COL380

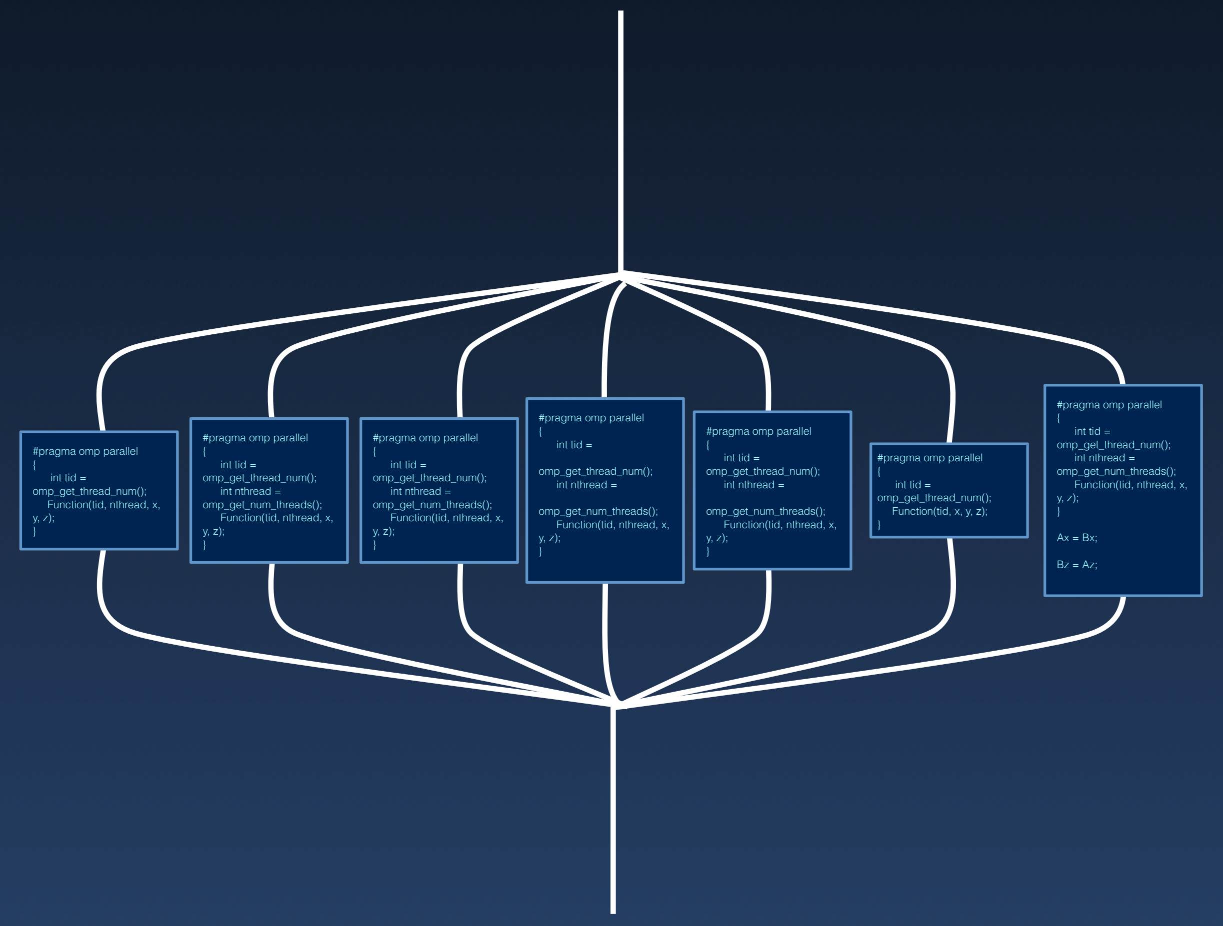
Introduction to
Parallel & Distributed Programming

Agenda

- Introduction to Message Passing
  - ➡ OpenMP review

OpenMP Review

- Fork-Join programming model
  - ➡ Teams of threads
  - ➡ Implicit barriers
- Shared Memory programming model
- Well defined memory model
- High level synchronization



```
#pragma omp parallel
{
    int tid = omp_get_thread_num();
    int nthread = omp_get_num_threads();
    Function(tid, nthread, x, y, z);
}
```

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More OpenMP

- Shared and private variables
  - ➡ Temporary view of shared memory
  - ➡ Option to reduce private variables
- Work sharing
  - ➡ Section, for, simd

```
#pragma omp parallel for simd
for(i = 0; i < num; i++) {
    c[i] += a[i] * b[i];
}
```

See: nowait, ordered

```
int sum;
#pragma omp parallel reduction(+:sum)
sum = partial_sum(data, omp_get_thread_num());
```

```
#pragma omp target map(tofrom:c[0:num])
for (int i = 0; i < num; i++) {
    c[i] += a[i] * b[i];
}
```

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Efficiency Issues

- Minimize synchronization
  - ➡ Avoid BARRIER, CRITICAL, ORDERED, and locks
  - ➡ Use NOWAIT
  - ➡ Use named CRITICAL sections for fine-grained locking
  - ➡ Use MASTER (instead of SINGLE)
- Parallelize at the highest level possible
  - ➡ such as outer FOR loops
  - ➡ keep parallel regions/tasks large

Efficiency Issues

- FLUSH is expensive
- LASTPRIVATE has synchronization overhead
- Thread safe malloc/free are expensive
- Reduce False sharing
  - ➡ Careful design of data structures
  - ➡ Use PRIVATE

Avoiding Errors

- Try to
  - Avoid nested locks
  - Release locks religiously
  - Avoid “while true” (especially, during testing)
- Be careful with
  - Non thread-safe libraries
  - Concurrent access to shared data
  - IO inside parallel regions
  - Differing views of shared memory (FLUSH)
  - NOWAIT

Programming Models

- Shared Memory model
- Distributed Memory model
- Task based model
- Work-queue model
- Stream processing model
- Map-reduce model
- Client-server model

Other Models

pthread

```
void *threadFn(void *argp)
{
    // Do something with argp
}
…
{
    int arg;
    pthread_t thread_id;;
    pthread_create(&thread_id, NULL, threadFn, &arg);
    // Continue doing other things
    pthread_join(thread_id, NULL);
}
```

Other Models

go

```
func threadFn(id int, arg string, wg *sync.WaitGroup)
{
    defer wg.Done()
    // Do thing 'id' with 'arg'

}
…
{
    var wg sync.WaitGroup

    wg.Add(1)
    go threadFn(1, "a string", &wg)
    // Continue doing other things
    wg.Wait()

}
```

pthread

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    // Do something with argp
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    int arg;
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}
```

go

```
func threadFn(id int, arg string, wg *sync.WaitGroup,
                                              ch chan int)
{
    defer wg.Done()
    // Do thing ‘id’ with ‘arg’
                        x <- ch
}
…
{
    var wg sync.WaitGroup
                        chA := make(chan int)
    wg.Add(1)
    go threadFn(1, “a string”, &wg, chA)
    // Continue doing other things
    wg.Wait()
                        chA <- result
}
```

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Other Models

chapel

```
var loc = 0;
sync {
    while((taski = taskQ.dequeue()) != nil) { // Next queue item
        begin { on Locales[loc] workOnTask(taski); } // Non-local task
        loc = (loc + 1)%numLocales
    }
} // sync ⇒ implicit join with children tasks
```

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Other Models

chapel

```
var loc = 0;
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    while((taski = taskQ.dequeue()) != nil) { // Next queue item
        begin { on Locales[loc] workOnTask(taski); } // Non-local task
        loc = (loc + 1)%numLocales
    }
```

```
const D1 = {0..#n} dmapped BlockCyclic(startIdx=(0), blocksize=(8));
var distA: [D1] int; // Distributed distA as
on Locales[1] { // Executes on Locales[1]
    var second = 2; // variable is native to Locales[1]
    coforall loc in Locales { // Create concurrent tasks, 1 per iteration
        on loc { // On Locales[loc]
            var local = distA[0] + distA[here.id*8] + second; // Fetch non-local
        }
    } // Implicit join with children tasks
}
```

Message Passing

- Communication network (and infrastructure)
  - ➡ Ethernet, Infiniband, Custom-made
- Processor-local memory
- Access to other threads' data through explicit instructions
  - ➡ Implicit synchronization semantics
- Can double as inter-process synchronization

Shared Memory

<u>Multiple Threads of Execution</u>

OP operands	OP operands
OP operands	OP operands
OP operands	OP operands
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Shared Variable Store

(May not share actual memory)

- How are they instantiated?
- Execution and memory model
- How do the interact?

Separate from HW
(Who does the execution?)

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(Could share actual memory)

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- Multiple "threads" of execution
  - Do not share address space (Processes)
  - Each process may further have multiple threads of control that share memory with each other

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Shared Memory Model

Read Input
Create Sharing threads:
Process(sharedInput, myID)

Message Passing

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<u>Message Passing Model</u>

Read Input
Create Remote Processes
Loop: Send data to each process
Wait and collect results

: Recv data
Process(data)
Send results

+/- of Shared Memory

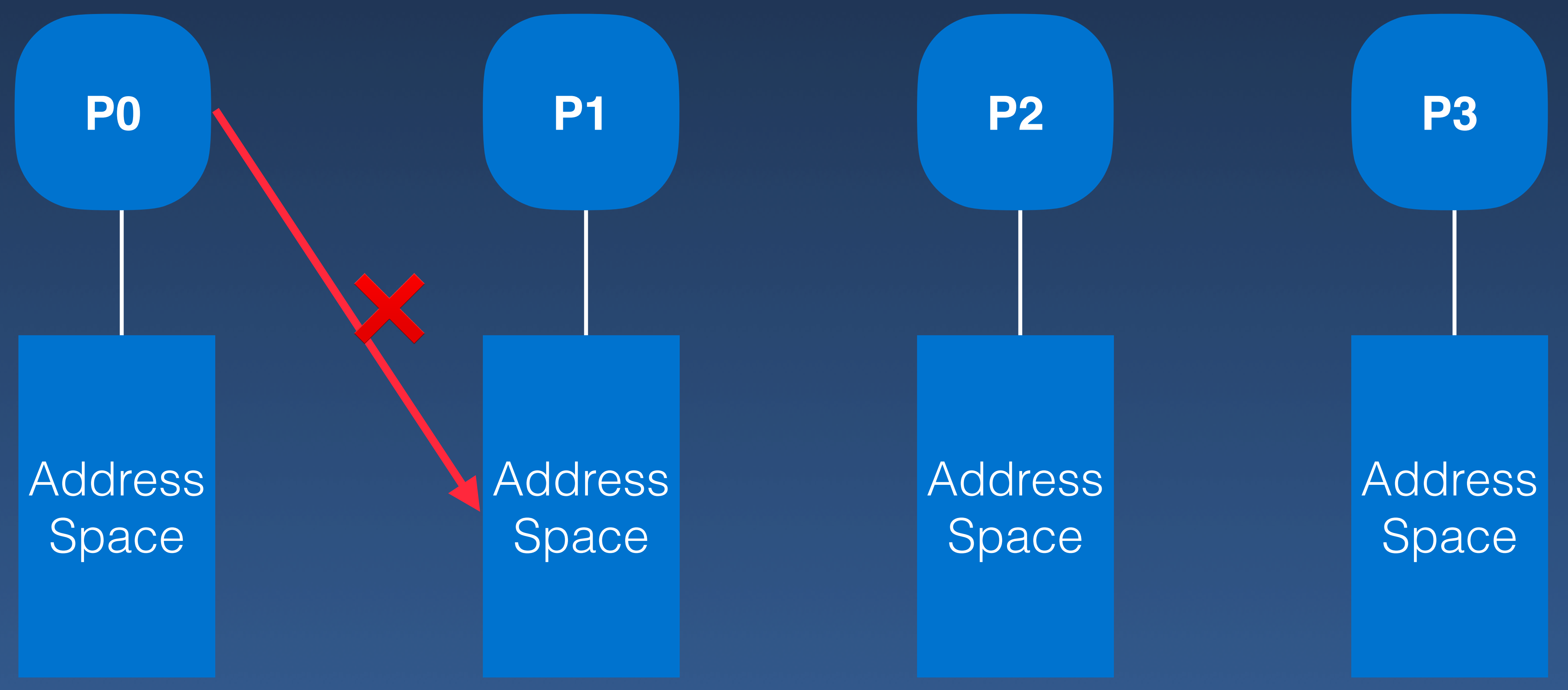
- \+ Easier to program with global address space
- \+ Typically fast memory access
  - ➡ (when hardware supported)
- \- Hard to scale
  - \- Adding CPUs (geometrically) increases traffic
- \- Programmer initiated synchronization of memory accesses

+/- of Message Passing

+ Memory is scalable with number of processors
+ Local access is fast (no cache coherency overhead)
+ Cost effective, with off-the-shelf processor/ network

- Programs often looks more complex
- Data communication needs to be managed

Distributed Memory



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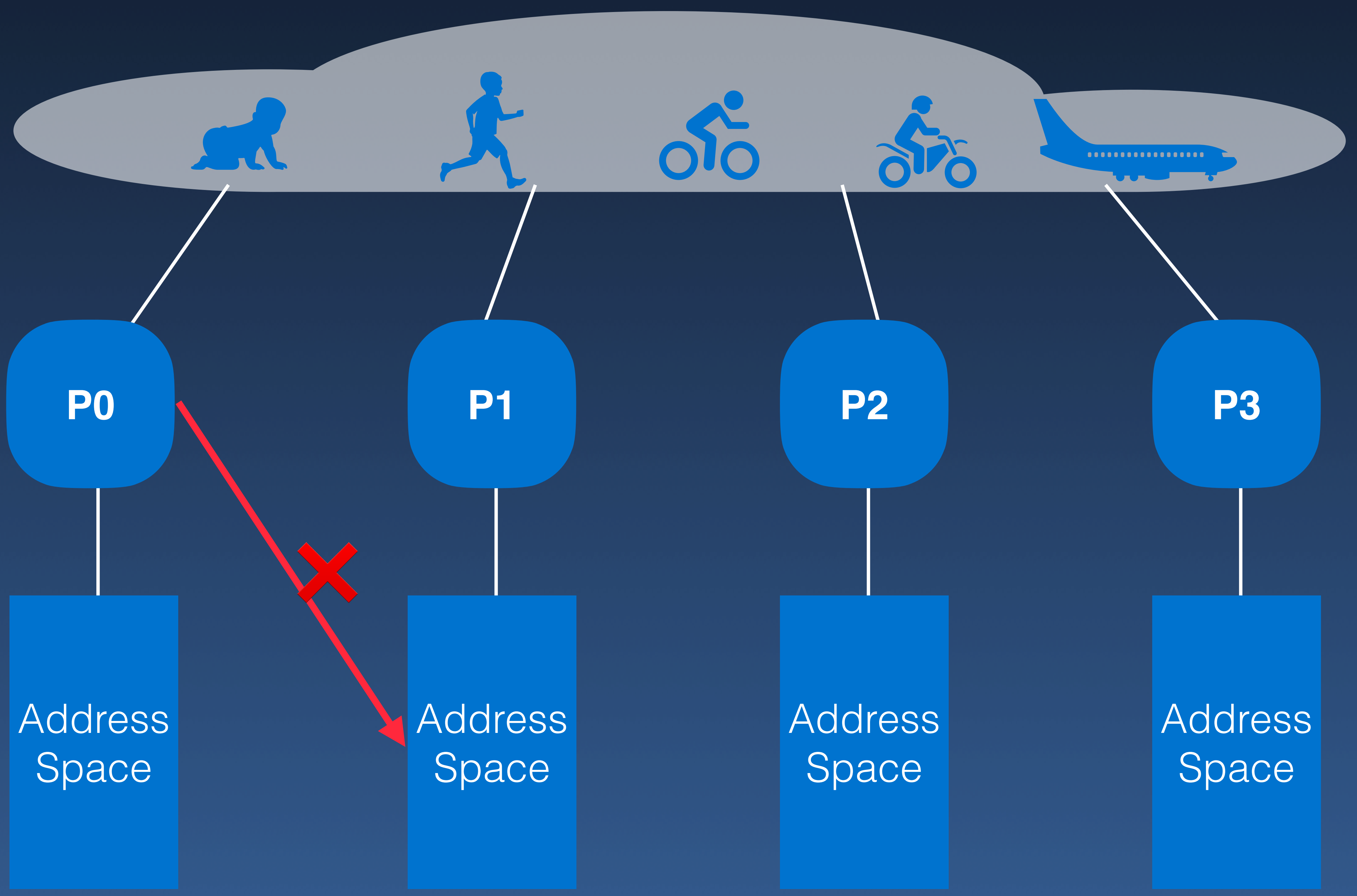
Distributed Memory



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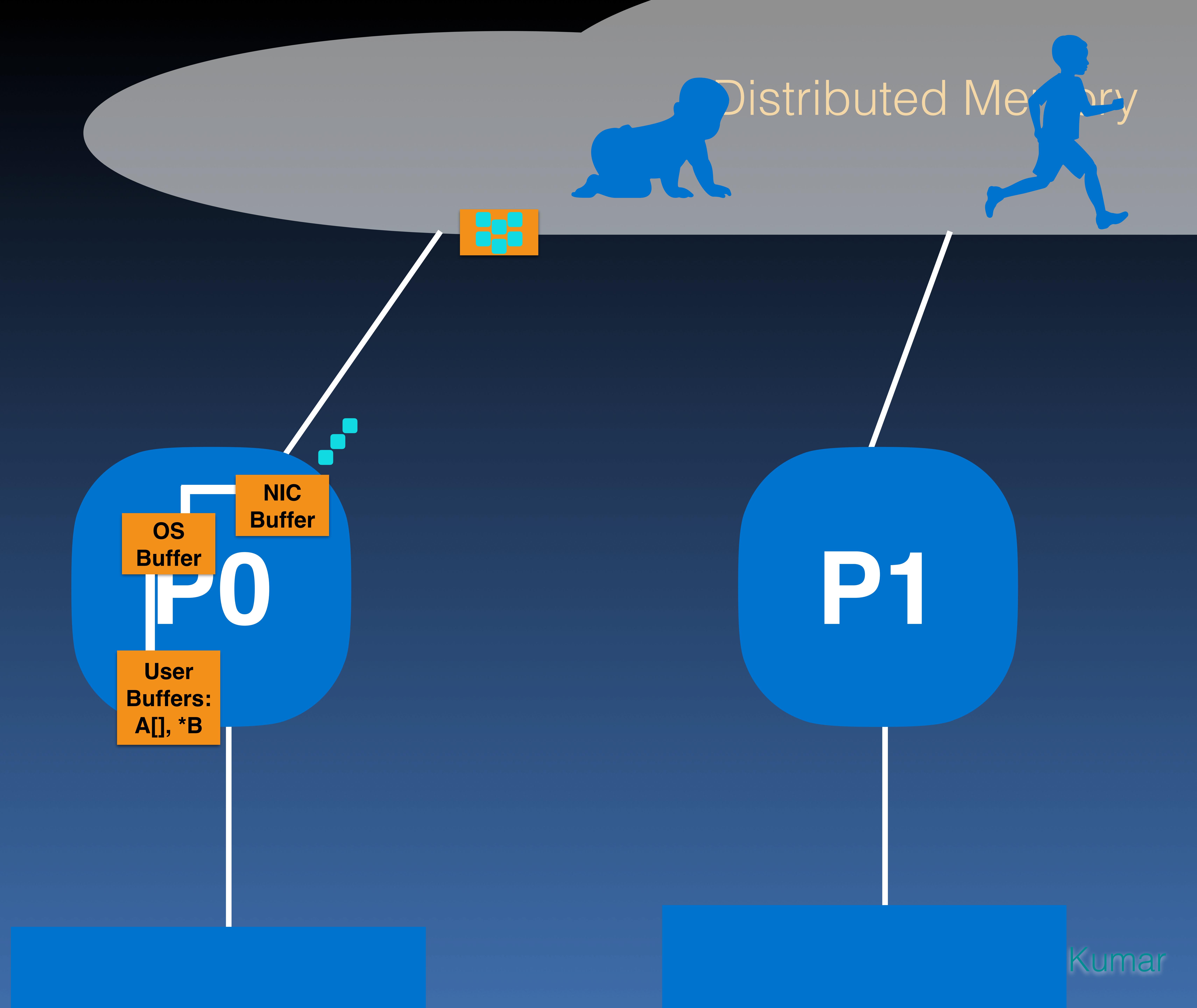
Distributed Me ry
NIC
Buffer
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Buffers:
A[], *B
P1
Kumar


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RDMA solutions also exist
Subo

- MPI is for inter-process communication
  - ➡ Process creation
  - ➡ Data communication (Buffering, Book-keeping ..)
  - ➡ Synchronization
- Allows
  - ➡ Synchronous communication
  - ➡ Asynchronous communication
    - compare to shared memory

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Functions, Types, Constants

- Allows
  - ➡ Synchronous communication
  - ➡ Asynchronous communication
    - compare to shared memory

- High-level constructs
  - broadcast, reduce, scatter/gather message
  - Collective functions
- Interoperable across architectures

Running MPI Programs

- **Compile:** mpiCC -o exec code.cpp
  - script to compile and link
  - Automatically adds include, library flags
- **Run:**
  - mpirun -host host1,host2 exec args
  - Or, use hostfile
- **Useful:**
  - mpirun -mca <key> <value>

- mpirun -mca mpi_show_handle_leaks 1
- mpirun -mca btl openib,tcp
- mpirun -mca btl_tcp_min_rdma_size
- Check out "ompi_info"

- Key based remote shell execution
- Use ssh-keygen to create public-private key pair
  - ➡ Private key stays in subdirectory ~/.ssh on your client
  - ➡ Public key on server in ~/.ssh/authorized_keys
  - ➡ Test: ‘ssh <server> ls’ works
  - ➡ On hpc/css, client and server share the same home directory
- PBS automatically creates appropriate host files
  - ➡ See also: -l select=2:ncpus=1:mpiprocs=1 -l place=scatter

- Variables, Buffers, and Packets
  - ➡ Application to application
- Lossy?
  - ➡ Deal with loss
  - ➡ Acks
- FIFO?
- Point to Point vs Collective?
- Addressing?

Message Semantics

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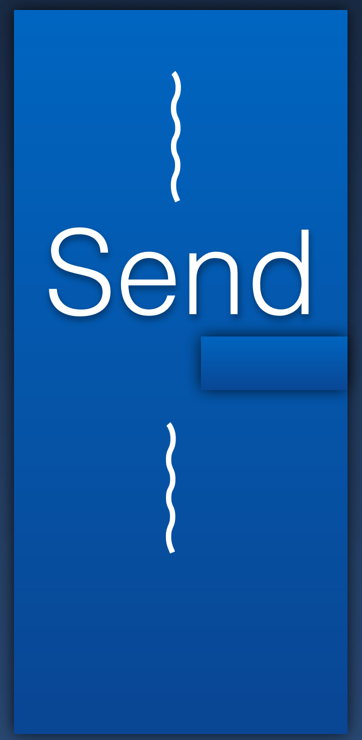

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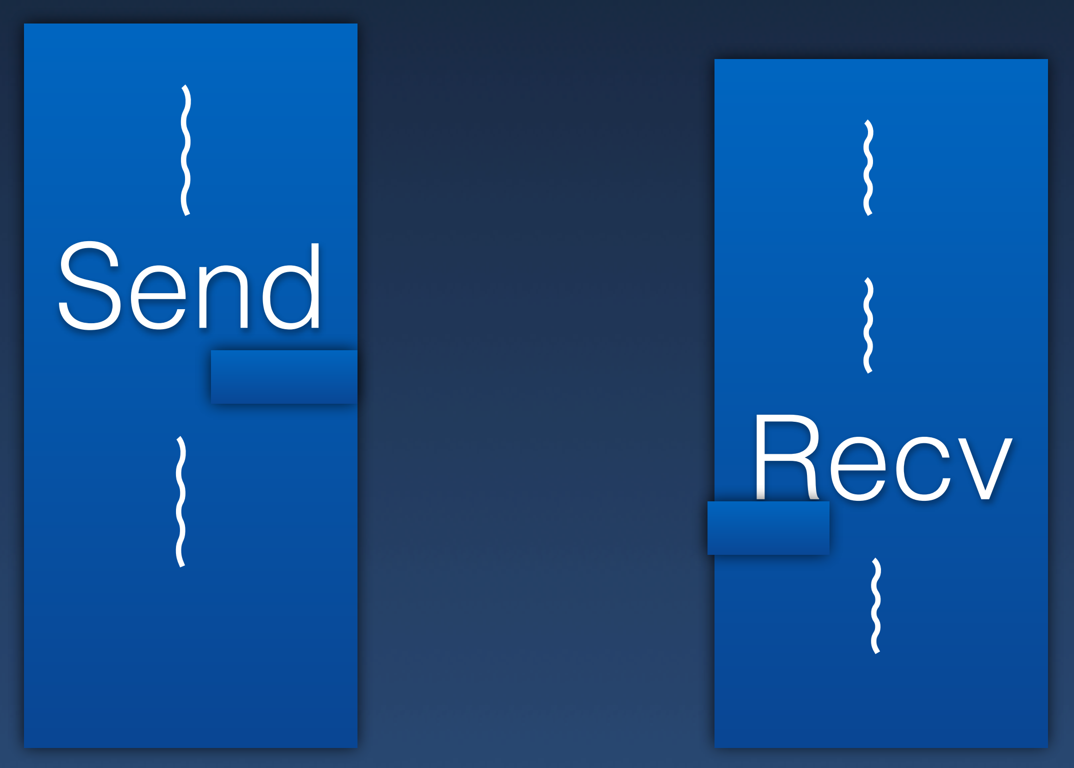

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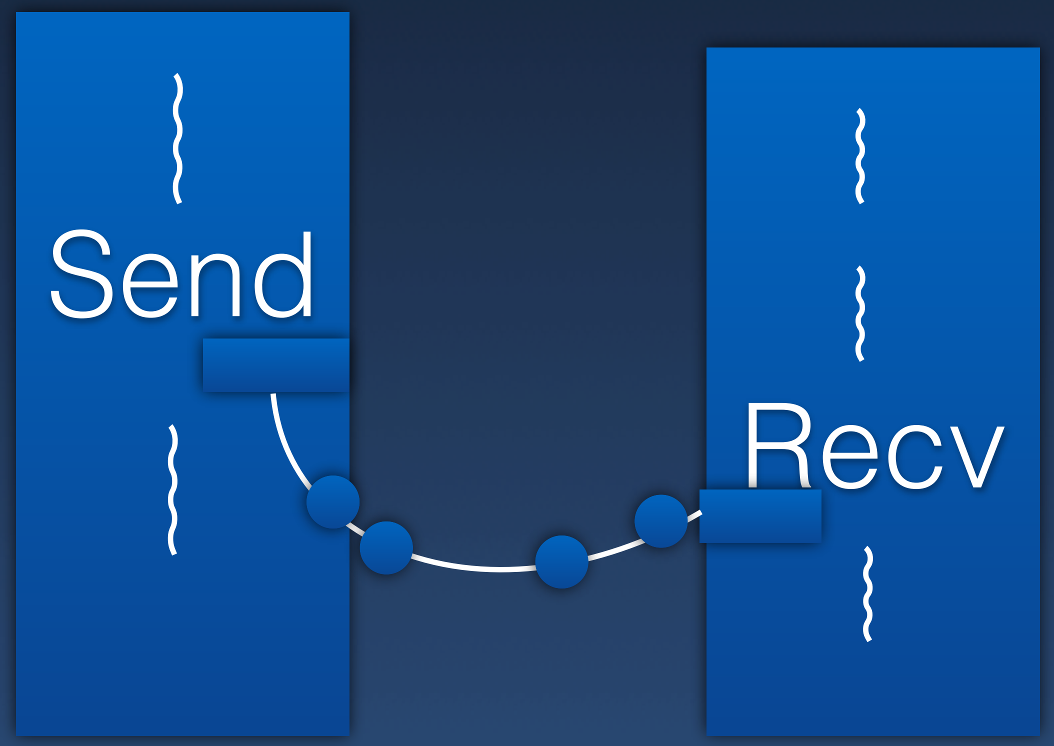

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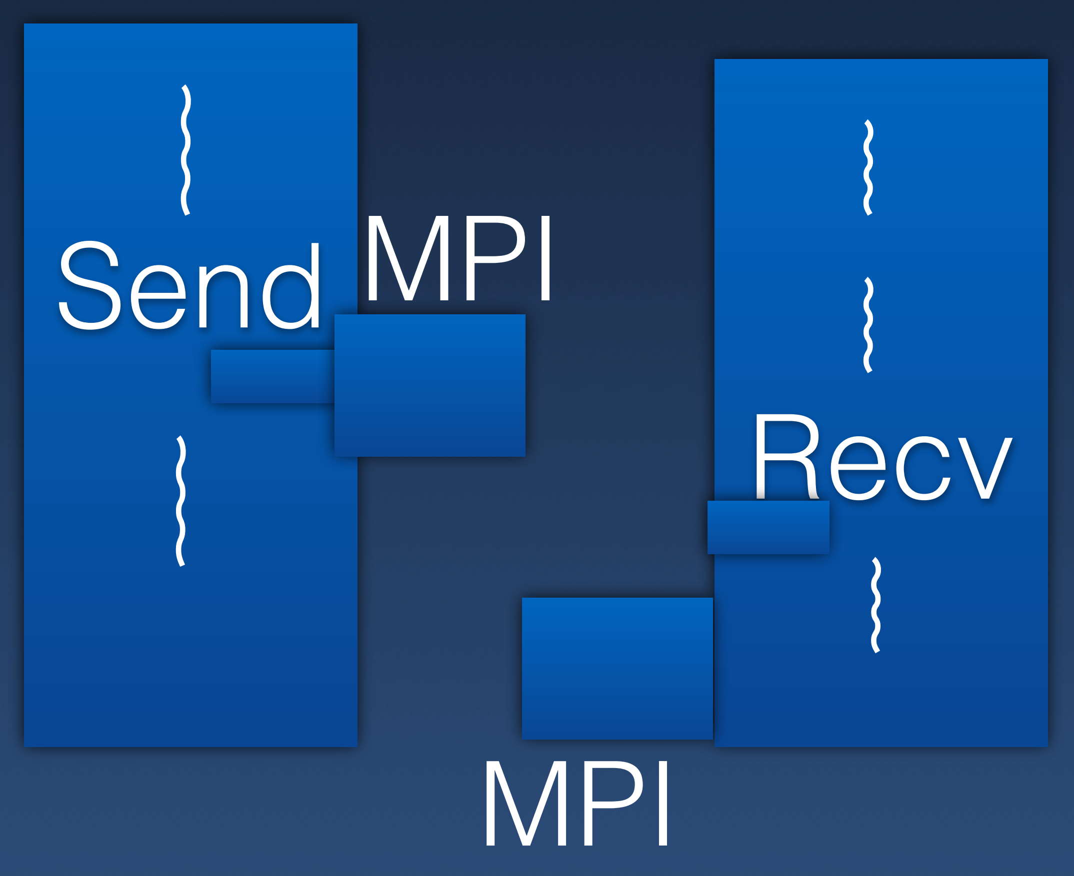

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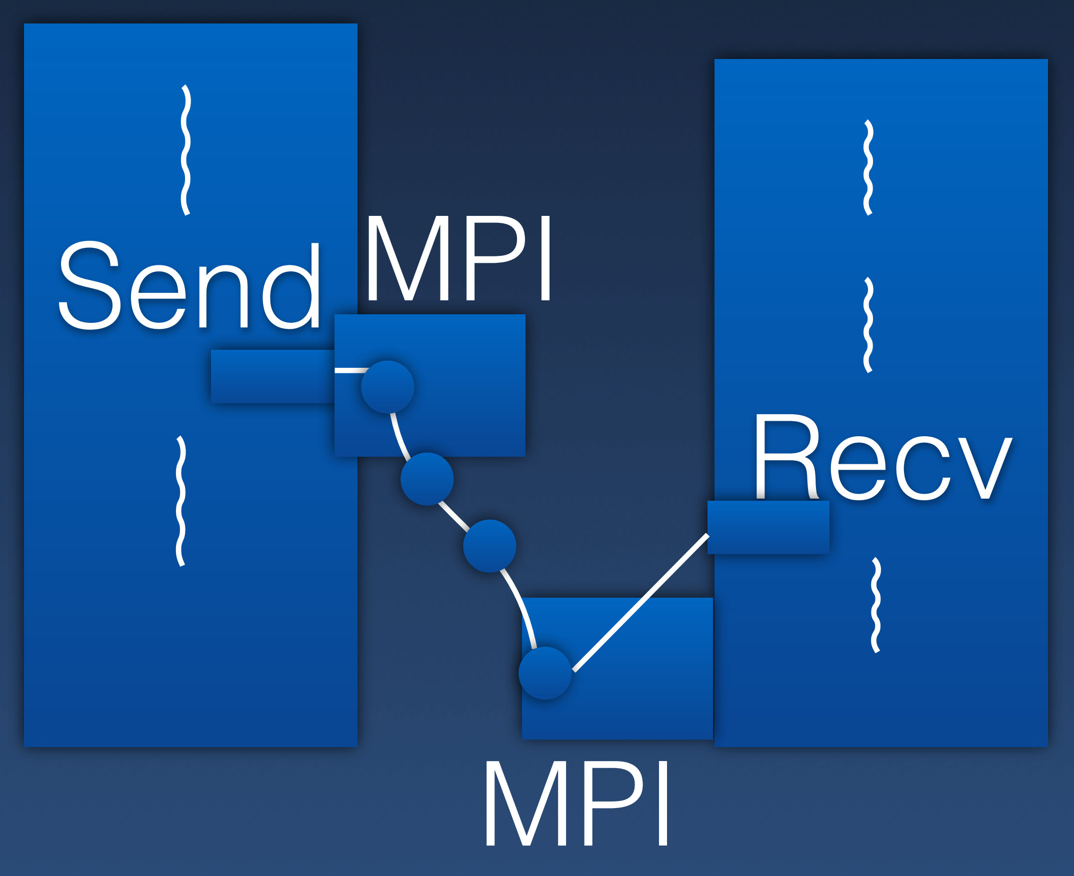

Process Organization

- Communicator

  Topology

  - Groups of processes sharing a context
  - Intra and inter-communicator

  Predefined constant: MPI_COMM_WORLD

- Context
  - "communication universe"
  - Messages across context have no 'interference'
- Groups
  - Collection of processes (can build hierarchy)
  - Ordered

  Use group-rank to address

Hello MPI

```
#include "mpi.h"      /* includes MPI library code specs */

#define MAXSIZE 100

int main(int argc, char* argv[])
{
  MPI_Init(&argc, &argv);                      // start MPI
  int nProcs, myRank, dat[2] = {5,6};
  MPI_Status status;
  MPI_Comm_size(MPI_COMM_WORLD, &nProcs); // Group size
  MPI_Comm_rank(MPI_COMM_WORLD, &myRank); // get my rank
  If(myRank == 0)
      MPI_Send(dat, 2, MPI_INT, nProcs-1, 11, MPI_COMM_WORLD);
  If(myRank == nProcs-1)
      MPI_Recv(dat, 9, MPI_INT, 0, 11, MPI_COMM_WORLD, &status);
  MPI_Finalize();                              // stop MPI
}
```

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#define MAXSIZE 100

int main(int argc, char* argv[])
{
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  int nProcs, myRank, dat[2] = {5,6};
  MPI_Status status;
  MPI_Comm_size(MPI_COMM_W
  MPI_Comm_rank(MPI_COMM_W
  If(myRank == 0)
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  MPI_Finalize();                            // stop MPI
}
```

```
status.MPI_TAG

status.MPI_SOURCE

MPI_Get_count(&status, MPI_INT,  &count);
```

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Review

- Message Passing and MPI
- The spectrum from shared memory to Message passing style programing