Chapel Unblocked:

Recent Communication Optimizations in Chapel

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CRAY

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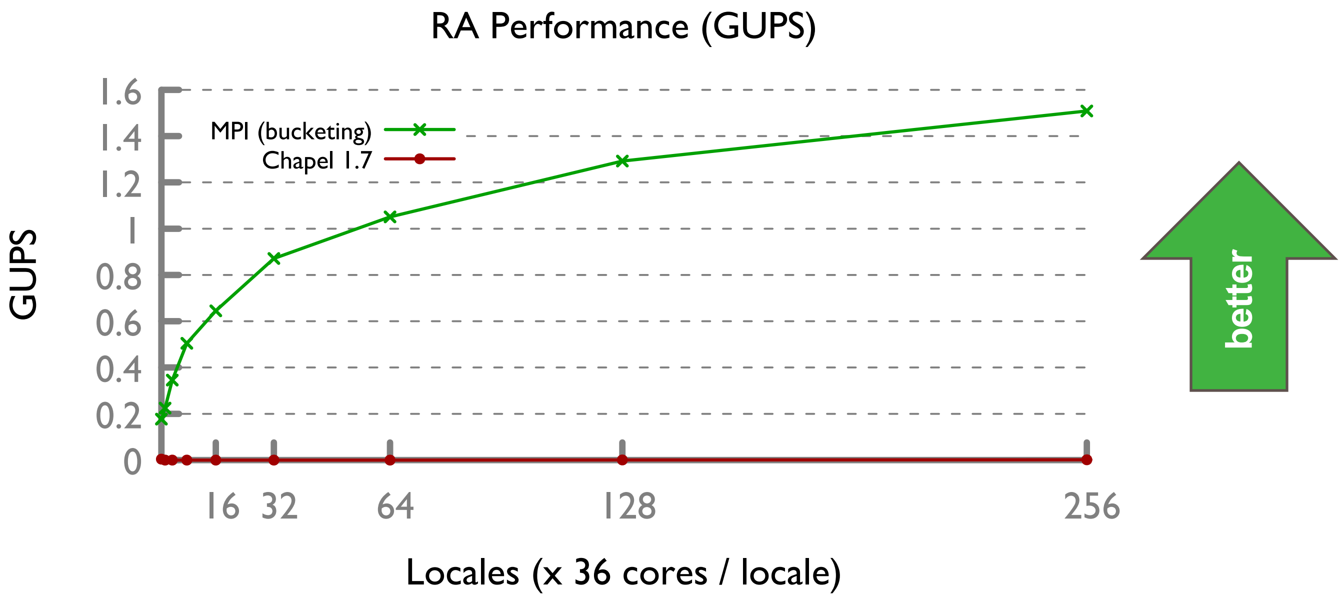
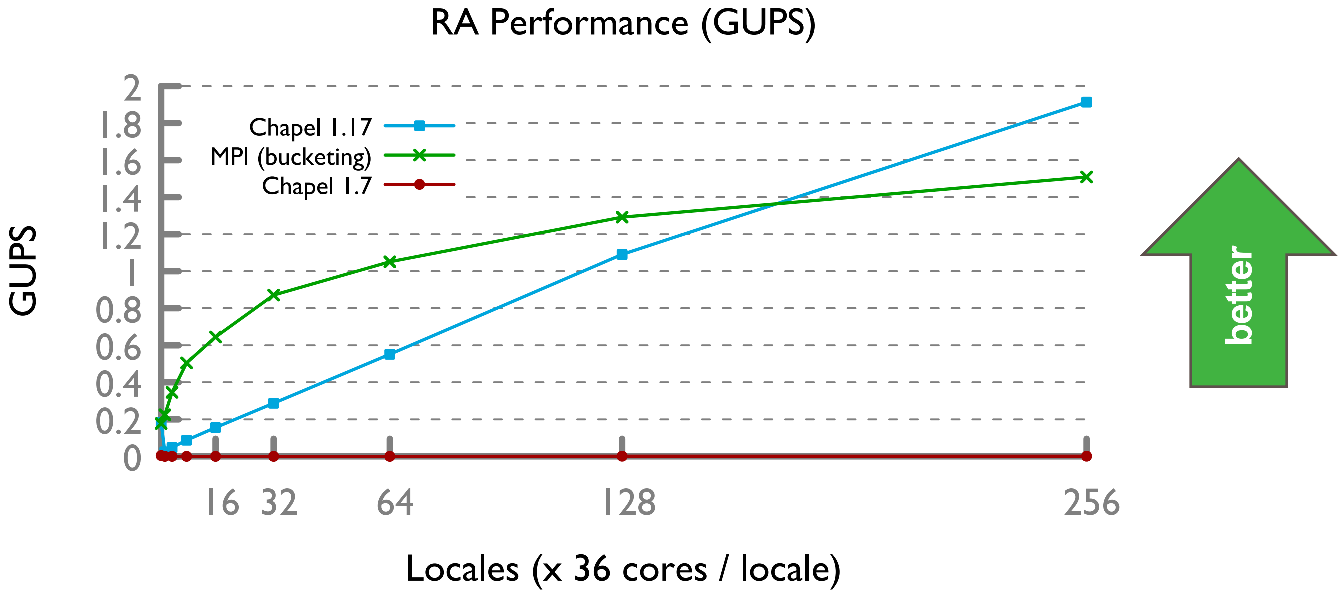
CHIUW 2018 Performance Summary

- In Chapel 1.7 performance was very far off from reference MPI/UPC/SHMEM



CHIUW 2018 Performance Summary

- With 1.17 many applications could achieve performance parity
  - However, still possible to fall off a performance cliff for other applications



Plan for this Talk

- We have implemented dozens of significant optimizations since last year
  - Our performance optimizations are largely benchmark driven

- This talk will focus on 3 key benchmarks and communication optimizations
  - ISx -- Bulk communication optimizations
  - Stream -- Remote task spawning optimizations
  - Random Access -- Fine-grained communication optimizations

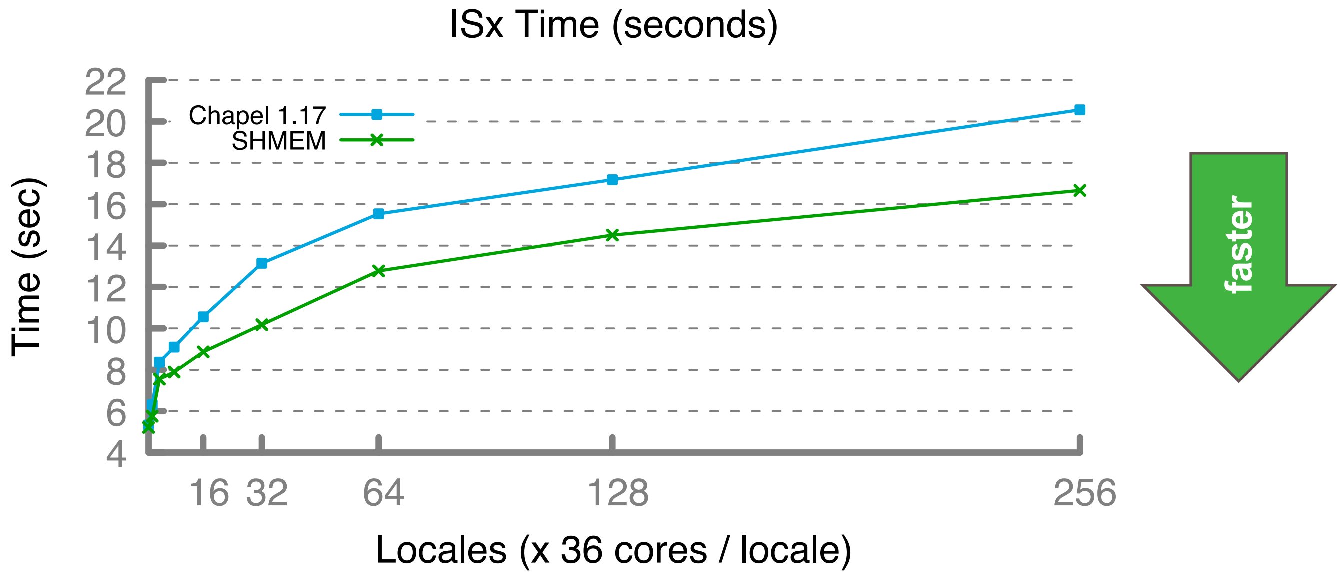
ISx Optimization

ISx: Background

- Scalable Integer Sort benchmark
  - Developed at Intel, published at PGAS 2015
  - SPMD-style computation with barriers
  - Punctuated by all-to-all bucket-exchange pattern
    - buckets being exchanged are relatively large (100's of MBs)
  - References implemented in SHMEM and MPI

ISx: Background

- Chapel 1.17 scaled well, but raw performance was up to 30% behind SHMEM



ISx: Large Message Optimization

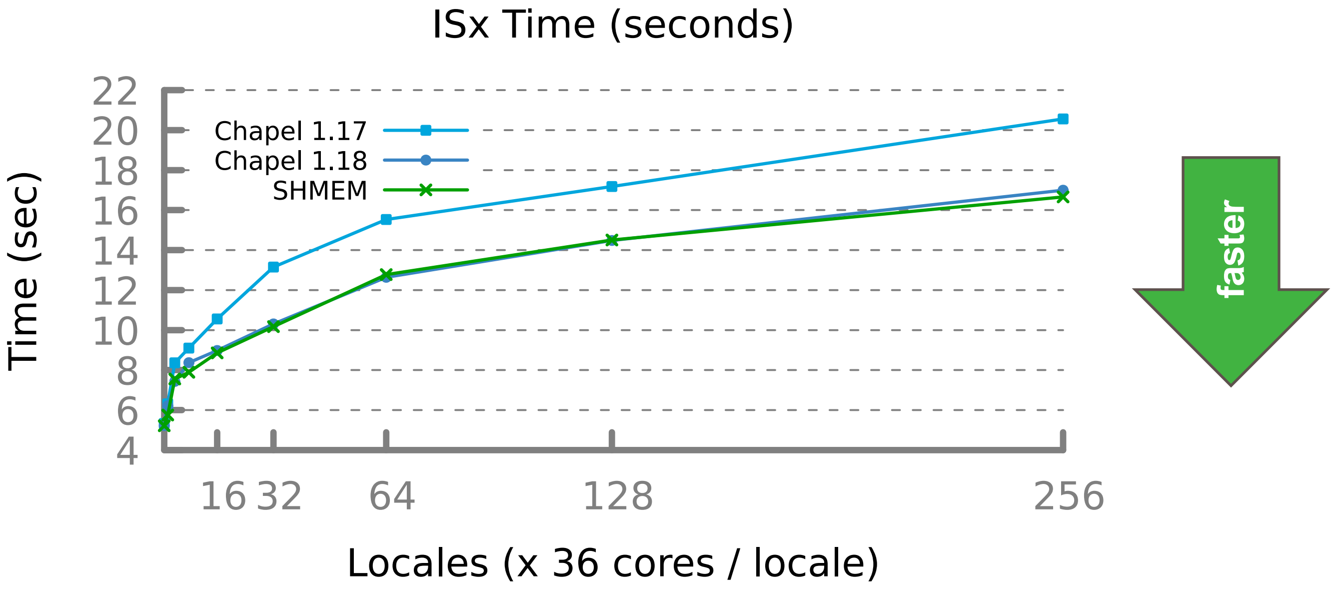
- On Crays Chapel uses the uGNI library to implement communication
  - uGNI provides 2 remote memory access mechanisms
    - Fast Memory Access (FMA)
    - Block Transfer Engine (BTE)

- Prior to 1.18, all communication was initiated with FMA
  - Discovered that BTE offers significantly better performance for large transfers

- In 1.18 we switched to initiating large transfers (4K or larger) with BTE
  - Significantly increased sustained bandwidth, can fully saturate network now

ISx: Performance Impact

- Chapel 1.18 performs on par with reference SHMEM version



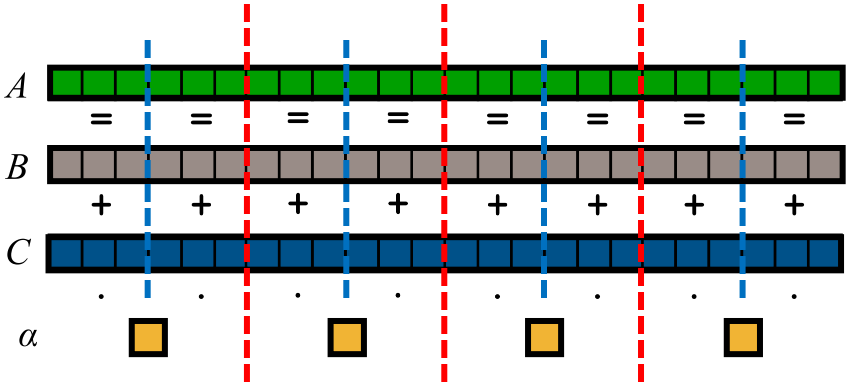
Stream Optimization

STREAM Triad: a trivial parallel computation

Given: m-element vectors A, B, C

Compute: $\forall i \in 1..m,\ A_i = B_i + \alpha \cdot C_i$

In pictures, in parallel (distributed memory multicore):



Stream: Background

- Multiple variants of Stream benchmark exist, e.g.:
  - **EP:** Explicit SPMD, uses local arrays, task spawning not included in time
  - **Global:** Elegant, uses block distributed arrays, task spawning included in time

Stream EP

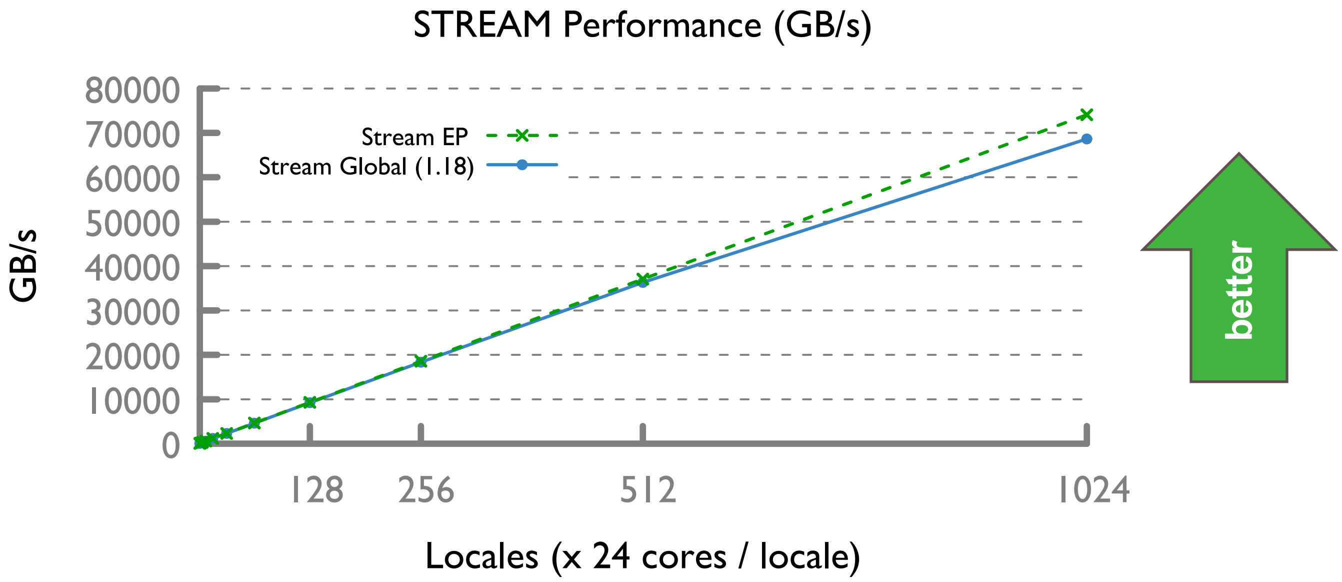
```
coforall loc in Locales do on loc {
  var A, B, C: [1..m] real;
  initVectors(B, C);

  startTimer();

  forall (a, b, c) in zip(A, B, C) do
    a = b + alpha * c;

  stopTimer();
}
```

Global Stream

```
const Space = {1..m} dmapped Block({1..m});
var A, B, C: [Space] real;
initVectors(B, C);

startTimer();

forall (a, b, c) in zip(A, B, C) do
  a = b + alpha * c;

stopTimer();
```

Stream: Background

- In 1.18, Global Stream performance lagged at higher locale counts



Stream: Task Spawning Optimization

- Task creation and on-statements are used to create remote tasks
- A common idiom is to create a task on each locale

```
coforall loc in Locales do on loc { body(args); }
```

Stream: Task Spawning Optimization

- Under 'ugni' in 1.18, remote-coforalls were translated into something like:

```
var endCount: atomic int = Locales.size;
for loc in Locales {
  var ACK = startRemoteTask(loc, bodyWrap, args, endCount);
  while (!received(ACK)) {}



}
endCount.waitFor(0);

proc bodyWrap(args, endCount) { body(args); endCount.sub(1); }
```

Stream: Task Spawning Optimization

- Under 'ugni' in 1.18, remote-coforalls were translated into something like:

```
var endCount: atomic int = Locales.size;
for loc in Locales {
  var ACK = startRemoteTask(loc, bodyWrap, args, endCount);
  while (!received(ACK)) {} // problem, network round trip wait



}
endCount.waitFor(0);


proc bodyWrap(args, endCount) { body(args); endCount.sub(1); }
```

Stream: Task Spawning Optimization

- They are now translated into something like:

```
var endCount: atomic int = Locales.size;
for loc in Locales {
  var ACK = startRemoteTask(loc, bodyWrap, args, endCount);
  ackBuff[ackIndex()] = ACK;
  if ackBuff.full() then          // normally not full, so no waiting
    retireAtLeastOneTX();         // fast, usually a few ready to retire
}
endCount.waitFor(0);

proc bodyWrap(args, endCount) { body(args); endCount.sub(1); }
```

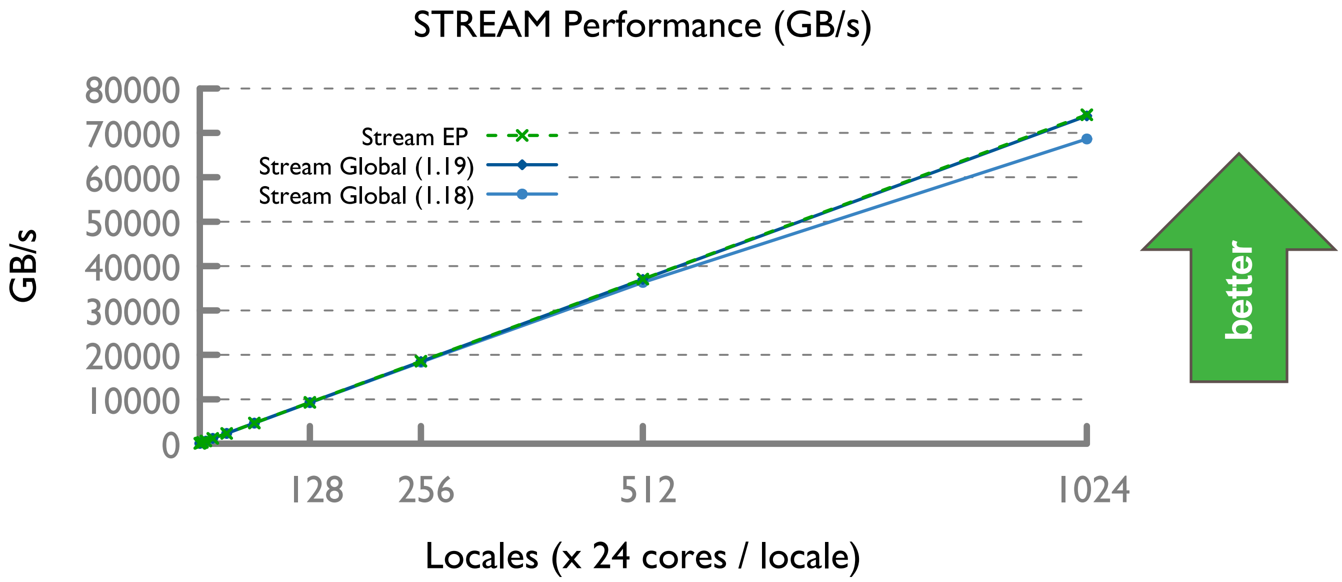
Stream: Task Spawning Optimization

- Other optimizations reduced the amount of communication required
  - Most remote tasks can be initiated with a single non-blocking transaction

- Combined, these optimizations resulted in 9x faster task creation at 1,024 locales

Stream: Performance Impact

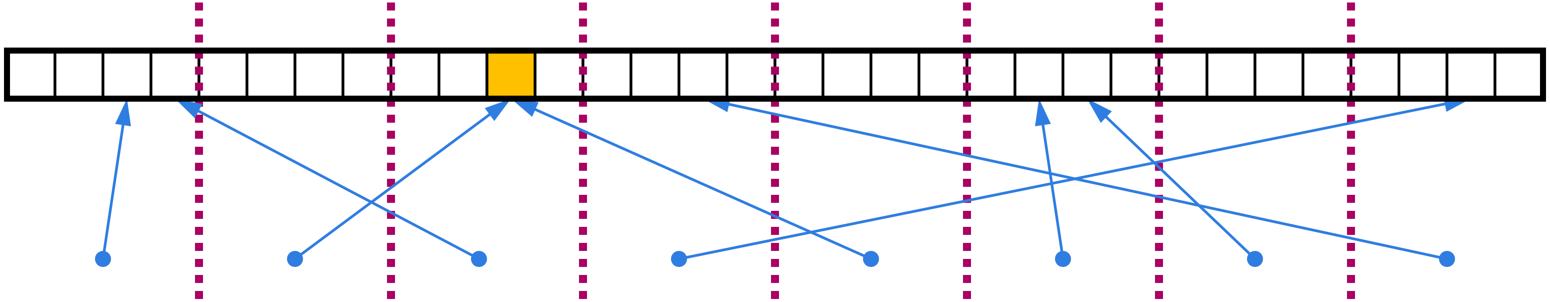
- Stream Global performance now on par with EP at 1,024 locales



Random Access Improvements

HPCC Random Access (RA)

Data Structure: distributed table



Computation: update random table locations in parallel

HPCC RA: MPI kernel

```
/* Perform updates to main table.  The scalar equivalent is:
 *
 *   for (i=0; i<Updates; i++) {
 *     r = (r << 1) ^ ((r < 0) ? POLY : 0);
 *     T[r & indexMask] ^= r;
 *   }
 */

MPI_Irecv(&LocalRecvBuffer, localBufferSize, tparams.dtype64,
          MPI_ANY_SOURCE, MPI_ANY_TAG, MPI_COMM_WORLD, &inreq);
 while (i < SendCnt) {
   /* receive messages */
   do {
     MPI_Test(&inreq, &have_done, &status);
     if (have_done) {
       if (status.MPI_TAG == UPDATE_TAG) {
         MPI_Get_count(&status, tparams.dtype64, &recvUpdates);
         bufferBase = 0;
         for (j=0; j < recvUpdates; j ++) {
           inmsg = LocalRecvBuffer[bufferBase+j];
           LocalOffset = (inmsg & (tparams.TableSize - 1)) -
                         tparams.GlobalStartMyProc;
           HPCC_Table[LocalOffset] ^= inmsg;
         }
       } else if (status.MPI_TAG == FINISHED_TAG) {
         NumberReceiving--;
       } else
         MPI_Abort( MPI_COMM_WORLD, -1 );
       MPI_Irecv(&LocalRecvBuffer, localBufferSize, tparams.dtype64,
                 MPI_ANY_SOURCE, MPI_ANY_TAG, MPI_COMM_WORLD, &inreq);
     }
   } while (have_done && NumberReceiving > 0);
   if (pendingUpdates < maxPendingUpdates) {
     Ran = (Ran << 1) ^ ((s64Int) Ran < ZERO64B ? POLY : ZERO64B);
     GlobalOffset = Ran & (tparams.TableSize-1);
     if ( GlobalOffset < tparams.Top)
       WhichPe = ( GlobalOffset / (tparams.MinLocalTableSize + 1) );
     else
       WhichPe = ( (GlobalOffset - tparams.Remainder) /
                   tparams.MinLocalTableSize );
     if (WhichPe == tparams.MyProc) {
       LocalOffset = (Ran & (tparams.TableSize - 1)) -
                     tparams.GlobalStartMyProc;
       HPCC_Table[LocalOffset] ^= Ran;
     }  else {
       HPCC_InsertUpdate(Ran, WhichPe, Buckets);
        pendingUpdates++;
     }
     i++;
   }
   else {
     MPI_Test(&outreq, &have_done, MPI_STATUS_IGNORE);
     if (have_done) {
       outreq = MPI_REQUEST_NULL;
       pe = HPCC_GetUpdates(Buckets, LocalSendBuffer, localBufferSize,
                            &peUpdates);
       MPI_Isend(&LocalSendBuffer, peUpdates, tparams.dtype64, (int)pe,
                 UPDATE_TAG, MPI_COMM_WORLD, &outreq);
       pendingUpdates -= peUpdates;
     }
   }
 }
/* send remaining updates in buckets */
while (pendingUpdates > 0) {
  /* receive messages */
  do {
    MPI_Test(&inreq, &have_done, &status);
    if (have_done) {
      if (status.MPI_TAG == UPDATE_TAG) {
        MPI_Get_count(&status, tparams.dtype64, &recvUpdates);
        bufferBase = 0;
        for (j=0; j < recvUpdates; j ++) {
          inmsg = LocalRecvBuffer[bufferBase+j];
          LocalOffset = (inmsg & (tparams.TableSize - 1)) -
                        tparams.GlobalStartMyProc;
          HPCC_Table[LocalOffset] ^= inmsg;
        }
      } else if (status.MPI_TAG == FINISHED_TAG) {
        /* we got a done message.  Thanks for playing... */
        NumberReceiving--;
      } else {
        MPI_Abort( MPI_COMM_WORLD, -1 );
      }
      MPI_Irecv(&LocalRecvBuffer, localBufferSize, tparams.dtype64,
                MPI_ANY_SOURCE, MPI_ANY_TAG, MPI_COMM_WORLD, &inreq);
    }
  } while (have_done && NumberReceiving > 0);

  MPI_Test(&outreq, &have_done, MPI_STATUS_IGNORE);
  if (have_done) {
    outreq = MPI_REQUEST_NULL;
    pe = HPCC_GetUpdates(Buckets, LocalSendBuffer, localBufferSize,
                         &peUpdates);
    MPI_Isend(&LocalSendBuffer, peUpdates, tparams.dtype64, (int)pe,
              UPDATE_TAG, MPI_COMM_WORLD, &outreq);
    pendingUpdates -= peUpdates;
  }
}
/* send our done messages */
for (proc_count = 0 ; proc_count < tparams.NumProcs ; ++proc_count) {
  if (proc_count == tparams.MyProc) { tparams.finish_req[tparams.MyProc] =
                                      MPI_REQUEST_NULL; continue; }
  /* send garbage - who cares, no one will look at it */
  MPI_Isend(&Ran, 0, tparams.dtype64, proc_count, FINISHED_TAG,
            MPI_COMM_WORLD, tparams.finish_req + proc_count);
}
/* Finish everyone else up... */
while (NumberReceiving > 0) {
  MPI_Wait(&inreq, &status);
  if (status.MPI_TAG == UPDATE_TAG) {
    MPI_Get_count(&status, tparams.dtype64, &recvUpdates);
    bufferBase = 0;
    for (j=0; j < recvUpdates; j ++) {
      inmsg = LocalRecvBuffer[bufferBase+j];
      LocalOffset = (inmsg & (tparams.TableSize - 1)) -
                    tparams.GlobalStartMyProc;
      HPCC_Table[LocalOffset] ^= inmsg;
    }
  } else if (status.MPI_TAG == FINISHED_TAG) {
    /* we got a done message.  Thanks for playing... */
    NumberReceiving--;
  } else {
    MPI_Abort( MPI_COMM_WORLD, -1 );
  }
  MPI_Irecv(&LocalRecvBuffer, localBufferSize, tparams.dtype64,
            MPI_ANY_SOURCE, MPI_ANY_TAG, MPI_COMM_WORLD, &inreq);
}

MPI_Waitall( tparams.NumProcs, tparams.finish_req, tparams.finish_statuses);
```

HPCC RA: MPI kernel comment vs. Chapel


```
/* Perform updates to main table.  The scalar equivalent is:
 *
 *     for (i=0; i<Updates; i++) {
 *       r = (r << 1) ^ ((r < 0) ? POLY : 0);
 *       T[r & indexMask] ^= r;
 *     }
 */
```


Chapel Kernel

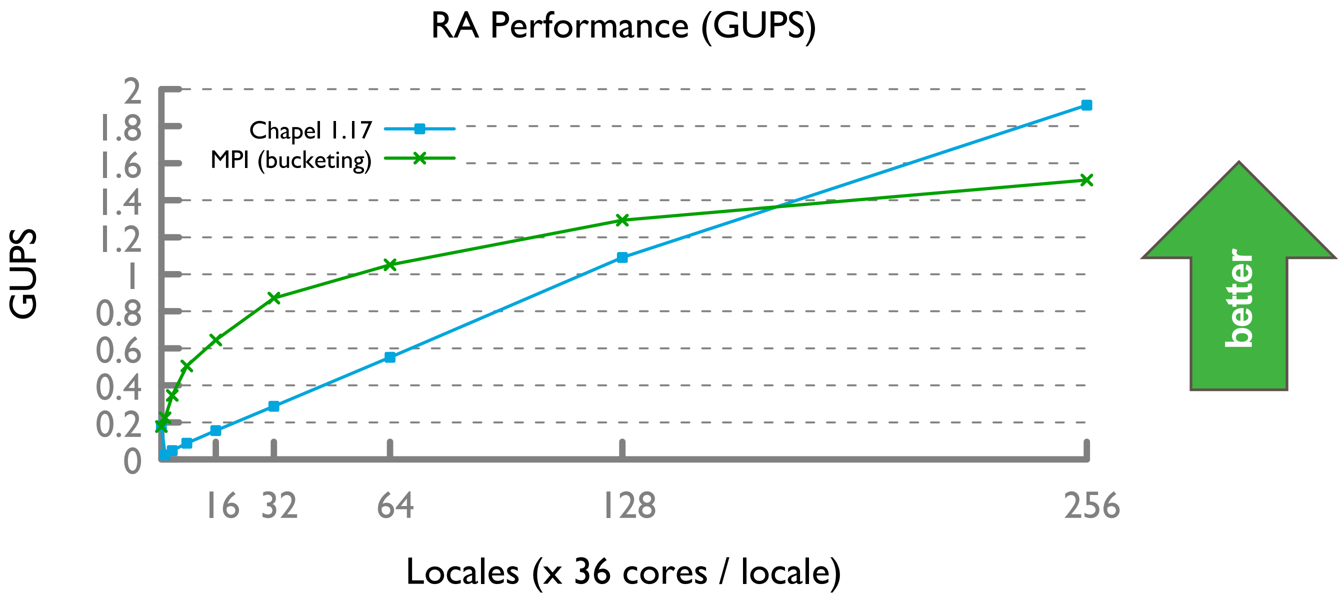
```
forall (_, r) in zip(Updates, RAStream()) do
  T[r & indexMask].xor(r);
```

MPI Comment

```
/* Perform updates to main table. The scalar equivalent is:
 *
 *     for (i=0; i<Updates; i++) {
 *       r = (r << 1) ^ ((r < 0) ? POLY : 0);
 *       T[r & indexMask] ^= r;
 *     }
 */
```

RA Performance

- In 1.17 Chapel already outperformed reference MPI
  - We have made significant improvements since then



Blocking Communication

- By default, remote operations in Chapel are blocking/ordered
  - Supports Memory Consistency Model (MCM)
    - “sequential consistency for data-race-free programs”

```
var a: atomic int;
a.add(1);
writeln(a); // must print 1
```

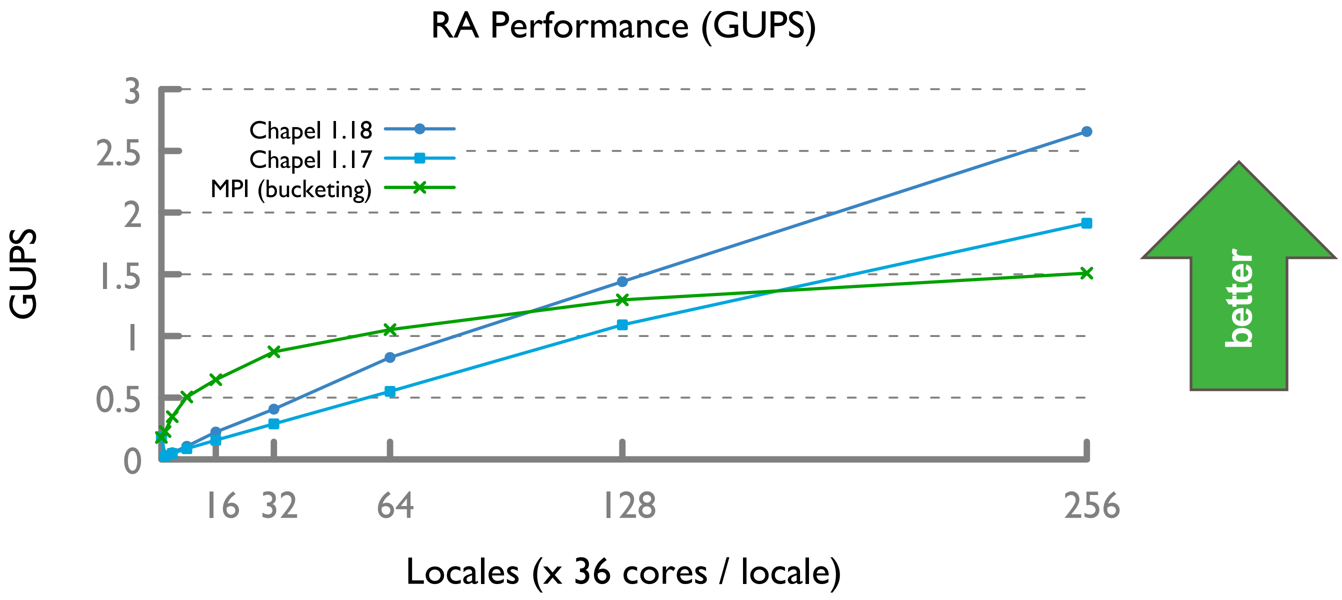
Blocking Communication

- Blocking is implemented with initiation, then task yields until ACK is received
  - Yielding allows for comm/compute overlap

```
var ACK = initiateAtomic(locale, …);
while (!received(ACK)) {
  chpl_task_yield();
}
```

Blocking Operations

- In 1.18 we optimized how we wait for blocking operations to complete
  - Yield less frequently to allow for faster ACK processing



Unordered Operations

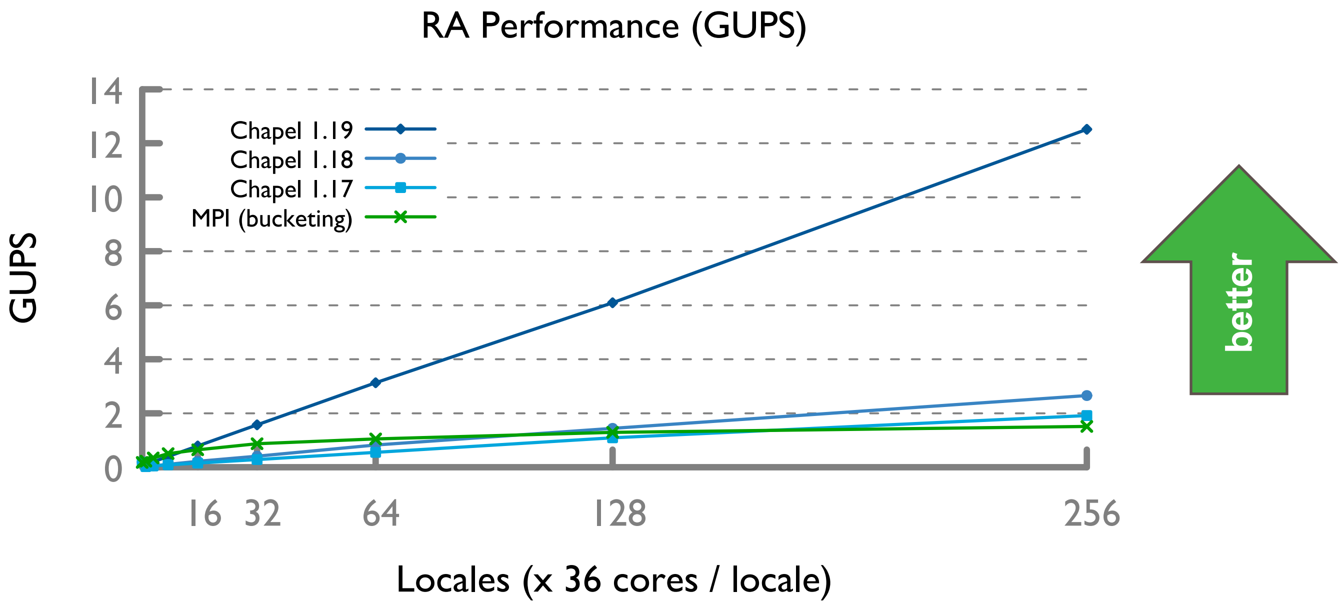
- 1.19 introduced unordered operations (including unordered atomics)
  - Unordered operations are not consistent with normal operations
  - Results are only visible at task/forall termination or with an explicit fence

```
var a: atomic int;
a.unorderedAdd(1);
writeln(a); // can print 0 or 1
unorderedAtomicTaskFence();
writeln(a); // must print 1
```

  - Allows for significant optimization leeway

Unordered Operations

- Unordered operations have significant performance advantages
  - 4.5x speedup over already optimized blocking/ordered performance



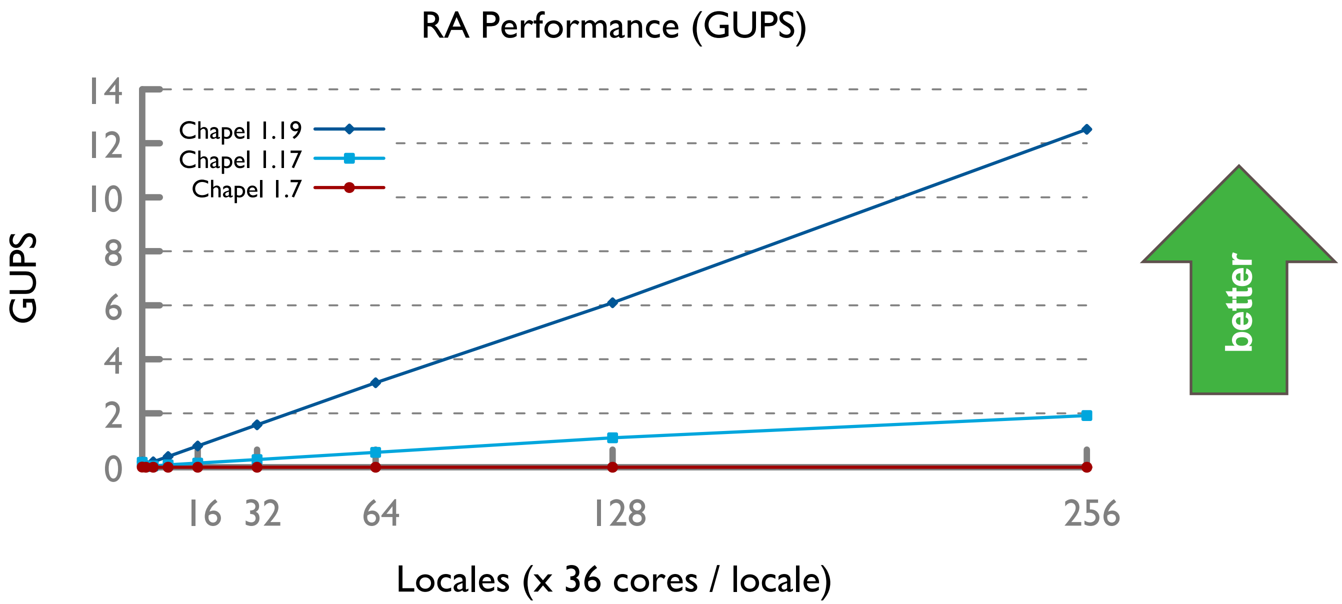
Unordered Compiler Optimization

- Since 1.19 we have enabled an unordered compiler optimization
  - Automatically transforms ordered communication into unordered when legal
  - Compiler is able to automatically optimize when …
    - Inside a forall loop (no ordering requirements across iterations)
    - Lifetime of operands is longer than forall loop scope
    - Operations are not used for synchronization
    - Result of operation is not used within the same iteration

```
forall (_, r) in zip(Updates, RAStream()) do
  T[r & indexMask].xor(r);
```

RA Summary

- RA performance has improved significantly with no changes to the benchmark
  - Now achieves network injection rate for small messages



Performance Summary

- These communication optimizations have had significant performance impacts
  - 30% improvement for ISx at 256 locales (~10K cores)
  - 10% improvement for Stream Global at 1,024 locales (~25K cores)
  - 6x improvement for Random Access at 256 locales (~10K cores)

Performance Summary

- There have been dozens of other performance optimizations over the last year
  - Optimized Sync variables
  - Reduced Communication
  - Optimized Distributed Array Iteration
  - Optimized Sorting
  - Optimized Large Transfers
  - Optimized Network Atomics
  - Improved on-stmt Performance
  - Optimized Barriers
  - Improved Task Placement/Affinity
  - Optimized Linear Algebra Routines
  - Optimized Scan Performance
  - Improved String Performance
  - Optimized Locks
  - Defaulted to cstdlib Atomics
  - Improved Vectorization
  - Optimized Fine-Grained Comm
  - Added Unordered Operations
  - Improved Comm/Compute Overlap

Next Steps

- Continue benchmark driven optimizations
  - User Applications
  - Bale
  - DOE Proxy Apps
  - Intel Parallel Research Kernels
- Optimize for non-Cray networks
  - In particular optimize for InfiniBand

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