Examining MPI and its Extensions for Asynchronous Multithreaded Communication

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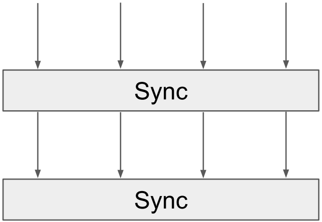
Introduction

BSP and MPI Legacy

- MPI initially designed in a world where
  - Most processors are single-core.
  - Most applications are BSP.



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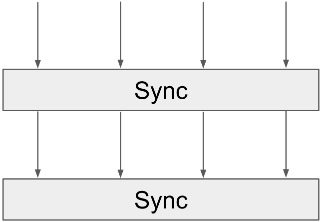

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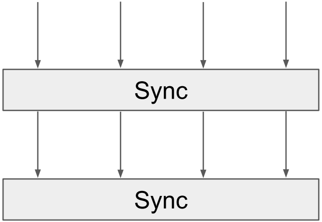
- Modern workloads and architectures are evolving beyond these assumptions.



HPC Trends and AMTs

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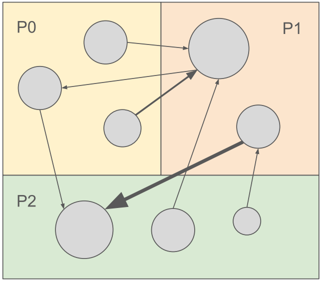
- Architectures are getting more complex.
  - Modern nodes: 100+ CPU cores, 4–8 GPUs.
- Applications are evolving towards irregularity.
  - Adaptive mesh refinement, sparse data structures, etc.
- New programming models emerge to address these trends.
  - We focus on the *Asynchronous Many-Task (AMT)* model.
    - Task oversubscription, dynamic scheduling, communication overlap.
    - Charm++, Legion, HPX, PaRSEC, StarPU, etc.

AMT Communication Characteristics

- AMTs exhibit distinct communication patterns:



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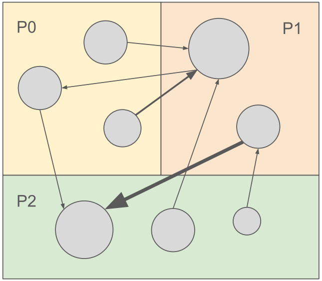

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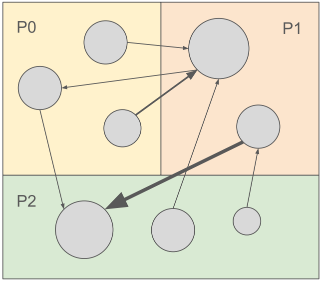

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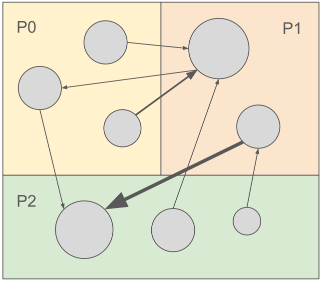

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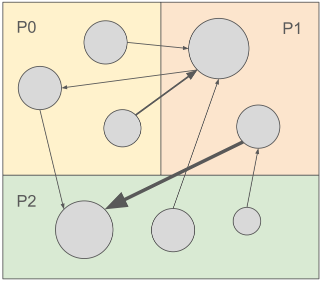

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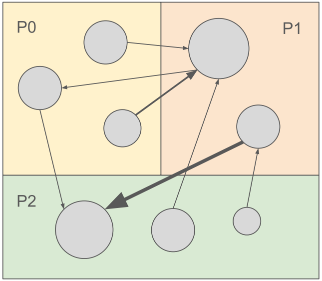
- MPI has introduced extensions to better support these patterns.



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- Evaluate how well MPI and recent extensions support AMT communication.
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- Focus on two key MPI extensions:
  - Virtual Communication Interfaces (VCIs).
  - Continuations.
- Focus on MPICH and HPX.

Background

MPI Threading Model

- We focus on MPI_THREAD_MULTIPLE.
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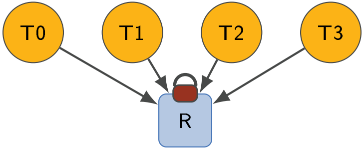
- We focus on `MPI_THREAD_MULTIPLE`.
  - Multiple threads can call MPI concurrently.
- However, thread-safety != thread efficiency.
- Common implementations serialize communication calls with coarse-grained locks.

Virtual Communication Interface (VCI) [0]

- Replicates MPI internal resources per VCI.
  - Typically via separate `MPI_Comm`.



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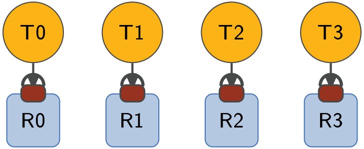

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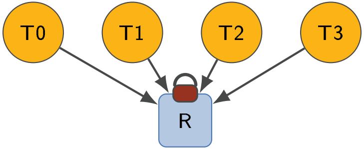

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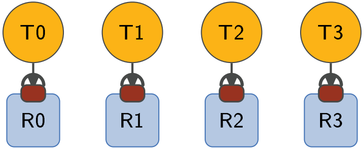

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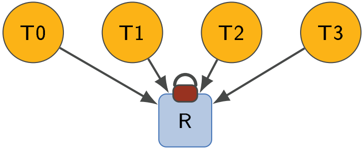
  - *We will revisit this advice later.*



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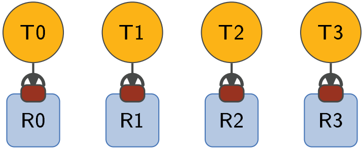

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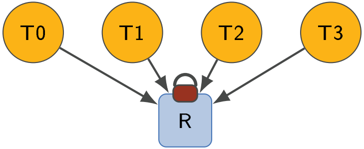
- Hybrid progress strategy:
  - By default, one global progress for every 255 local progress.



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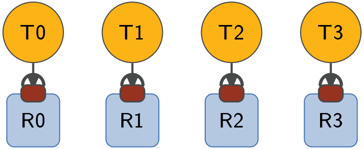

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MPI Continuation [0]

- Callback-based completion mechanism.
- Reduces need for polling many requests.

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int complete_cb(int rc, void *user_data);

MPI_Request cont_req;
MPIX_Continue_init(..., &cont_req);
MPI_Start(&cont_req);
// ...
MPI_Request op_req;
MPI_Irecv(..., &op_req);
MPIX_Continue(&op_req, &complete_cb,
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// ...
int is_done = 0;
MPI_Test(&cont_req, &is_done,
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- MPICH extension allows bypassing the continuation request (`MPI_REQUEST_NULL`) to reduce overhead.

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HPX Integration

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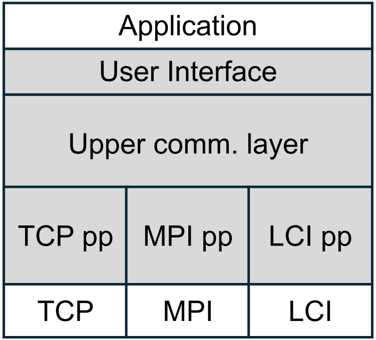
  - An actor model.
  - Any process can invoke arbitrary actions on any other process.



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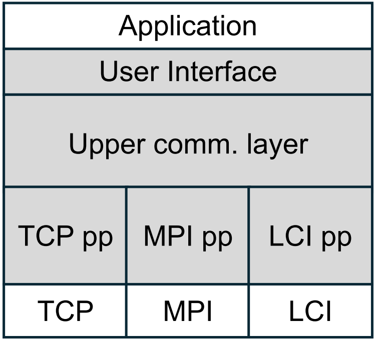

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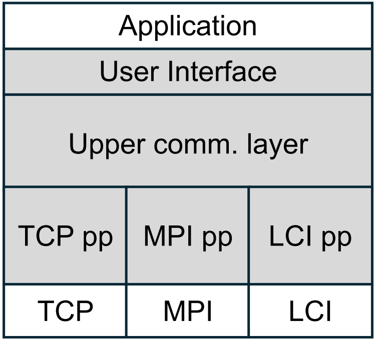
- Parcelport layer (main focus).
  - Actual send the parcel (serialized action metadata and arguments) to the target rank.
  - A parcel = one or multiple buffers.



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- Old MPI parcelport uses a single shared communicator.
- New MPIx parcelport adds an option to split the traffic across multiple communicators (VCIs).
    - Roughly, every thread has a statically assigned communicator.

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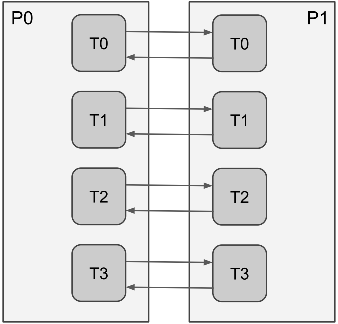
  - Replace polling with Continuations.

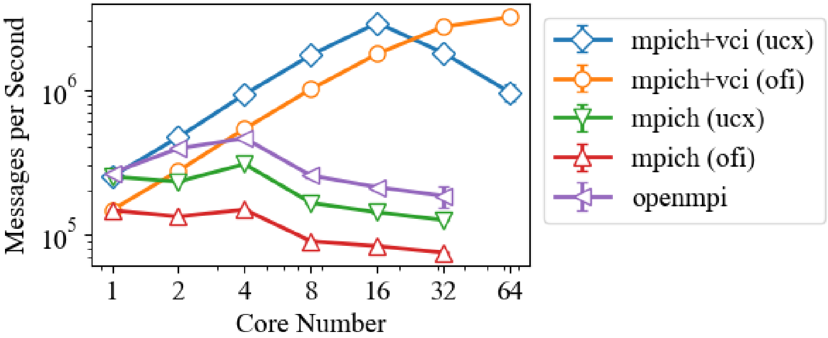
Experiments

MPI-level Multithreaded Ping-Pong

- 2 nodes; 1 MPI rank/node; N threads; thread-to-thread ping-pong.
- 8-byte messages.
- Turn hybrid progress and continuation request off.
- Platform: SDSC Expanse (IB) and NCSA Delta (SS-11).

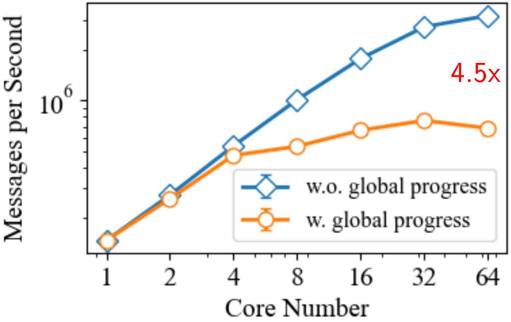


VCI Impact



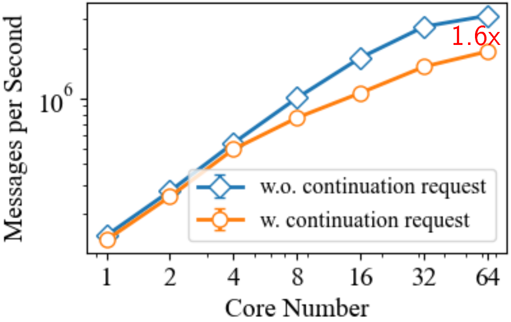
Multi-VCI improves multithreaded message rate; Trade-off between UCX/OFI.

Occasional Global Progress Cost



Occasional global progress increases cross-VCI contention.

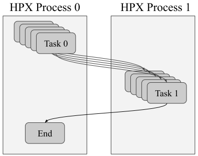
Continuation Request Overhead



Current continuation request adds overhead at high thread counts.

HPX Benchmarks

- Flood microbenchmark:
  - 2 nodes, 1 process/node, 63 threads/process.
  - Process 0 sends a flood of messages to process 1.
  - 8 bytes or 16 KiB payloads.



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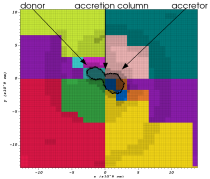

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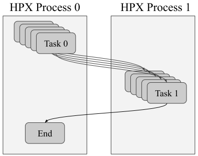

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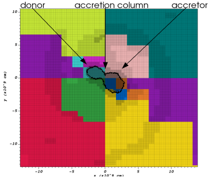

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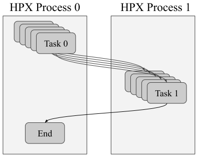
- Comparing: standard MPI, LCI [0], MPIx, MPIx (w/o continuation).



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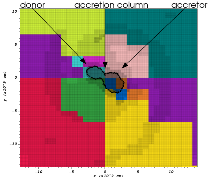

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Flood Microbenchmark

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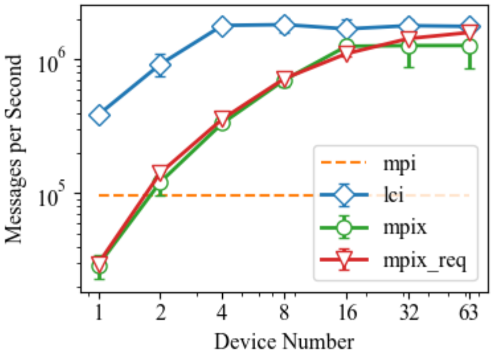
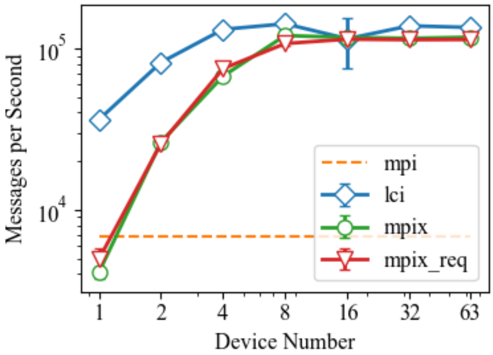


(b) 16KiB payloads.



MPIx (especially the usage of VCIs) closes gap vs LCI.

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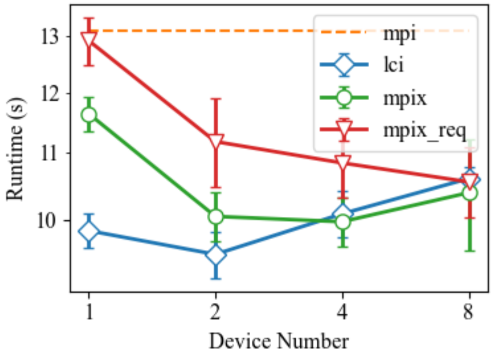

VCI keeps help, but too many VCIs hurt. Continuation benefits are modest.

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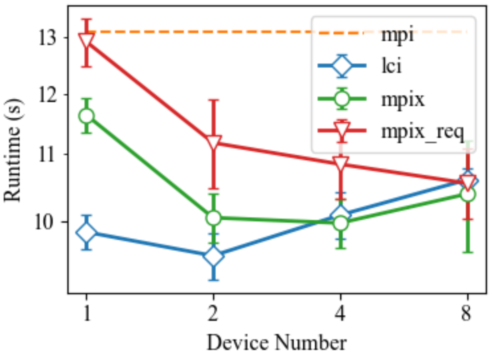

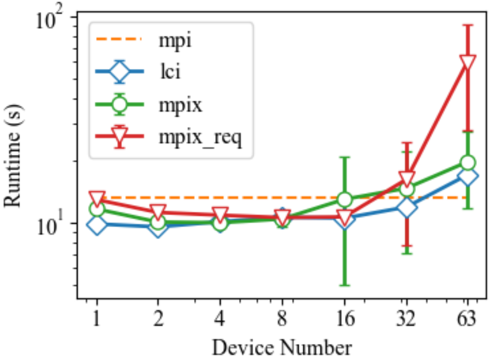

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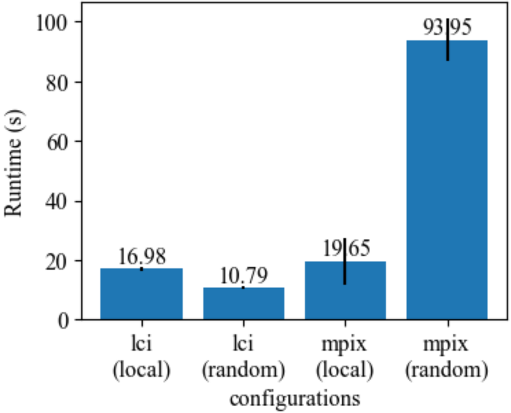
- Assumption: Lack of attentiveness due to heavy computation.
  - Each VCI is polled by only one thread.
  - If that thread is busy computing, the VCI is not polled often enough.
  - Even if other threads are idle, they cannot help.

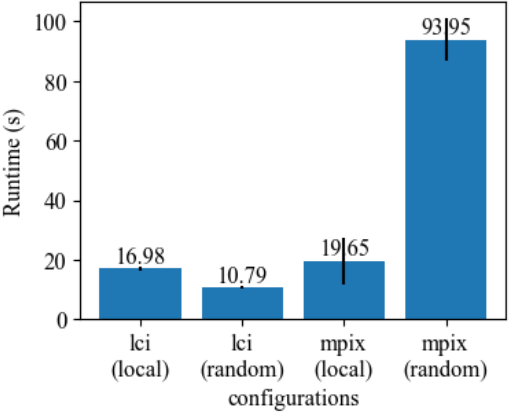
Random Progress Strategy

- To verify attentiveness assumption:
  - Randomly select a VCI/device to poll.



Random Progress Strategy

- To verify attentiveness assumption:
  - Randomly select a VCI/device to poll.
- Random polling helps LCI but hurts MPIx
  - VCI has coarser-grained locking than LCI device.
  - Tradeoff between attentiveness and contention.



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- One VCI per thread may not be perfect: attentiveness problem.
- Some level of sharing is needed. We need better VCI implementation than coarse-grained locks.

Q&A

Questions?

Examining MPI and its Extensions for Asynchronous Multithreaded Communication

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