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Notice revision #20110804
OpenSHMEM* and the Impact of System Evolution
OpenSHMEM* vs MPI-3 RMA

```
shmem_int_put(
    char *target,
    const char *source,
    size_t nelems,
    int pe
);  
shmem_int_p(
    char *target,
    const char *source,
    int pe
);
```

```
MPI_Put(
    MPI_Datatype origin_dtype,
    MPI_Datatype target_dtype,
    MPI_Aint target_disp,
    MPI_Win win,
    const void *origin,
    int origin_count,
    int target_count,
    int target_rank,
    );
```
OpenSHMEM*: Thin and Light

OpenSHMEM* API is very thin
- As small as target PE, target address, and immediate data
- Also has source pointer and length version

Smallest implementations used 3 flit (8B flit) Put Request
- Limited node space
- Limited framing
- Depended on link level reliability
- As little as 1 flit response

T3D*/T3E* used more bits of overhead

<table>
<thead>
<tr>
<th>Element</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Node</td>
<td>15 bits</td>
</tr>
<tr>
<td>Source Node</td>
<td>15 bits</td>
</tr>
<tr>
<td>Framing</td>
<td>34 bits</td>
</tr>
<tr>
<td>Target Address</td>
<td>64 bits</td>
</tr>
<tr>
<td>8B Payload</td>
<td>64 bits</td>
</tr>
<tr>
<td>Total#</td>
<td>24 B</td>
</tr>
<tr>
<td>Total# w/ Resp.</td>
<td>32 B</td>
</tr>
</tbody>
</table>

#These totals are not indicative of any specific implementation
Early SHMEM* System Environment

Systems were small(er)
  • No more than 2048 nodes
  • Two cores per node

Memory was symmetric
  • Simplifies programming and implementation

Round-trip bandwidth delay product was small
  • Hundreds of megabytes per second
  • 1.5 μs of round-trip latency

Applications were simple
  • Written in a single API/language
  • Written by a single author (effectively)

MPI was new
  • Could be layered on SHMEM* at small scale

Systems were single user (sort of)
  • At a minimum, partitioned
  • Limited need for protection

Filesystems were (almost) an afterthought
## System Characteristics: Then and Now

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Then</th>
<th>Now</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Scale (Nodes)</td>
<td>2048</td>
<td>128K</td>
</tr>
<tr>
<td>Cores per Node</td>
<td>2</td>
<td>16-60 (and growing)</td>
</tr>
<tr>
<td>Memory per Node</td>
<td>Hundreds of MB</td>
<td>Tens of GB</td>
</tr>
<tr>
<td>OS</td>
<td>Microkernel</td>
<td>“Standard” Linux*</td>
</tr>
<tr>
<td>Protection need</td>
<td>“Hard” Partitioned</td>
<td>Multi-user</td>
</tr>
<tr>
<td>Network Ordering</td>
<td>Deterministic Request / Adaptive Response</td>
<td>Adaptive</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>150 MB/s</td>
<td>10 GB/s</td>
</tr>
<tr>
<td>Round-trip delay</td>
<td>1.5 µs</td>
<td>1.5 µs</td>
</tr>
<tr>
<td>Message Rate</td>
<td>18 Mmsgs/s</td>
<td>120 Mmsgs/s</td>
</tr>
<tr>
<td>Messaging API</td>
<td>None Established</td>
<td>MPI dominant, PGAS emerging</td>
</tr>
<tr>
<td>Applications</td>
<td>(relatively) simple</td>
<td>Tens of Libraries</td>
</tr>
</tbody>
</table>
What do those changes bring?(1)

More bits! Lots more bits...

- Bigger LID space
- Many more packets in flight (transaction tracking bits)
- Protection
  - Pkey
  - Other protection bits
- End-to-end reliability

<table>
<thead>
<tr>
<th>Item</th>
<th>Bits</th>
<th>Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>LID</td>
<td>+4</td>
<td>Both</td>
</tr>
<tr>
<td>transactions</td>
<td>+3</td>
<td>Both</td>
</tr>
<tr>
<td>PKey</td>
<td>+16</td>
<td>Both</td>
</tr>
<tr>
<td>End-to-End</td>
<td>+32</td>
<td>Both</td>
</tr>
<tr>
<td>Sequence #</td>
<td>+16</td>
<td>Both</td>
</tr>
<tr>
<td></td>
<td>(or more)</td>
<td></td>
</tr>
<tr>
<td>RKey</td>
<td>+32</td>
<td>Request</td>
</tr>
</tbody>
</table>
What do those changes bring? (2)

Harder translation
- Local to the target node, and process context specific
- Hard to do at system level
- Deeper page table hierarchies

Symmetric addresses are harder to guarantee
- Can be done (if you turn off some options in Linux*)...
  - ...most of the time

Fence is not free
- Fence is typically quiet

More process contexts
- Wire must ID context at initiator/target
- Allow more processes than cores (resource allocation issue)
OpenSHMEM* over Portals 4
http://code.google.com/p/portals-shmem/
Portals Philosophy

Use building blocks...
- Use composable pieces
- Maintain API symmetry where reasonable
- If done properly, one functionality serves many needs

...to capture application semantics for many APIs...
- Portals does not implement fence(), quiet(), or barrier(), but has the tools to build them
- Portals is not MPI_Isend()/MPI_Irecv(), but does handle:
  - Matching
  - Unexpected messages

...in a way that is friendly to offload.
- Blocks are “simple”
Attempt #1: Initial Extensions to Portals 4

Added several general purpose building blocks

- Nonmatching interface
- Counting events for lightweight completion
- Breadth of atomic operations
  - MPI sets a high bar for this one
- Triggered operations for collectives

Achieved fundamental goal: building blocks were reusable

- Counting events + Atomic operations + triggered operations == collectives
What We Learned

Nonmatching interface must be very limited to get it right
  • Wanted something that could be fully pipelined
  • Multiple substantial revisions to achieve that

Needed a path for blocking puts
  • SHMEM* puts expected to be locally complete on return
  • Portals puts were fully nonblocking
    – Added query for size below which Portals could locally complete

Ordering is... hard...
  • Many, many assumptions about ordering, atomicity, operation interactions in various PGAS implementations
  • Completely rewrote the ordering definition
Memory Layout

---

stack

heap

Sym. heap

data

text
Memory Layout

- Stack
- Put MD
- Get MD
- Heap
- Sym.
- Heap LE
- Data
- Data LE
- Text
Portals Data Structures

portal table

- Heap PT
- Data PT
- Put MD
- Get MD
- Heap LE
- Data LE
- Err EQ
- Put CT
- Get CT
- Target CT

NI
Put Operations

void shmem_long_p(long *addr, long value, int pe) {
    ptl_process_t peer;
    ptl_pt_index_t pt;
    long offset;
    peer.rank = pe;
    GET_REMOTE_ACCESS(addr, pt, offset);

    PtlPut(shmem_internal_put_md_h,
            (ptl_size_t) &value,
            sizeof(value),
            PTL_CT_ACK_REQ,
            peer,
            pt,
            0,
            offset,
            NULL,
            0);

    shmem_transport_portals4_pending_put_counter++;
GET_REMOTE_ACCESS()

#ifdef ENABLE_REMOTE_VIRTUAL_ADDRESSING
#define PORTALS4_GET_REMOTE_ACCESS_ONEPT(target, pt, offset)
   do {
      pt = (one_pt);
      offset = (uintptr_t) target;
   } while (0)
#endif

#else
#define PORTALS4_GET_REMOTE_ACCESS_TWOPT(target, pt, offset)
   do {
      if ((void*) target < shmem_internal_heap_base) {
         pt = (data_pt);
         offset = (char*) target - (char*) shmem_internal_data_base;
      } else {
         pt = (heap_pt);
         offset = (char*) target - (char*) shmem_internal_heap_base;
      }
   } while (0)
#endif

# Memory Layout

<table>
<thead>
<tr>
<th></th>
<th>stack</th>
<th>heap</th>
<th>Sym. heap</th>
<th>data</th>
<th>text</th>
</tr>
</thead>
<tbody>
<tr>
<td>Put MD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Get MD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One LE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Variant: Portals Data Structures

- NI
- Portal Table
  - One PT
  - Err EQ
  - Put MD
  - Get MD
  - One LE
  - Put CT
  - Get CT
- Target CT
Get Operations

void shmem_double_get(double *target, const double *source,
                       size_t len, int pe) {

    ptl_ct_event_t ct;
    peer.rank = pe;
    GET_REMOTE_ACCESS(source, pt, offset);

    PtlGet(shmem_internal_get_md_h,
           (ptl_size_t) target,
           len * sizeof(double),
           peer,
           pt,
           0,
           offset,
           0);
    shmem_internal_pending_get_counter++;  
    PtlICTWait(shmem_internal_get_ct_h,
               shmem_internal_pending_get_counter,
               &ct);

}
Fence & Quiet

```c
void shmem_quiet(void) {
    ptl_ct_event_t ct;

    /* wait for remote completion (acks) of all pending events*/
    PtlCTWait(shmem_internal_put_ct_h,
              shmem_internal_pending_put_counter, &ct);
}

void shmem_fence(void) {
    if (shmem_internal_total_data_ordering == 0) {
        shmem_quiet();
    }
}
```
Address Wait

```c
void shmem_int_wait(int *var, int value) {
    ptl_ct_event_t ct;

    while (*var == value) {
        PtlCTGet(target_ct_h, &ct);
        if (*var != value) return;
        PtlCTWait(target_ct_h, ct.success + 1, &ct);
    }
}
```
Lock

Implements MCS locks

Encodes last/next/signal into one 64 bit field

Uses masked swap to change individual bits
Strided Operations: Still Open...

Portals 4 team has evaluated strided operations multiple times

Strided operation definitions are not very consistent across APIs

- SHMEM*
- MPI
- GASNet*
- ARMCII*
Impacts on Hardware
Some Challenges

Remote completions: is a quiet really quiet?
- PCI* Express uses a posted write model
- Hard to know when it is “really done” without a lot of overhead

Atomics have implementation challenges
- Caches on a PCI* Express device would require a way to flush that cache to re-enter a “safe” state. When would you do that?
- No caches on a PCI* Express device mean repeated atomics (e.g. lock contention) would be slow

Hardware collective engines require setup
- Would be nice to have an allocated descriptor of PEs that will be in a collective
System Scale Challenges

End-to-end reliability and blocking puts are incompatible

• Old way:
  – TCP: we will copy your data into the kernel and do end-to-end retransmit
  – RDMA: we will retransmit from user space
  – Custom networks: we will send your data once and work really hard on getting it there

• End-to-end (user space to user space) retransmits is one of the few tools left in the reliability toolbox

Where did I put that PE?

• At 10 million PEs, there is a table lookup that is bad
• Hardware can help – if you can help us help you
Longer Term

How can we make OpenSHMEM* better?

• SHMEM* has always been focused on being a thin layer

• Let’s keep it that way
  – Perform hardware / software co-design
  – Only add the things that hardware can reasonably support
Thoughts on the Future
Evolution

Threading: we need a definition of how threading works

- This will impact hardware
- This will take time to get right...
  - ...for the API/users
  - ...for the hardware

Learn from MPI: Communicators are probably too heavyweight, but...

- Collectives could use a place to attach a fixed set of nodes
- It would be nice to support layered libraries
  - Collective isolation
  - Completion semantics
  - Library relative addressing / protection

Consider fault tolerance: what trade-offs belong in hardware vs software?

- Portals can tell you when individual messages fail:
  - Can you use that information?
  - How would OpenSHMEM* tell the user?
Think about the ecosystem

Transparency is good
- Set objectives for releases
- Set target dates for releases
- Discuss everything before changing it: the crowd can be wiser than you think
- Prototype *everything* in open source before adding it

Don’t move randomly
- Document motivations
- Be transparent

Don’t break compatibility (often)
- Extensions are good, changing existing semantics is bad

Don’t require weird OS hooks or configurations
- “Most of the time” is not good enough
Call for Participation: OFA WG

https://www.openfabrics.org/downloads/OFWG/

http://lists.openfabrics.org/cgi-bin/mailman/listinfo/openframeworkwg
