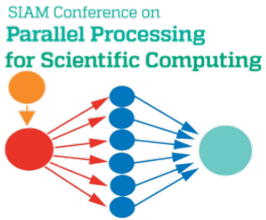
Chapel: Task-Based Communication in a Productive Language

Elliot Ronaghan, Chapel Team, Cray Inc.

SIAM PP18

March 8 2018



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What is Chapel?

Chapel: A productive parallel programming language

- portable
- open-source
- a collaborative effort

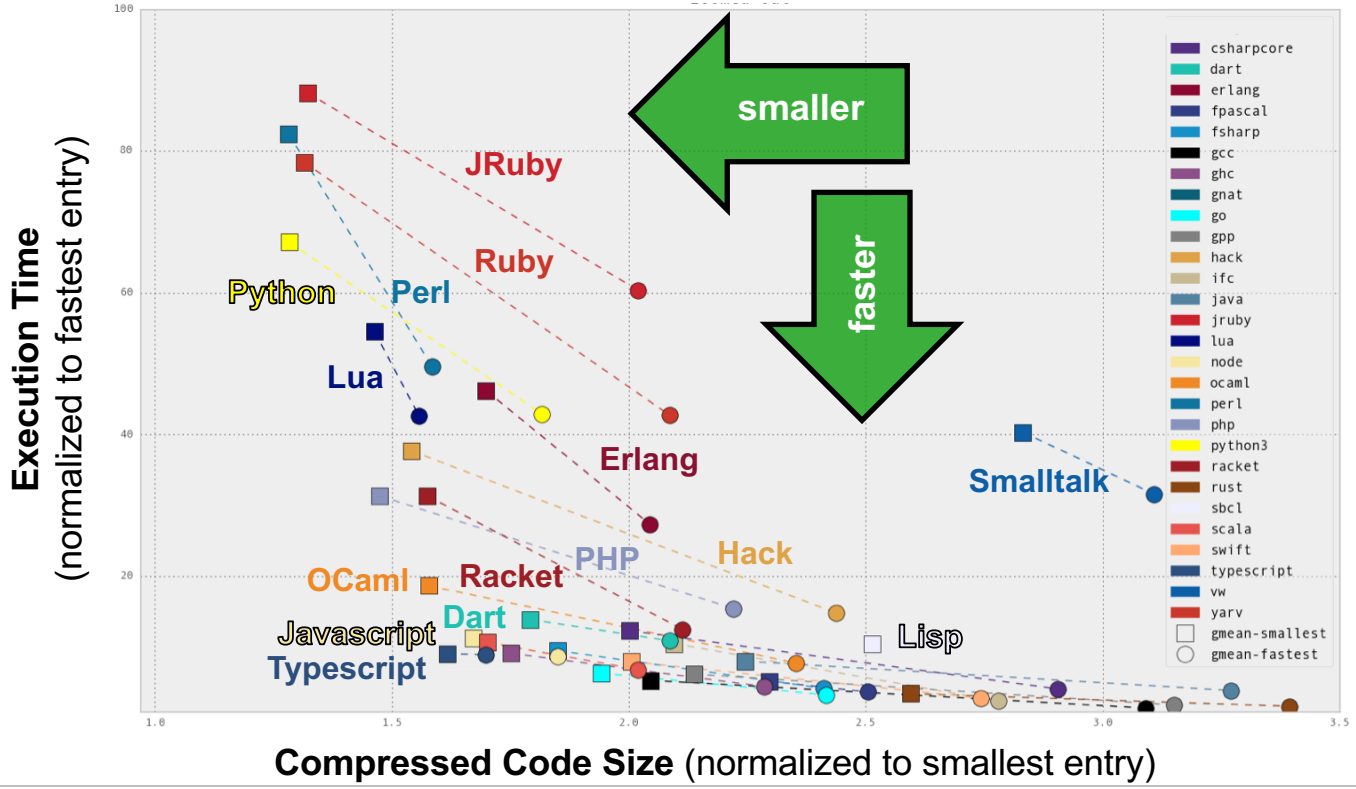
Goals:

- Support general parallel programming
  - "any parallel algorithm on any parallel hardware"
- Make parallel programming at scale far more productive

Chapel and Productivity

- **Chapel strives to be…**
  - …as programmable as Python
  - …as fast as Fortran
  - …as scalable as MPI, SHMEM, or UPC
  - …as portable as C
  - …as flexible as C++
  - …as fun as [your favorite programming language]

CLBG Cross-Language Summary
(Oct 2017 standings)



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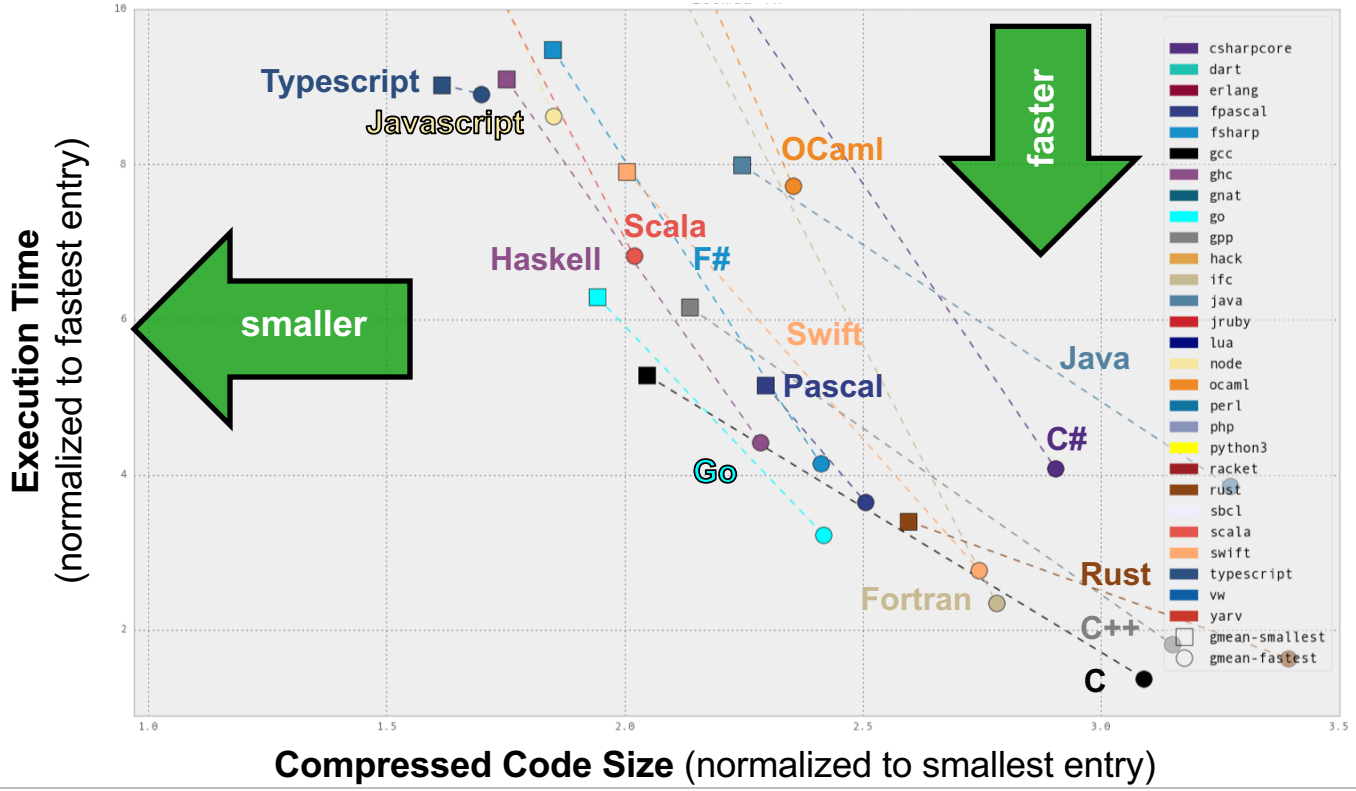
(Oct 2017 standings, zoomed in)



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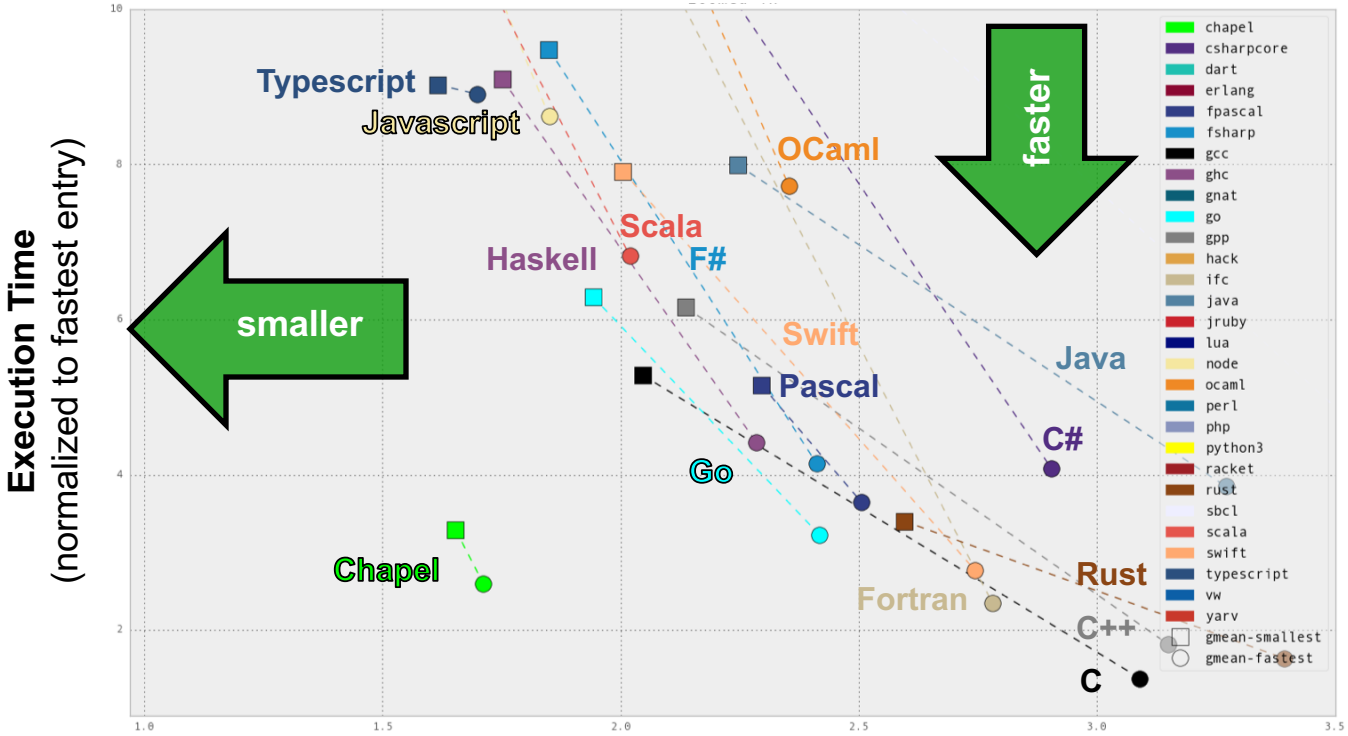

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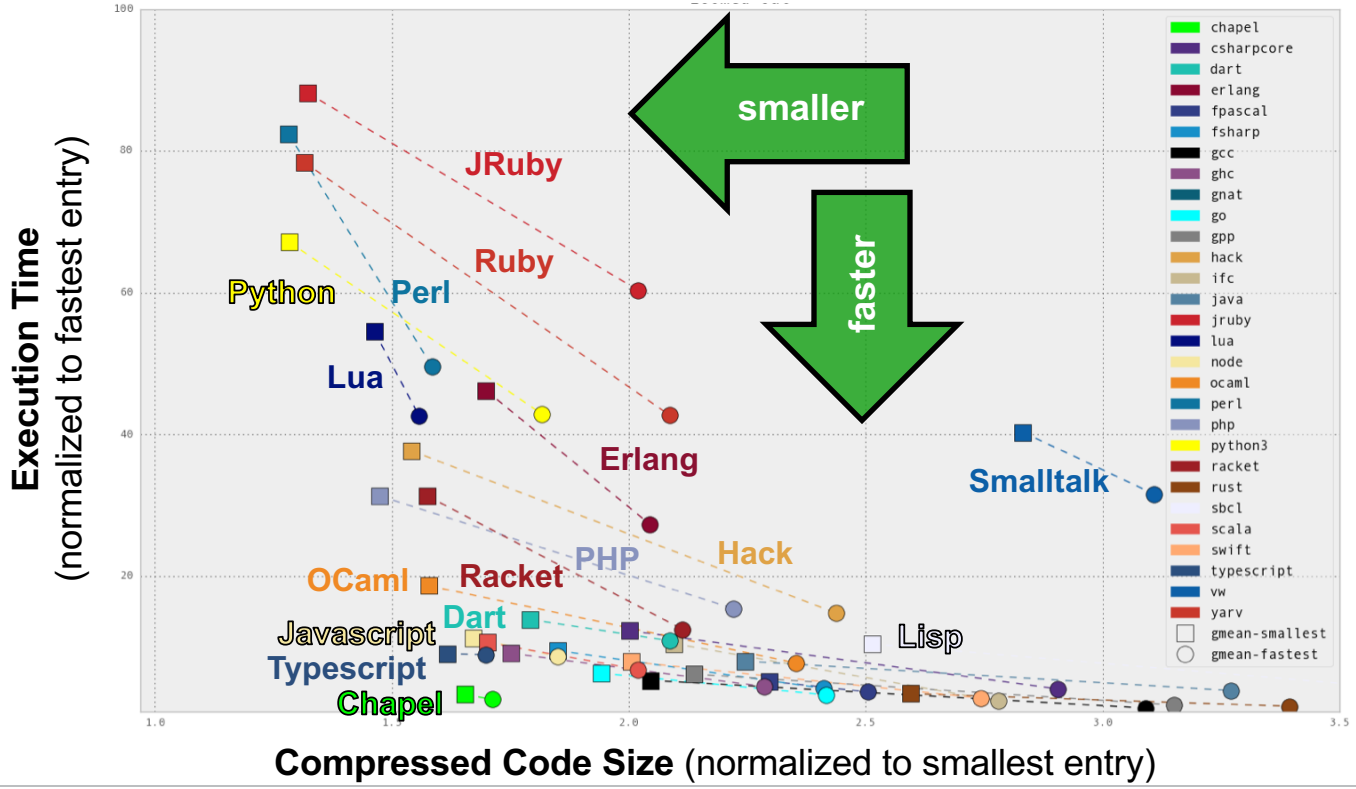
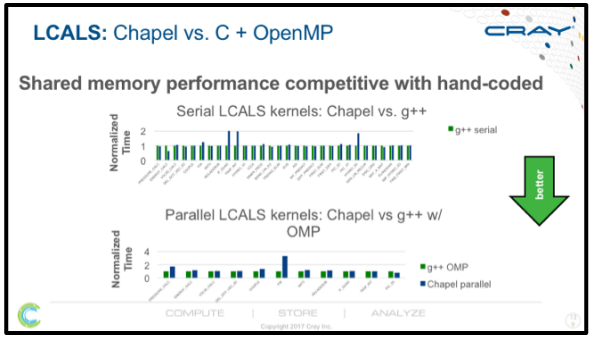
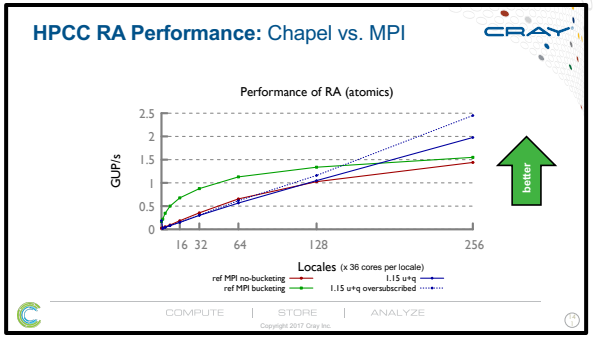


Chapel Performance: HPC Benchmarks



LCALS

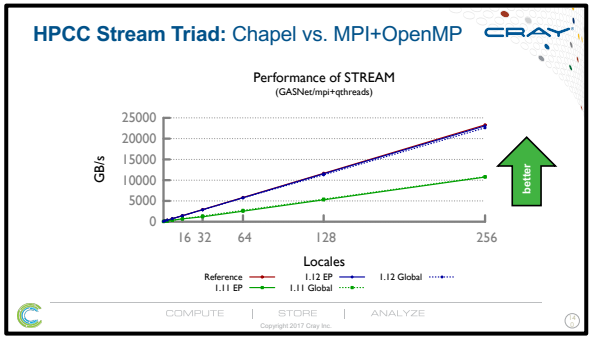
HPCC RA

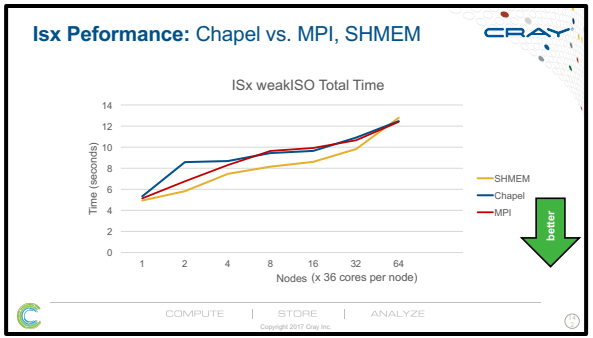


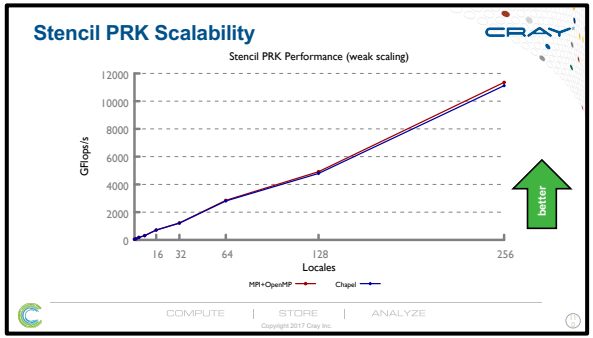
STREAM Triad

ISx

PRK Stencil

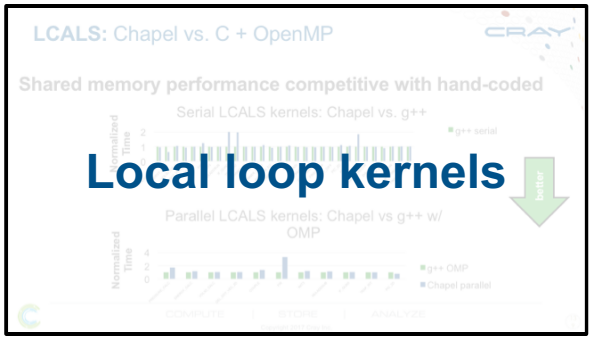






Nightly performance graphs online at: https://chapel-lang.org/perf

Chapel Performance: HPC Benchmarks



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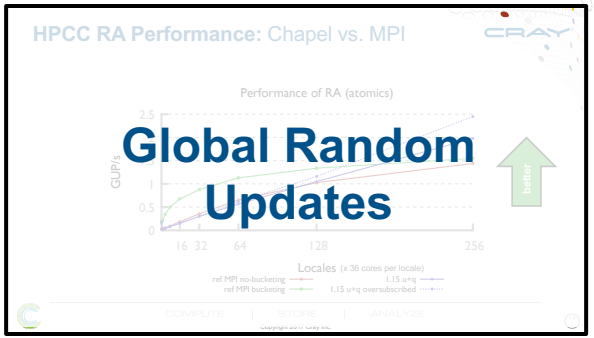
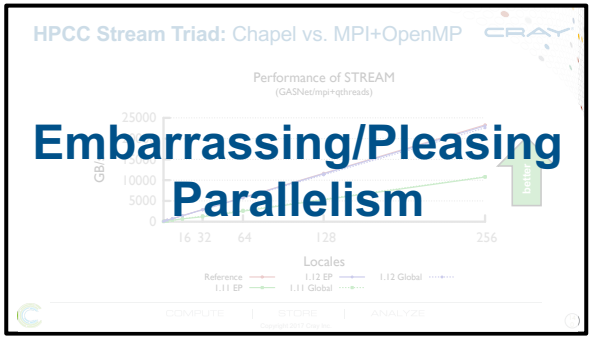


HPCC RA

STREAM Triad



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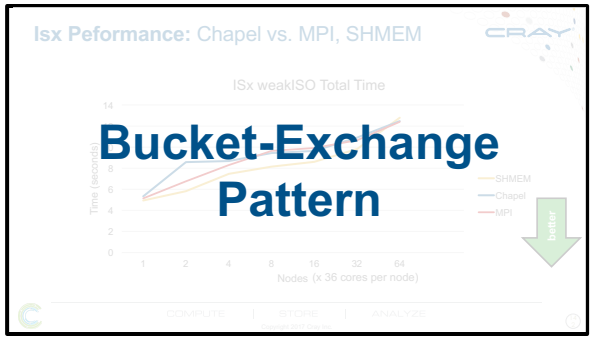
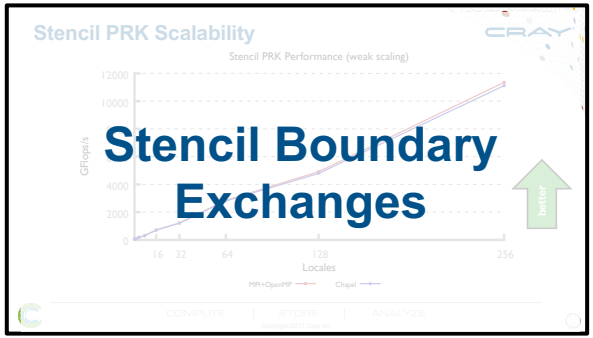


PRK Stencil



Nightly performance graphs online at: https://chapel-lang.org/perf

The Chapel Team at Cray (May 2017)

14 full-time employees + 2 summer interns + 2–4 GSoC students

Chapel Community Partners

(and several others…)

https://chapel-lang.org/collaborations.html

Plan for this talk

- Chapel by comparison: Random Access
- Runtime overview
- Performance optimizations enabled by runtime

Chapel by Comparison

HPCC Random Access

- **Random Access (RA) benchmark**
  - make random xor-updates to a distributed array of integers
  - stresses fine-grained communication (in its purest form)
  - benchmark allows up to 1% of updates to be missed/dropped

Random Access (GUPS) Kernel: MPI

```
/* Perform updates to main table.  The scalar equivalent is:
 *
 *     for (i=0; i<NUPDATE; i++) {
 *       Ran = (Ran << 1) ^ (((s64Int) Ran < 0) ? POLY : 0);
 *       Table[Ran & (TABSIZE-1)] ^= Ran;
 *     }
 */

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;
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      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);
```

Random Access (GUPS) Kernel: Chapel

MPI Comment

```
/* Perform updates to main table. The scalar equivalent is:
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 */
```

Chapel Code

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

Random Access (GUPS) Kernel: Chapel

Chapel RMO

```
forall (_, r) in zip(Updates, RAStream()) do
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Random Access (GUPS) Kernel: Chapel

Chapel RMO

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

Chapel On-stmt

```
forall (_, r) in zip(Updates, RAStream()) do
  on TableDist.idxToLocale[r & indexMask] do
    T[r & indexMask] ^= r;
```

Random Access (GUPS) Kernel: Chapel

Chapel RMO

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

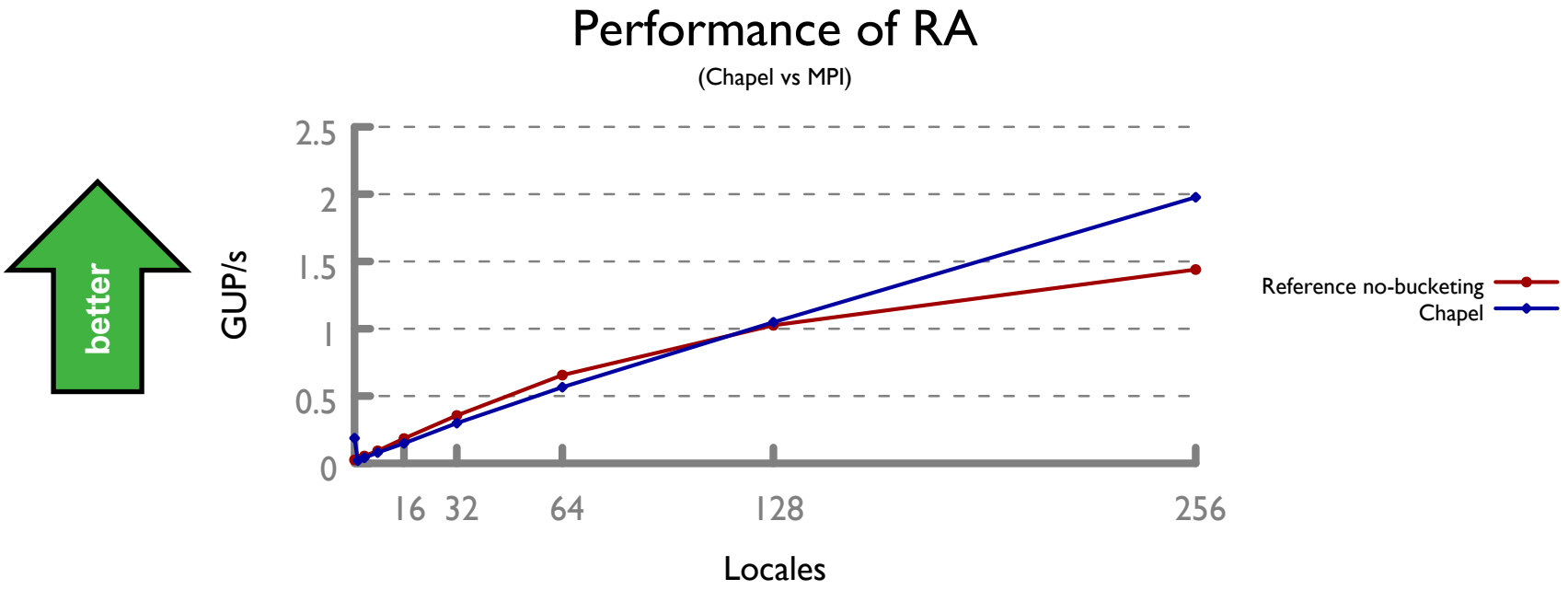
Chapel On-stmt

```
forall (_, r) in zip(Updates, RAStream()) do
  on TableDist.idxToLocale[r & indexMask] do
    T[r & indexMask] ^= r;
```

Chapel Atomic

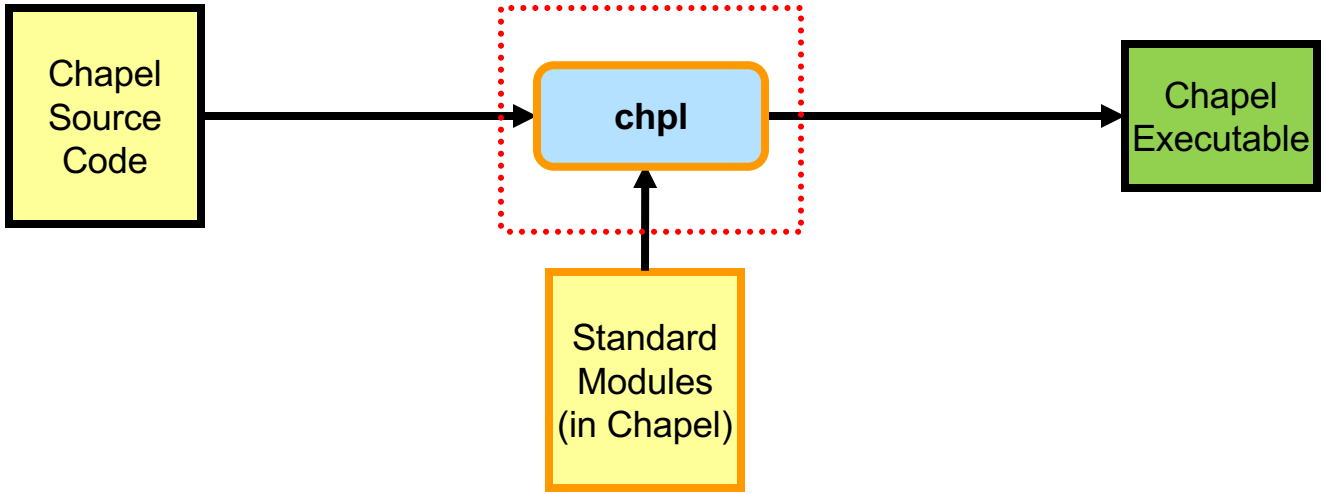
```
forall (_, r) in zip(Updates, RAStream()) do
    T[r & indexMask].xor(r);
```

HPCC RA Performance: Chapel vs. MPI

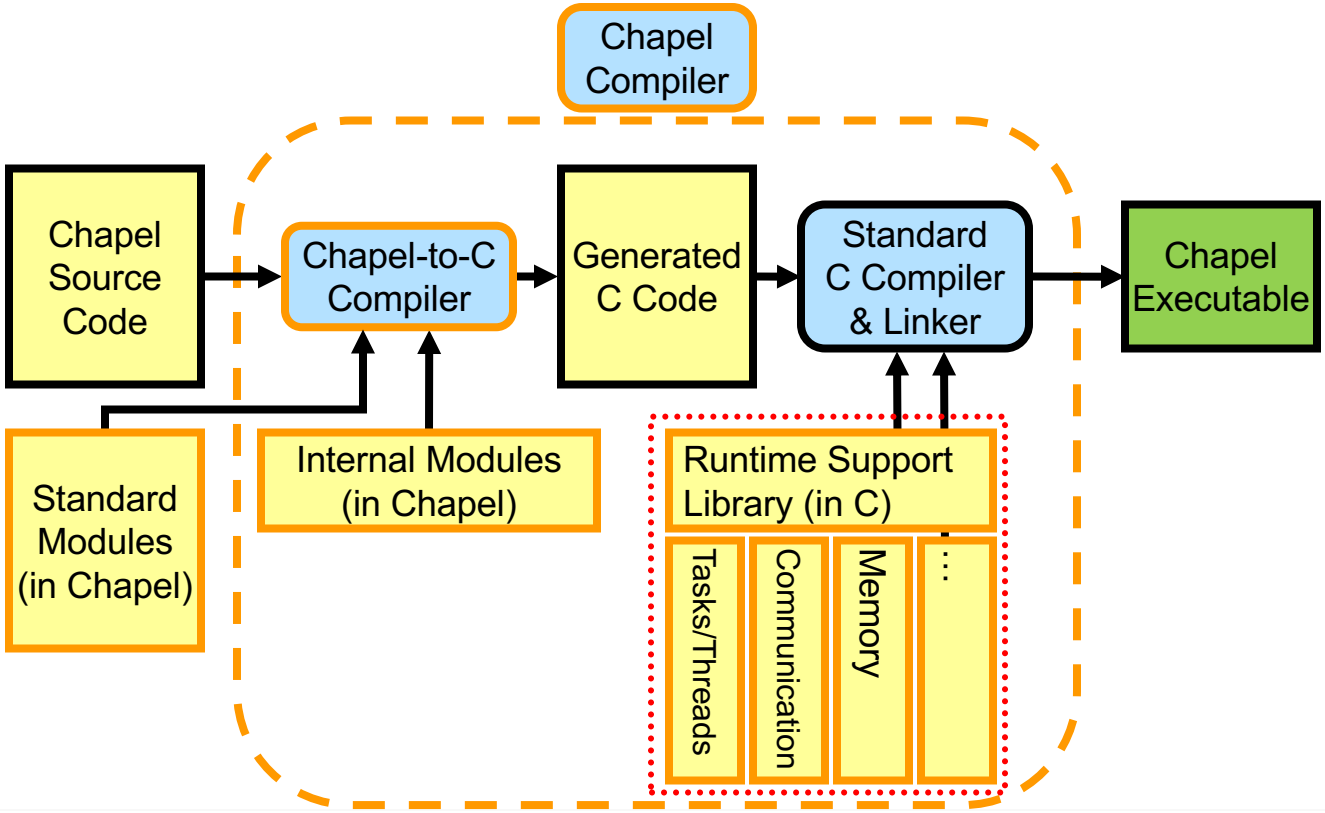


Chapel Runtime

Compiling Chapel



Chapel Compilation Architecture



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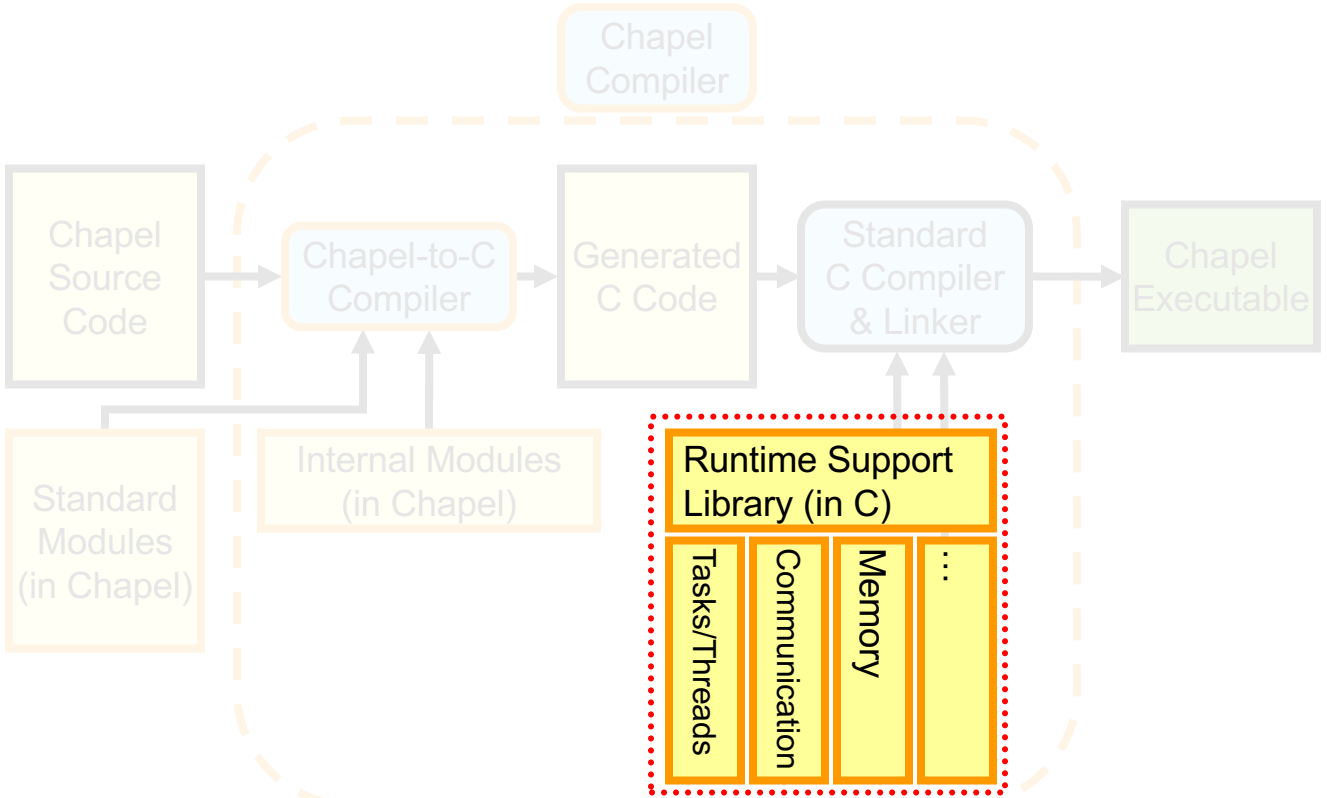
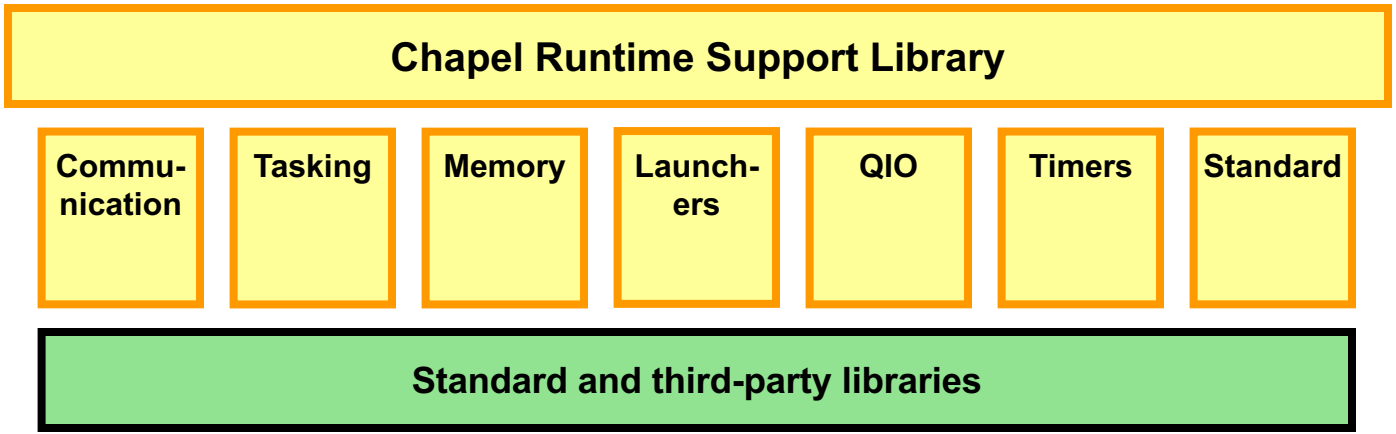


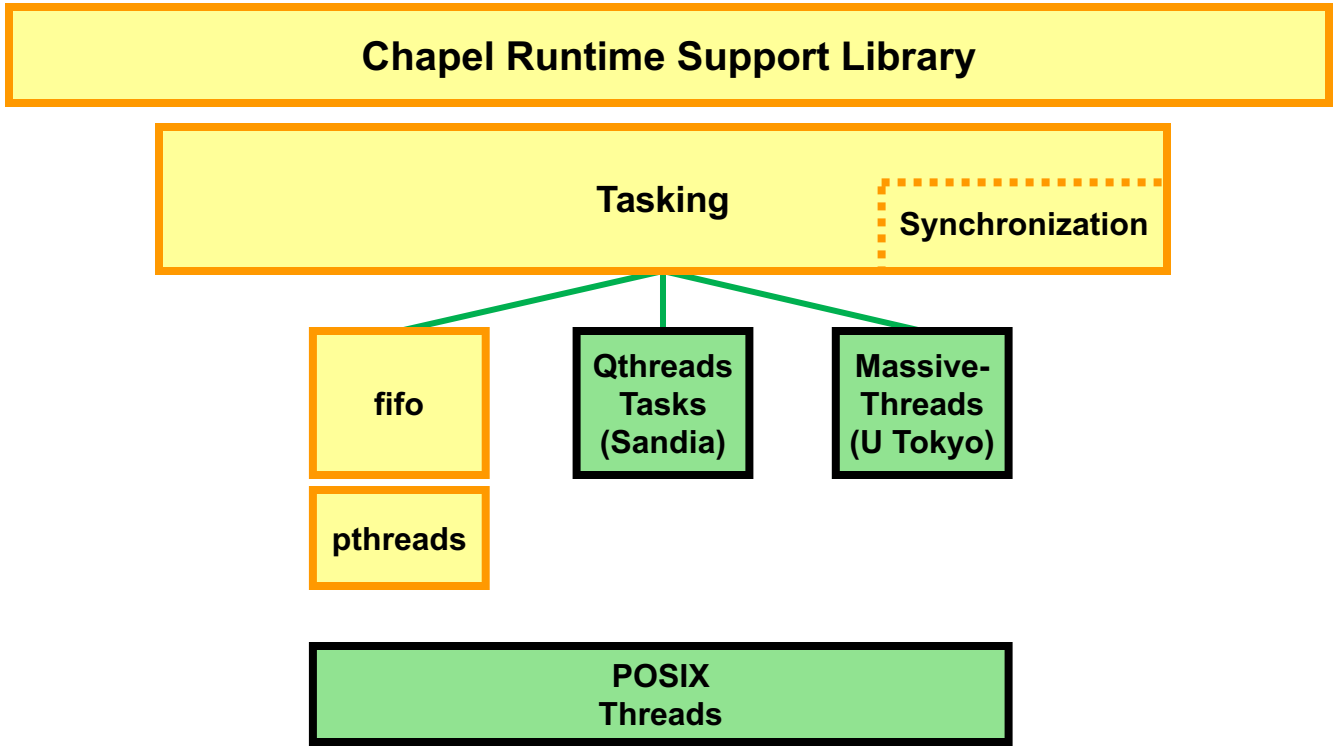
Chapel Runtime

- **Lowest level of Chapel software stack**
- **Supports language concepts and program activities**
  - Task creation, communication, memory allocation
- **Composed of *layers***
  - Standardized interfaces
  - Interchangeable implementations

Chapel Runtime Organization



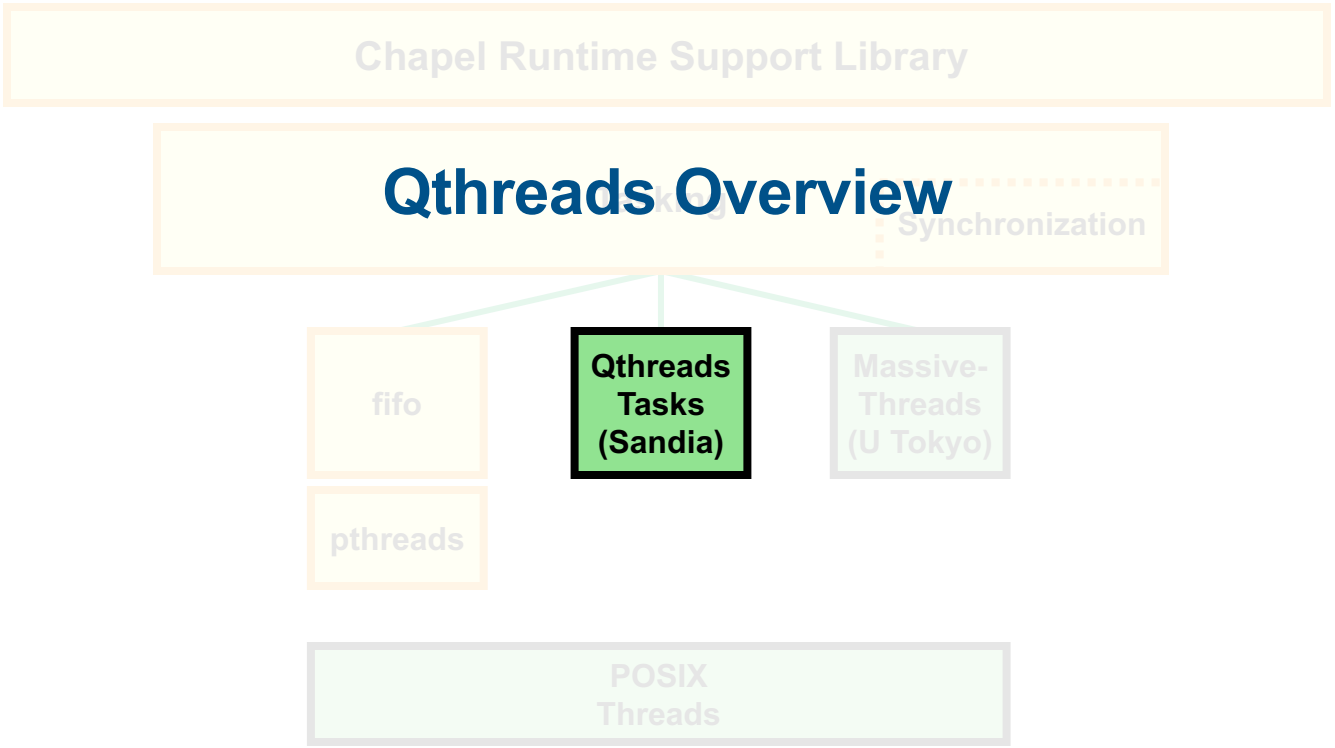
Runtime Tasking Layer



Runtime Tasking Layer

- **Supports parallelism**
- **Operations**
  - Create a group of tasks
  - Start a “moved” task
    - Start a remote task “moved” by the comm layer

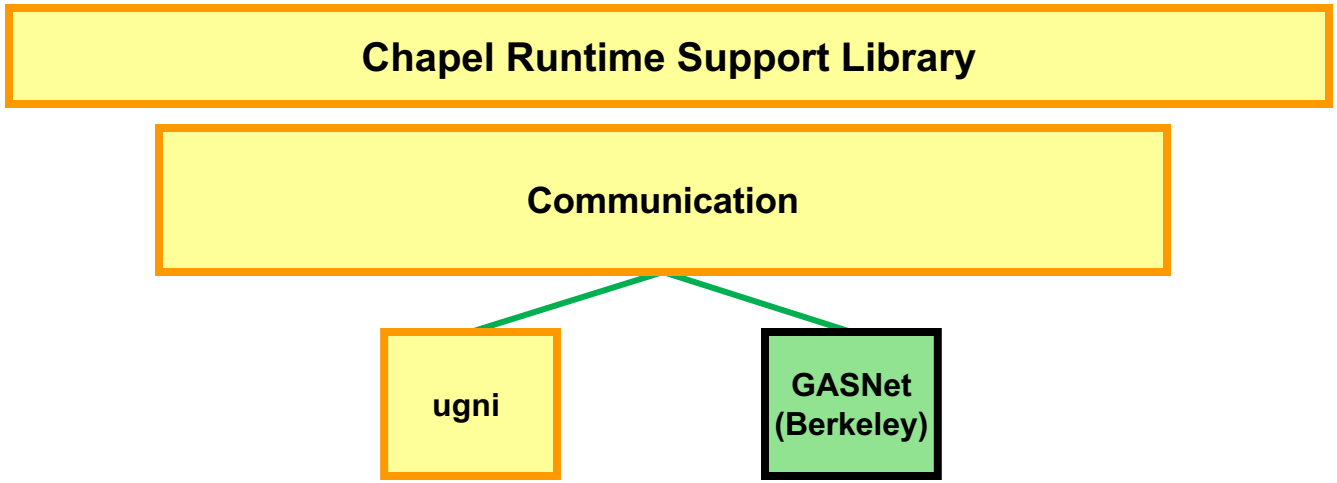
Runtime Tasking Layer



Qthreads Overview

- **Lightweight, locality-aware tasking library**
  - cooperative scheduling
  - qthreads are entirely in user space
    - extremely fast task creation and switching
  - designed to be highly concurrent
    - run millions of qthreads, limited only by available memory
  - locality-aware
  - multiple scheduler options
    - From simple fifo queues to advanced work-stealing schedulers

Runtime Communication Layer



Runtime Communication Layer

- **Supports Communication**
  - gets, puts, remote-task-creation
- **Works with tasking layer (through API)**
  - allows arbitrary comm/compute overlap

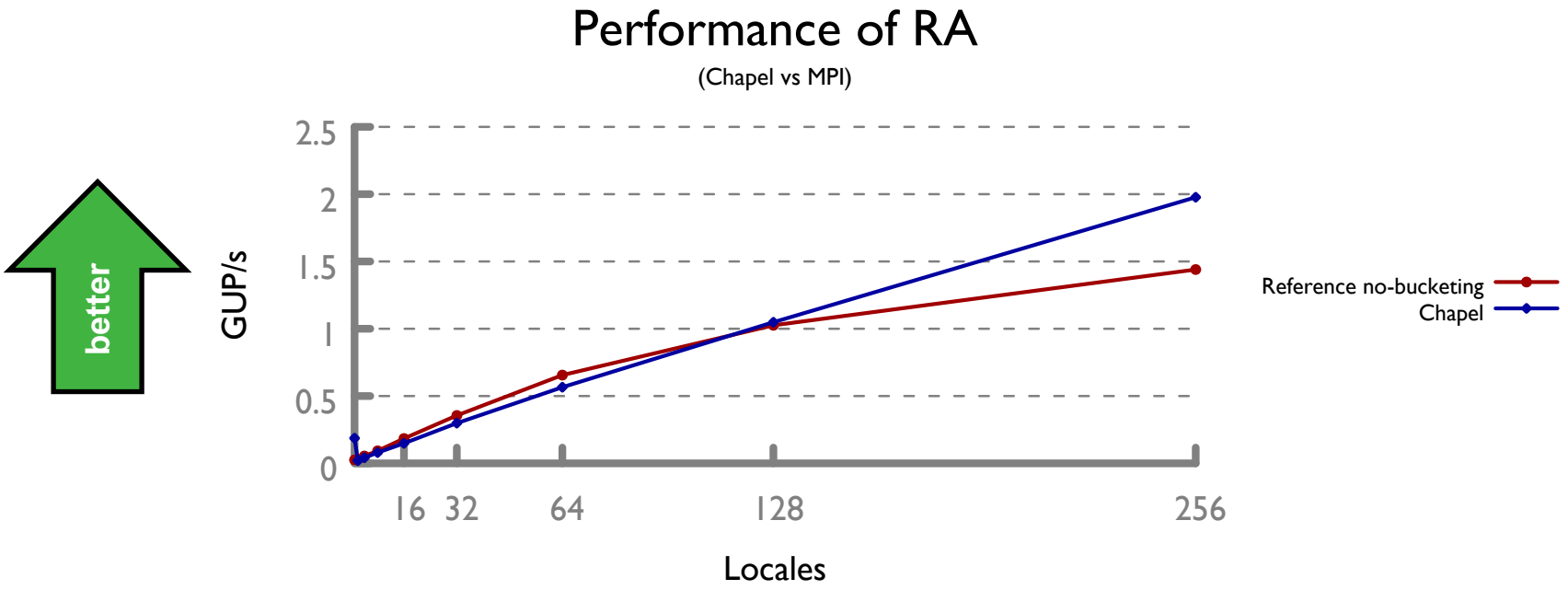
```
chpl_comm_put(…){
  done = do_remote_put(…);
  while (!complete(&done)) {
    chpl_task_yield(); // yield while waiting for network
  }
}
```

Communication + Tasking Overview

- **“Unified” runtime permits many optimizations**
  - standardized APIs prevent unnecessary/harmful coupling
- **e.g. allows communication and computation overlap**
  - in a trivial to implement manner
  - task switching in user-space makes this fast
  - cooperative tasking minimizes overhead for creating many tasks

Comm/compute overlap with RA

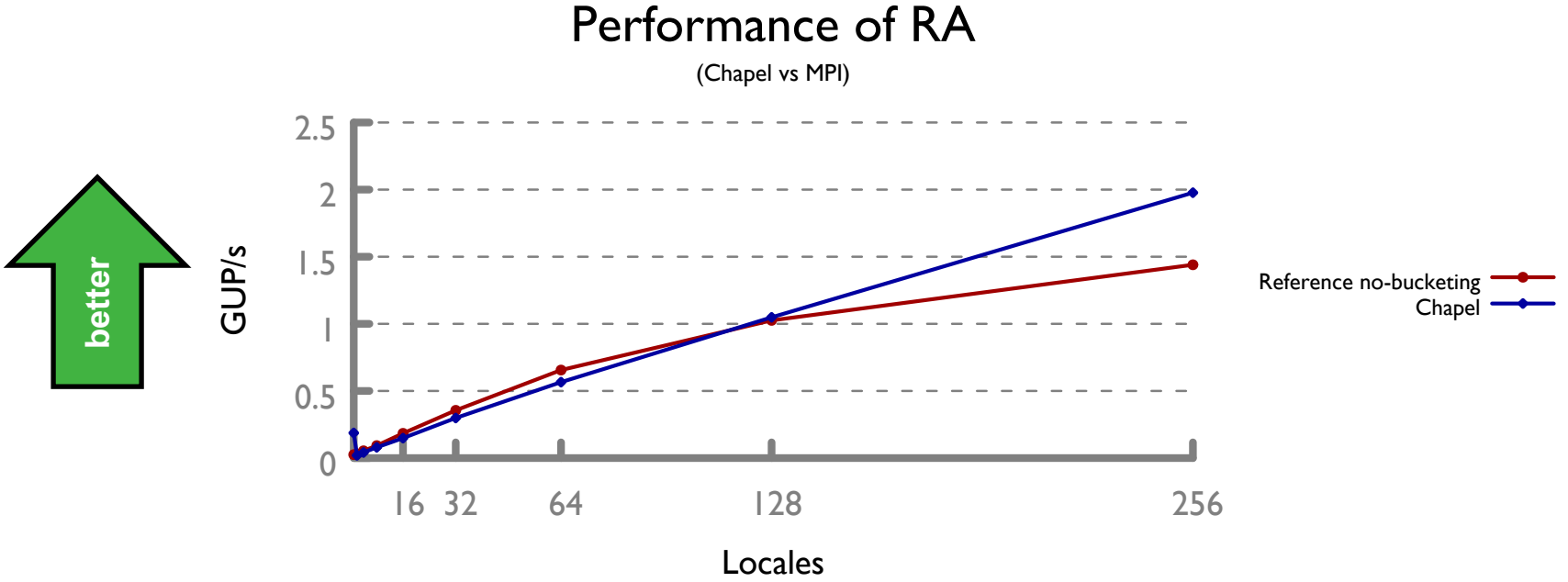
HPCC RA Performance: Chapel vs. MPI



HPCC RA Performance: Chapel vs. MPI

Update Dist Declaration

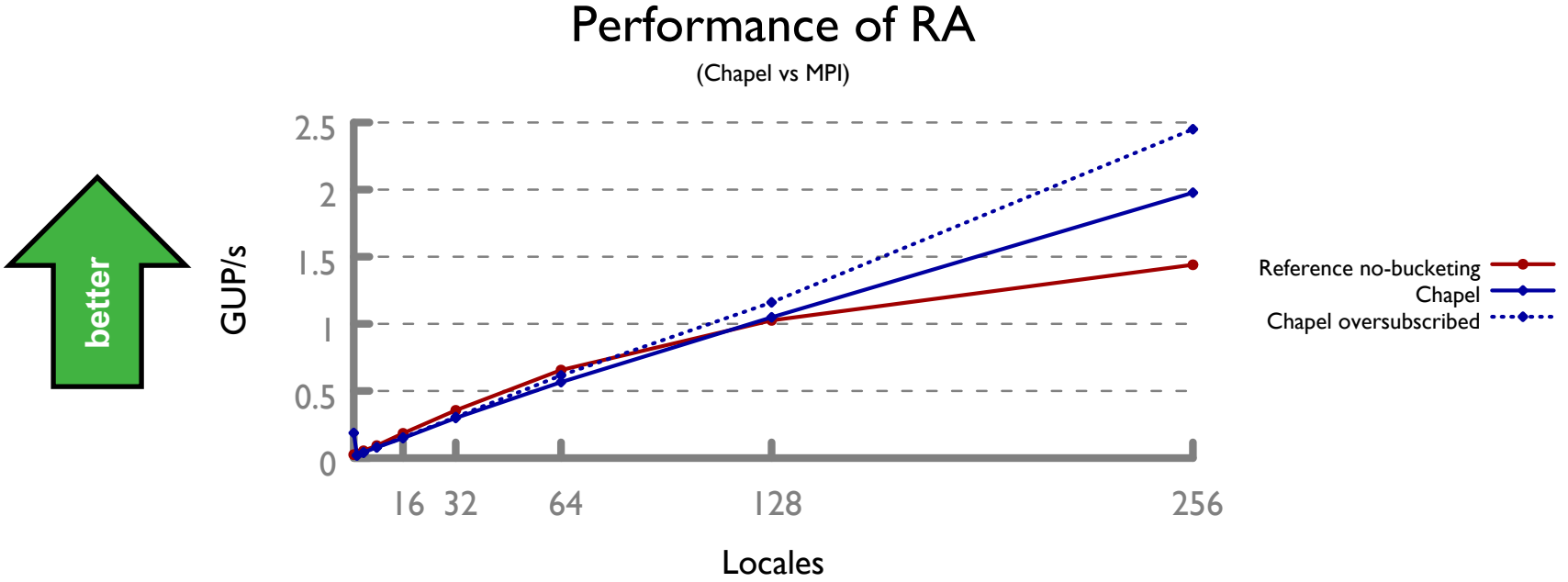
```
UpdateDist = new dmap(new Block(boundingBox={0..N_U-1}));
```



HPCC RA Performance: Chapel vs. MPI

Update Dist Declaration

```
UpdateDist = new dmap(new Block(boundingBox={0..N_U-1},
                                tasksPerLocale=2*here.maxTaskPar));
```



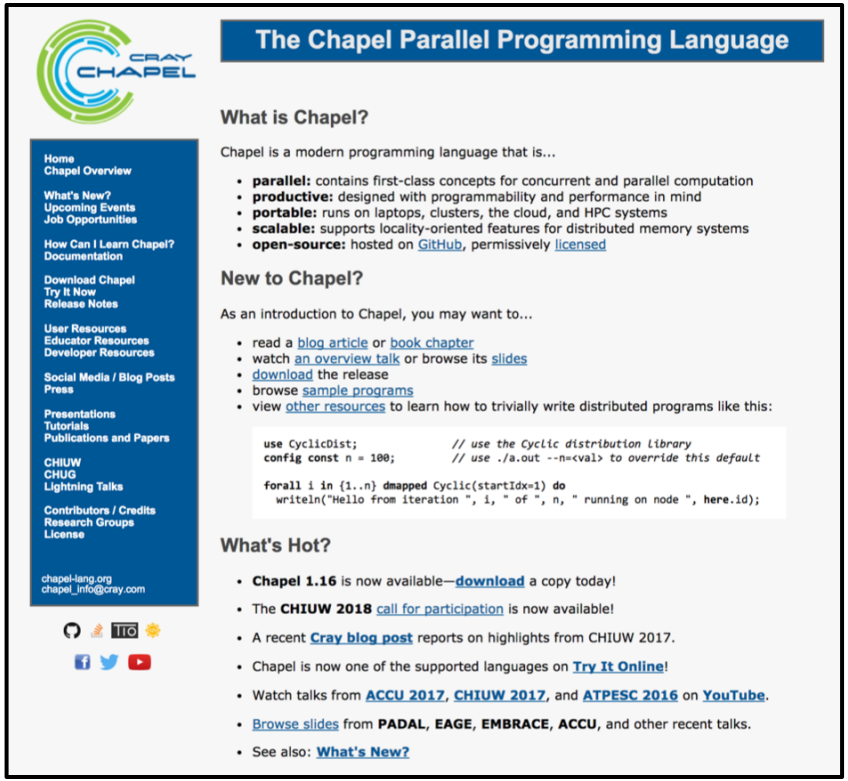
Wrapping Up

Summary

- **Chapel is a productive parallel programming language**
  - productivity enabled by rich tasking and communication runtime
- **Flexible, but cohesive runtime enables optimizations**
  - e.g. comm/compute overlap
  - future avenues: distributed work stealing, comm aggregation
- **Chapel performance can match C+MPI+OpenMP**
  - with improvements in readability, writability, code size

Chapel Resources

Chapel Central: https://chapel-lang.org/



How to Track Chapel

http://facebook.com/ChapelLanguage

http://twitter.com/ChapelLanguage

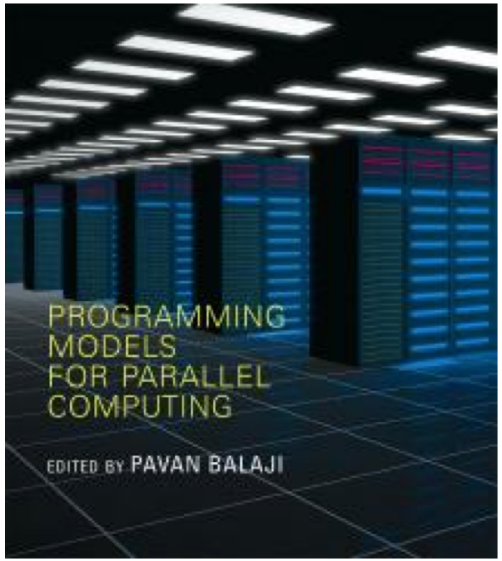
https://www.youtube.com/channel/UCHmm27bYjhknK5mU7ZzPGsQ/

chapel-announce@lists.sourceforge.net

Suggested Reading (healthy attention spans)

Chapel chapter from ***Programming Models for Parallel Computing***

- a detailed overview of Chapel's history, motivating themes, features
- published by MIT Press, November 2015
- edited by Pavan Balaji (Argonne)
- chapter is now also available online



Other Chapel papers/publications available at **https://chapel-lang.org/papers.html**

Suggested Reading (short attention spans)

CHIUW 2017: Surveying the Chapel Landscape, Cray Blog, July 2017.

- *a run-down of recent events*

Chapel: Productive Parallel Programming, Cray Blog, May 2013.

- *a short-and-sweet introduction to Chapel*

Six Ways to Say "Hello" in Chapel **(parts 1, 2, 3)**, Cray Blog, Sep-Oct 2015.

- *a series of articles illustrating the basics of parallelism and locality in Chapel*

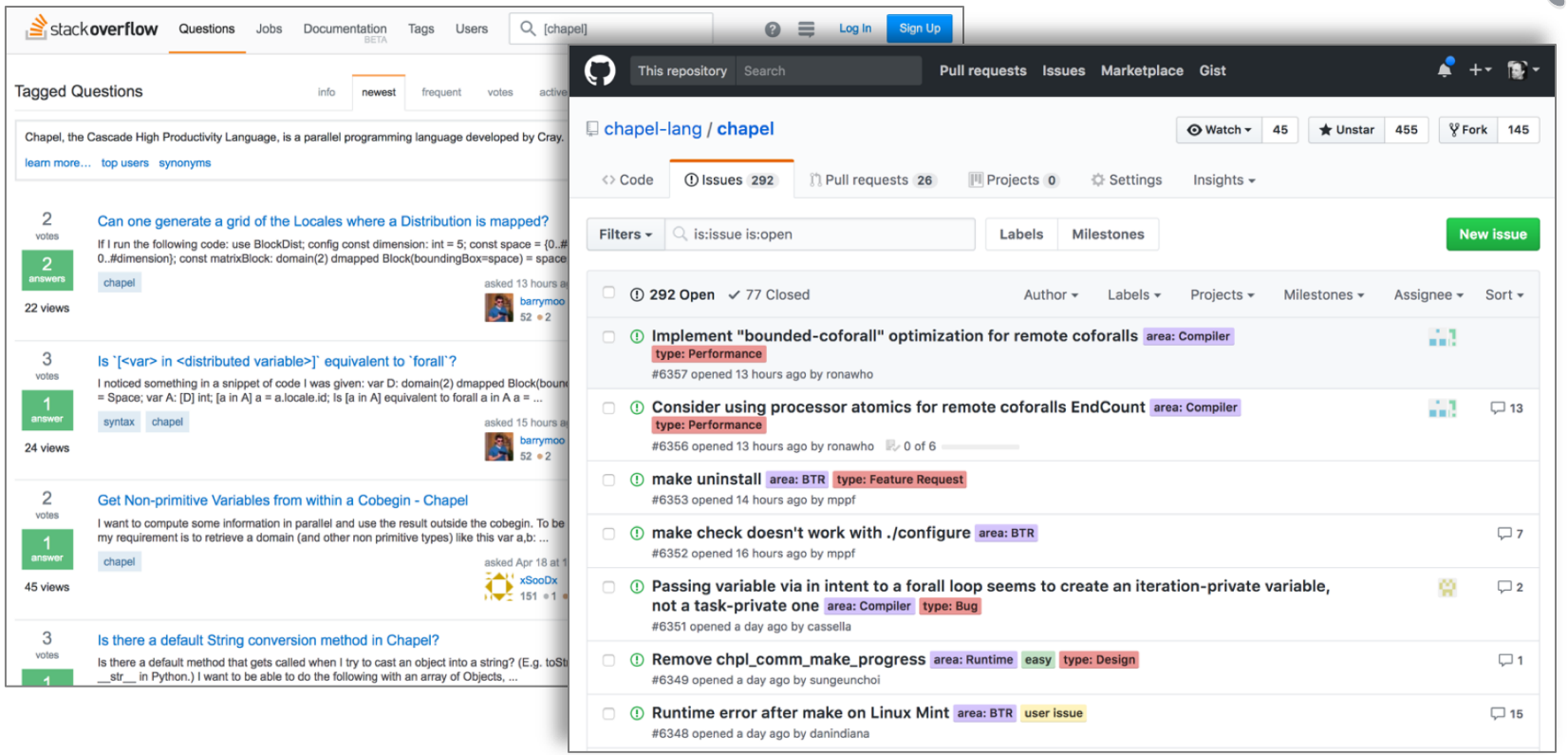
Why Chapel? **(parts 1, 2, 3)**, Cray Blog, Jun-Oct 2014.

- *a series of articles answering common questions about why we are pursuing Chapel in spite of the inherent challenges*

[Ten] Myths About Scalable Programming Languages, IEEE TCSC Blog (index available on chapel-lang.org "blog posts" page), Apr-Nov 2012.

- *a series of technical opinion pieces designed to argue against standard reasons given for not developing high-level parallel languages*

Chapel StackOverflow and GitHub Issues



Where to..

Submit bug reports:

GitHub issues for chapel-lang/chapel: public bug forum

chapel_bugs@cray.com: for reporting non-public bugs

Ask User-Oriented Questions:

StackOverflow: when appropriate / other users might care

#chapel-users (irc.freenode.net): user-oriented IRC channel

chapel-users@lists.sourceforge.net: user discussions

Discuss Chapel development

chapel-developers@lists.sourceforge.net: developer discussions

#chapel-developers (irc.freenode.net): developer-oriented IRC channel

Discuss Chapel's use in education

chapel-education@lists.sourceforge.net: educator discussions

Directly contact Chapel team at Cray: chapel_info@cray.com

Questions?

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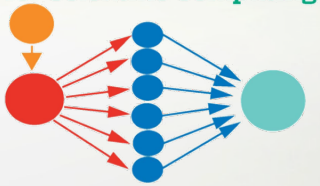

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