategies
  - Stackable

Interface

Basic Operations

- Explicit creation of execution streams
- Creation of ULTs and tasklets (needs the target pool)
- Yield and yield to
- Migration
- Synchronization
  - Termination (join)
  - Future, mutex, barrier, condition variable…



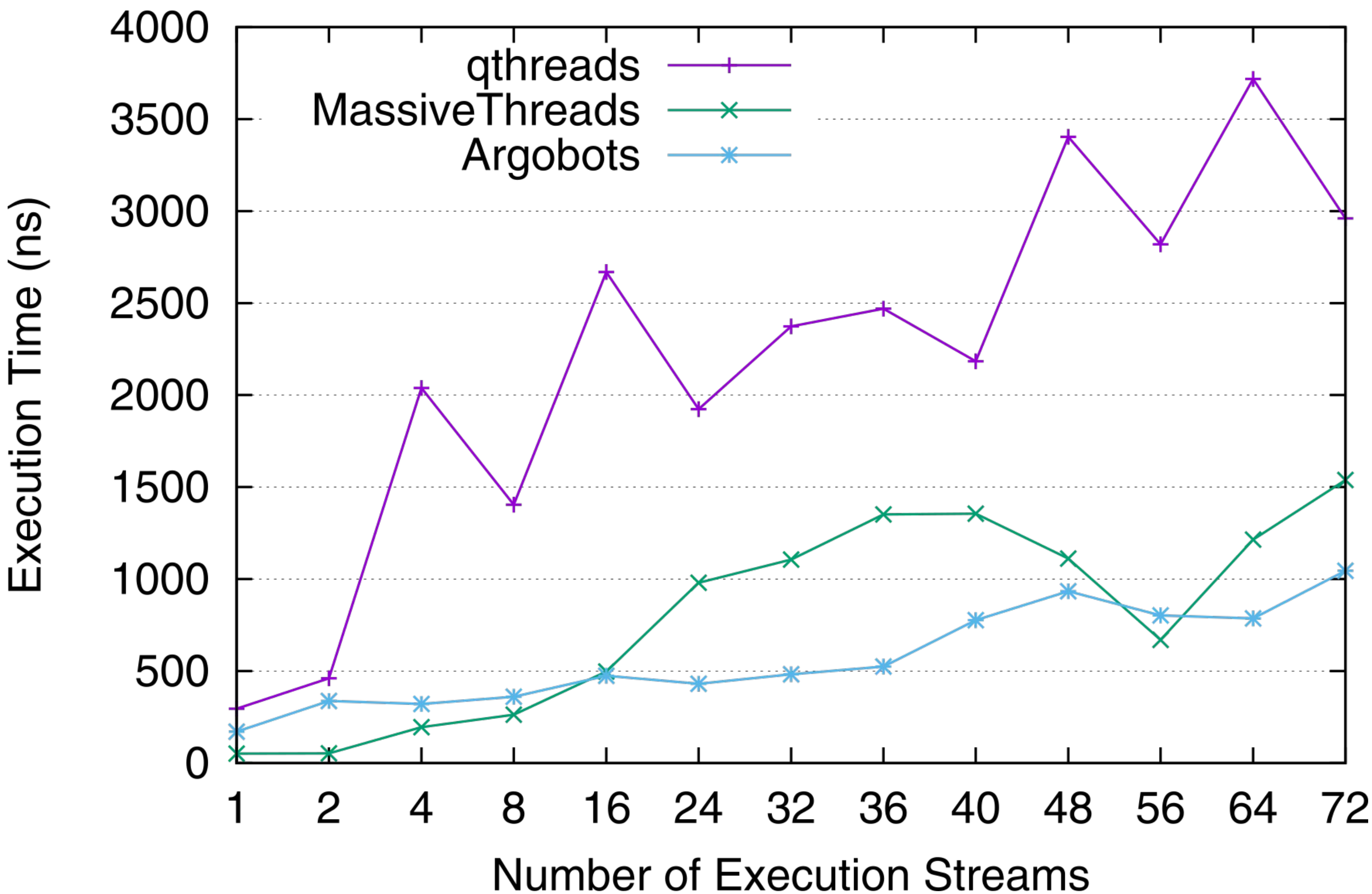
Hello world example

```
int main(int argc, char *argv[])
{
  int num_xstreams = 4;
  ABT_xstream xstreams[num_xstreams];
  ABT_pool    pools[num_xstreams];

  /* Initialization */
  ABT_init(argc, argv);
  ABT_xstream_self(&xstreams[0]);
  for (int i = 1; i < num_xstreams; i++)
    ABT_xstream_create(ABT_SCHED_NULL, &xstreams[i]);

  /* Get the first pool associated with each ES */
  for (int i = 0; i < num_xstreams; i++)
    ABT_xstream_get_main_pools(xstreams[i], 1, &pools[i]);

  /* Create tasks */
  for (int i = 0; i < num_xstreams; i++)
    ABT_task_create(pools[i], task_hello, NULL, NULL);

  /* Switch to other work units */
  ABT_thread_yield();

  /* Finalize */
  for (int i = 1; i < num_xstreams; i++) {
    ABT_xstream_join(xstreams[i]);
    ABT_xstream_free(&xstreams[i]);
  }
  ABT_finalize();
  return 0;
}
```

```
/* Task function */
void task_hello(void *arg)
{
  printf("Hello, world!\n");
}
```

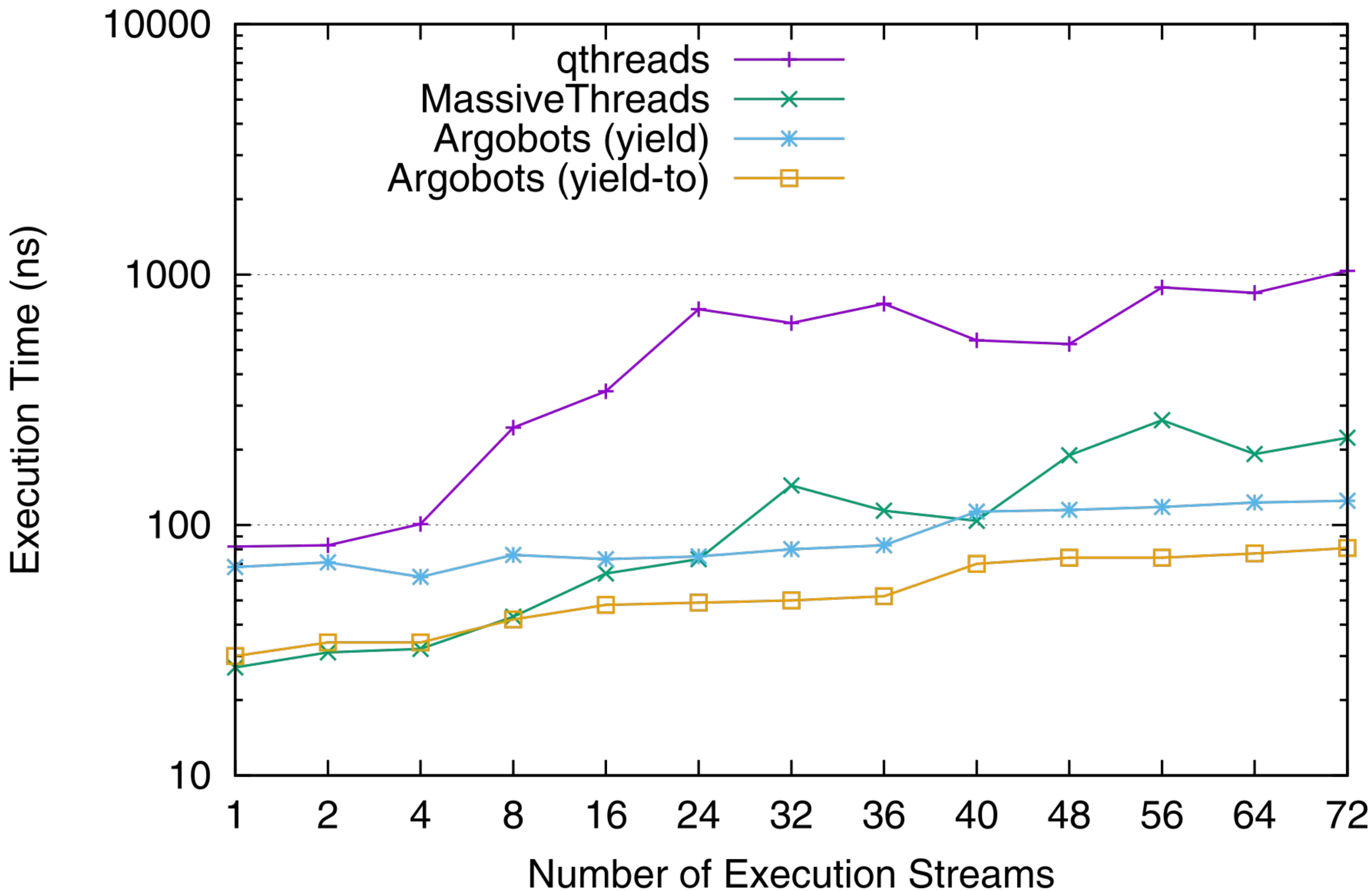
Evaluation

Microbenchmarks: create and join



Tests on 2 Intel Xeon E5-2699 (2.3GHz, 36 cores, 72 threads)

Microbenchmarks: yield



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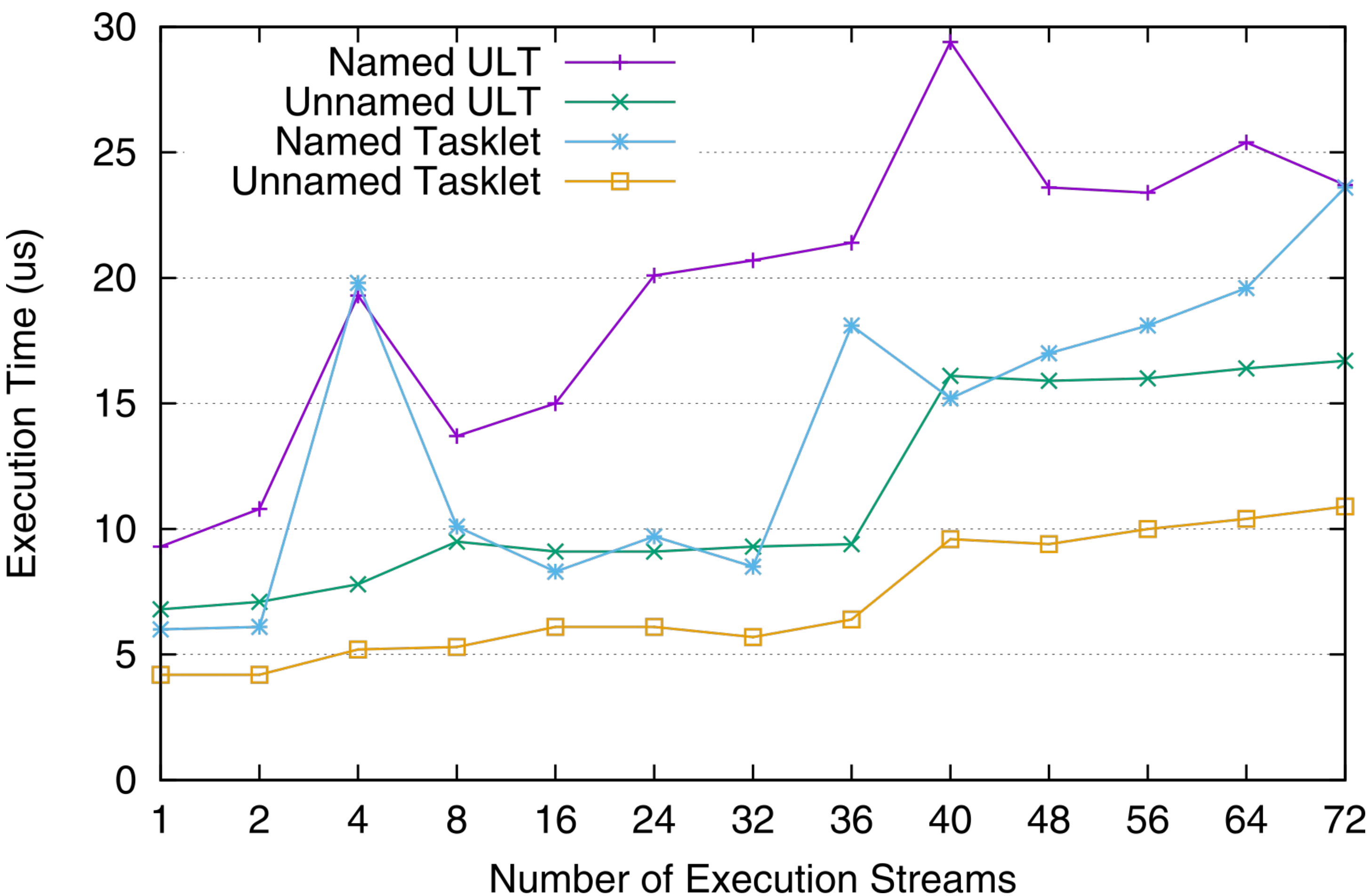
Microbenchmarks: different work units



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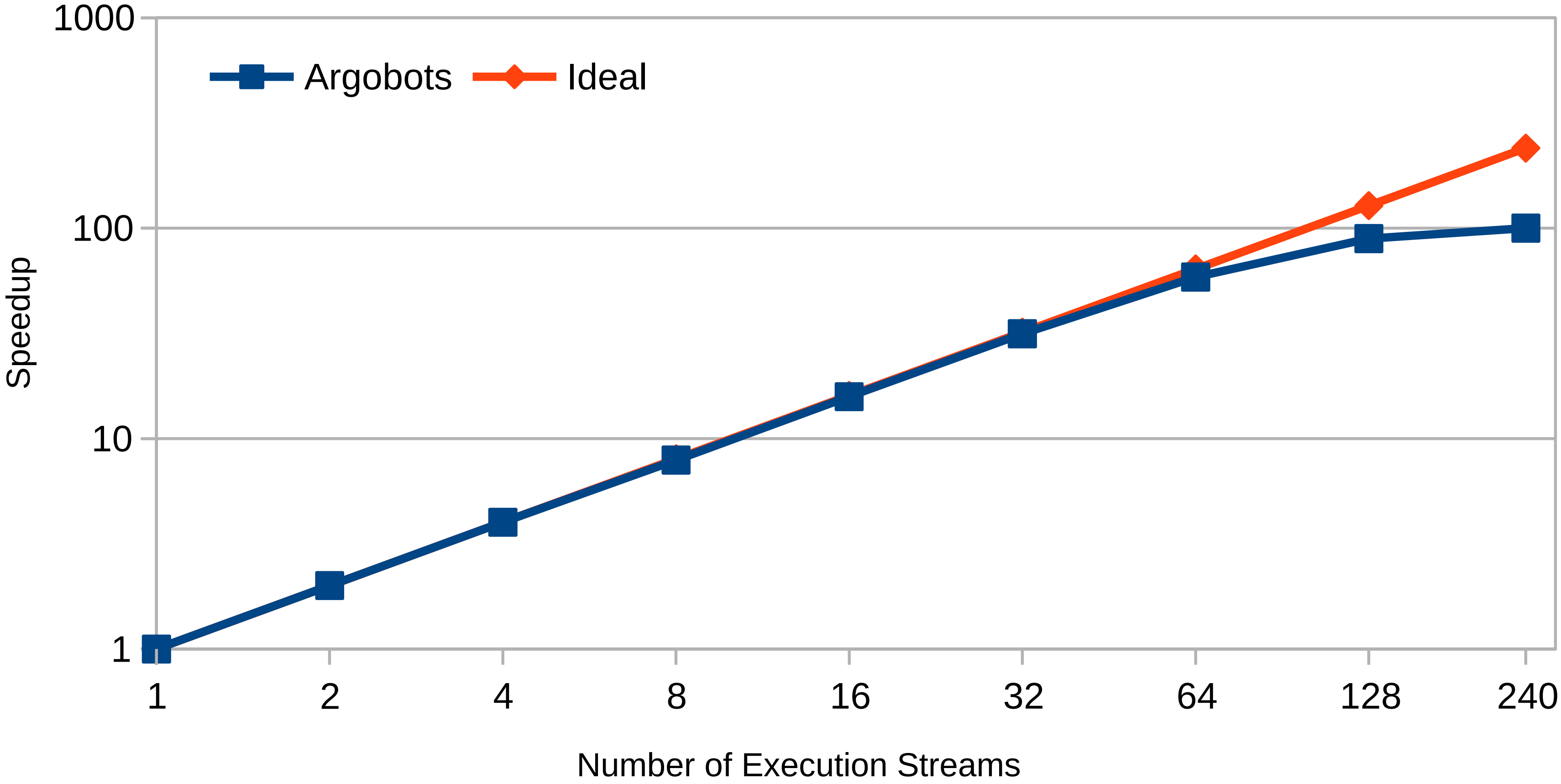
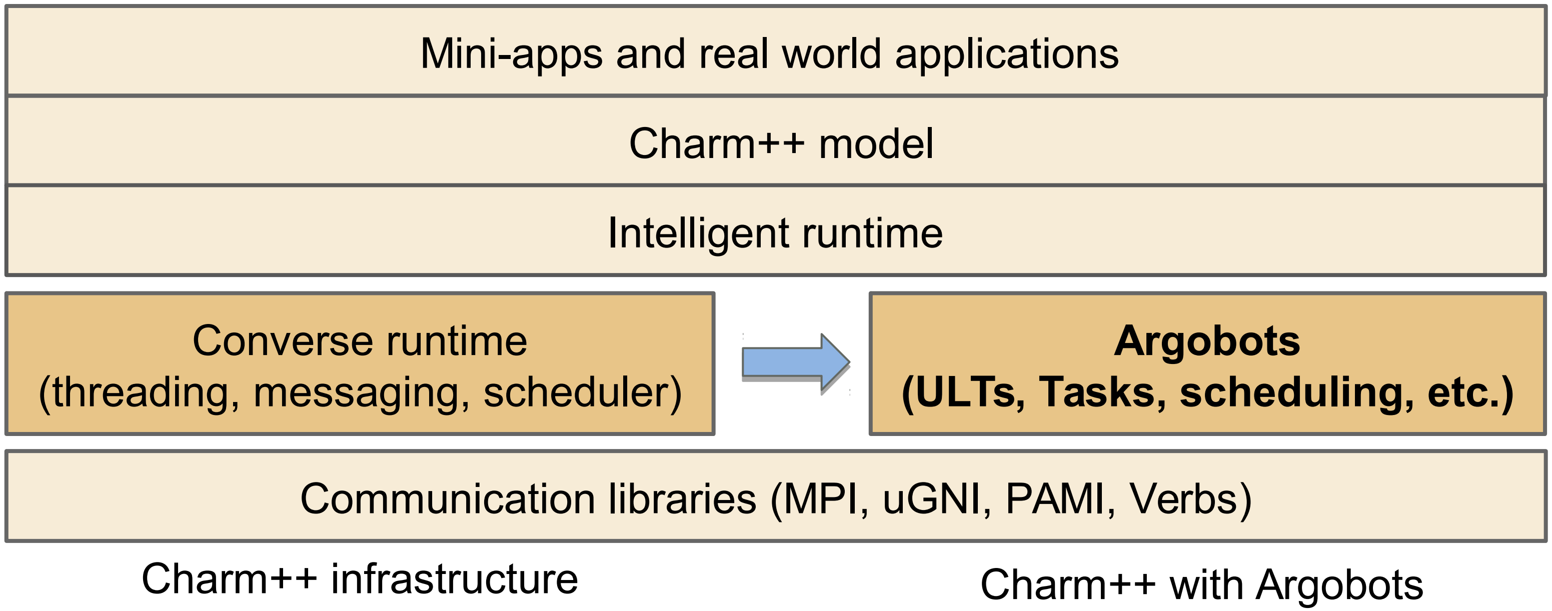
LeanMD with Argobots: speedup



Speedup on Intel Xeon Phi

Programming models

Charm++ with Argobots: integration



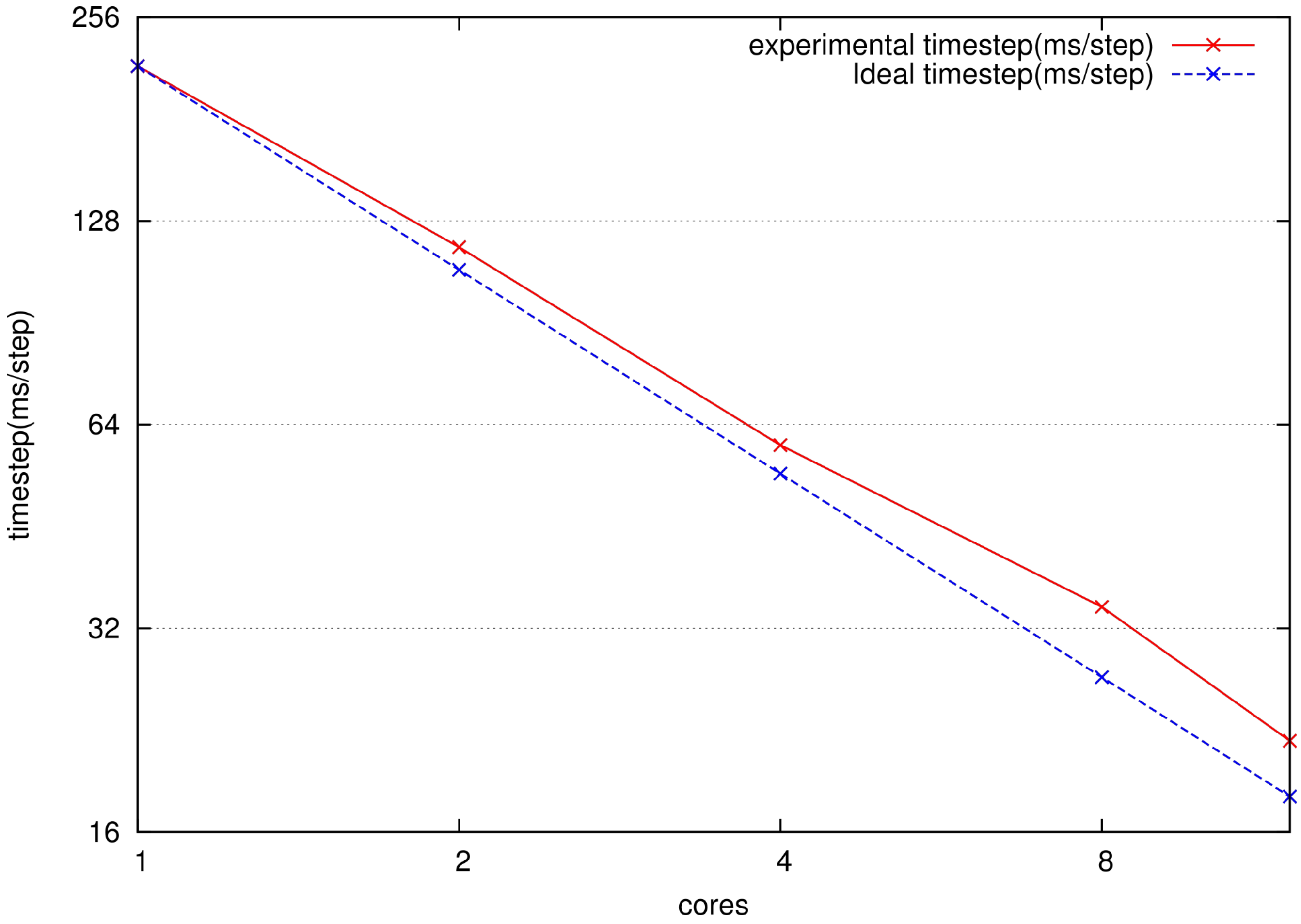
Goal:

1. Test the completeness and performance of Argobots APIs with Charm++ programming model
2. For Charm++ programs, interoperate with programs written in other models (MPI, Cilk, etc.)

Approach:

1. Create an Execution Stream for each Charm++ Instance
2. All Charm++ messages are enqueued as tasks into the Argobots pool
3. Argobots schedules the messages in pool

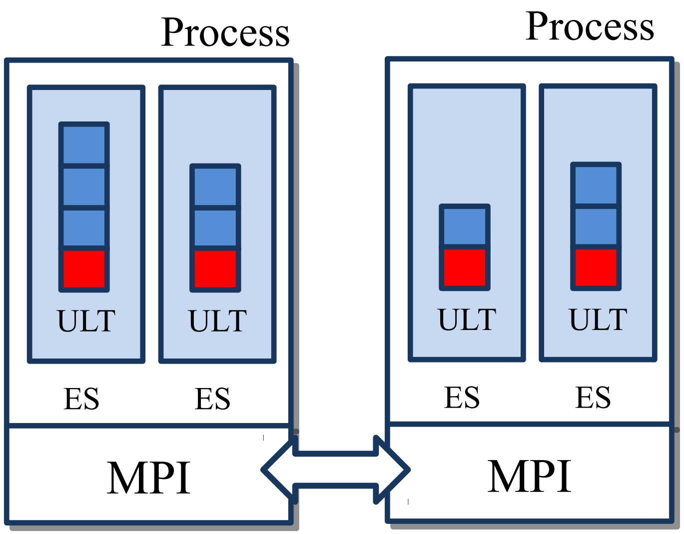
Charm++ with Argobots: preliminary test

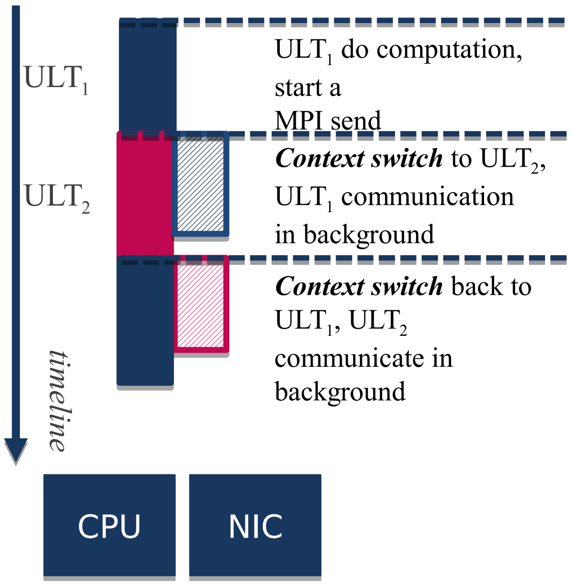


Test of LeanMD

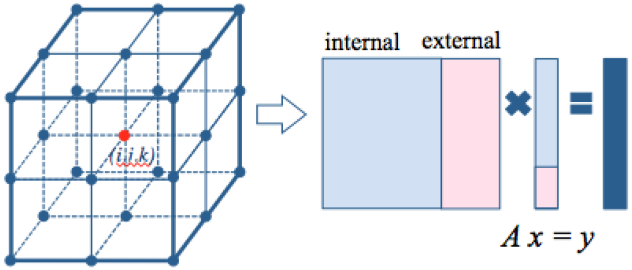
MPI+Argobots: Data Movement in Distributed Memory Systems with Lightweight Threads

- Hybrid runtime of MPI and Argobots
  - Lightweight and dynamically adapt to the hardware resources
- Two level of threads provide an explicit semantic for concurrency
  - Execution Stream (ES) provides concurrent execution
  - User Level Thread (ULT) provides fast context switch
- Overlap communication with computation using ULT
  - Helps turn a MPI blocking call to a nonblocking one
  - ULT is lightweight because no lock is needed between two ULTs in the same kernel thread





MPI+Argobots: HPCG App



- High Performance Conjugate Gradient (HPCG)
  - Solves $Ax=b$, large and sparse matrix.
- Hiding Global Collective Communication
  - Overlap communication and computation between iterations
  - Fork a ULT to do ult_ddot and join in the next iteration
- Hiding Neighborhood Communication
  - For each neighbor, fork a ULT to do halo exchange and a small part of SpMV (communication)
  - Main ULT computes local spmv (computation)

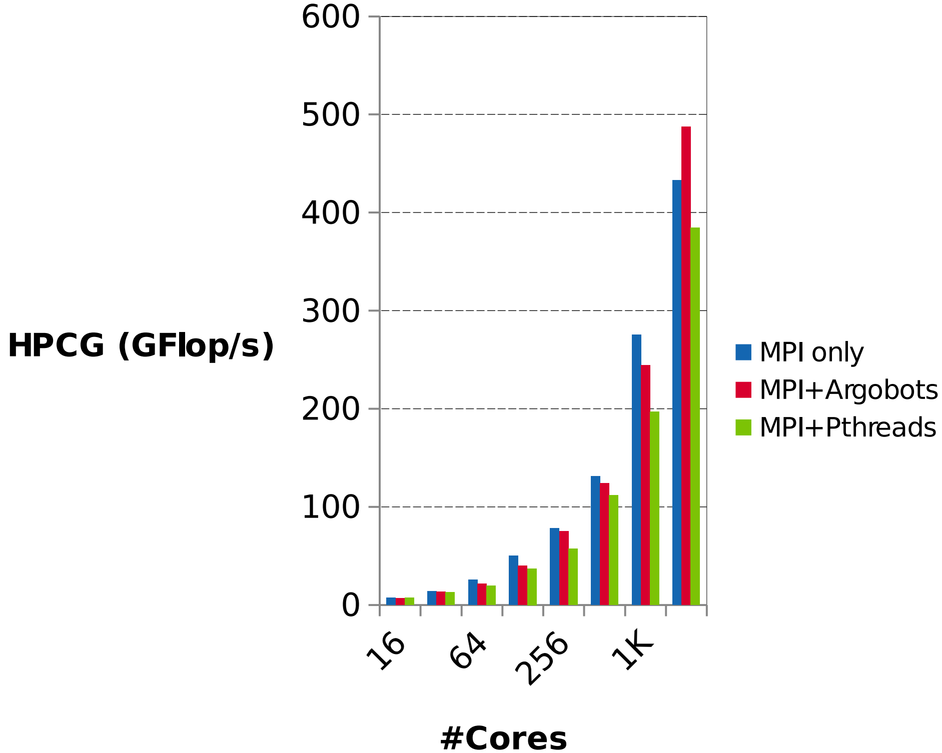
HPCG

```
for k = [1: max_iter]:
    MG(A, r, z);
    if k > 1:
        ult_join (thread);
        if (normr <= tolerance) break;
    ……
    ult_fork(ult_ddot, &param, &thread)
```

SpMV

```
SpMV(A, x, &y):
    for each neighbor:
        ult_fork(es, ult_spmv, &t[i]);
    for i in [0: nRows]:
        ult_yield();
        for each j in row i:
            y[i] += val[j] * x[idx[j]];
    for each neighbor i:
        ult_join(t[i]);
```

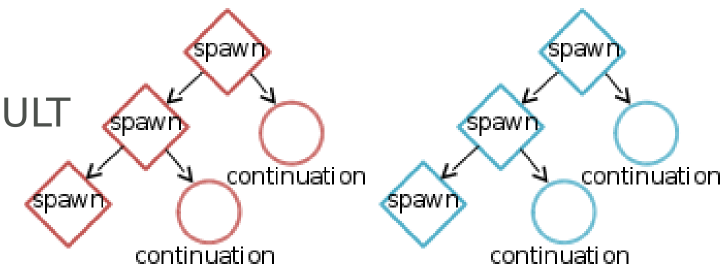
MPI+Argobots: HPCG Preliminary Results

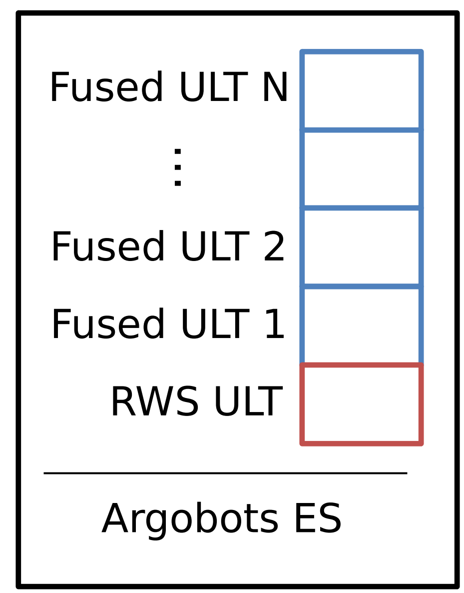


- On 2,048 cores, HPCG using MPI+Argobots shows performance improvement of 12.6% over MPI-only version, or 26.9% over MPI+Pthreads version.
  - As core number increases, the benefit of communication hiding begins to reveal.

Cilk with Argobots: Dynamic Task Splicing

- Cilk built on Argobots
  - Each Cilk worker (previously pthread) is now an Argobots Execution Stream
  - The Cilk work stealing scheduler runs in a Argobots ULT
- Fuse together multiple spawn trees to improve locality
  - Distinct spawn trees require their own stack
    - Create a new Argobots ULT for each spawn tree root to fuse
    - Modify Cilk compiler to generate Argobots ULT function wrapper
  - A steal may require stealing from multiple ULTs (or spawn trees)
- Motivation
  - Code may be in different libraries, manual fusion not possible
  - Dependencies between phases may inhibit manual fusion
- Implemented simple application
  - Matrix Vector Product and Transpose (PolyBench: `mtv`)
    - Two concurrent phases that read entire matrix A
    - Cache locality can be improved if they are fused



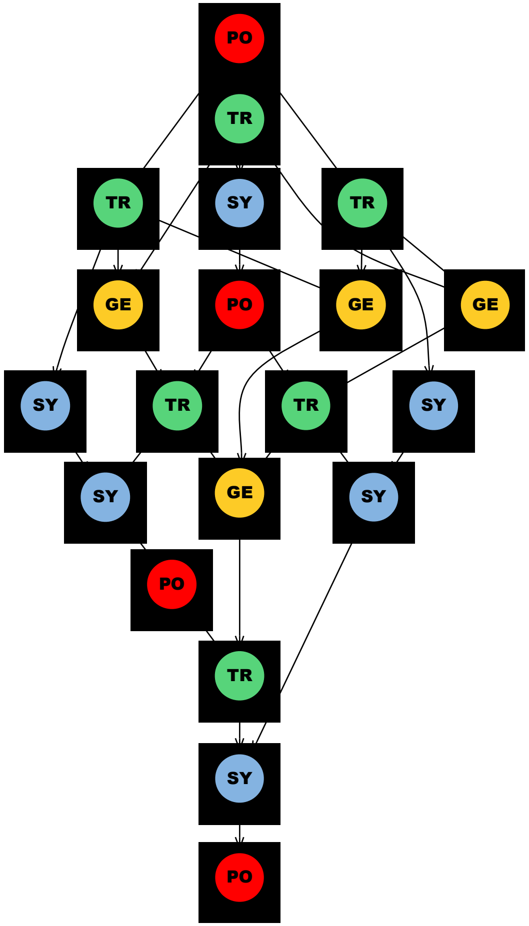


Cilk “Worker”

PTGE (Pluggable Task Graph Engine) with Argobots

- Motivation
  - A decent scale application encompasses thousands of tasks
  - It is critical to minimize the number of tasks

- PTGE
  - Data centric task definition
  - Minimize the number of tasks by defining symbolic dependencies between sets of tasks
    - for(i = 0; i < SIZE; i++) task(A[i]) become: task([A[i], i in [0 .. SIZE-1]])
  - Integrate with the communication engine to allow for dynamic creation of incoming data, matched with expected input for task(s)
- Hierarchical task scheduling
  - With the PTGE approach the first stage of scheduling is creating the task
    - Many possible strategies: first data available, all local data available, I/O prediction cost …
  - Once the task is created, the graph of tasks is decorated with cost information for the upper level scheduling
  - Enable task stealing between hierarchies (both ways)



Conclusion

Conclusion

- Argobots is a lightweight threading/task Infrastructure
- Argobots is highly optimized and has good scalability on many-core processors
- Argobots can be easily integrated with different programming models (MPI, Charm++, Cilk, PTGE)

- Ongoing works
  - More applications with different programming models
  - Interoperability between different models

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Thanks!
Questions?