Enabling Parallel Computing in Chapel with Clang and LLVM

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Outline

- Introducing Chapel
- C interoperability
- Combined Code Generation
- Communication Optimization in LLVM
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
What does “Productivity” mean to you?

Recent Graduates:
“something similar to what I used in school: Python, Matlab, Java, …”

Seasoned HPC Programmers:
“that sugary stuff that I don’t need because I was born to suffer”
want full control to ensure performance

Computational Scientists:
“something that lets me express my parallel computations without having to wrestle with architecture-specific details”

Chapel Team:
“something that lets computational scientists express what they want, without taking away the control that HPC programmers want, implemented in a language as attractive as recent graduates want.”
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:
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 (shared memory / multicore):

![Diagram showing parallel computation of the STREAM Triad](image-url)
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):
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):
```c
#include <hpcc.h>

static int VectorSize;
static double *a, *b, *c;

int HPCC_StarStream(HPCC_Params *params) {
    int myRank, commSize;
    int rv, errCount;
    MPI_Comm comm = MPI_COMM_WORLD;

    MPI_Comm_size( comm, &commSize );
    MPI_Comm_rank( comm, &myRank );

    rv = HPCC_Stream( params, 0 == myRank);
    MPI_Reduce( &rv, &errCount, 1, MPI_INT, MPI_SUM, 0, comm );
    return errCount;
}

int HPCC_Stream(HPCC_Params *params, int doIO) {
    register int j;
    double scalar;

    VectorSize = HPCC_LocalVectorSize( params, 3, sizeof(double), 0 );

    a = HPCC_XMALLOC( double, VectorSize );
    b = HPCC_XMALLOC( double, VectorSize );
    c = HPCC_XMALLOC( double, VectorSize );

    if (!a || !b || !c) {
        if (c) HPCC_free(c);
        if (b) HPCC_free(b);
        if (a) HPCC_free(a);
        if (doIO) {
            fprintf( outFile, "Failed to allocate memory (%d).\n", VectorSize );
            fclose( outFile );
        }
        return 1;
    }

    for (j=0; j<VectorSize; j++) {
        b[j] = 2.0;
        c[j] = 1.0;
    }

    scalar = 3.0;
    for (j=0; j<VectorSize; j++)
        a[j] = b[j]+scalar*c[j];

    HPCC_free(c);
    HPCC_free(b);
    HPCC_free(a);
    return 0;
}
```
#include <hpcc.h>
#include _OPENMP
#include <omp.h>
#endif

static int VectorSize;
static double *a, *b, *c;

int HPCC_StarStream(HPCC_Params *params) {
    int myRank, commSize;
    int rv, errCount;
    MPI_Comm comm = MPI_COMM_WORLD;
    MPI_Comm_size( comm, &commSize );
    MPI_Comm_rank( comm, &myRank );
    rv = HPCC_Stream( params, 0 == myRank);
    MPI_Reduce( &rv, &errCount, 1, MPI_INT, MPI_SUM, 0, comm );
    return errCount;
}

int HPCC_Stream(HPCC_Params *params, int doIO) {
    register int j;
    double scalar;
    VectorSize = HPCC_LocalVectorSize( params, 3,
        sizeof(double), 0 );
    a = HPCC XMALLOC( double, VectorSize );
    b = HPCC XMALLOC( double, VectorSize );
    c = HPCC XMALLOC( double, VectorSize );
    if (!a || !b || !c) {
        if (c) HPCC_free(c);
        if (b) HPCC_free(b);
        if (a) HPCC_free(a);
        if (doIO) {
            fprintf( outFile, "Failed to allocate memory (%d)\n", VectorSize );
            fclose( outFile );
        }
        return 1;
    }
#ifdef _OPENMP
#pragma omp parallel for
#endif
    for (j=0; j<VectorSize; j++) {
        b[j] = 2.0;
        c[j] = 1.0;
    }
    scalar = 3.0;
#ifdef _OPENMP
#pragma omp parallel for
#endif
    for (j=0; j<VectorSize; j++)
        a[j] = b[j]+scalar*c[j];
    HPCC_free(c);
    HPCC_free(b);
    HPCC_free(a);
    return 0; }
#include <hpcc.h>
#ifdef _OPENMP
#include <omp.h>
#endif

static int VectorSize;
static double *a, *b, *c;

int HPCC_StarStream(HPCC_Params *params) {
  int myRank, commSize;
  int rv, errCount;
  MPI_Comm comm = MPI_COMM_WORLD;
  MPI_Comm_size( comm, &commSize);
  MPI_Comm_rank( comm, &myRank);
  rv = HPCC_Stream( params, 0 == myRank);
  MPI_Reduce( &rv, &errCount, 1, MPI_INT, MPI_SUM, 0, comm );
  return errCount;
}

int HPCC_Stream(HPCC_Params *params, int doIO) {
  register int j;
  double scalar;
  VectorSize = HPCC_LocalVectorSize( params, 3,
      sizeof(double), 0 );
  a = HPCC_XMALLOC( double, VectorSize );
  b = HPCC_XMALLOC( double, VectorSize );
  c = HPCC_XMALLOC( double, VectorSize );
  if (!a || !b || !c) {
    if (c) HPCC_free(c);
    if (b) HPCC_free(b);
    if (a) HPCC_free(a);
    if (doIO) {
      fprintf( outFile, "Failed to allocate memory (%d)\n",
          VectorSize );
      fclose( outFile );
    }
    return 1;
  }
  #ifdef _OPENMP
  #pragma omp parallel for
  #endif
  for (j=0; j<VectorSize; j++) {
    b[j] = 2.0;
    c[j] = 1.0;
  }
  scalar = 3.0;
  #ifdef _OPENMP
  #pragma omp parallel for
  #endif
  for (j=0; j<VectorSize; j++)
    a[j] = b[j]+scalar*c[j];
  HPCC_free(c);
  HPCC_free(b);
  HPCC_free(a);
  return 0;
}

#define N 2000000

int main() {
  float *d_a, *d_b, *d_c;
  float scalar;
  cudaMalloc((void**)&d_a, sizeof(float)*N);
  cudaMalloc((void**)&d_b, sizeof(float)*N);
  cudaMalloc((void**)&d_c, sizeof(float)*N);
  dim3 dimBlock(128);
  dim3 dimGrid(N/dimBlock.x);
  if( N % dimBlock.x != 0)
    dimGrid.x+=1;
  set_array<<<dimGrid,dimBlock>>>(d_b, .5f, N);
  set_array<<<dimGrid,dimBlock>>>(d_c, .5f, N);
  scalar=3.0f;
  STREAM_Triad<<<dimGrid,dimBlock>>>(d_b, d_c, d_a, scalar, N);
  cudaThreadSynchronize();
  cudaFree(d_a);
  cudaFree(d_b);
  cudaFree(d_c);
  return 0;  }
STREAM Triad: MPI+OpenMP

```c
#include <hpcc.h>
#include _OPENMP
#include <omp.h>
#endif
#endif

define N 2000000

tmain() {
  float *d_a, *d_b, *d_c;
  float scalar;
  cudaMalloc((void**)&d_a, sizeof(float)*N);
  cudaMalloc((void**)&d_b, sizeof(float)*N);
  cudaMalloc((void**)&d_c, sizeof(float)*N);
  dim3 dimBlock(128);
  dim3 dimGrid(N/dimBlock.x);
  if( N % dimBlock.x != 0 )
    dimGrid.x+=1;
  set_array<<<dimGrid,dimBlock>>>(d_b, .5f, N);
  set_array<<<dimGrid,dimBlock>>>(d_c, .5f, N);
  scalar=3.0f;
  STREAM_Triad<<<dimGrid,dimBlock>>>(d_b, d_c, d_a, scalar, N);
  cudaThreadSynchronize();
  cudaFree(d_a);
  cudaFree(d_b);
  cudaFree(d_c);
}

__global__
void set_array(float *a, float value, int len) {
  int idx = threadIdx.x + blockIdx.x * blockDim.x;
  if (idx < len) a[idx] = value;
}

__global__
void STREAM_Triad( float *a, float *b, float *c, float scalar, int len) {
  int idx = threadIdx.x + blockIdx.x * blockDim.x;
  if (idx < len) c[idx] = a[idx]+scalar*b[idx];
}
```

CUDA

```c
#include <hpcc.h>
#endif
#endif

define N 2000000

tmain() {
  float *d_a, *d_b, *d_c;
  float scalar;
  cudaMalloc((void**)&d_a, sizeof(float)*N);
  cudaMalloc((void**)&d_b, sizeof(float)*N);
  cudaMalloc((void**)&d_c, sizeof(float)*N);
  dim3 dimBlock(128);
  dim3 dimGrid(N/dimBlock.x);

cudaThreadSynchronize();
  cudaFree(d_a);
  cudaFree(d_b);
  cudaFree(d_c);
}
```

HPC suffers from too many distinct notations for expressing parallelism and locality. This tends to be a result of **bottom-up** language design.
STREAM Triad: Chapel

Philosophy: Good, top-down language design can tease system-specific implementation details away from an algorithm, permitting the compiler, runtime, applied scientist, and HPC expert to each focus on their strengths.

The special sauce: How should this index set—and any arrays and computations over it—be mapped to the system?
Chapel+LLVM History

- Chapel project starts
- LLVM 1.0 released
- first Chapel release
- public Chapel release
- clang released
- -llvm backend
- -llvm-wide-opt
- extern { c code }
- -llvm perf competitive
- -llvm default?

2003
2006
2009
2012
2015
2018
Chapel+LLVM History

- Chapel project grew up generating C code
chpl compilation flow

```
chpl
  \rightarrow
  a.chpl
  b.chpl
  \vdots

chpl
  \rightarrow
  a.c
  b.c
  \vdots

CC

  \rightarrow
  Chapel runtime (.h, .a)

  \rightarrow
  Executable
```
chpl --llvm compilation flow

runtime .h
extern { }

a.chpl

b.chpl

clang

chpl

LLVM module

LLVM Opt

linker

runtime .a

Executable
C Interoperability

- runtime.h
- extern {}
- a.chpl
- b.chpl

clang

chpl

LLVM module

LLVM Opts

linker

Executable

runtime.a
Goals of C Interoperability

- Chapel is a new language
- Libraries are important for productivity
- Easy use of libraries in another language is important!

- Chapel supports interoperability with C
- Need to be able to use an existing C library
  - functions, variables, types, and macros
- Using C functions needs to be efficient
  - performance is a goal here!
C Interoperability Example

// add1.h
static inline
int add1(int x) { return x+1; }

// addone.chpl
extern proc add1(x:c_int):c_int;
writeln(add1(4));

$ chpl addone.chpl add1.h
$ ./addone
5
With extern {}

// add1.h
static inline
int add1(int x) { return x+1; }

// addone.chpl
extern { #include "add1.h" }
writeln(add1(4));

$ chpl addone.chpl
$ ./addone
5
extern block compilation flow

frontend passes

parse .chpl

readExternC

extern {  
    int add1(int x);
}  

clang parse:  
C ➔ clang AST

readExternC:  
clang AST ➔ chapel extern decls

extern proc add1(x:c_int):c_int;
Combined Code Generation

runtime .h extern { }

a.chpl

b.chpl

clang

chpl

LLVM module

LLVM Opts

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Inlining with C code

- Some C functions expect to be inlined
  - if not, there is a performance penalty
- Runtime is written primarily in C
  - Enabling easy use of libraries like qthreads
- Chapel uses third-party libraries such as GMP
  - Library authors control what might be inlined
- Since Chapel generated C, it became normal to assume:
  - functions can be inlined
  - C types are available
  - fields in C structs are available
  - C macros are available
Example: Accessing a Struct Field

// sockaddr.h
#include <sys/socket.h>
typedef struct my_sockaddr_s {
    struct sockaddr_storage addr;
    size_t len;
} my_sockaddr_t;

// network.chpl
require "sockaddr.h";
extern record my_sockaddr_t {
    var len: size_t;
}
var x:my_sockaddr_t;
x.len = c_sizeof(c_int);
writeln(x.len);
Implementing Combined Code Generation

- clang
  - AST -> IR codegen
- chpl
  - AST -> IR codegen

Call to C proc? Use of C global?
  - `GetAddrOfGlobal`
Use of extern type?
  - `CodeGen::convertTypeForMemory`*
Use of field in extern record?
  - `CodeGen::getLLVMFieldNumber`**

* new to clang 5
** will be new in clang 6
C Macros

// usecs.h
#define USECS_PER_SEC 10000000

// microseconds.chpl

require "usecs.h";
const USECS_PER_SEC:c_int;
config const secs = 1;
writeln(secs, " seconds is ",
        secs*USECS_PER_SEC,
        " microseconds");

$ chpl macrodemo.chpl
$ ./macrodemo
5

How can this work when we generate LLVM IR?
'forall' parallelism

● The earlier example used
  \[ A = B + \alpha \cdot C \]

● Which is equivalent to:

\[
\text{forall } (a,b,c) \text{ in } \text{zip}(A,B,C) \text{ do } \\
a = b + \alpha \cdot c;
\]

● Chapel's forall loop represents a data parallel loop
  ● iterations can run in any order
  ● typically divides iterations up among some tasks
  ● parallelism is controlled by what is iterated over
forall\ lowering (1)

// user-code.chpl
forall x in MyIter() {
  body(x);
}

// library.chpl
iter MyIter(...) {
  coforall i in 1..n do // creates n tasks
    for j in 1..m do
      yield i*m+j;
  }

coforall i in 1..n do
  for j in 1..m do
    body(i*m+j);
forall' lowering (2)

coforall i in 1..n do
    for j in 1..m do
        body(i*m+j);

count = n
for i in 1..n do
    spawn(taskfn, i)
wait for count == 0

proc taskfn(i) {
    for j in 1..m do
        body(i*m+j);
}
Vectorizing

- We'd like to vectorize 'forall' loops
- Recall, 'forall' means iterations can run in any order
- Two strategies for vectorization:
  A. Vectorize in Chapel front-end
     - Chapel front-end creates vectorized LLVM IR
     - Challenges: not sharing vectorizer, might be a deoptimization
  B. Vectorize in LLVM optimizations (LoopVectorizer)
     - Chapel front-end generates loops with parallel_loop_access
     - Challenges: user-defined reductions, querying vector lane
Vectorizing in the Front-End

- It would be lower level than most front end operations
  - a lot depends on the processor:
    - vector width
    - supported vector operations
    - whether or not vectorizing is profitable
- Front-end vectorization reasonable if details are simple
- Presumably there is a reason that vectorization normally runs late in the LLVM optimization pipeline...
- Misses out on a chance to share with the community
Vectorizing in as an LLVM optimization

- parallel_loop_access good for most of loop body...
- ... but what about user-defined reductions?
- Would opaque function calls help?
  - front-end generates opaque_accumulate function calls
  - after vectorization, these are replaced with real reduction ops
  - vectorizer would see something like this:
    ```
define opaque_accumulate(...) readnone
  for ... {
    load/stores with parallel_loop_access ...
    %acc = opaque_accumulate(%acc, %value)
  }
```
- Would it interfere too much with the vectorizer? Harm cost modelling?
- Does LLVM need a canonical way to express custom reductions?
Communication Optimization in LLVM

```
include <runtime.h>
extern { }
```
Aside: Introducing PGAS Communication
Parallelism and Locality: Distinct in Chapel

- This is a parallel, but local program:

```chapel
coforall i in 1..msgs do 
  writeln("Hello from task ", i);
```

- This is a distributed, but serial program:

```chapel
writeln("Hello from locale 0!");
on Locales[1] do writeln("Hello from locale 1!");
on Locales[2] do writeln("Hello from locale 2!");
```

- This is a distributed parallel program:

```chapel
coforall i in 1..msgs do 
  on Locales[i%numLocales] do 
    writeln("Hello from task ", i,
      " running on locale ", here.id);
```
Partitioned Global Address Space (PGAS) Languages (Or more accurately: partitioned global namespace languages)

- **abstract concept:**
  - support a shared namespace on distributed memory
    - permit parallel tasks to access remote variables by naming them
  - establish a strong sense of ownership
    - every variable has a well-defined location
    - local variables are cheaper to access than remote ones

- **traditional PGAS languages have been SPMD in nature**
  - best-known examples: Fortran 2008’s co-arrays, Unified Parallel C (UPC)
shared int i(*); // declare a shared variable i

\[ i = \text{[values]} \]
SPMD PGAS Languages (using a pseudo-language, not Chapel)

shared int $i(*);$ // declare a shared variable $i$

function main() {
  $i = 2 * this_image();$ // each image initializes its copy
SPMD PGAS Languages (using a pseudo-language, not Chapel)

shared int i(*);  // declare a shared variable i
function main() {
    i = 2*this_image();  // each image initializes its copy
}

private int j;  // declare a private variable j

\[
\begin{array}{cccccc}
  i &= 0 & 2 & 4 & 6 & 8 \\
  j &= & & & & \\
\end{array}
\]
SPMD PGAS Languages (using a pseudo-language, not Chapel)

shared int i(*); // declare a shared variable i
function main() {
    i = 2*this_image(); // each image initializes its copy
    barrier();
    private int j; // declare a private variable j
    j = i( (this_image()+1) % num_images() );
    // ^^ access our neighbor’s copy of i; compiler and runtime implement the communication
    // Q: How did we know our neighbor had an i?
    // A: Because it’s SPMD – we’re all running the same program so if we have an i, so do they.

    i = 0 2 4 6 8
    j = 2 4 6 8 0
Chapel and PGAS

- Chapel is PGAS, but unlike most, it’s not inherently SPMD
  - never think about “the other copies of the program”
  - “global name/address space” comes from lexical scoping
    - as in traditional languages, each declaration yields one variable
    - variables are stored on the locale where the task declaring it is executing

![Locales](image)

Locales (think: “compute nodes”)
Chapel: Scoping and Locality

```chapel
var i: int;
```
Chapel: Scoping and Locality

```chapel
var i: int;
on Locales[1] {
```

Locales (think: “compute nodes”)
var i: int;
on Locales[1] {
    var j: int;
}
Chapel: Scoping and Locality

var i: int;
on Locales[1] {
    var j: int;
    coforall loc in Locales {
        on loc {

Locales (think: “compute nodes”)
Chapel: Scoping and Locality

```chapel
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
      var k: int;
      ...
    }
  }
}
```

**Locales** (think: “compute nodes”)
Chapel: Scoping and Locality

```chapel
var i: int; 
on Locales[1] { 
  var j: int; 
  coforall loc in Locales { 
    on loc { 
      var k: int; 
      k = 2*i + j; 
    } 
  } 
}
```

**Locales** (think: “compute nodes”)

OK to access `i`, `j`, and `k` wherever they live

\[ k = 2 * i + j; \]
Chapel: Scoping and Locality

```chapel
var i: int;

on Locales[1] {
    var j: int;
    coforall loc in Locales {
        on loc {
            var k: int;
            k = 2*i + j;
        }
    }
}
```

Here, \(i\) and \(j\) are remote, so the compiler + runtime will transfer their values.

\[ k = 2i + j; \]
Chapel: Locality queries

```chapel
var i: int;
on Locales[1] {
    var j: int;
    coforall loc in Locales {
        on loc {
            var k: int;

            ..here...  // query the locale on which this task is running
            ...
            j.locale...  // query the locale on which j is stored
        }
    }
}
```

Locales (think: “compute nodes”)
Communication Optimization in LLVM

```
// runtime.h
extern {}

a.chpl

b.chpl

clang

chpl

LLVM module

LLVM Opt

linker

Executable

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Communication Optimization: Overview

- Idea is to use LLVM passes to optimize GET and PUT
- Enabled with --llvm-wide-opt compiler flag
- First appeared in Chapel 1.8
- Unfortunately was not working in 1.15 and 1.16 releases
// x is possibly remote
var sum = 0;
for i in 1..100 {
    %1 = get(x);
    sum += %1;
}

var sum = 0;
for i in 1..100 {
    %1 = get(x);
    sum += %1;
}

var sum = 0;
for i in 1..100 {
    %1 = load <100> %x
    sum += %1;
}

var sum = 0;
for i in 1..100 {
    %1 = load <100> %x
    sum += %1;
}

load <100> %x = load i64 addrspace(100)* %x
Communication Optimization: Details

- Uses existing LLVM passes to optimize GET and PUT
  - GET/PUT represented as load/store with special pointer type
  - normal LLVM optimizations run and optimize load/store as usual
  - a custom LLVM pass lowers them back to calls to the Chapel runtime

- Optimization gains from this strategy can be significant
  - See "LLVM-based Communication Optimizations for PGAS Programs"

- Historically, needed packed wide pointers as workaround
  - wide pointer normally stored as a 128-bit struct: {node id, address}
  - bugs in LLVM 3.3 prevented using 128-bit pointers
  - packed wide pointers store node id in high bits of a 64-bit address
  - led to scalability constraints - maximum of 65536 nodes
  - sometimes made --llvm-wide-opt code slower than C backend
Communication Optimization: Recent Work

- Fixed --llvm-wide-opt
- Removed reliance on packed wide pointers
- Now generates LLVM IR with 128-bit pointers
  - revealed (only) a few LLVM bugs (so far)
    - BasicAA - needed to use APInt more (not just int64_t)
    - ValueTracking - error using APInt
Comm Opt: Impact

Speedup of --llvm and --llvm-wide-opt vs C on 16 nodes XC

<table>
<thead>
<tr>
<th>Benchmark</th>
<th>C</th>
<th>llvm</th>
<th>llvm-wide-opt</th>
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<tbody>
<tr>
<td>HPCC PTRANS</td>
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</tbody>
</table>

Times Faster

0 1 2 3
Future Work

- Chapel 1.17 - hope to make --llvm the default
- Migrate some Chapel-specific optimizations to LLVM
- Continue improving the LLVM IR that Chapel generates
- Separate compilation & link-time optimization
- Chapel interpreter using LLVM JIT
- Using a shared parallel LLVM IR
Thanks

● Thanks for your
  ● attention
  ● great discussions
  ● patch reviews
  ● related work!

● Check us out at https://chapel-lang.org
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Backup Slides
Chapel Community R&D Efforts

(and several others…)

http://chapel.cray.com/collaborations.html
Contributions to LLVM/clang

- Add clang CodeGen support for generating field access
  - supports 'extern record'
  - [https://reviews.llvm.org/D38473](https://reviews.llvm.org/D38473)

- Fix a bug in BasicAA – crashing with 128-bit pointers
  - enables --llvm-wide-opt with {node, address} wide pointers
  - [https://reviews.llvm.org/D38499](https://reviews.llvm.org/D38499)

- Fix a bug in ValueTracking – crashing with 128-bit pointers
  - enables --llvm-wide-opt with {node, address} wide pointers
  - [https://reviews.llvm.org/D38501](https://reviews.llvm.org/D38501)
ISx Execution Time: MPI, SHMEM

ISx weakISO Total Time

Time (seconds)

Nodes (x 36 cores per node)

better

MPI
SHMEM
ISx Execution Time: MPI, SHMEM, Chapel

ISx weakISO Total Time

Time (seconds)

Nodes (x 36 cores per node)

Chapel 1.15
MPI
SHMEM

better
RA Performance: Chapel vs. MPI

Performance of RA (atomics)

GUP/s

Locales (x 36 cores per locale)

ref MPI no-bucketing
ref MPI bucketing
1.15 u+q

better
Chapel+LLVM - Google Summer of Code

- Przemysław Leśniak contributed many improvements:
  - mark signed integer arithmetic with 'nsw' to improve loop optimization
  - command-line flags to emit LLVM IR at particular points in compilation
  - new tests that use LLVM tool FileCheck to verify emitted LLVM IR
  - mark order-independent loops with llvm.parallel_loop_access metadata
  - mark const variables with llvm.invariant.start
  - enable LLVM floating point optimization when --no-ieee-float is used
  - add nonnull attribute to ref arguments to functions
  - add a header implementing clang built-ins to improve 'complex' performance
Performance Regression: LLVM 3.7 to 4 upgrade

LCALS find_first_min went from 2x faster than C to 3x slower
Performance Improvements: LLVM 3.7 to 4
Performance Improvements: GSoC nsw

PRK stencil got 3x faster with no-signed-wrap on signed integer addition – loop induction variable now identified
Performance Improvement: GSoC fast float

LCALS fir got 3x faster with LLVM floating point optimizations enabled for --no-ieee-float
Performance Improvements: Built-ins Header

complex version of Mandelbrot got 3x faster with header implementing clang built-ins
--llvm is Now Competitive

- Benchmark runtime now competitive or better with --llvm
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