To INT_MAX...and beyond!

Exploring large-count support in MPI

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The large-count problem

- A count in MPI refers the number of elements of the specified type, e.g. Send(buf,count,FLOAT,…).
- In_ILn_LPn_P to refer to the sizes of the C types *int*, *long*, and *void**, respectively.
- Circa MPI-1, most systems were ILP32 or at least had less than 2 GiB of memory per node.
- On IL32P64 and I32LP64 systems, one can allocate more than 2 GiB and thus potentially have buffers with more elements than can be represented as an 32-bit integer (such as C *int*).
- Let’s not talk about Fortran…

Example 1

```
size_t n = INT_MAX+(size_t)42;
char * stuff = malloc(n);
if (myrank==0) memset(stuff, 7, n);
MPI_Bcast(stuff, n, MPI_CHAR, 0, mycomm);
```

Q: Assuming your compiler let's you pass a size_t into an int, what will happen?

A: You will not get what you want.

Example 2

```
int n = INT_MAX/2;
double * stuff = malloc(n);
if (myrank==0) memset_double(stuff, 42.0, n);
MPI_Bcast(stuff, n, MPI_DOUBLE, 0, mycomm);
```

The count does not overflow, but if the implementation converts all communication to bytes internally, then there will be an internal overflow.

This is the *other* large-count problem.

What MPI-3 offers

- MPI_Foo_x routines provide a large-count equivalent of an existing MPI_Foo to make rudimentary large-count support possible:
  - MPI_Get_elements_x
  - MPI_Type_size_x
  - MPI_Type_get_extent_x
  - MPI_Type_get_true_extent_x
  - MPI_Status_set_elements_x
- The MPI Forum decided that these routines, in conjunction with intelligent use of MPI datatypes, was sufficient for large-count support.

What is this paper about?

- Evaluate the Forum's assertion that a handful of utility routines and user-defined datatypes are sufficient for large-count support.
- Implement a high-level library on top of MPI (called BigMPI) that makes it possible to enable large-count support in applications with minimal source changes.
- Otherwise demonstrate how large-count support can be achieved with MPI-3 features.
- Investigate count-safety of MPI implementations.
- Suggest improvements to the MPI standard (MPI-4) related to large-counts.

```c
int BigMPI_Send_x(const void *buf,
                  MPI_Count count, MPI_Datatype dt,
                  int dest, int tag, MPI_Comm comm)
{
    int rc = MPI_SUCCESS;
    if (likely (count <= INT_MAX )) {
        rc = MPI_Send(buf, (int)count, dt, dest, tag, comm)
    }else{
        MPI_Datatype newtype;
        BigMPI_Type_contiguous_x(count, dt, &newtype);
        MPI_Type_commit(&newtype);
        rc = MPI_Send(buf, 1, newtype, dest, tag, comm);
        MPI_Type_free(&newtype);
    }
    return rc;
}
```

```
int BigMPI_Type_contiguous_x(MPI_Count count, MPI_Datatype oldtype,
                             MPI_Datatype * newtype)
{
    assert(count<SIZE_MAX); /* has to fit into MPI_Aint */
    MPI_Count c = count/INT_MAX, r = count%INT_MAX;
    MPI_Datatype chunks, remainder;
    MPI_Type_vector(c, INT_MAX, INT_MAX, oldtype, &chunks);
    MPI_Type_contiguous(r, oldtype, &remainder);

    MPI_Aint lb /* unused */, extent;
    MPI_Type_get_extent(oldtype, &lb, &extent);
    MPI_Aint remdisp = (MPI_Aint)c*INT_MAX*extent;
    int blklens[2] = {1,1};
    MPI_Aint disps[2] = {0,remdisp};
    MPI_Datatype types[2] = {chunks,remainder};
    MPI_Type_create_struct(2, blklens, disps, types, newtype);
    MPI_Type_free(&chunks);
    MPI_Type_free(&remainder);
    return MPI_SUCCESS;
}
```

BigMPI Design

- Only focused on IL32P64 and I32LP64 systems with less than 2^{64} bytes of memory.
- Focus on large-count buffers of built-in datatypes: BigMPI_Type_contiguous_x is used throughout to turn (large_count,built_in_type) into (1,large_count_type).
- Assume that all library overhead is negligible compared to moving >2 GiB of data.
- All-or-nothing w.r.t. large-counts; no specialization if only some counts are large.
- Avoid things that require init/finalize...

Things that are easy

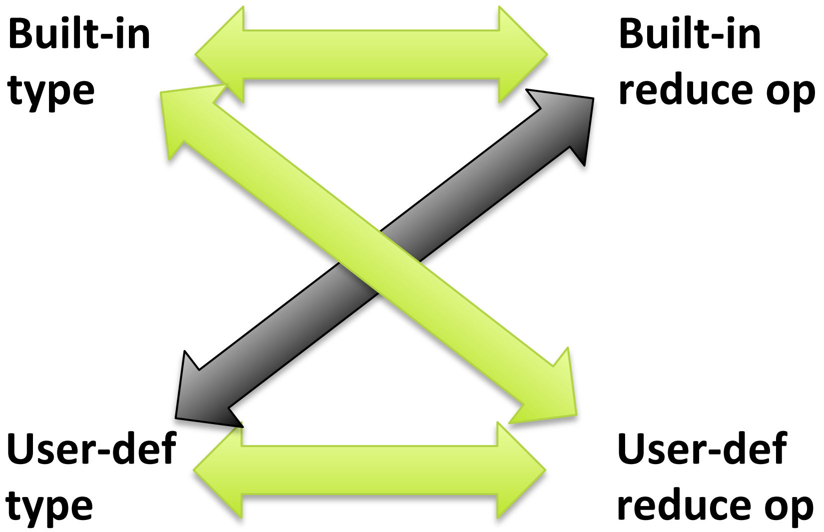
- Point-to-point (two-sided and one-sided) are trivial using the aforementioned template.
- Scalar-argument data-moving collectives – Bcast, Scatter, Gather, Allgather, Alltoall – are similarly trivial.

These are the most common MPI operations and thus for some applications, the large-count problem is minor.

`BigMPI_Type_contiguous_x` wasn’t trivial to get right the first time…

Reductions are a problem

- Blocking collectives can be broken into **multiple operations** with normal counts.
- Blocking operations can use a large-count type and associated **user-defined reduce operation**.
- Implementations do not optimize user-defined reductions…



This situation is only true for reductions! RMA allows the black arrow as long as the user-def type is homogeneous.

In-place reductions

```
MPI_User_function(void* invec, void* inoutvec,
                  int *len, MPI_Datatype *datatype);
```

It is impossible to use MPI_IN_PLACE within a user-defined reduction!

There are other issues with this function signature…

Nonblocking reductions

- A reduction of e.g. 2^{32} doubles is something one would like to overlap with computation…
- Can't break into multiple messages and return a single request. Defining special request object and test/wait operations within BigMPI is gross.
- No way to free the large-count type or reduce op when the reduction is finished due to lack of callbacks in request completion.
- MPI generalized requests are terrible; MPICH generalized requests are good but non-portable.

Large-count in user-defined reductions

```
int BigMPI_Decode_contiguous_x(
    MPI_Datatype intype,
    MPI_Count * count, MPI_Datatype * basetype)
```

Repeated calls to `MPI_Type_get_envelope` and `MPI_Type_get_contents` are required to determine the original large-count associated with a type.

81 lines of tedious code for the trivial case of a contiguous large-count type!

Vector-argument collectives

- Scatterv, Gatherv, Allgatherv, Alltoallv take a vector of counts and a *single datatype*.
- Vector of (count,type) turns into vector of (1,large_count_type), which means a *vector of types*.
- Only Alltoallw supports a vector of types…

```
int MPI_Gatherv(const void * sendbuf, int sendcount,
                MPI_Datatype sendtype,
                void * recvbuf, const int recvcounts[],
                const MPI_Aint rdispls[], MPI_Datatype recvtype,
                int root, MPI_Comm comm)
```

Vector-argument collectives

1. Implementation in terms of two-sided is easy if we do a naïve implementation (not bad), but requires Comm_dup for THREAD_MULTIPLE at any target (who could post wildcard Recv).
2. Can implement in terms of one-sided in the same manner if we create and destroy a window on-the-fly.
3. Try to use a more general collective: Alltoallw.

BigMPI aspires to implement all three strategies, but 2 is not finished and 1 lacks MULTIPLE support.

Alltoallw to the rescue???

- Scatterv/Gatherv -> Alltoallw is gross.
- …*to allow maximum flexibility, the displacement of blocks within the send and receive buffers is specified in bytes*. [MPI-3 page 173]
- We have a large-count problem with the displacements even if none of the original counts overflows (just their sum has to)!

```
int MPI_Alltoallw(const void* sbuf, const int scounts[],
    const int sdispls[], const MPI_Datatype stypes[],
    void* rbuf, const int rcounts[],
    const int rdispls[], const MPI_Datatype rtypes[],
    MPI_Comm comm)
```

Neighborhood_alltoallw to the rescue!

- New in MPI-3; requires topological communicator.
- Displacement problem solved by MPI_Aint.
- Large-count Scatterv requires:
  - A distributed-graph communicator unique for each (root,comm).
  - Vector(s) of all ones (the counts).
  - Vector(s) of displacements, which are all zero in some cases.
  - Vector(s) of large-count types.

```
int MPI_Neighborhood_alltoallw(const void* sbuf, const int scounts[],
    const MPI_Aint sdispls[], const MPI_Datatype stypes[],
    void* rbuf, const int rcounts[],
    const MPI_Aint rdispls[], const MPI_Datatype rtypes[],
    MPI_Comm comm)
```

Associated utility functions

```
int BigMPI_Create_graph_comm(MPI_Comm mycomm,
                             int root, MPI_Comm * dist_graph_comm);

void BigMPI_Convert_vectors(int num, int splat_old_count,
     const MPI_Count oldcount, const MPI_Count oldcounts[],
     int splat_old_type, const MPI_Datatype oldtype,
     const MPI_Datatype oldtypes[],
     int zero_new_displs, const MPI_Aint olddispls[],
     int newcounts[], MPI_Datatype newtypes[],
     MPI_Aint newdispls[]);
```

Both of these functions are O(nproc) but negligible compared to Alltoallw.

The nonblocking problem

- Point-to-point approach entails a vector of requests…
- MPI-3 lacks nonblocking RMA epochs, but win create/free cannot be nonblocking. Nonblocking RMA epochs proposed in SC14 paper…
- Nowhere to deallocate temporary vectors in the case of nonblocking alltoallw.
- Even if deallocation done during generalized request, cannot free comm there. Creating likely graph comms for each user comm is evil.

Addressing implementation issues

- Prior to 3.1, MPICH used C int internally in dataloop code and ROMIO. Rob and Clang did the heavy lifting required to eliminate all places where truncation/overflow could occur (at least according to test suite…).
- Linux, BSD and Darwin do one of two evil things with `ssize_t write(int fd, const void *buf, size_t count);` that will affect both I/O and sockets code. MPI implementations must chunk calls to this operation in spite of its apparent large-count safety.

MPI-4: Suggestion #1

Reconcile reductions and accumulate by generalizing reductions to include the features of accumulate.

This is a glaring asymmetry in the MPI standard that was noticed independent of large-count support.

1. G. Bosilca, "Extend predefined MPI Op's to user defined datatypes composed of a single, predefined type," 2008. https://svn.mpi-forum.org/trac/mpi-forum-web/ticket/34
2. D. Goodell and J. Dinan, "MPI Accumulate-style behavior for predefined reduction operations," 2012. https://svn.mpi-forum.org/trac/mpi-forum-web/ticket/338

MPI-4: Suggestion #2

Enhance user-defined reductions to support MPI_IN_PLACE as well as pipelining.

There needs to be a new proposal here, because the existing ticket isn't likely to move forward.

1. J. Dinan, "User-defined op with derived datatypes yields space-inefficient reduce," 2012.
   https://svn.mpi-forum.org/trac/mpi-forum-web/ticket/339

MPI-4: Suggestion #3

Add large-count datatype support explicitly.

Only the contiguous case has been proposed, but it leads to an obvious consistency if not done for all cases.

MPI_Type_get_envelope_x and MPI_Type_get_contents_x are required as well as all of the large-count combiners.

1. J. Hammond, "Add MPI_Type_contiguous_x," 2014. https://svn.mpi-forum.org/trac/mpi-forum-web/ticket/423

MPI-4: Suggestion #4

Support large-count vector collectives explicitly.

Fixes the glaring problem with unsafe displacements where the sum but not the individual counts exceed INT_MAX.

Makes the standard longer but the implementations are straightforward.

1. J. Hammond, "Large-count v-collectives," 2014. https://svn.mpi-forum.org/trac/mpi-forum-web/ticket/430

MPI-4: Suggestion #5

Improve the generalized request progress model.

This would solve all of the issues with nonblocking operations in BigMPI.

There are a myriad of other good uses of MPICH-style generalized requests…

1. J. Träff and T. Höfler, "Exposing progress in generalized requests," 2007. https://svn.mpi-forum.org/trac/mpi-forum-web/ticket/457

Related Work

Model	Count	Displacement	Implementations
OpenSHMEM	size_t	ptrdiff_t	unknown; conduit-dependent
GASNet	size_t	size_t	unknown; conduit-dependent
GA/ARMCI	int	int	N/A

Good system software appears to have transitioned from int to size_t, but the MPI Forum stubbornly insists upon backwards ABI-compatibility.

https://github.com/jeffhammond/BigMPI

This is research software, not an Intel product.

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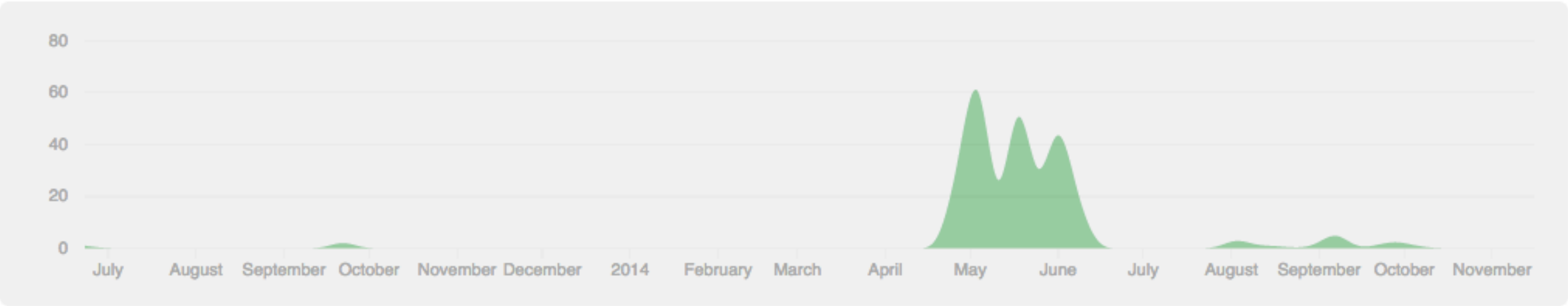
Application motivation

- **Why *shouldn't* users be able to straightforwardly do MPI stuff with any buffer they can allocate?**
- HDF [http://blogs.cisco.com/performance/new-things-in-mpi-3-mpi_count/]
- Quantum chemists in Europe asked me for help with this, which is what inspired the idea of BigMPI; some of their issues are Fortran-related…
- Andreas – a bona fide application developer – blog-shamed me into making BigMPI happen.
- I/O aggregation (e.g. ALCF GLEAN project) can easily end up with large-count subcomm Gatherv as memory per node increases.

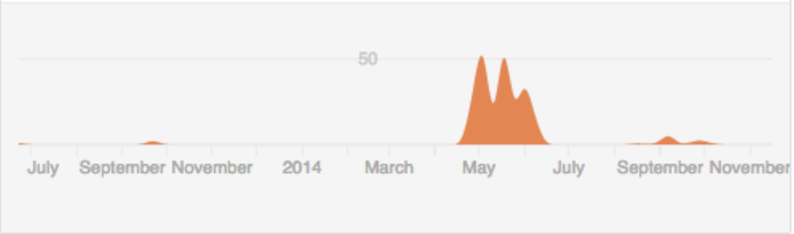
Jun 23, 2013 – Nov 16, 2014

Contributions to master, excluding merge commits

Contributions: **Commits**



jeffhammond #1
261 commits / 45,067 ++ / 9,088 --



gentryx #2
34 commits / 971 ++ / 65 --

roblatham00 #3
5 commits / 80 ++ / 21,000 --