Parallelism at Scale: MPI
Outline for Today

Rust Closures
Project Comments
Scale: MPI

Acknowledgements:
Portions of the lectures slides were adopted from:
- Argonne National Laboratory, MPI tutorials.
- Lawrence Livermore National Laboratory, MPI tutorials
See online tutorial links in course webpage


fn main() {
    let var = Structure::new();
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Key ideas:
• Use reference counting wrapper to pass refs
• Use scoped lock for mutual exclusion
• Actually compiles → works 1st time!
fn test() {
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    let var_arc = Arc::new(var_lock);
    for i in 0..N {
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Sharing State: Arc and Mutex, really

Why doesn’t “&” fix it? (&var_arc, instead of just var_arc)
fn test() {
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Sharing State: Arc and Mutex, really

Why doesn’t “&” fix it? (&var_arc, instead of just var_arc)

Would cloning var_arc fix it?

error[E0302]: use of moved value: `var_arc`
→ src/main.rs:166:22
| 164 | let var_arc = Arc::new(var_lock); |
| 165 | ------- move occurs because `var_arc` has type `std::sync::Arc<std::sync::Mutex<message::ProtocolMessage>>`, which does not implement the `Copy` |
| 166 | for _i in 0..N {
| 167 |     thread::spawn(move || {
| 168 |         //------- value moved into closure here, in previous iteration of loop
| 169 |         let ldata = Arc::clone(&var_arc);
| 170 |     });

--------- use occurs due to use in closure
fn test() {
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    let var_arc = Arc::new(var_lock);
    for i in 0..N {
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   |  for _i in 0..N {
   |  thread::spawn(move || {
   |  ^^^^^^^^ value moved into closure here, in previous iteration of loop
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Sharing State: Arc and Mutex, really

Compiling concurrency-2pc v0.1.6 /u/roebach/src/utds-concurrency/labs/2pc/solution
error[E0302]: use of moved value: `var_arc`
  --> src/main.rs:166:22
   |  
   | let var_arc = Arc::new(var_lock);
   |     move occurs because `var_arc` has type `std::sync::Arc<std::sync::Mutex<message::ProtocolMessage>>`, which does not implement the `Copy`
   | for i in 0..N { 
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   |         let ldata = Arc::clone(&var_arc);
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   |     });
   | }
   | ^^^^^^ value moved into closure here, in previous iteration of loop
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            let vdata = ldata.lock();
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        });
    }
}

Sharing State: Arc and Mutex, really

Same problem!

What if we just don’t move?
fn test() {
    let var = Structure::new();
    let var_lock = Mutex::new(var);
    let var_arc = Arc::new(var_lock);
    for i in 0..N {
        thread::spawn(|| {
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    let var_arc = Arc::new(var_lock);
    for i in 0..N {
        let clone_arc = var_arc.clone();
        thread::spawn(move || {
            let ldata = Arc::clone(&clone_arc);
            let vdata = ldata.lock();
            // ok to mutate var (vdata)!
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        thread::spawn(move || {
            let ldata = Arc::clone(&clone_arc);
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        });
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Sharing State: Arc and Mutex, really

```rust
fn test() {
    let var = Structure::new();
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    for i in 0..N {
        thread::spawn(move || {
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    for i in 0..N {
        thread::spawn(move || {
            let ldata = Arc::clone(&var_arc);
            let vdata = ldata.lock();
            // ok to mutate var (vdata)!
        });
    }
}
```

Why does this compile?
fn test() {
    let var = Structure::new();
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    for i in 0..N {
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            let ldata = Arc::clone(&var_arc);
            let vdata = ldata.lock();
            // ok to mutate var (vdata)!
        });
    }
    for i in 0..N { join(); }
}
fn test() {
    let var = Structure::new();
    let var_lock = Mutex::new(var);
    let var_arc = Arc::new(var_lock);
    for i in 0..N {
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    for i in 0..N {
        thread::spawn(move || {
            let ldata = Arc::clone(&var_arc);
            let vdata = ldata.lock(); // ok to mutate var (vdata)!
            // Annotation is identical to function annotation but is optional
            // as are the `{}` wrapping the body. These nameless functions
            // are assigned to appropriately named variables.
            let closure_annotated = |i: i32| -> i32 { i + 1 };
            let closure_inferred = |i| i + 1 ;
        });
    }
}

Could we use a vec of JoinHandle to keep var_arc in scope?

What if I need my lambda to own some things and borrow others?
Project Proposal

CS378: Concurrency

Project Proposal

The goal of this assignment is to come up with a plan for your course project.

The project is a more open-ended assignment, where you have the flexibility to pursue an topic or area that interests you. The goal of the first part of this assignment then, is to identify roughly what you want to do.

I encourage you to come up with your own project idea, but there are suggestions at the end of this assignment for projects for those wishing for more guidance.

You must submit a proposal (1-2 pages long), meeting the guidelines and answering the basic questions enumerated below:

- Provide a detailed timeline of how you plan to build the system. It is really important to have intermediate milestones where some subset of functionality is completely working by date X run on the deadline. Give a list of 4 key milestones.
- What infrastructure will you have to build to run the experiments you want to run?
- What hardware will you need and where will you get it? (Talk to me early if you have an experiment that needs hardware support but you don't know where to get the hardware from.)
- What kind of experiments do you plan to run?
- How will you know if you have succeeded?
- What kind of performance or functionality problems do you anticipate?

Planning is important. So I will review your proposal and give you feedback. If significant refinement is needed, I will ask you to hand in a revised proposal in the few weeks after the proposal deadline.

You can work in groups for your project.

- A very good example
Project Proposal

CS378: Concurrency

Project Proposal

The goal of this assignment is to come up with a plan for your course project.

The project is a more open-ended assignment, where you have the flexibility to pursue an topic of your choice. The main point of this assignment then, is to identify roughly what you want to do and how you will do it. I encourage you to come up with your own project idea, but there are suggestions at the end of this page you may want to consider for more guidance.

You must submit a proposal (1-2 pages long), meeting the guidelines and answering the basic questions:

- Provide a detailed timeline of how you plan to build the system. It is really important to have a realistic schedule.
- What infrastructure will you have to build to run the experiments you want to run?
- What kind of experiments do you plan to run?
- How will you know if you have succeeded?
- What kind of performance or functionality problems do you anticipate?

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You can work in groups for your project.

- **A very good example**

**Ideas:**
- Heterogeneity
- Transactional Memory
- Julia, X10, Chapel
- Actor Models: Akka
- Dataflow Models
- Race Detection
- Lock-free data structures
- ....

*The sky is the limit*
Project Proposal

CS378: Concurrency

Project Proposal

The goal of this assignment is to come up with a plan for your course project.

The project is a more open-ended assignment, where you have the flexibility to pursue an topic that you are interested in. The primary purpose of this assignment then, is to identify roughly what you would like to work on more guidance.

I encourage you to come up with your own project idea, but there are suggestions at the end of the syllabus.

You must submit a proposal (1-2 pages long), meeting the guidelines and answering the basic:

• Provide a detailed timeline of how you plan to build the system. It is really important to have a timeline.
• What infrastructure will you have to build to run the experiments you want to run?
• What hardware will you need and where will you get it? (Talk to me early if you have an experiment that needs hardware support but you don’t know where to get the hardware from.)
• What kind of experiments do you plan to run?
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Planning is important. So I will review your proposal and give you feedback. If significant refinement is needed, I will ask you to hand in a revised proposal in the few weeks after the proposal deadline.

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• **A very good example**

---

**Ideas:**

- Heterogeneity
- Transactional Memory
- Julia, X10, Chapel
- Actor Models: Akka
- Dataflow Models
- Race Detection
- Lock-free data structures
- ....

*The sky is the limit*

**Questions?**
Scale Out vs Scale Up
Scale Out vs Scale Up

Vertical Scaling → Make boxes bigger

Horizontal Scaling → Make more boxes
Scale Out vs Scale Up

**Vertical Scaling**
- Make boxes bigger

**Horizontal Scaling**
- Make more boxes

<table>
<thead>
<tr>
<th>Vertical Scaling</th>
<th>Horizontal Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher Capital Investment</td>
<td>On Demand Investment</td>
</tr>
<tr>
<td>Utilization concerns</td>
<td>Utilization can be optimized</td>
</tr>
<tr>
<td>Relatively Quicker and works with the current design</td>
<td>Relatively more time consuming and needs redesigning</td>
</tr>
<tr>
<td>Limiting Scale</td>
<td>Internet Scale</td>
</tr>
</tbody>
</table>
Parallel Systems Architects Wanted
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Hot Startup Idea:

www.purchase-a-pooch.biz
Parallel Systems Architects Wanted
Parallel Systems Architects Wanted

1. User Browses Potential Pets
Parallel Systems Architects Wanted

1. User Browses Potential Pets
2. Clicks “Purchase Pooch”
Parallel Systems Architects Wanted

1. User Browses Potential Pets
2. Clicks “Purchase Pooch”
3. Web Server, CGI/EJB + Database complete request
Parallel Systems Architects Wanted

1. User Browses Potential Pets
2. Clicks “Purchase Pooch”
3. Web Server, CGI/EJB + Database complete request
4. Pooch delivered (not shown)
Parallel Systems Architects Wanted

1. User Browses Potential Pets
2. Clicks “Purchase Pooch”
3. Web Server, CGI/EJB + Database complete request
4. Pooch delivered (not shown)

How to handle lots and lots of dogs?
3 Tier architecture
3 Tier architecture

Web Servers (Presentation Tier) and App servers (Business Tier) scale *horizontally*. 

[Diagram showing 3 tier architecture with user request flowing to web servers and then to app servers]
3 Tier architecture

Web Servers (Presentation Tier) and App servers (Business Tier) scale horizontally.

Database Server scales vertically.

Horizontal Scale → "Shared Nothing"
3 Tier architecture

Web Servers (Presentation Tier) and App servers (Business Tier) scale horizontally. Database Server scales vertically.

**Horizontal Scale** → "Shared Nothing"

Why is this a good arrangement?
3 Tier architecture

Web Servers (Presentation Tier) and App servers (Business Tier) scale horizontally

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Horizontal Scale → “Shared Nothing”

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- **Horizontal Scale**: “Shared Nothing”
- **Why is this a good arrangement?**
3 Tier architecture

Web Servers (Presentation Tier) and App servers (Business Tier) scale horizontally.

Database Server scales vertically.

Vertical scale gets you a long way, but there is always a bigger problem size.

Why is this a good arrangement?

Web Servers (Presentation Tier) and App servers (Business Tier) scale horizontally.
Horizontal Scale: Goal
Design Space

- Internet
- Private data center
- Throughput
- Latency
- Shared nothing
- Shared something
Design Space

Throughput

Latency

Internet

Private data center

Shared nothing

Transaction

Grid
Design Space

Throughput vs Latency

- Internet
- Private data center
- Shared nothing
- Shared something

Transaction

Search

Grid
Design Space

- Internet
- Private data center

- Throughput
- Latency

- Shared nothing
- Shared something

- Grid
- MapReduce
- Spark
- Dryad

- Search
- Transaction
Design Space

- Throughput
- Latency
- Internet
- Private data center
- Shared nothing
- Shared something
- Search
- Transaction
- HPC MPI
- Grid
- MapReduce
- Dryad
- Spark
Parallel Architectures and MPI
Parallel Architectures and MPI
Parallel Architectures and MPI

Distributed Memory
Multiprocessor
Messaging between nodes

- Processor
- Memory
- Interconnection Network
Parallel Architectures and MPI

Distributed Memory Multiprocessor
  Messaging between nodes

Massively Parallel Processor (MPP)
  Many, many processors
Parallel Architectures and MPI

Distributed Memory Multiprocessor
Messaging between nodes

Massively Parallel Processor (MPP)
Many, many processors
Parallel Architectures and MPI

Distributed Memory Multiprocessor
- Messaging between nodes
  - memory
  - processor
  - interconnection network
  - memory
  - processor
  - interconnection network
  - memory
  - processor
  - interconnection network

Massively Parallel Processor (MPP)
- Many, many processors

Cluster of SMPS
- Shared memory in SMP node
- Messaging ↔ SMP nodes

- also regarded as MPP if processor # is large
Parallel Architectures and MPI

Distributed Memory Multiprocessor
Messaging between nodes

Cluster of SMPS
- Shared memory in SMP node
- Messaging $\leftrightarrow$ SMP nodes

Massively Parallel Processor (MPP)
Many, many processors

Multicore SMP+GPU Cluster
- Shared mem in SMP node
- Messaging between nodes

- also regarded as MPP if processor # is large
- GPU accelerators attached
Parallel Architectures and MPI

Distributed Memory Multiprocessor

- Messaging between nodes

- Massively Parallel Processor (MPP)
  - Many, many processors

Cluster of SMPs

- Shared memory in SMP node
- Messaging \(\leftrightarrow\) SMP nodes

- also regarded as MPP if processor # is large

Multicore SMP+GPU Cluster

- Shared mem in SMP node
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What have we left out?
Parallel Architectures and MPI

Distributed Memory Multiprocessor
- Messaging between nodes

Cluster of SMPs
- Shared memory in SMP node
- Messaging $\leftrightarrow$ SMP nodes

Multicore SMP+GPU Cluster
- Shared mem in SMP node
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Massively Parallel Processor (MPP)
- Many, many processors

What have we left out?
- DSMs
- CMPs
- Non-GPU Accelerators
What requires extreme scale?
What requires extreme scale?

Simulations—why?
What requires extreme scale?

Simulations—why?

Simulations are sometimes more cost effective than experiments
What requires extreme scale?

Simulations—why?
Simulations are sometimes more cost effective than experiments

Why extreme scale?
More compute cycles, more memory, etc, lead for faster and/or more accurate simulations
What requires extreme scale?

Simulations—why?
Simulations are sometimes more cost effective than experiments

Why extreme scale?
More compute cycles, more memory, etc, lead for faster and/or more accurate simulations

Climate Change

Astrophysics

Image credit: Prabhat, LBNL

Nuclear Reactors
How big is “extreme” scale?

Measured in FLOPs

Floating point Operations Per second
- 1 GigaFLOP = 1 billion FLOPs
- 1 TeraFLOP = 1000 GigaFLOPs
- 1 PetaFLOP = 1000 TeraFLOPs
  Most current super computers
- 1 ExaFLOP = 1000 PetaFLOPs
  Arriving in 2018 (supposedly)
### How big is “extreme” scale?

Measured in FLOPs

**Floating point Operations Per second**

<table>
<thead>
<tr>
<th>Rank</th>
<th>System</th>
<th>Cores</th>
<th>Rmax</th>
<th>Rpeak</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sunway TaihuLight - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway, NRCPC National Supercomputing Center in Wuxi China</td>
<td>10,649,600</td>
<td>93,014.6</td>
<td>125,435.9</td>
<td>15,371</td>
</tr>
<tr>
<td>2</td>
<td>Tianhe-2 [MilkyWay-2] - TH-IVB-FEP Cluster, Intel Xeon E5-2692 12C 2.20GHz, TH Express-2, Intel Xeon Phi 3151P, NUDT National Super Computer Center in Guangzhou China</td>
<td>3,120,000</td>
<td>33,862.7</td>
<td>54,902.4</td>
<td>17,808</td>
</tr>
<tr>
<td>3</td>
<td>Piz Daint - Cray XC50, Xeon E5-2690v3 12C 2.6GHz, Aries interconnect, NVIDIA Tesla P100, Cray Inc. Swiss National Supercomputing Centre (CSCS) Switzerland</td>
<td>367,460</td>
<td>19,590.0</td>
<td>25,326.3</td>
<td>2,272</td>
</tr>
<tr>
<td>4</td>
<td>Gyoukou - ZettaScaler-2.2 HPC system, Xeon D-1571 16C 1.3GHz, Infiniband EDR, PEZY-SC2 700Mhz, ExaScaler Japan Agency for Marine-Earth Science and Technology Japan</td>
<td>19,860,000</td>
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<td>560,640</td>
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</tr>
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<td>Sequoia - BlueGene/Q, Power BQC 16C 1.60 GHz, Custom, IBM DOE/NNSA/LLNL</td>
<td>1,572,864</td>
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</tr>
</tbody>
</table>
How big is “extreme” scale?

Measured in FLOPs

Floating point Operations Per second

<table>
<thead>
<tr>
<th>Rank</th>
<th>System</th>
<th>Cores</th>
<th>$R_{max}$ [TFlop/s]</th>
<th>$R_{peak}$ [TFlop/s]</th>
<th>Power [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sunway TaihuLight - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway, NRCPC National Supercomputing Center in Wuxi China</td>
<td>914.6</td>
<td>125,435.9</td>
<td>15,371</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Tianhe-2 [MilkyWay-2] - TH-IVB-FEP Cluster, Intel Xeon E5-2692 12C 2.200GHz, TH Express-2, Intel Xeon Phi 3151P , NUDT National Super Computer Center in Guangzhou China</td>
<td>3,120,000</td>
<td>33,862.7</td>
<td>54,902.4</td>
<td>1,808</td>
</tr>
<tr>
<td>3</td>
<td>Plz Daint - Cray XC50, Xeon E5-2690v3 12C 2.6GHz, Aries interconnect , NVIDIA Tesla P100 , Cray Inc. Swiss National Supercomputing Centre (CSCS) Switzerland</td>
<td>361,760</td>
<td>19,599.9</td>
<td>25,262.3</td>
<td>2,272</td>
</tr>
<tr>
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Distributed Memory Multiprocessors
Distributed Memory Multiprocessors

![Network diagram](image-url)
Distributed Memory Multiprocessors

- Nodes: complete computer
  - Including I/O
- Nodes communicate via network
  - Standard networks (IP)
  - Specialized networks (RDMA, fiber)
Distributed Memory Multiprocessors

Each processor has a local memory
Physically separated address space

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*Message passing architecture*
Processor interconnection network

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Scalable architecture
Incremental cost to add hardware (cost of node)

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Performance: Latency and Bandwidth
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Bandwidth

- Need high bandwidth in communication
- Match limits in network, memory, and processor
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if network is bisected, bisection bandwidth == bandwidth
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- E.g.: communication/computation overlap, prefetch
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Is this different from metrics we’ve cared about so far?
Ostensible Advantages of Distributed Memory Architectures
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Hardware simpler (especially versus NUMA), more scalable
Ostensible Advantages of
Distributed Memory Architectures

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Can you think of any disadvantages?
Running on Supercomputers
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- Programmer plans a **job**; job ==
  - parallel binary program
  - “input deck” (specifies input data)
- Submit job to a **queue**
- Scheduler allocates resources when
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Sometimes 1 job takes whole machine
These are called “hero runs”...
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- MPI library interprets this information, hides the details
The Message-Passing Model

Process: a program counter and address space
Processes: multiple threads sharing a single address space

MPI is for communication among \textit{processes}
Not threads

Inter-process communication consists of
Synchronization
Data movement
The Message-Passing Model

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P2

P3

P4

address

space

(memory)

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- Two flavors for communication
  - Cooperative operations
  - One-sided operations
Cooperative Operations
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Data is cooperatively exchanged in message-passing
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Explicitly sent by one process and received by another

- Process 0: Send(data)
- Process 1: Receive(data)
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Advantage of local control of memory
   Change in the receiving process’s memory made with receiver’s explicit participation
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Communication and synchronization are combined

- Process 0
  Send(data)
  time

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  Receive(data)
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<table>
<thead>
<tr>
<th>Process 0</th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Send</strong>(data)</td>
<td><strong>Receive</strong>(data)</td>
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Familiar argument?
One-Sided Operations
One-Sided Operations

Process 0

**Put**(data)

(memory)

Process 1

(memory)

Get**(data)**

time
One-Sided Operations

One-sided operations between processes
Include remote memory reads and writes
One-Sided Operations

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Only one process needs to explicitly participate
There is still agreement implicit in the SPMD program

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Implication:
Communication and synchronization are decoupled

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(memory)
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  Include remote memory reads and writes
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  There is still agreement implicit in the SPMD program
Implication:
  Communication and synchronization are decoupled

Are 1-sided operations better for performance?
A Simple MPI Program

```c
#include "mpi.h"
#include <stdio.h>

int main( int argc, char *argv[] )
{
    MPI_Init( &argc, &argv );
    printf( "Hello, world!\n" );
    MPI_Finalize();
    return 0;
}
```
MPI_Init
MPI_Init

Hardware resources allocated
  MPI-managed ones anyway...
MPI_Init

Hardware resources allocated
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Start processes on different nodes
  Where does their executable program come from?
MPI_Init

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  Can bad things happen otherwise?
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• The user can cause routines to return (with an error code)
  • In C++, exceptions are thrown (MPI-2)
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Executive Summary

• Undo all of init
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• By default, an error causes all processes to abort
• The user can cause routines to return (with an error code)
  • In C++, exceptions are thrown (MPI-2)
• A user can also write and install custom error handlers
• Libraries may handle errors differently from applications
Running MPI Programs
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MPI-1 does not specify how to run an MPI program
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Starting an MPI program is dependent on implementation
  Scripts, program arguments, and/or environment variables
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% mpirun -np <procs> a.out
   For MPICH under Linux
Running MPI Programs

MPI-1 does not specify how to run an MPI program
Starting an MPI program is dependent on implementation

Scripts, program arguments, and/or environment variables

% mpirun -np <procs> a.out

For MPICH under Linux

mpiexec <args>

Recommended part of MPI-2, as a recommendation

mpiexec for MPICH (distribution from ANL)

mpirun for SGI’s MPI
Finding Out About the Environment
Finding Out About the Environment

Two important questions that arise in message passing
   How many processes are being use in computation?
   Which one am I?
Finding Out About the Environment

Two important questions that arise in message passing
   How many processes are being use in computation?
   Which one am I?

MPI provides functions to answer these questions

- **MPI_Comm_size** reports the number of processes
- **MPI_Comm_rank** reports the rank
   - number between 0 and size-1
   - identifies the calling process
```
#include "mpi.h"
#include <stdio.h>

int main( int argc, char *argv[] )
{
    int rank, size;
    MPI_Init( &argc, &argv );
    MPI_Comm_rank( MPI_COMM_WORLD, &rank );
    MPI_Comm_size( MPI_COMM_WORLD, &size );
    printf( "I am %d of %d\n", rank, size );
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What does this program do?
Hello World Revisited

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What does this program do?
Basic Concepts

Processes can be collected into *groups*

Each message is sent in a *context*
   - Must be received in the same context!

A group and context together form a *communicator*

A process is identified by its *rank*
   - With respect to the group associated with a communicator

There is a default communicator **MPI_COMM_WORLD**
   - Contains all initial processes
MPI Datatypes
MPI Datatypes

Message data (sent or received) is described by a triple address, count, datatype
MPI Datatypes

Message data (sent or received) is described by a triple address, count, datatype

An MPI *datatype* is recursively defined as:
- Predefined data type from the language
- A contiguous array of MPI datatypes
- A strided block of datatypes
- An indexed array of blocks of datatypes
- An arbitrary structure of datatypes
MPI Datatypes

Message data (sent or received) is described by a triple address, count, datatype

An MPI datatype is recursively defined as:
  Predefined data type from the language
  A contiguous array of MPI datatypes
  A strided block of datatypes
  An indexed array of blocks of datatypes
  An arbitrary structure of datatypes

There are MPI functions to construct custom datatypes
  Array of (int, float) pairs
  Row of a matrix stored columnwise
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• Enables heterogeneous communication
  • Support communication between processes on machines with different memory representations and lengths of elementary datatypes
  • MPI provides the representation translation if necessary
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• Allows application-oriented layout of data in memory
  • Reduces memory-to-memory copies in implementation
  • Allows use of special hardware (scatter/gather)
MPI Tags
MPI Tags

Messages are sent with an accompanying user-defined integer *tag*

Assist the receiving process in identifying the message
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Messages can be screened at receiving end by specifying specific tag

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\texttt{MPI\_ANY\_TAG} matches any tag in a receive

Tags are sometimes called “message types”

MPI calls them “tags” to avoid confusion with datatypes
MPI Basic (Blocking) Send

MPI_SEND (start, count, datatype, dest, tag, comm)

The message buffer is described by:

- start, count, datatype

The target process is specified by dest

- Rank of the target process in the communicator specified by comm

Process blocks until:

- Data has been delivered to the system
- Buffer can then be reused

Message may not have been received by target process!
MPI with Only Six Functions
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Many parallel programs can be written using:

- `MPI_INIT()`
- `MPI_FINALIZE()`
- `MPI_COMM_SIZE()`
- `MPI_COMM_RANK()`
- `MPI_SEND()`
- `MPI_RECV()`
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Why have any other APIs (e.g. broadcast, reduce, etc.)?

Point-to-point (send/recv) isn’t always the most efficient...

Add more support for communication
Excerpt: Barnes-Hut

```c
int ctr=nLocalOriginal;
int offset=nLocalOriginal-nLocal;
for(i=0;i<worldSize;i++){
    if(i==rank){
        MPI_Bcast(s_particles,N_POS_ELEMS*nLocalMax+1,MPI_DOUBLE,i,MPI_COMM_WORLD);
    } else {
        MPI_Bcast(l_particles,N_POS_ELEMS*nLocalMax+1,MPI_DOUBLE,i,MPI_COMM_WORLD);
        for(k=0;k<l_particles[0];k++, ctr++){
            if(l_particles[MASS(k)]<0){
                offset++;
                _nparticles--;
            } else {
                s_particles[FX(ctr)]=l_particles[FX(k)];
                s_particles[FY(ctr)]=l_particles[FY(k)];
                s_particles[FZ(ctr)]=l_particles[FZ(k)];
                s_particles[MASS(ctr)]=l_particles[MASS(k)];
                indexes[ctr-offset]=ctr;
            }
        }
    }
}
```
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int offset=nLocalOriginal-nLocal;
for(i=0;i<worldSize;i++)
if(i==rank){
    MPI_Bcast(s_particles,N_POS_ELEMS*nLocalMax+1,MPI_DOUBLE,i,MPI_COMM_WORLD);
} else {
    MPI_Bcast(l_particles,N_POS_ELEMS*nLocalMax+1,MPI_DOUBLE,i,MPI_COMM_WORLD);
    for(k=0;k<l_particles[0];k++, ctr++){
        if(l_particles[MASS(k)]<0){
            offset++;
            nparticles--;
        } else {
            s_particles[FX(ctr)]=l_particles[FX(k)];
            s_particles[FY(ctr)]=l_particles[FY(k)];
            s_particles[FZ(ctr)]=l_particles[FZ(k)];
            s_particles[MASS(ctr)]=l_particles[MASS(k)];
            indexes[ctr-offset]=ctr;
        }
    }
}
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int ctr=nLocalOriginal;
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for(i=0;i<worldSize;i++)
if(i==rank){
    MPI_Bcast(s_particles,N_POS_ELEMS*nLocalMax+1,MPI_DOUBLE,rank,0,worldSize);
  } else {
    MPI_Bcast(l_particles,N_POS_ELEMS*nLocalMax+1,MPI_DOUBLE,rank,0,worldSize);
    for(k=0;k<l_particles[0];k++, ctr++)
      if(l_particles[MASS(k)]<0){
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        nparticles--;  
      } else {
        s_particles[FX(ctr)]=l_particles[FX(k)];
        s_particles[FY(ctr)]=l_particles[FY(k)];
        s_particles[FZ(ctr)]=l_particles[FZ(k)];
        s_particles[MASS(ctr)]=l_particles[MASS(k)];
        indexes[ctr-offset]=ctr;
      }
    
  }
}
To use or not use MPI?
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• USE
  • You need a portable parallel program
  • You are writing a parallel library
  • You have irregular or dynamic data relationships
  • You care about performance
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• **USE**
  • You need a portable parallel program
  • You are writing a parallel library
  • You have irregular or dynamic data relationships
  • You care about performance

• **NOT USE**
  • You don’t need parallelism at all
  • You can use libraries (which may be written in MPI) or other tools
  • You can use multi-threading in a concurrent environment
    • You don’t need extreme scale