Portals Programming on the XT3

Ron Brightwell Rolf Riesen
Sandia National Laboratories
Scalable Computing Systems Department

Barney Maccabe
University of New Mexico
Scalable System Lab

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Outline

- Overview
- Portals objects
- Portals API
- Portals semantics
- XT3 implementation
- Upcoming work

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Portals Timeline

- Portals 0.0 - 1991
  - SUNMOS (Sandia/UNM OS)
  - nCUBE, Intel Paragon
  - Direct access to network FIFOs
  - Message co-processor
- Portals 1.0 - 1993
  - Message passing data structures in user-space
  - Kernel-managed and user-managed memory descriptors
  - Published but never implemented
- Portals 2.0 - 1994
  - Puma/Cougar lightweight operating system
  - Message selection capability (match lists)
  - Four types of memory descriptors (three implemented)
- Portals 3.0 - 1998
  - Cplant Linux clusters
  - Functional API
  - Target intelligent/programmable network interfaces (Myrinet)

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Portals 3.3 Features

- Best effort, in-order delivery
- One-sided operations
  - Put, Get, Atomic swap
- Supports zero-copy
- Supports OS-bypass
- Supports application offload
  - No polling or threads to move data
  - No host CPU overhead
- Well-defined transport failure semantics
- Unexpected operations are discarded
- Receive-side access control
- Runtime-system independent

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What Makes Portals Different?

- Connectionless RDMA with matching
- Provides elementary building blocks for supporting higher-level protocols well
  - MPI, RPC, Lustre, etc.
- Allows structures to be placed in user-space, kernel-space, or NIC-space
- Receiver-managed offset allows for efficient and scalable buffering of MPI “unexpected” messages
- Supports multiple protocols within a process
  - Needed for compute nodes where everything is a message

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Basic Objects: Memory Descriptors and Addresses

- Memory descriptors
  - Logically contiguous region of memory
  - Explicit creation
    - Pin pages (for Linux)
    - Pass address map to network interface
  - Scatter/gather semantics
- Remote addresses include:
  - Destination id (node id, process id)
  - Portal table index (protocol switch)
  - Message selection bits (MPI style matching)
  - Offset – sender-managed memory descriptors
  - Access control cookie

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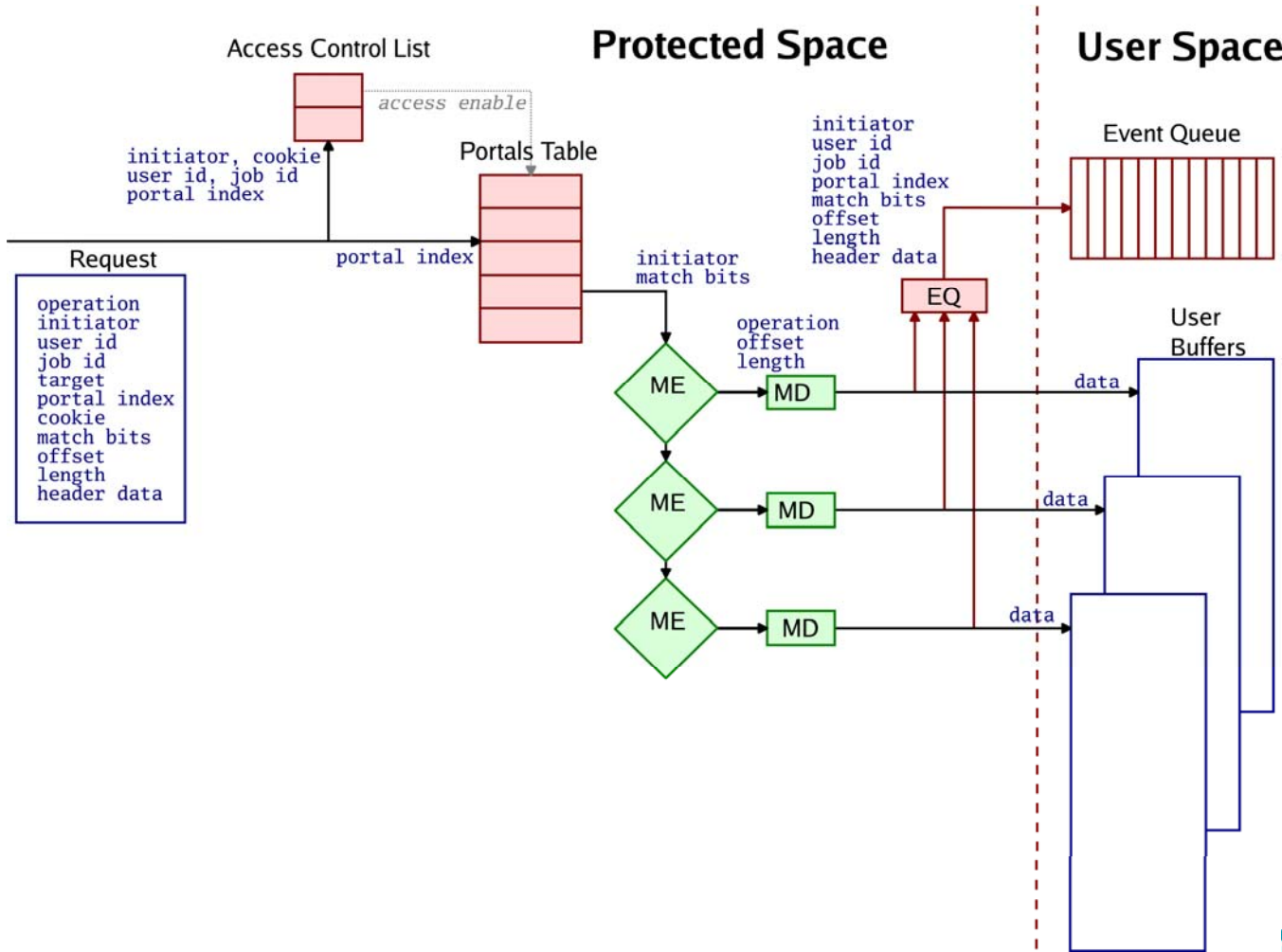
Addressing



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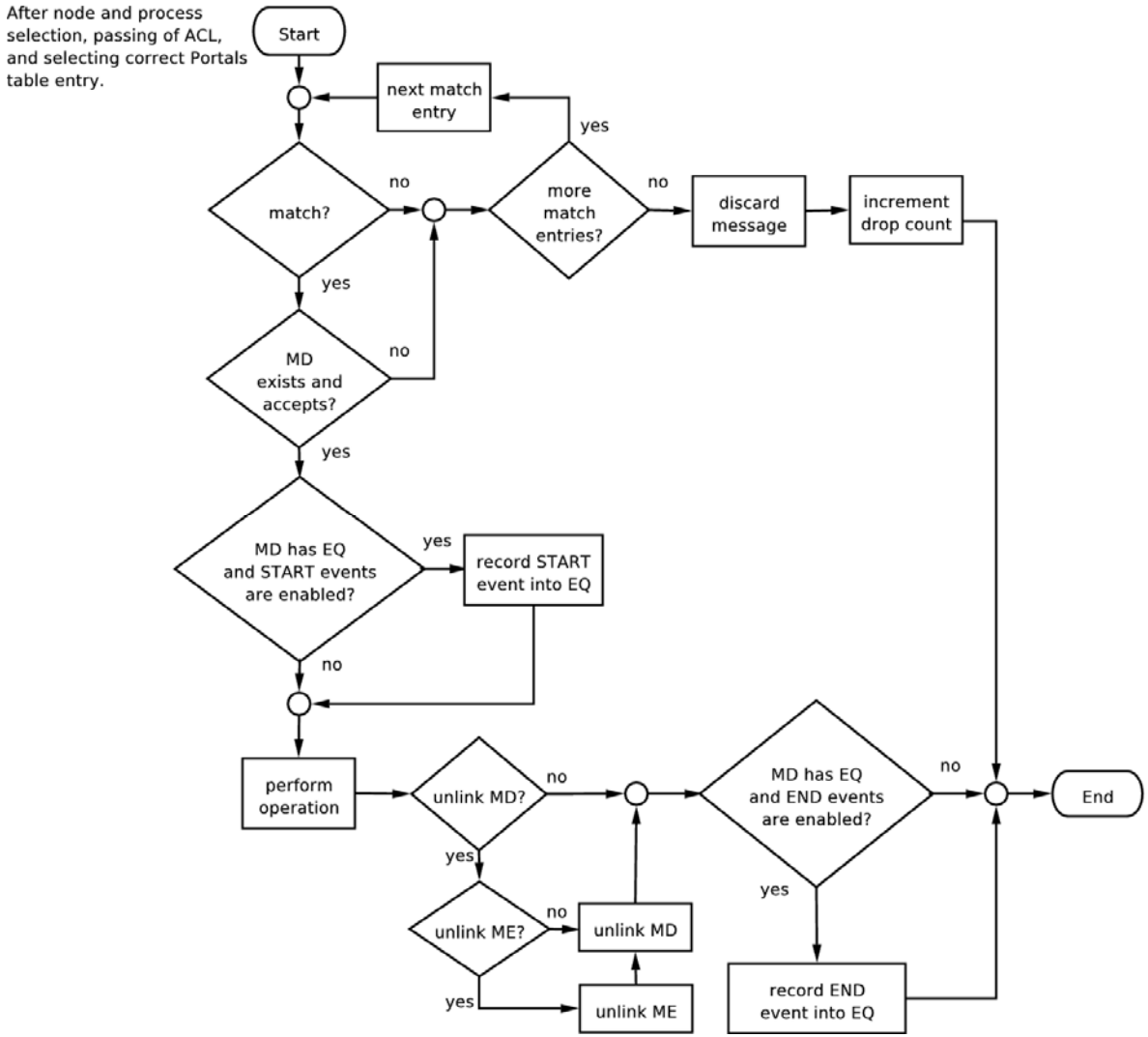
Steps for Address Translation



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Library Initialization/Shutdown

- `int PtlInit( int *max_interfaces );`
- `void PtlFini( void );`

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Network Interfaces

- Supports the use of multiple network interfaces
- Each interface is independent
- Each interface provides
  - A portal table
    - With at least 8 entries
  - An access control table
  - Status registers
- Every portals object is associated with a specific interface

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Network Interface Creation & Destruction Functions

- int PtlNIInit(
    ptl_interface_t iface,
    ptl_pid_t pid,
    ptl_ni_limits_t *desired,
    ptl_ni_limits_t *actual,
    ptl_handle_ni_t *ni_handle
  );

- int PtlNIFini(
    ptl_handle_ni_t ni_handle
  );

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Network Interface Utility Functions

- int PtlNIStatus(
  ptl_handle_ni_t ni_handle,
  ptl_sr_index_t status_register,
  ptl_sr_value_t *status
  );

- int PtlNIDist(
  ptl_handle_ni_t ni_handle,
  ptl_process_id_t pid,
  unsigned long *distance
  );

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Identification

- User Id
  - Every process runs on behalf of a user
  - Mandates trusted header information
- Process Id
  - Uniquely identifies a process on a portals network
- Job Id
  - Allows for processes to be aggregated
  - Useful for parallel jobs

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Identification Functions

- ```
  int PtlGetUid (
       ptl_handle_ni_t      ni_handle,
       ptl_uid_t            *uid
   );
  ```

- ```
  int PtlGetId(
       ptl_handle_ni_t      ni_handle,
       ptl_process_id_t     *pid
   );
  ```

- ```
  int PtlGetJid(
       ptl_handle_ni_t      ni_handle,
       ptl_job_id_t         *jid
    );
  ```

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  ```

Match Entry (ME) and Match Lists

- Each match entry contains
  - Source node id
  - Source process id
  - 64 match bits
  - 64 ignore bits
- A match entry is attached to a portal table entry
- Match entries can be linked to create a match list
- Can be automatically unlinked and freed from list when used up

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Match Entry Creation Functions

```
• int PtlMEAttach(
        ptl_handle_ni_t     ni_handle,
        ptl_pt_index_t      pt_index,
        ptl_process_id_t    match_id,
        ptl_match_bits_t    match_bits,
        ptl_match_bits_t    ignore_bits,
        ptl_unlink_t        unlink_op,
        ptl_ins_pos_t       position,
        ptl_handle_me_t     *me_handle
   );

• int PtlMEAttachAny(
        ptl_handle_ni_t     ni_handle,
        ptl_pt_index_t      *pt_index,
        ptl_process_id_t    match_id,
        ptl_match_bits_t    match_bits,
        ptl_match_bits_t    ignore_bits,
        ptl_unlink_t        unlink_op,
        ptl_ins_pos_t       position,
        ptl_handle_me_t     *me_handle
   );
```

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Match Entry Insertion Function

```
int PtlMEInsert(
    ptl_handle_me_t   base,
    ptl_process_id_t  match_id,
    ptl_match_bits_t  match_bits,
    ptl_match_bits_t  ignore_bits,
    ptl_unlink_t      unlink_op,
    ptl_ins_pos_t     position,
    ptl_handle_me_t   *me_handle
);
```

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Match Entry Destruction Function

- `int PtlMEUnlink( ptl_handle_me_t me_handle );`

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Memory Descriptor (MD)

- Describes regions of memory for data movement operations
- Defines what operations can be performed on the memory
- Can be automatically freed when used up

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Memory Descriptor Structure

- start
  - Starting address of memory region
- length
  - Length in bytes of memory region
- threshold
  - Maximum number of operations
- max_size
  - Largest incoming request
- options
  - See next slide
- user_ptr
  - User-specific value returned in events
- eq_handle
  - Event queue where operations are recorded

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Memory Descriptor Options

- **`PTL_MD_OP_PUT`**
  - Respond to put operations
- **`PTL_MD_OP_GET`**
  - Respond to get operations
- **`PTL_MD_MANAGE_REMOTE`**
  - Offset is specified in the request
- **`PTL_MD_TRUNCATE`**
  - Truncate incoming request to size of MD
- **`PTL_MD_ACK_DISABLE`**
  - Do not allow put acknowledgements
- **`PTL_MD_IOVEC`**
  - Start and length refer to a `ptl_md_iovec_t`
- **`PTL_MD_MAX_SIZE`**
  - Recognize the `max_size` value in the MD
- **`PTL_MD_EVENT_START_DISABLE`**
  - Turn off start events
- **`PTL_MD_EVENT_END_DISABLE`**
  - Turn off end events

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Scatter/Gather MD

- typedef struct {
    void   *iov_base;
    ptl_size_t   iov_len;
  } ptl_md_iovec_t;

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Memory Descriptor Creation Functions

- int PtlMDAttach(
  ptl_handle_me_t me_handle,
  ptl_md_t md,
  ptl_unlink_t unlink_op,
  ptl_handle_md_t *md_handle
  );

- int PtlMDBind(
  ptl_handle_ni_t ni_handle,
  ptl_md_t md,
  ptl_unlink_t unlink_op,
  ptl_handle_md_t *md_handle
  );

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Memory Descriptor Destruction Function

- `int PtlMDUnlink( ptl_handle_md_t md_handle );`

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Function to Change an Existing MD

```
int PtlMDUpdate(
    ptl_handle_md_t     md_handle,
    ptl_md_t            *old_md,
    ptl_md_t            *new_md,
    ptl_handle_eq_t     eq_handle
  );
```

- Primarily needed to allow for the atomic search-and-post function needed by MPI

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Event Queue (EQ)

- Circular queue that records operations on MDs
- Signal the start and end of data transmission into or out of an MD
- Finite number of entries
- Overflowing an event queue will overwrite events

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Event Entry Contents

- Event type
- Initiator of event (nid,pid)
- Portal table index
- Match bits
- Requested length
- Manipulated length
- Offset
- 64 bits of out-of-band data

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Type of Events

- PTL_EVENT_GET_START
- PTL_EVENT_GET_END
- PTL_EVENT_PUT_START
- PTL_EVENT_PUT_END
- PTL_EVENT_GETPUT_START
- PTL_EVENT_GETPUT_END
- PTL_EVENT_REPLY_START
- PTL_EVENT_REPLY_END
- PTL_EVENT_SEND_START
- PTL_EVENT_SEND_END
- PTL_EVENT_ACK
- PTL_EVENT_UNLINK

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Event Structure

```
• typedef struct {
        ptl_event_kind_t            type;
        ptl_process_id_t            initiator;
        ptl_uid_t                   uid;
        ptl_jid_t                   jid;
        ptl_pt_index_t              pt_index;
        ptl_match_bits_t            match_bits;
        ptl_size_t                  rlength;
        ptl_size_t                  mlength;
        ptl_handle_md_t             md_handle;
        ptl_md_t                    md;
        ptl_hdr_data_t              hdr_data;
        ptl_seq_t                   link;
        ptl_ni_fail_t               ni_fail_type;
        volatile ptl_seq_t          sequence;
} ptl_even_t;
```

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EQ Handlers

- **Not covered in this tutorial**

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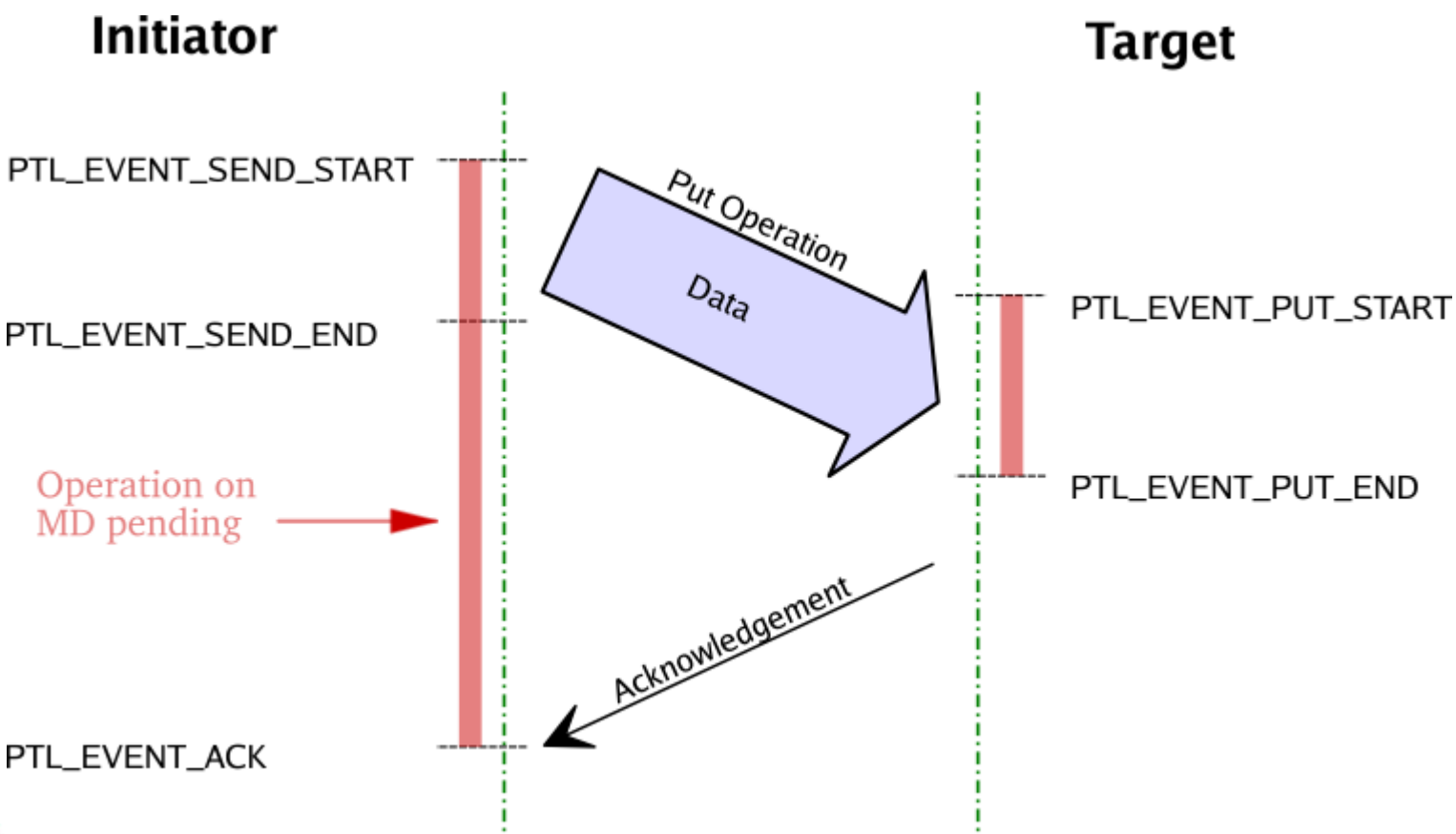
Events for a Put



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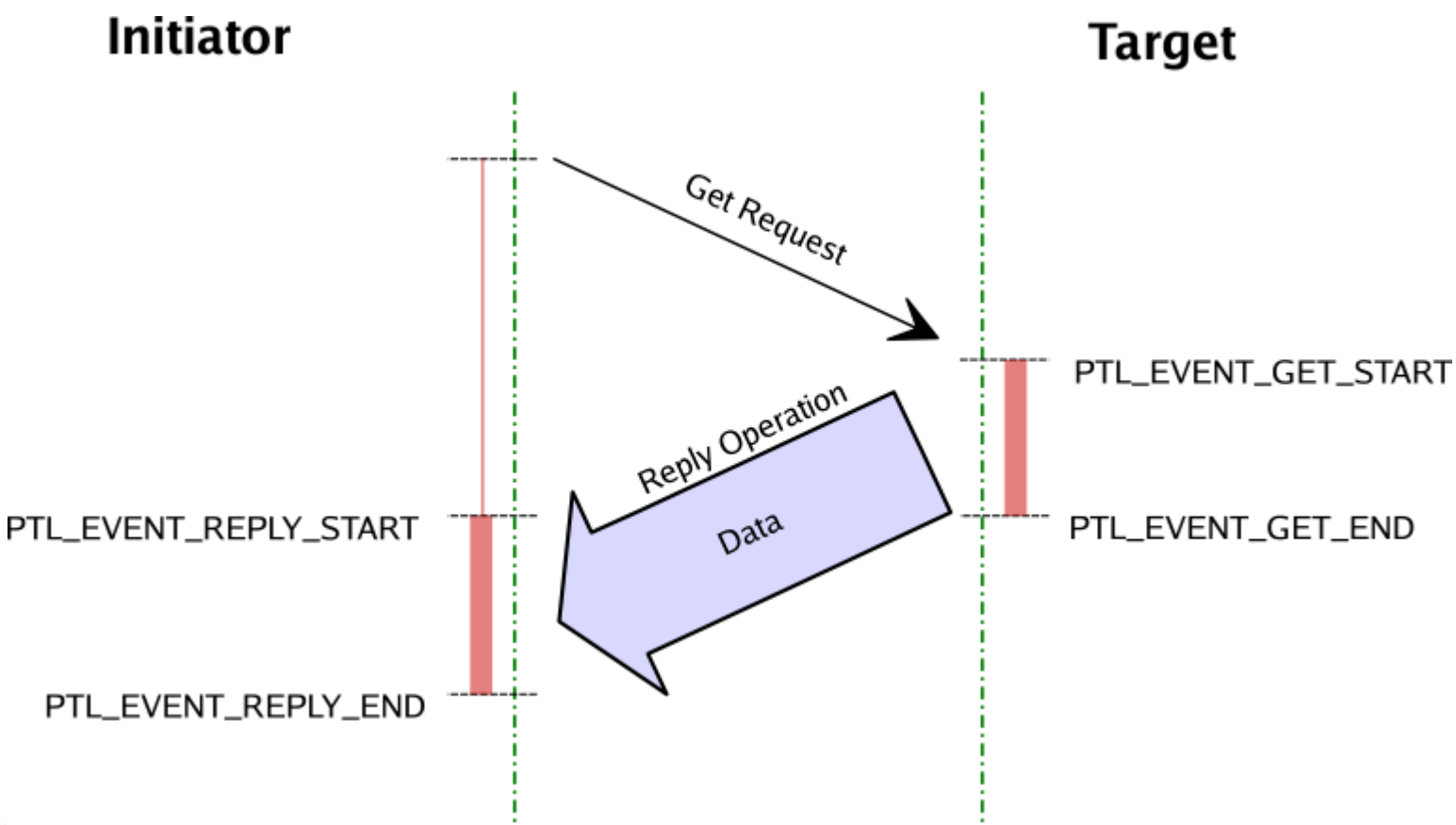
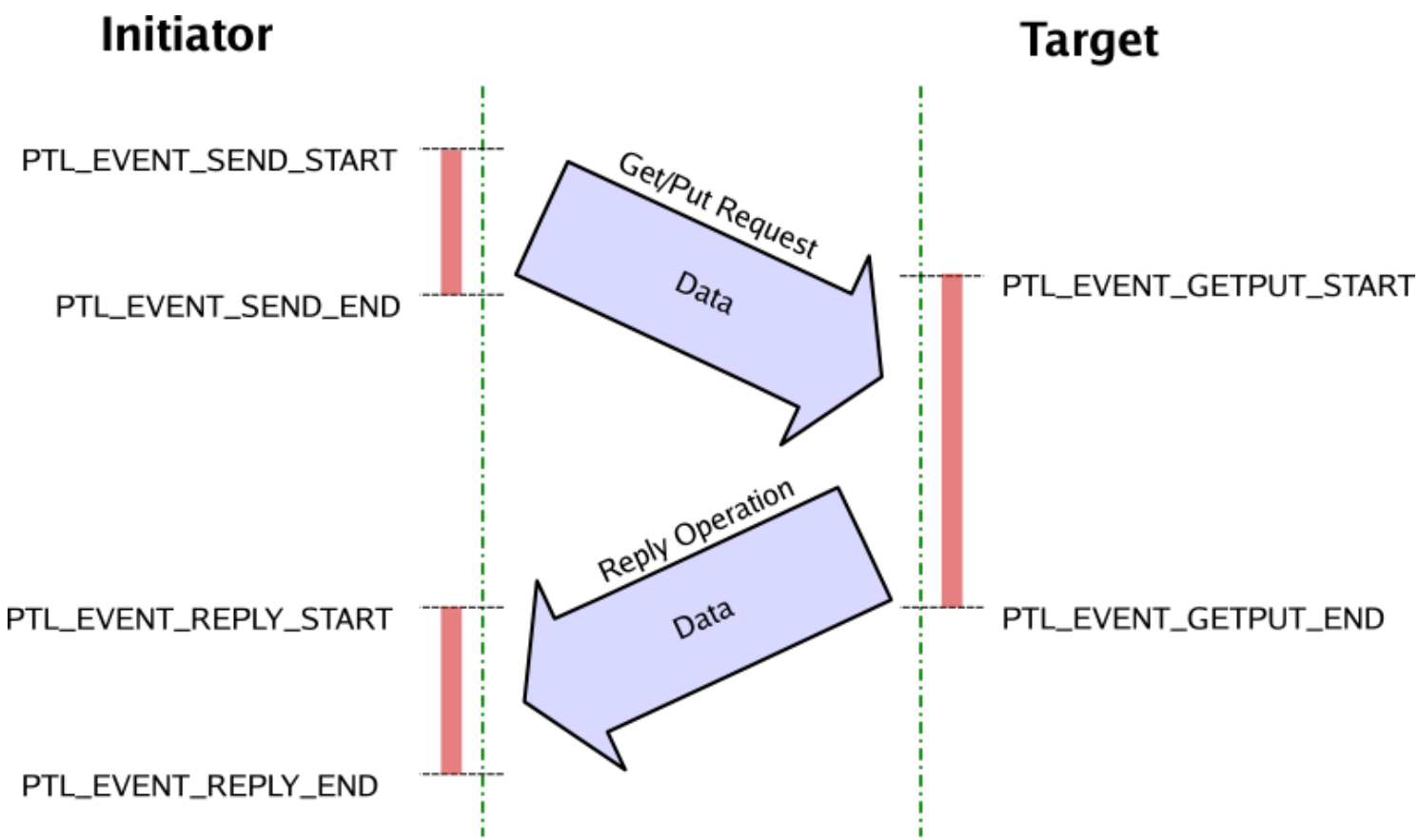
Events for a Get



Events for a GetPut



EQ Creation and Destruction Functions

```
• int PtlEQAlloc(
      ptl_handle_ni_t          ni_handle,
      ptl_size_t               count,
      ptl_eq_handler_t         eq_handler,
      ptl_handle_eq_t          *eq_handle
  );

• int PtlEQFree(
      ptl_handle_eq_t          *eq_handle
  );
```

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Functions for Obtaining Events

- int PtlEQGet(
    ptl_handle_eq_t eq_handle,
    ptl_event_t *event
  );

- int PtlEQWait(
    ptl_handle_eq_t eq_handle,
    ptl_event_t *event
  );

- int PtlEQPoll(
    ptl_handle_eq_t *eq_handles,
    int size,
    ptl_time_t timeout,
    ptl_event_t *event,
    int *which
  );

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Events, Packets, and Failure

- Portals ensures best effort delivery
- Underlying network may break messages into packets
- Two consequences
  - Out of order completion
    - Consequence of zero copy and packets
  - May trash application's memory
    - Consequence of failure, zero copy, and packets
- Event sequences
  - Start, followed by end (success) or fail
  - e.g., PUT_START, PUT_END
  - Failure is absolute
  - Nothing happens after end or fail

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Access Control

- Controls which processes are allowed to perform operations
- Default entry of 0 allows for all processes with the same user ID to communicate
- Operations that fail due to access control are not user-visible

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Access Control Table Manipulation Function

```
int PtlACEntry(
    ptl_handle_ni_t          ni_handle,
    ptl_ac_index_t           ac_index,
    ptl_process_id_t         match_id,
    ptl_uid_t                uid,
    ptl_jid_t                jid,
    ptl_pt_index_t           pt_index
  );
```

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Data Movement Operations

- **Put**
  - **Initiator sends data to a remote portal**
  - **Can receive an optional acknowledgment**
- **Get**
  - **Initiator sends request for remote data from a portal**
  - **Data is delivered to local memory descriptor**
- **GetPut**
  - **Atomic swap**

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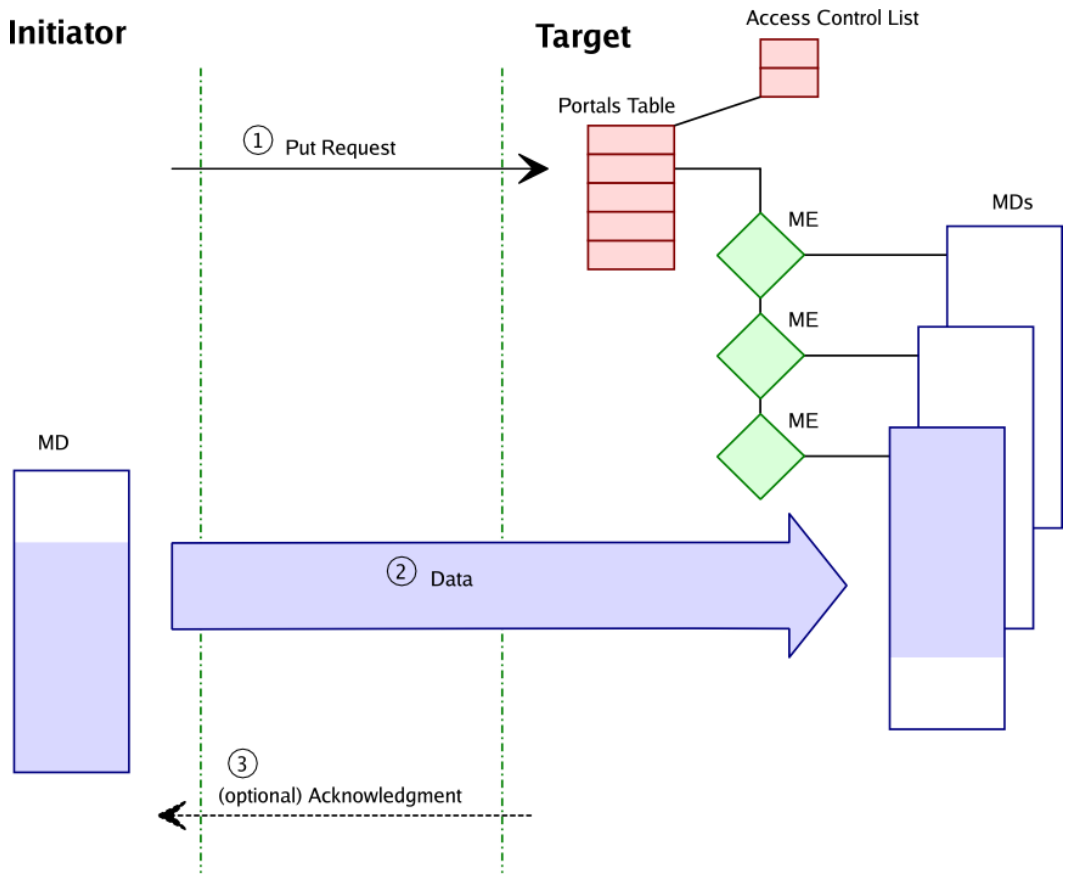
Put Operation



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Put Functions

- int PtlPut(
  ptl_handle_md_t md_handle,
  ptl_ack_req_t ack_req,
  ptl_process_id_t target_id,
  ptl_pt_index_t pt_index,
  ptl_ac_index_t ac_index,
  ptl_match_bits_t match_bits,
  ptl_size_t remote_offset,
  ptl_hdr_data_t hdr_data
  );

- int PtlPutRegion(
  ptl_handle_md_t md_handle,
  ptl_size_t local_offset,
  ptl_size_t length,
  ptl_ack_req_t ack_req,
  ptl_process_id_t target_id,
  ptl_pt_index_t pt_index,
  ptl_ac_index_t ac_index,
  ptl_match_bits_t match_bits,
  ptl_size_t remote_offset,
  ptl_hdr_data_t hdr_data
  );

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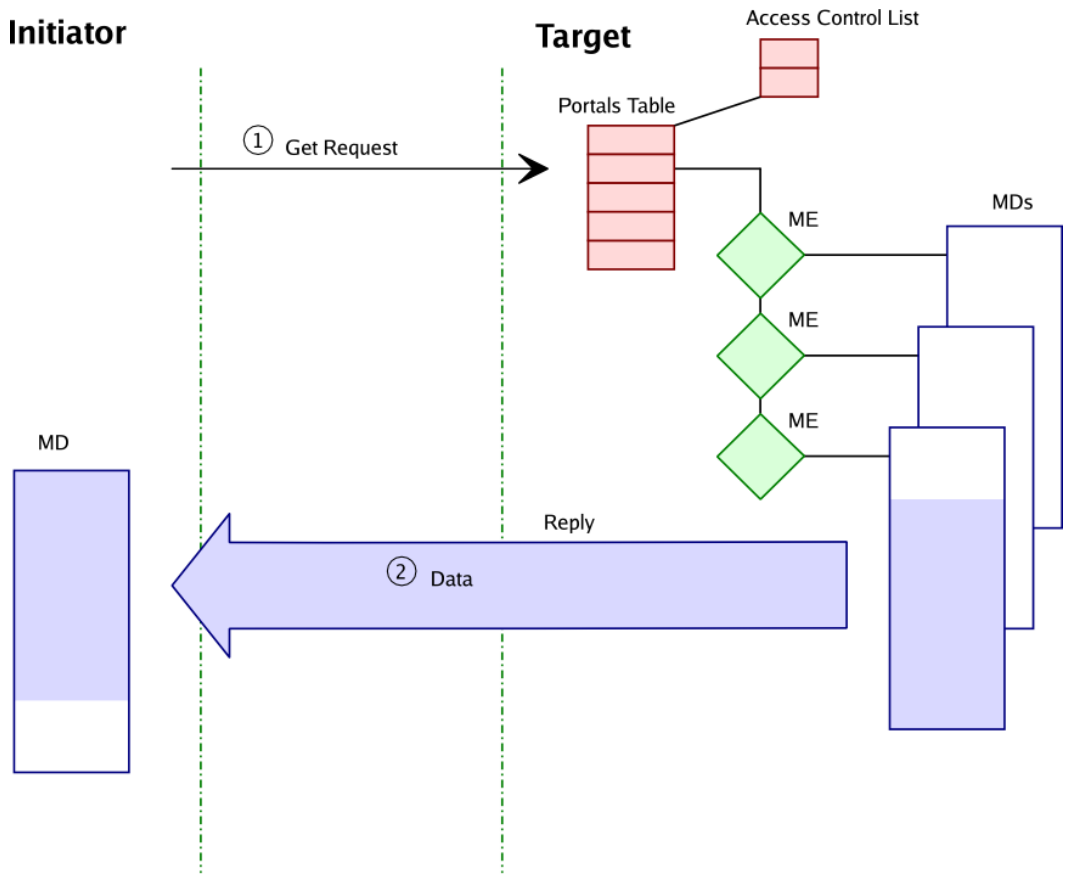
Get Operation



Get Functions

- int PtlGet(
  - ptl_handle_md_t md_handle,
  - ptl_process_id_t target_id,
  - ptl_pt_index_t pt_index,
  - ptl_ac_index_t ac_index,
  - ptl_match_bits_t match_bits,
  - ptl_size_t remote_offset
  -);
- int PtlGetRegion(
  - ptl_handle_md_t md_handle,
  - ptl_size_t local_offset,
  - ptl_size_t length,
  - ptl_process_id_t target_id,
  - ptl_pt_index_t pt_index,
  - ptl_ac_index_t ac_index,
  - ptl_match_bits_t match_bits,
  - ptl_size_t remote_offset,
  -);

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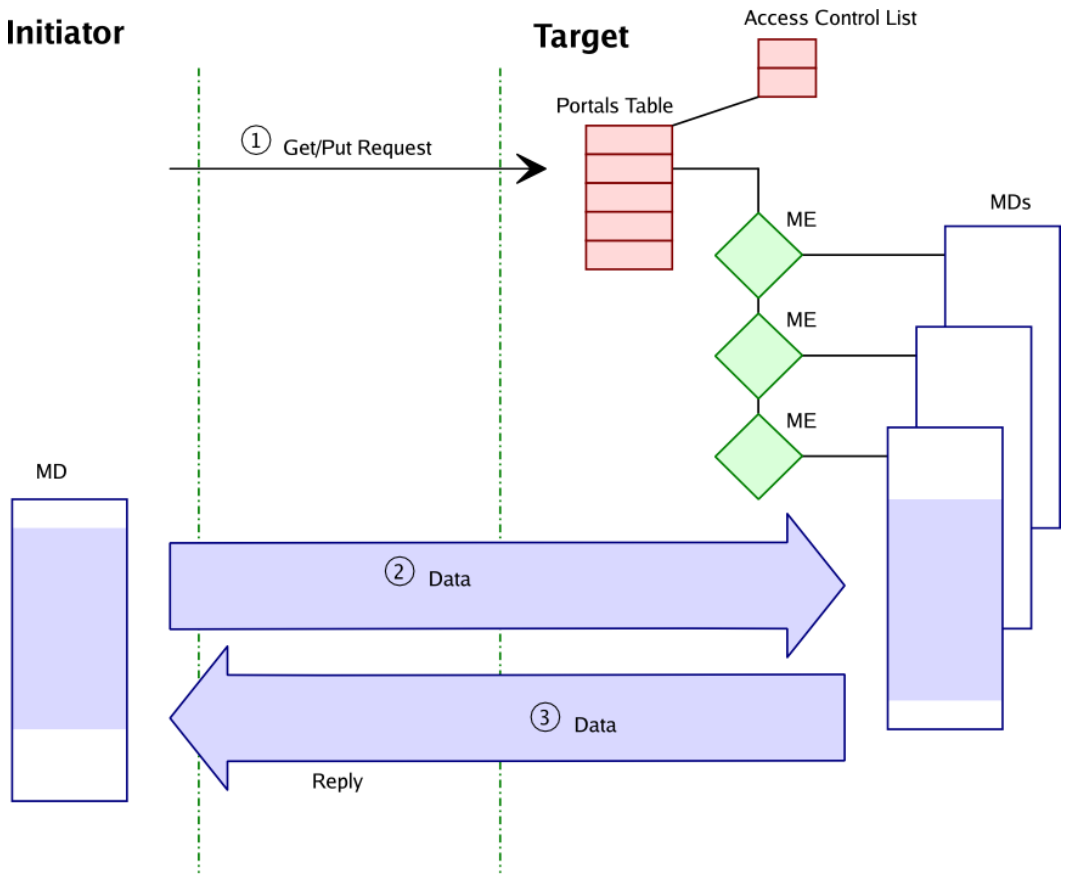
GetPut Operation



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GetPut Function

```
• int PtlGetPut(
      ptl_handle_md_t          get_md_handle,
      ptl_handle_md_t          put_md_handle,
      ptl_process_id_t         target_id,
      ptl_pt_index_t           pt_index,
      ptl_ac_index_t           ac_index,
      ptl_match_bits_t         match_bits,
      ptl_size_t               remote_offset
      ptl_hdr_data_t           hdr_data
    );
```

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Summary

- Minimal library space
  - Nothing depends on message size
  - All objects can be confirmed when created
- Designed for library writers
  - Not for application developers
  - Low-level API
    - We're happy to drop requests
    - Structures are complicated
    - Some functions (`PtlMDUpdate()`) are not obvious
- Designed to reflect underlying hardware
  - NICs
  - Packets and failure
- Provide the right amount of protection

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What Portals Does

- Separates communication space from computation space
  - Moderately dynamic
    - During descriptor construction
    - Any part of an application's memory can be used for communication
  - Simplifies coherence issues
    - Important for PCI implementations as well
- Handles important protocol processing
  - MPI long message strategy
    - Force rendezvous at receiver
    - Post and forget
  - Supports parallel servers

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What Portals Doesn't Do

- Dynamic integration of computation and communication space
  - May be needed for things like UPC
  - Race conditions
  - Memory consistency models
- Poor support for collectives
  - Each process must actively participate in collective operation
  - Would prefer to have a “contribute and forget” capability
  - Reduce variance in time for collective operations

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Example: Implementing MPI on Portals

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MPI on Portals

- Fundamental problem:
  - Rendezvous between sender and receiver
- Receiver can wildcard sender, sender cannot wildcard receiver
  - Destination is known
  - Origin may not be known
- Rendezvous must occur at the receiver
  - Easy if receiver is ready when send starts: use eager send
  - MPI standard recommends pre-posted receives

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How to do MPI

- Two portal entries
  - One for receiving messages
  - One for unexpected long messages
- Match list for receive portal
  - Expected, pre-posted, receives (MPI matching)
  - Unexpected short messages
  - Unexpected long messages
- Long MPI send – eager
  - Build an MD and add to unexpected long message portal
  - Perform the put
  - Unexpected messages are dropped and later read
- Short MPI send is eager
  - Build a free-floating MD
  - Perform the put
  - Unexpected messages held for matching receive
- Very short MPI send is eager
  - Copy user data into pre-allocated MD
  - Perform the put

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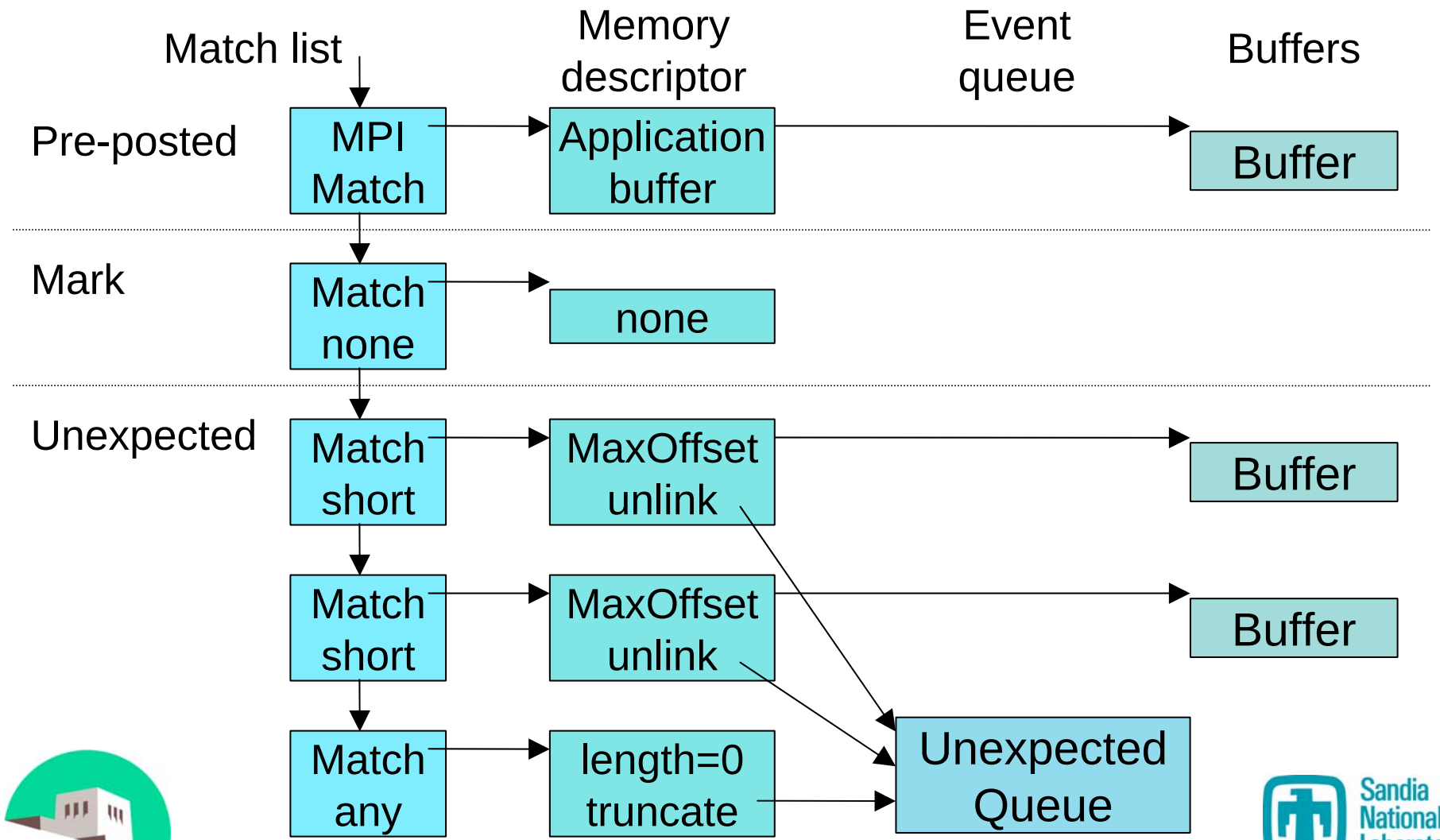
MPI Receive in Portals



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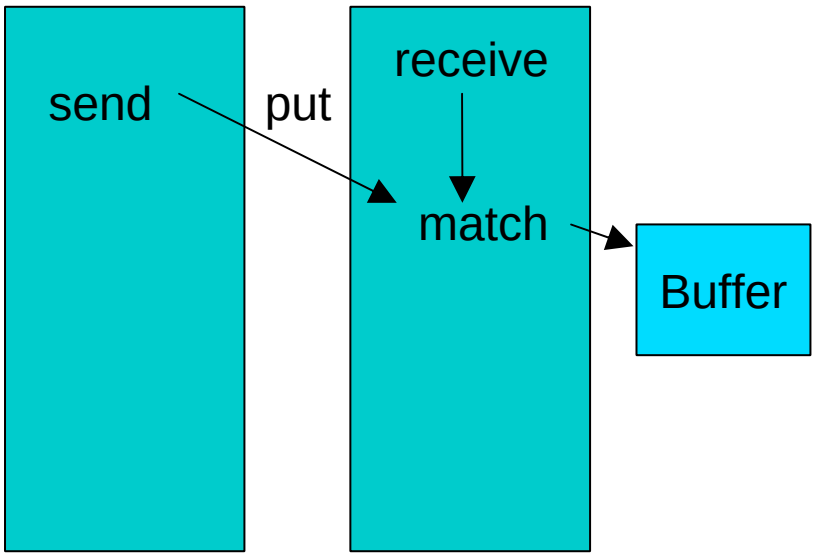
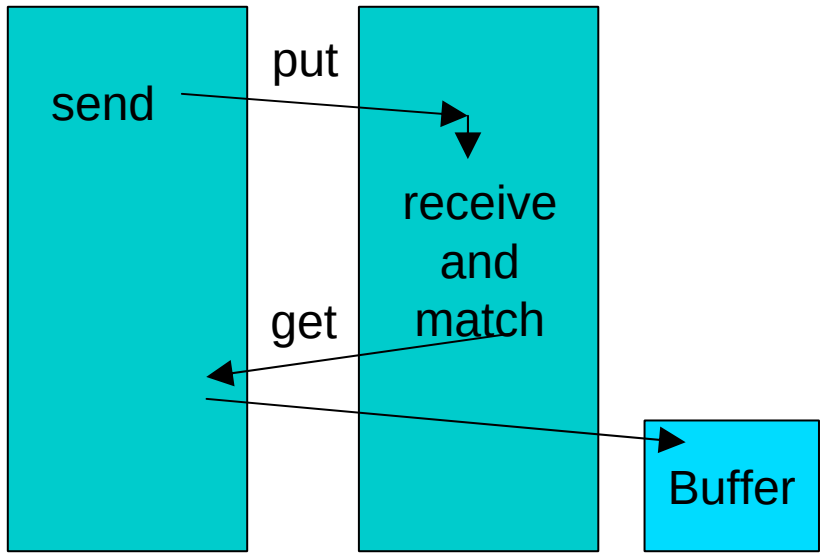
MPI Long Message Protocol

Pre-posted Receive



Late Receive



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Good Things to do with Portals

- Use catchalls at the end of every match list
  - Never have to worry about “losing” messages
  - Can be used to generate “negative” acknowledgments
- Use persistent MDs as much as possible
  - Catamount supports creating an MD over entire memory regions (data, stack, heap)
  - Can eliminate overhead of creating an MD each time

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XT3 Implementation

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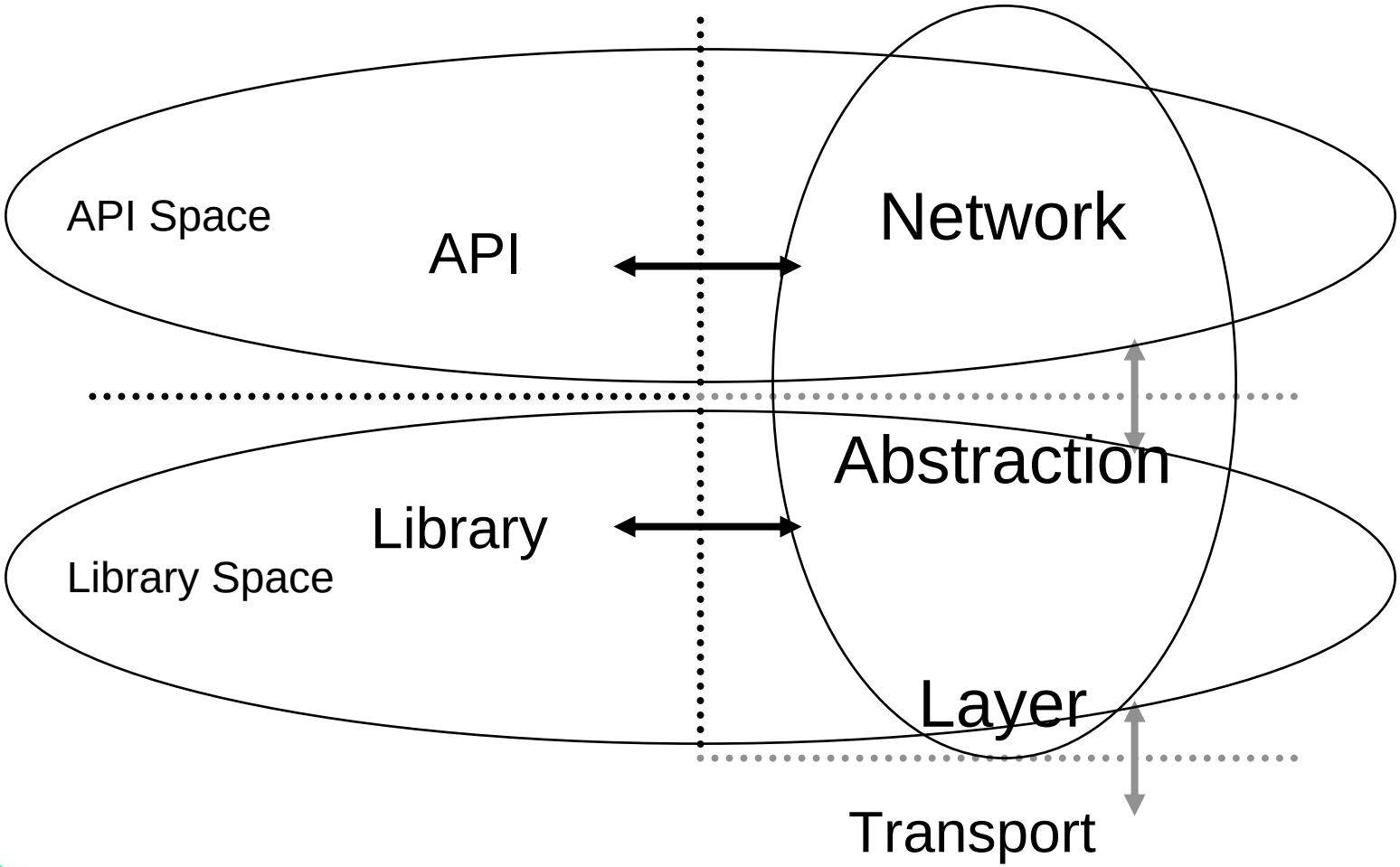
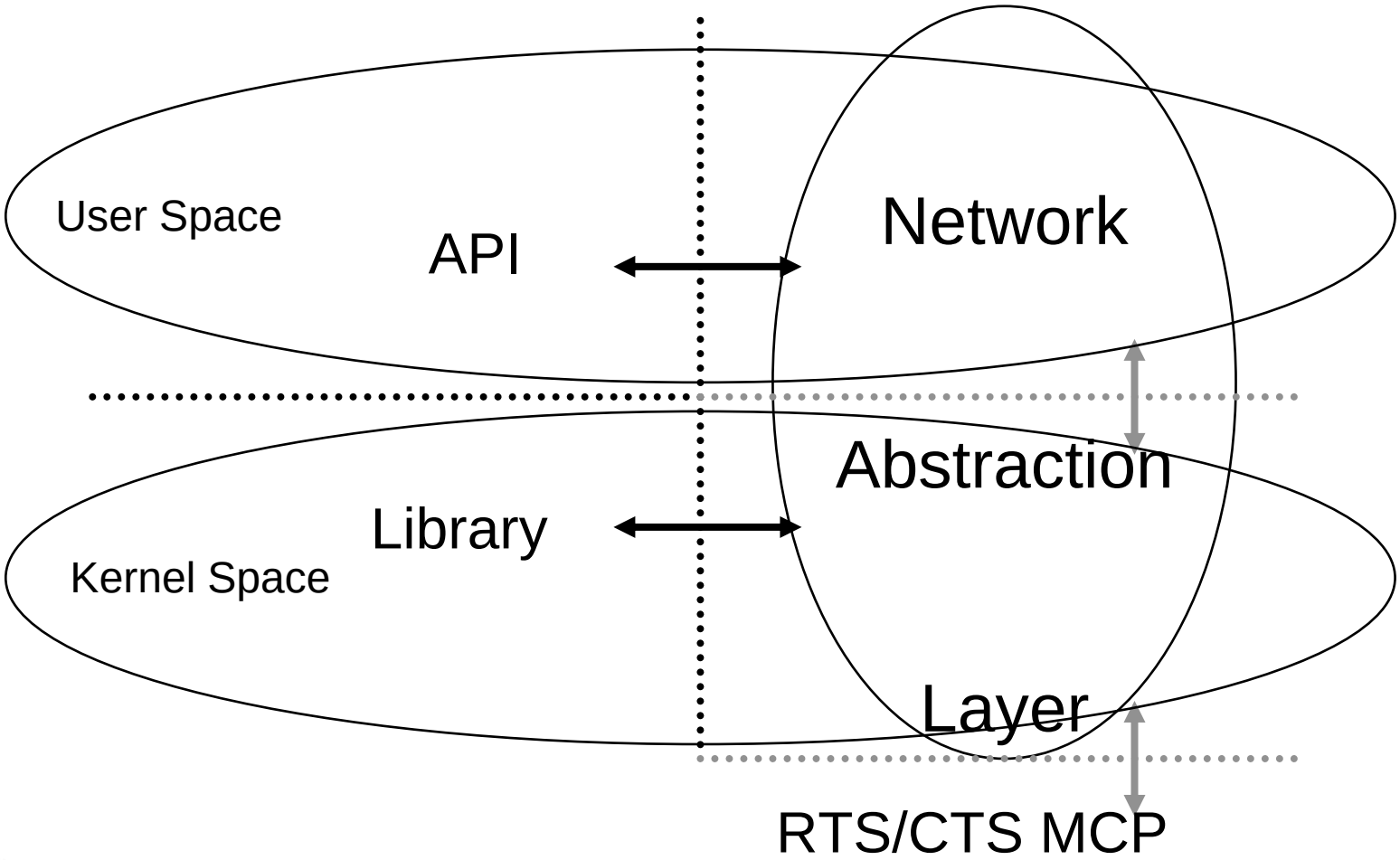
Portals Reference Implementation Design



Myrinet Kernel Implementation



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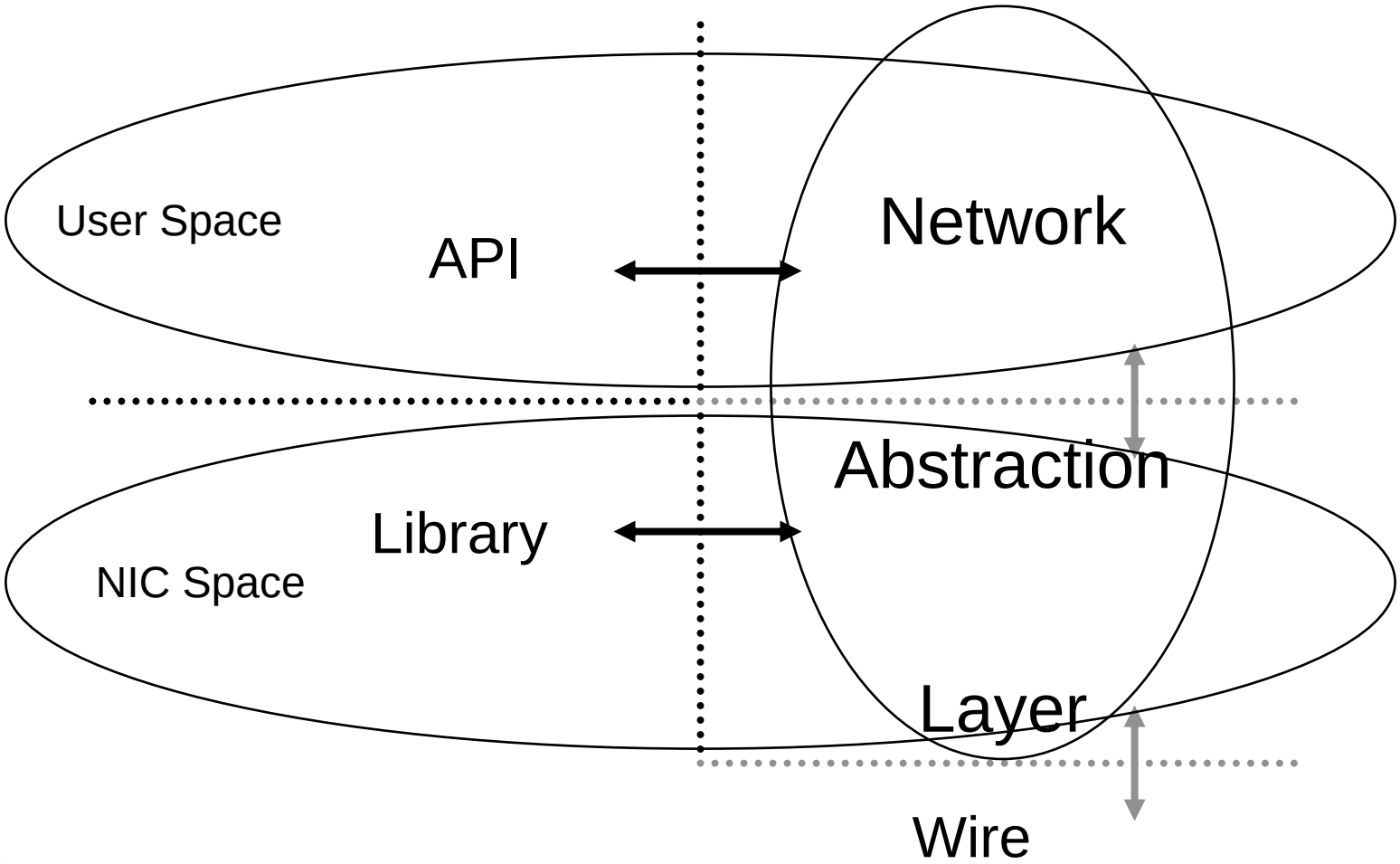
Myrinet MCP Implementation



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Cray SeaStar NIC/Router

- 16 1.6 Gb/s HyperTransport to Opteron
- 500 MHz embedded PowerPC 440
- 384 KB on-board scratch RAM
- Seven-port router
- Six 12-channel 3.2 Gb/s high-speed serial links

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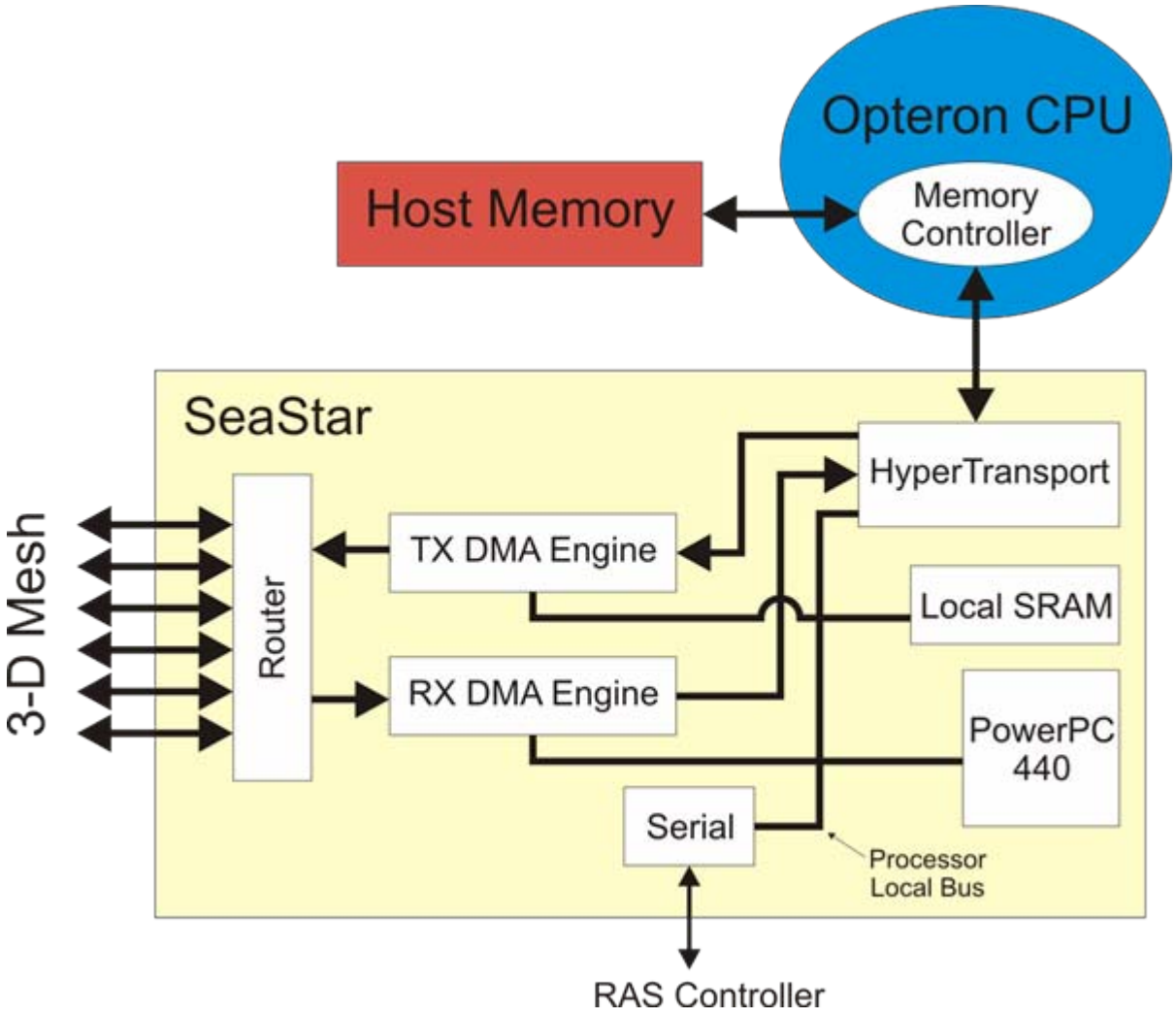
SeaStar Block Diagram



Portals 3.3 for SeaStar

- Cray started with Sandia reference implementation
- Needed single version of NIC firmware that supports all combinations of
  - User-level and kernel-level API
  - NIC-space and kernel-space library
- Cray added bridge layer to reference implementation to allow NAL to interface multiple API NALs and multiple library NALs
  - qkbridge for Catamount applications
  - ukbridge for Linux user-level applications
  - kbridge for Linux kernel-level applications

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SeaStar NAL

- Portals processing in kernel-space
  - Interrupt-driven
  - “generic” mode
- Portals processing in NIC-space
  - No interrupts
  - “accelerated” mode

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Upcoming

- "Accelerated" Portals – see talk on Thursday
- Portals collective library
  - Collective operations built on top of Portals
- Non-blocking collective functions
  - Collective operations integrated into Portals
  - SeaStar can support offloading collective operations
  - Barrier proof-of-concept is done and working
- Portals 4.0
  - Laundry list of issues with Portals 3.3 is too big
  - Unnecessary symmetry (`PTL_EVENT_SEND_START`)
  - Unneeded operations (arbitrary list insertion)

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XT3 Specifics

- Differences from the current specification
  - Send events are generated on a get
  - AC table is not implemented
- Keep N at 256 for N-to-1
- Use copy block for short messages to avoid wire-level acknowledgements
- No `PTL_EVENT_UNLINK`
- PtlNIDist() is not implemented
- Not all fields returned in an event structure are valid

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XT3 Portals Limits

- Max MEs: 2048
- Max MDs: 2048
- Max EQs: 512
- Max PT index: 128
- Max IOVECs: unlimited
- Max ME list: 2048
- Max GetPut size: 8
- Max outstanding messages: 2048

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Compiling for XT3

- #include”portals/portals3.h”
- module add PrgEnv-gcc or PrgEnv-pgi
- Must be compiled with qk-gcc
  - PGI and GNU don’t align consistently

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Compute Node OS Library

- #include”catamount/cnos_mpi_os.h”
- int cnos_get_rank()
- int cnos_get_size()
- cnos_nidpid_map_t *nidpid;
- nidpid_size = cnos_get_nidpid_map(&nidpid);
- int cnos_barrier()

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Questions?

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