# Chapel:
## Productive Parallel Programming at Scale

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Tutorial at JMU

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# Safe Harbor Statement

This presentation may contain forward-looking statements that are based on our current expectations. Forward looking statements may include statements about our financial guidance and expected operating results, our opportunities and future potential, our product development and new product introduction plans, our ability to expand and penetrate our addressable markets and other statements that are not historical facts. These statements are only predictions and actual results may materially vary from those projected. Please refer to Cray's documents filed with the SEC from time to time concerning factors that could affect the Company and these forward-looking statements.

# Cray: The Supercomputing Company

**1972: Seymour Cray founded Cray Research**

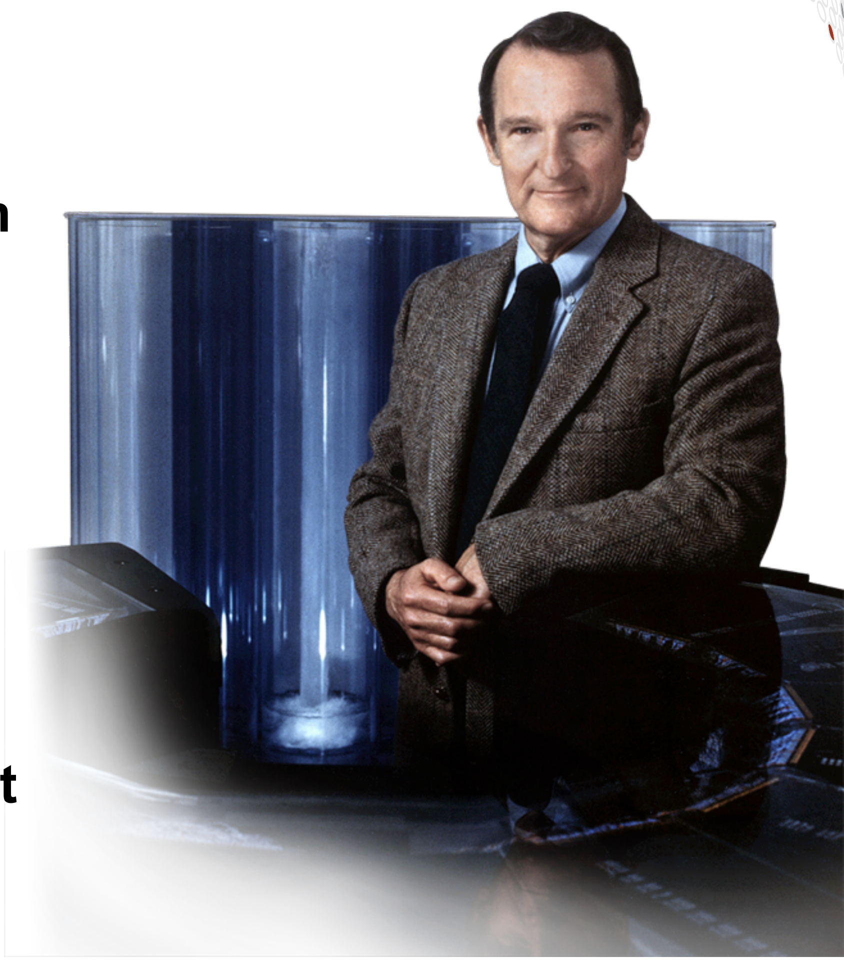
**2000: Tera purchased Cray Research from SGI and formed Cray Inc.**

- corporate headquarters based in Seattle, WA

**Technology Focus Areas:**

- Computation
- Storage
- Analytics

**Vision: Provide the systems and tools that our customers need to solve the world's hardest problems.**



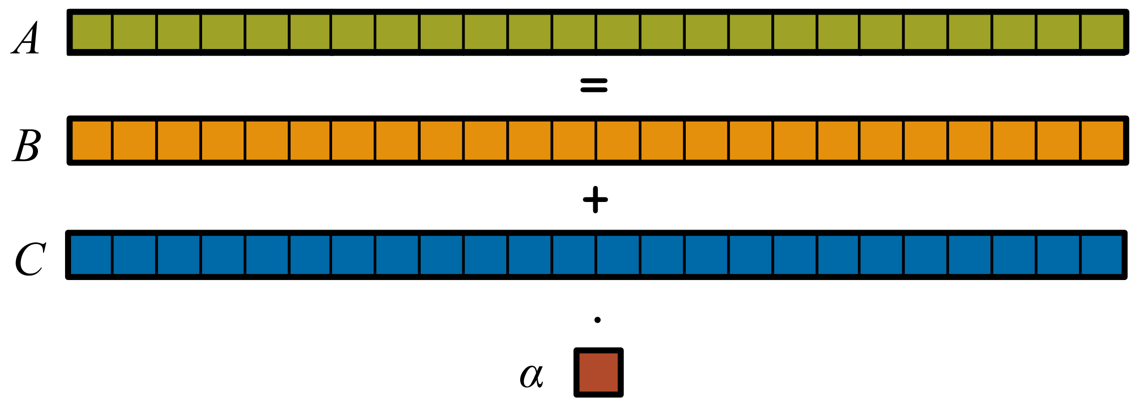
# High Performance Computing (HPC) Programming Models by Example

# 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

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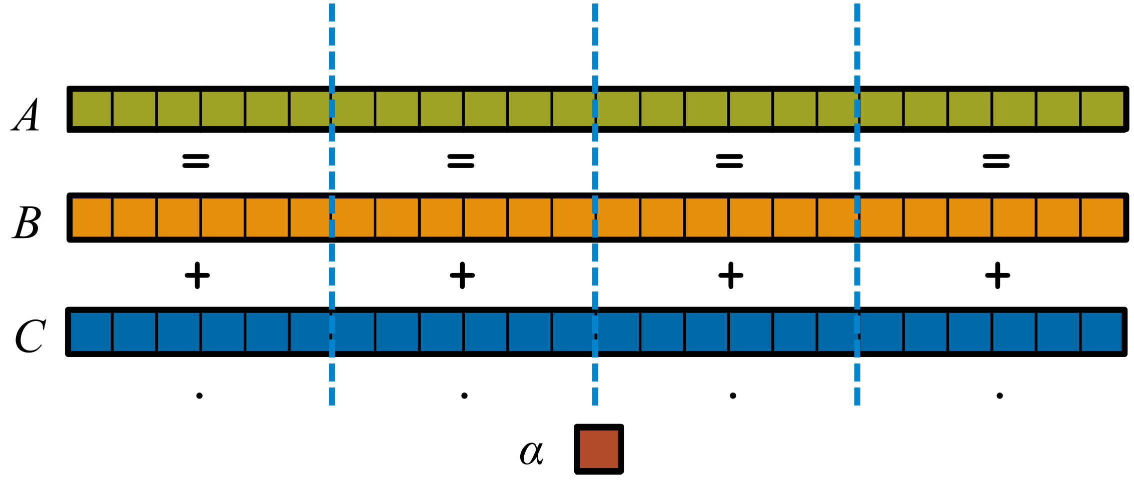
**In pictures, in parallel:**



# STREAM Triad: a trivial parallel computation

**Given:** $m$-element vectors $A, B, C$

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

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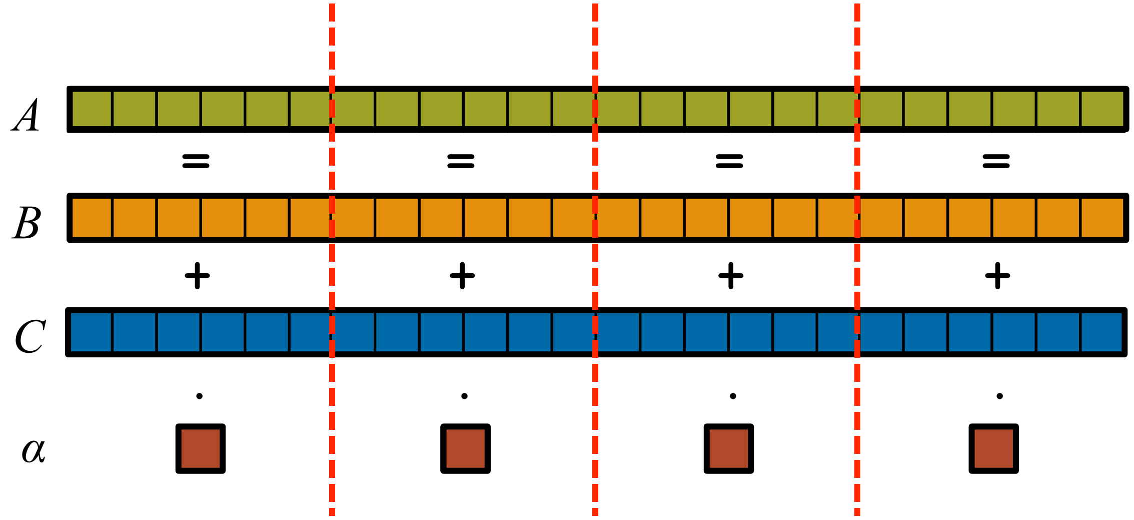
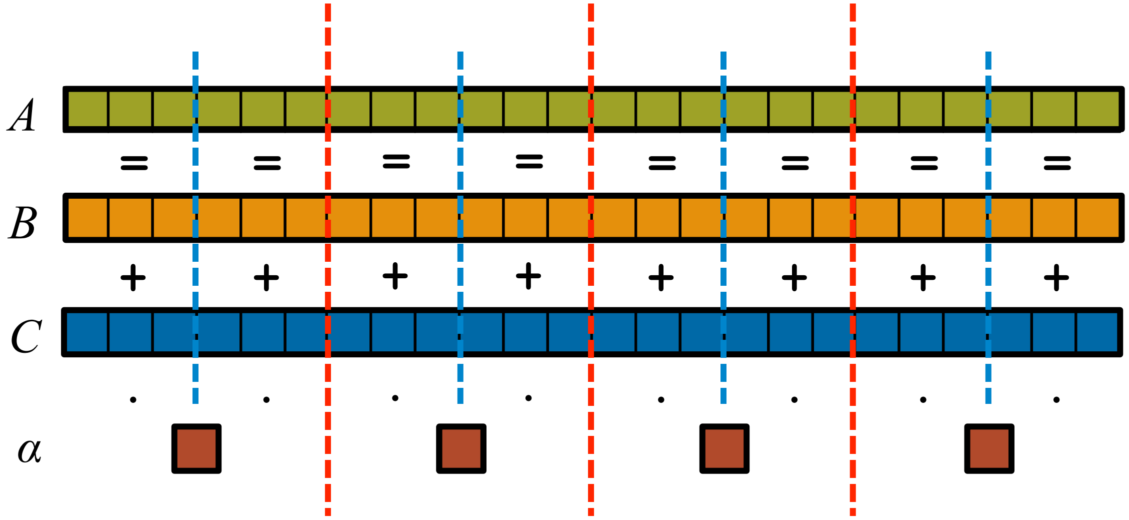


# STREAM Triad: a trivial parallel computation

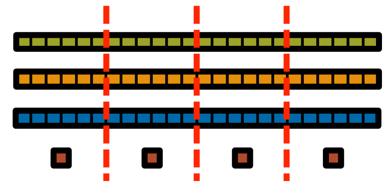
**Given:** $m$-element vectors $A, B, C$

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

**In pictures, in parallel (distributed memory multicore):**



# STREAM Triad: MPI

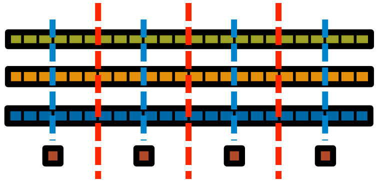


MPI

```
#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] = 0.0;
}

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);
```

# STREAM Triad: MPI+OpenMP



MPI + OpenMP

```
#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;
}

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  VectorSize = HPCC_LocalVectorSize( params, 3,
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  a = HPCC_XMALLOC( double, VectorSize );
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```
  if (!a || !b || !c) {
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    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] = 0.0;
  }

  scalar = 3.0;

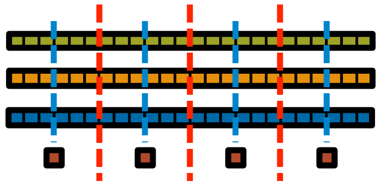
#ifdef _OPENMP
#pragma omp parallel for
#endif
  for (j=0; j<VectorSize; j++)
    a[j] = b[j]+scalar*c[j];

  HPCC_free(c);
  HPCC_free(b);
  HPCC_free(a);
```

# STREAM Triad: MPI+OpenMP vs. CUDA

*HPC suffers from too many distinct notations for expressing parallelism and locality*

## MPI + OpenMP



```
#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;

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  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 );

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    return 1;
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#ifdef _OPENMP
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#endif
  for (j=0; j<VectorSize; j++) {
    b[j] = 2.0;
    c[j] = 0.0;
  }

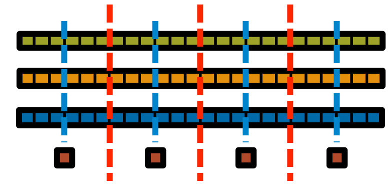
  scalar = 3.0;

#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;
}
```

## CUDA



```
#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

  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];
}
```

# Why so many programming models?

## HPC tends to approach programming models bottom-up:

Given a system and its core capabilities…

…provide features that can access the available performance.

- portability? generality? programmability? …not strictly required.

| Type of HW Parallelism | Programming Model | Unit of Parallelism |
|---|---|---|
| Inter-node | MPI | executable |
| Intra-node/multicore | OpenMP / pthreads | iteration/task |
| Instruction-level vectors/threads | pragmas | iteration |
| GPU/accelerator | CUDA / Open[CL\|MP\|ACC] | SIMD function/task |

benefits: lots of control; decent generality; easy to implement

downsides: lots of user-managed detail; brittle to changes

# Motivation for Chapel

**Q: Can a single language be…**

…as productive as Python?
…as fast as Fortran?
…as portable as C?
…as scalable as MPI?
…as fun as <your favorite language here>?

**A: We believe so.**

# The Challenge

**Q: So why don't we have such languages already?**

~~**A: Technical challenges?**~~

- while they exist, we don't think this is the main issue…

**A: Due to a lack of…**

…long-term efforts
…resources
…community will
…co-design between developers and users
…patience

***Chapel is our attempt to reverse this trend***

# What is Chapel?

**Chapel:** A productive parallel programming language

- extensible
- portable
- open-source
- a collaborative effort
- a work-in-progress

**Goals:**

- Support general parallel programming
  - "any parallel algorithm on any parallel hardware"
- Make parallel programming 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:

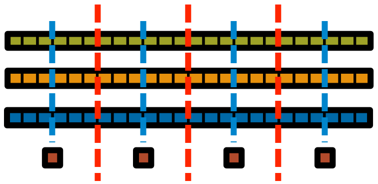
"something that lets me express my parallel computations without having to wrestle with architecture-specific details"

## Chapel Team:

"something that lets computational scientists express what they want, without taking away the control that HPC programmers need, implemented in a language as attractive as recent graduates want."

# Rewinding a few slides…

## MPI + OpenMP



```
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static int VectorSize;
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int HPCC_StarStream(HPCC_Params *params) {
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  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);
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    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;
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  }

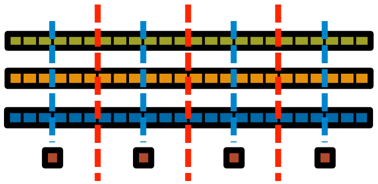
  scalar = 3.0;

#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;
}
```

## CUDA



```
#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);
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  dim3 dimBlock(128);
  dim3 dimGrid(N/dimBlock.x );
  if( N % dimBlock.x != 0 ) dimGrid

  set_array<<<dimGrid,dimBlock>>>(d_b, .5f, N);
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  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];
}
```

*HPC suffers from too many distinct notations for expressing parallelism and locality*

# STREAM Triad: Chapel

MPI + OpenMP

```
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#ifdef _OPENMP
#include <omp.h>
#endif

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

int HPCC_StarStream(HPCC_Params *par
  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 == myR
  MPI_Reduce( &rv, &errCount, 1, MPI

  return errCount;
}

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

  VectorSize = HPCC_LocalVectorSize(

  a = HPCC_XMALLOC( double, VectorSi
  b = HPCC_XMALLOC( double, VectorSi
  c = HPCC_XMALLOC( double, VectorSi

  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 );
```

**Chapel**

```
config const m = 1000,
             alpha = 3.0;

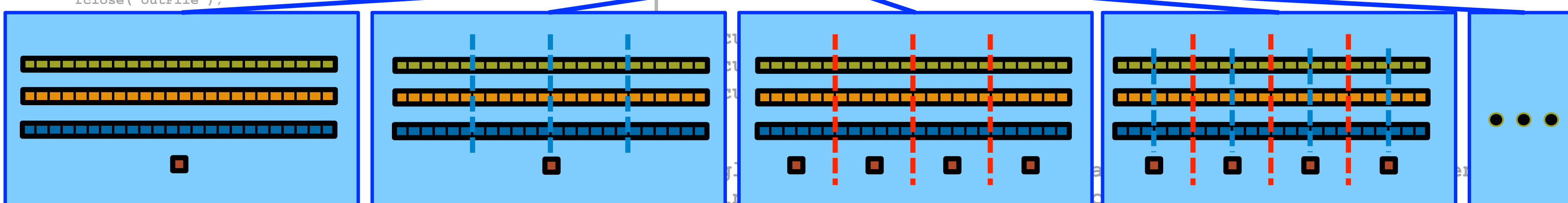
const ProblemSpace = {1..m} dmapped …;

var A, B, C: [ProblemSpace] real;

B = 2.0;
C = 3.0;

A = B + alpha * C;
```

the special sauce



<u>Philosophy:</u> 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.

# Outline

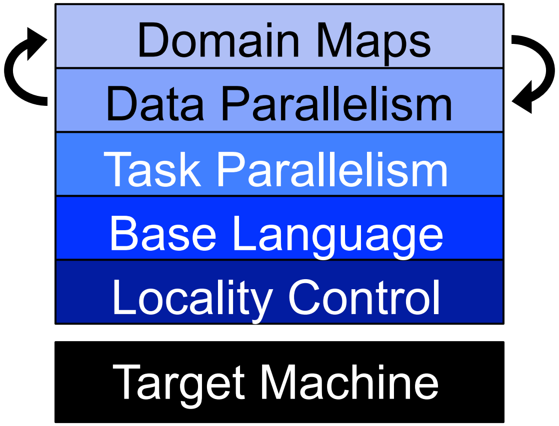
- ✓ Motivation for Chapel
- ➢ Survey of Chapel Concepts
- Chapel Project and Characterizations
- Chapel Resources

# Chapel's Multiresolution Philosophy

***Multiresolution Design:*** **Support multiple tiers of features**

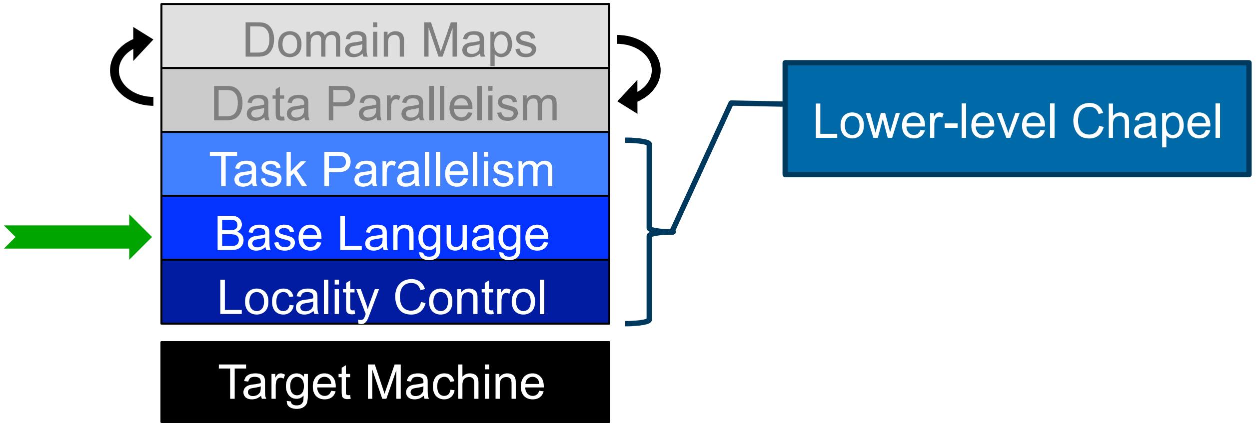
- higher levels for programmability, productivity
- lower levels for greater degrees of control

*Chapel language concepts*




- build the higher-level concepts in terms of the lower
- permit the user to intermix layers arbitrarily

# Base Language



# Base Language Features, by example

```
iter fib(n) {
  var current = 0,
      next = 1;

  for i in 1..n {
    yield current;
    current += next;
    current <=> next;
  }
}
```

```
config const n = 10;

for f in fib(n) do
  writeln(f);
```

```
0
1
1
2
3
5
8
…
```

# Base Language Features, by example

CLU-style iterators

```
iter fib(n) {
  var current = 0,
      next = 1;

  for i in 1..n {
    yield current;
    current += next;
    current <=> next;
  }
}
```

```
config const n = 10;

for f in fib(n) do
  writeln(f);
```

```
0
1
1
2
3
5
8
…
```

# Base Language Features, by example

Configuration declarations
(to avoid command-line argument parsing)
`./a.out –n=1000000`

```
iter fib(n) {
  var current = 0,
      next = 1;

  for i in 1..n {
    yield current;
    current += next;
    current <=> next;
  }
}
```

```
config const n = 10;

for f in fib(n) do
  writeln(f);
```

```
0
1
1
2
3
5
8
…
```

# Base Language Features, by example

Static type inference for:

- arguments
- return types
- variables

```
iter fib(n) {
  var current = 0,
      next = 1;

  for i in 1..n {
    yield current;
    current += next;
    current <=> next;
  }
}
```

```
config const n = 10;

for f in fib(n) do
  writeln(f);
```

```
0
1
1
2
3
5
8
…
```

# Base Language Features, by example

Zippered iteration

```
iter fib(n) {
  var current = 0,
      next = 1;

  for i in 1..n {
    yield current;
    current += next;
    current <=> next;
  }
}
```

```
config const n = 10;

for (i,f) in zip(0..#n, fib(n)) do
  writeln("fib #", i, " is ", f);
```

```
fib #0 is 0
fib #1 is 1
fib #2 is 1
fib #3 is 2
fib #4 is 3
fib #5 is 5
fib #6 is 8
…
```

# Base Language Features, by example

Range types and operators

```
iter fib(n) {
  var current = 0,
      next = 1;

  for i in 1..n {
    yield current;
    current += next;
    current <=> next;
  }
}
```

```
config const n = 10;

for (i,f) in zip(0..#n, fib(n)) do
  writeln("fib #", i, " is ", f);
```

```
fib #0 is 0
fib #1 is 1
fib #2 is 1
fib #3 is 2
fib #4 is 3
fib #5 is 5
fib #6 is 8
…
```

# Base Language Features, by example

tuples

```
iter fib(n) {
  var current = 0,
      next = 1;

  for i in 1..n {
    yield current;
    current += next;
    current <=> next;
  }
}
```

```
config const n = 10;

for (i,f) in zip(0..#n, fib(n)) do
  writeln("fib #", i, " is ", f);
```

```
fib #0 is 0
fib #1 is 1
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fib #6 is 8
…
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# Base Language Features, by example

```
iter fib(n) {
  var current = 0,
      next = 1;

  for i in 1..n {
    yield current;
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  }
}
```
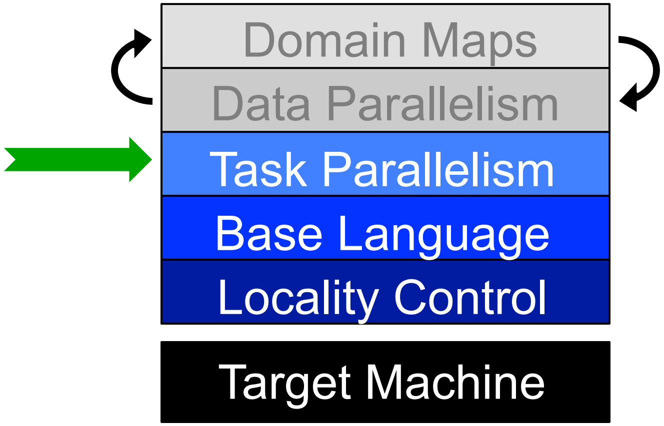

```
config const n = 10;

for (i,f) in zip(0..#n, fib(n)) do
  writeln("fib #", i, " is ", f);
```

```
fib #0 is 0
fib #1 is 1
fib #2 is 1
fib #3 is 2
fib #4 is 3
fib #5 is 5
fib #6 is 8
…
```

# Other Base Language Features

- **interoperability features**
- **OOP** (value- and reference-based)
- **overloading, where clauses**
- **argument intents, default values, match-by-name**
- **compile-time features for meta-programming**
  - e.g., compile-time functions to compute types, values; reflection
- **modules** (for namespace management)
- **rank-independent programming features**
- **…**

# Task Parallelism



# Task Parallelism: Begin Statements

```
// create a fire-and-forget task for a statement
begin writeln("hello world");
writeln("goodbye");
```

## Possible outputs:

```
hello world
goodbye
```

```
goodbye
hello world
```

# Task Parallelism: Coforall Loops

```
// create a task per iteration
coforall t in 0..#numTasks {
  writeln("Hello from task ", t, " of ", numTasks);
} // implicit join of the numTasks tasks here

writeln("All tasks done");
```

## Sample output:

```
Hello from task 2 of 4
Hello from task 0 of 4
Hello from task 3 of 4
Hello from task 1 of 4
All tasks done
```

# Task Parallelism: Data-Driven Synchronization

- **atomic variables:** support atomic operations
  - e.g., compare-and-swap; atomic sum, multiply, etc.
  - similar to C/C++

- **sync variables:** store full-empty state along with value
  - by default, reads/writes block until full/empty, leave in opposite state

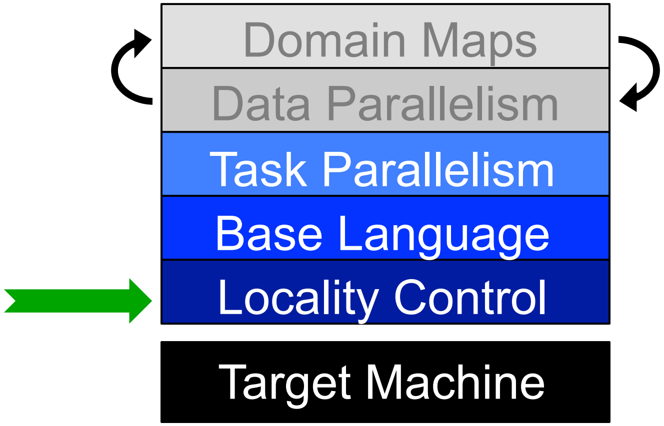
# Bounded Buffer Producer/Consumer Example

```
begin producer();
consumer();

// 'sync' types store full/empty state along with value
var buff$: [0..#buffersize] sync real;

proc producer() {
  var i = 0;
  for … {
    i = (i+1) % buffersize;
    buff$[i] = …;   // writes block until empty, leave full
} }

proc consumer() {
  var i = 0;
  while … {
    i= (i+1) % buffersize;
    …buff$[i]…;   // reads block until full, leave empty
} }
```

# Other Task Parallel Concepts

- **cobegins:** create tasks using compound statements
- **single variables:** like sync variables, but write-once
- **sync statements:** join unstructured tasks
- **serial statements:** conditionally squash parallelism

# Locality Control



# The Locale Type

**Definition:**

- Abstract unit of target architecture
- Supports reasoning about locality
  - defines "here vs. there" / "local vs. remote"
- Capable of running tasks and storing variables
  - i.e., has processors and memory

**Typically:** A compute node (multicore processor or SMP)

# Getting started with locales

- Specify # of locales when running Chapel programs

```
% a.out --numLocales=8
```

```
% a.out -nl 8
```

- Chapel provides built-in locale variables

```
config const numLocales: int = …;
const Locales: [0..#numLocales] locale = …;
```

*Locales*


- `main()` starts execution as a task on locale #0

# Locale Operations

- Locale methods support queries about the target system:

```
proc locale.physicalMemory(…) { … }
proc locale.numCores { … }
proc locale.id { … }
proc locale.name { … }
```

- *On-clauses* support placement of computations:

```
writeln("on locale 0");

on Locales[1] do
  writeln("now on locale 1");

writeln("on locale 0 again");
```

```
on A[i,j] do
  bigComputation(A);

on node.left do
  search(node.left);
```

# Parallelism and Locality: Orthogonal in Chapel

- **This is a parallel, but local program:**

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

- **This is a distributed, but serial program:**

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

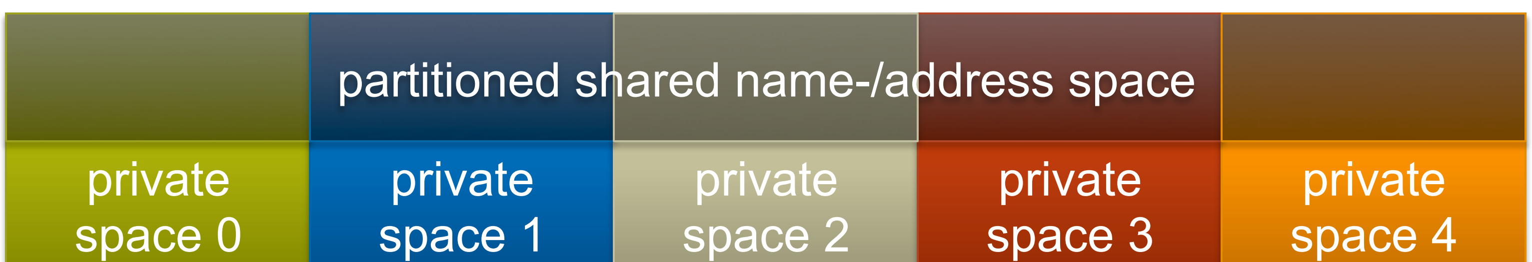
- **This is a distributed parallel program:**

```
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

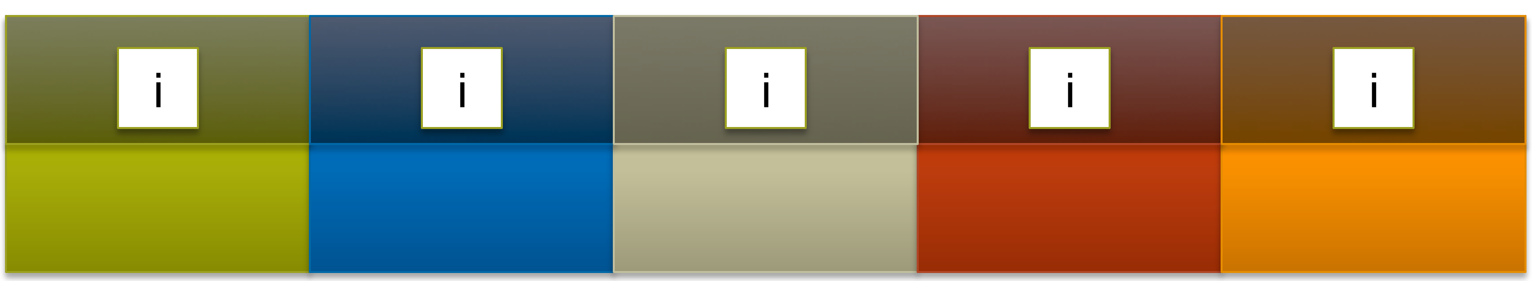
## (Or perhaps: partitioned global namespace languages)

- **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 Co-Arrays, UPC



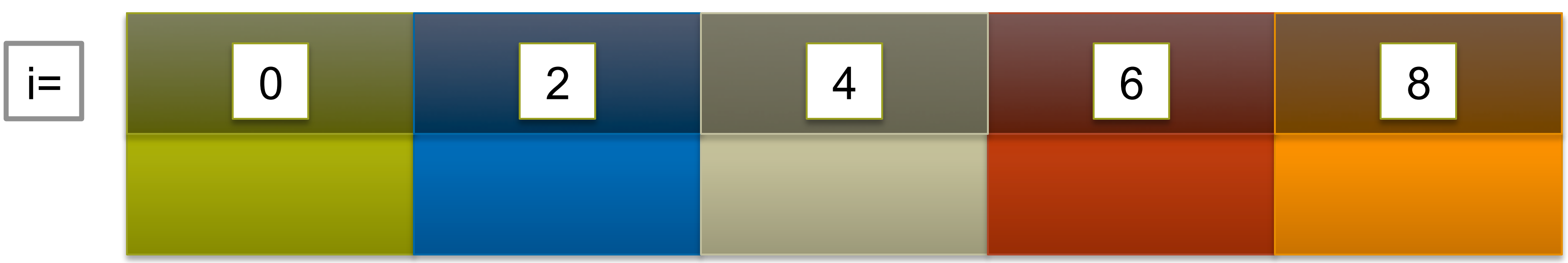
# SPMD PGAS Languages (using a pseudo-language, not Chapel)

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



# 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
```

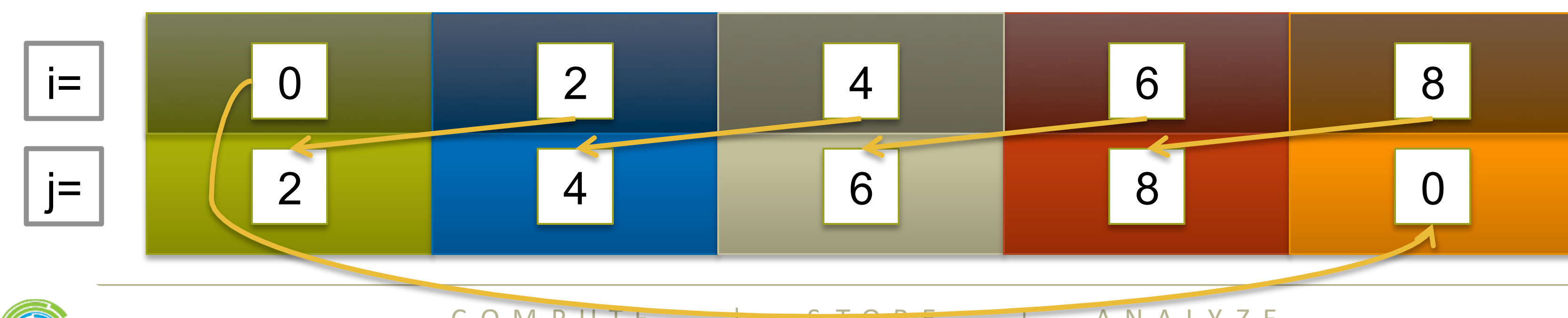


# SPMD PGAS Languages (using a pseudo-language, not Chapel)

```
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
```

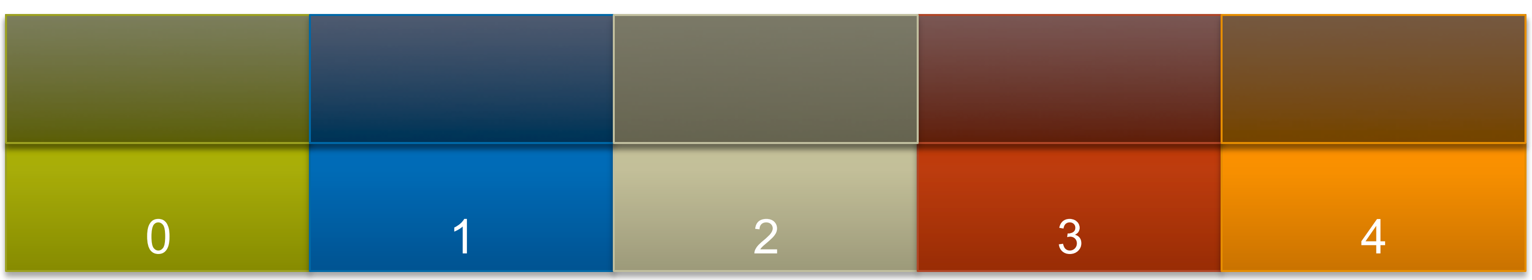
# SPMD PGAS Languages (using a pseudo-language, not Chapel)

```
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
    // communication implemented by compiler + runtime

    // How did we know our neighbor had an i?
    // Because it's SPMD – we're all running the same
    // program.  (Simple, but restrictive)
```



# Chapel and PGAS

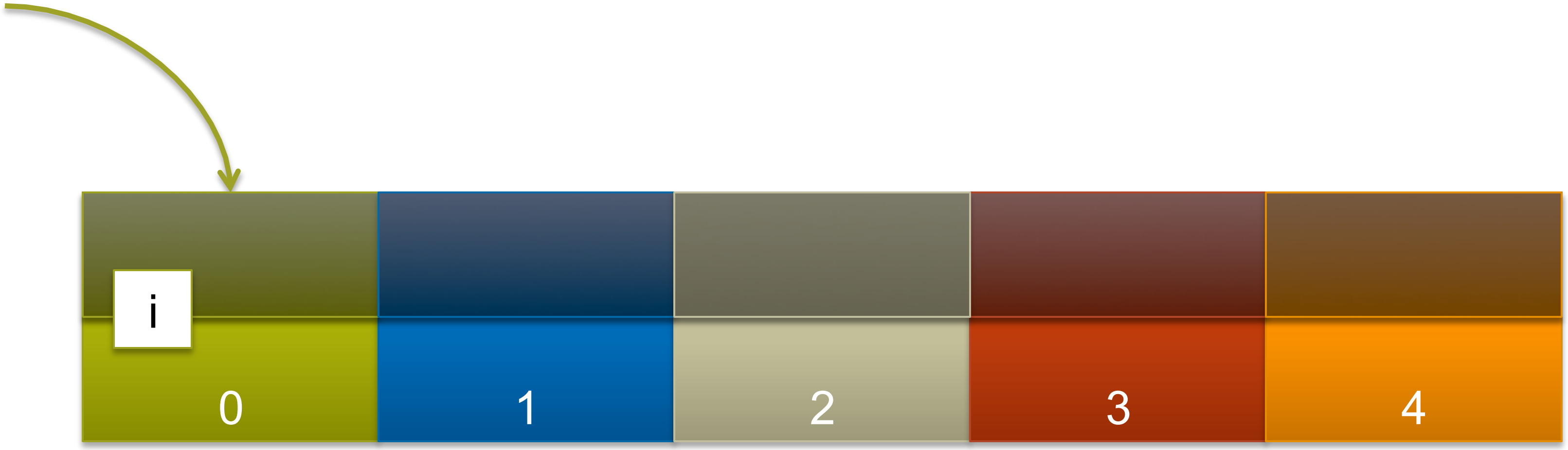
- **Chapel is PGAS, but unlike most, it's not inherently SPMD**
  - never think about "the other copies of the program"
  - "global name/address space" comes from lexical scoping
    - as in traditional languages, each declaration yields one variable
    - variables are stored on the locale where the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




*Locales* (think: "compute nodes")

# Chapel: Scoping and Locality

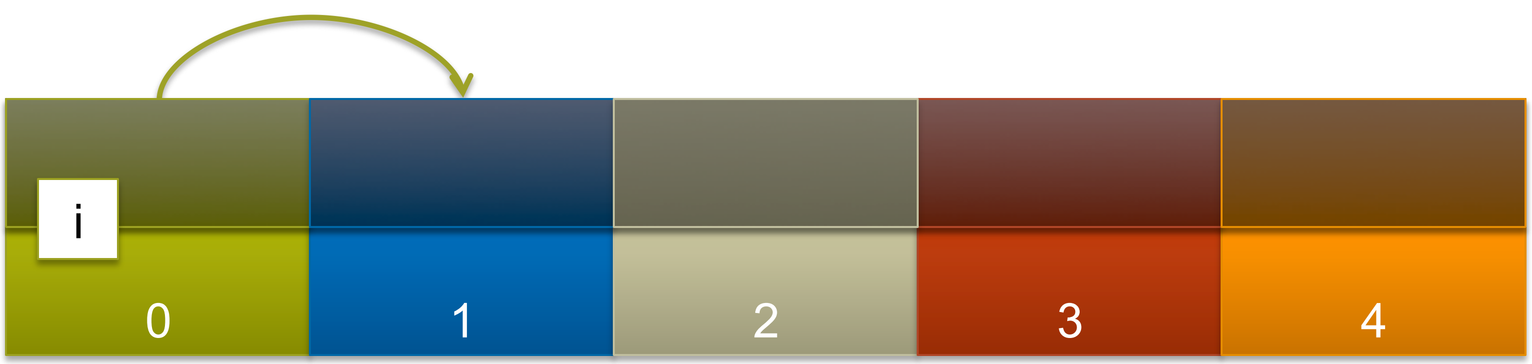
```
var i: int;
```




*Locales* (think: "compute nodes")

# Chapel: Scoping and Locality

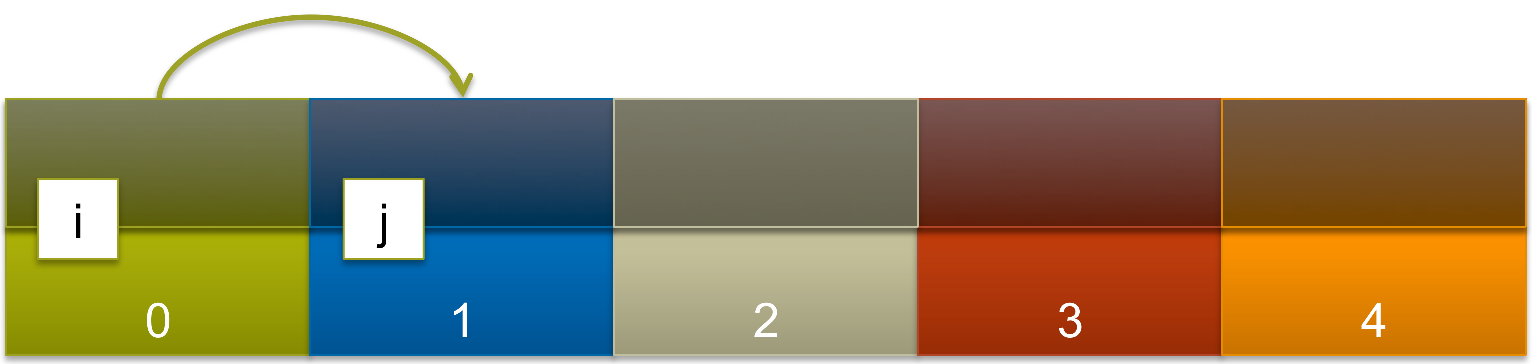
```
var i: int;
on Locales[1] {
```




*Locales* (think: "compute nodes")

# Chapel: Scoping and Locality

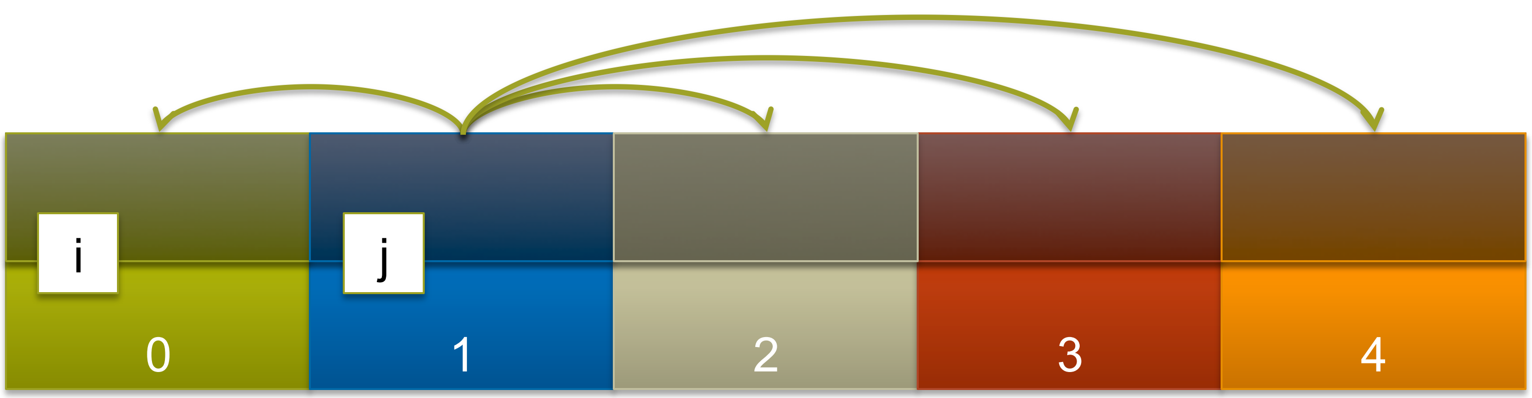
```
var i: int;
on Locales[1] {
  var j: int;
```




*Locales* (think: "compute nodes")

# Chapel: Scoping and Locality

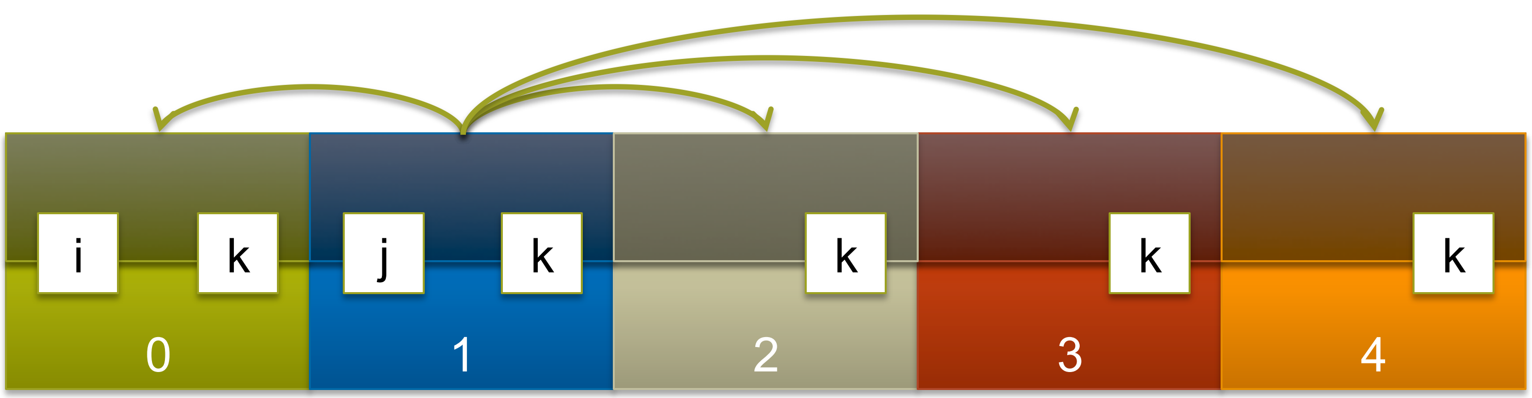
```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
```




*Locales* (think: "compute nodes")

# Chapel: Scoping and Locality

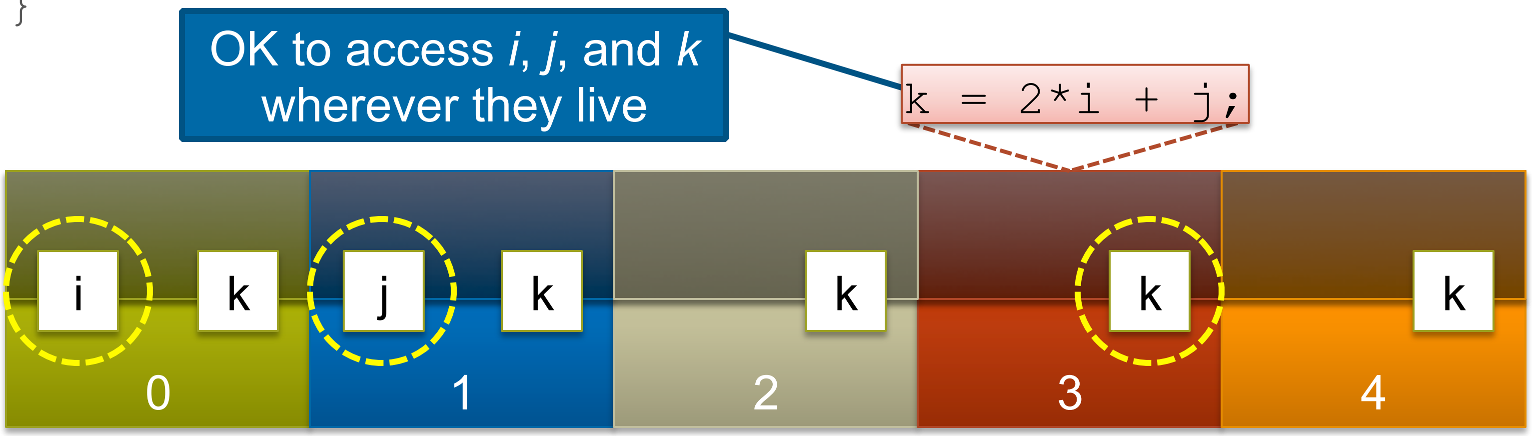
```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
      var k: int;
      …
    }
  }
}
```




*Locales* (think: “compute nodes”)

# Chapel: Scoping and Locality

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

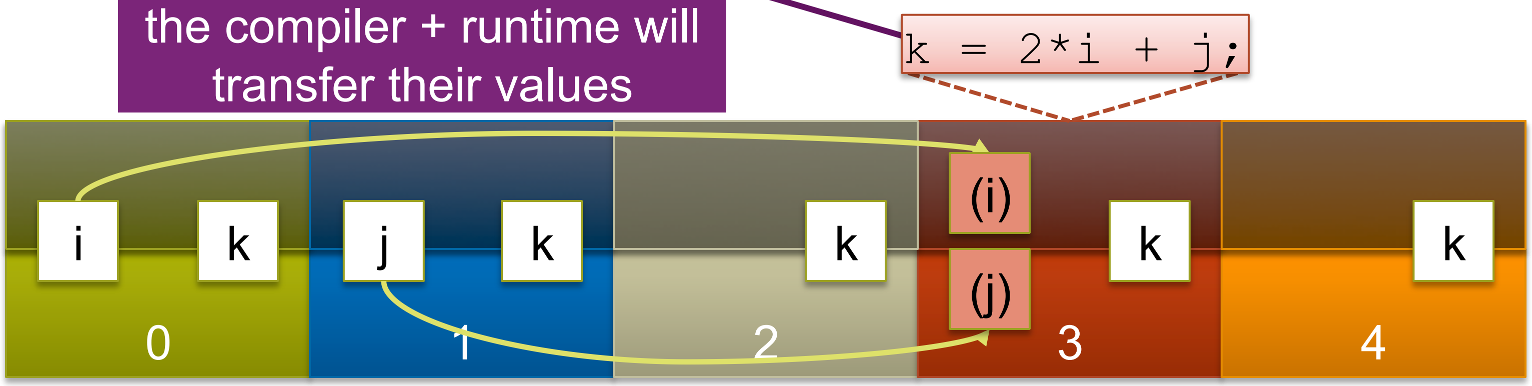



*Locales* (think: "compute nodes")

# Chapel: Scoping and Locality

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

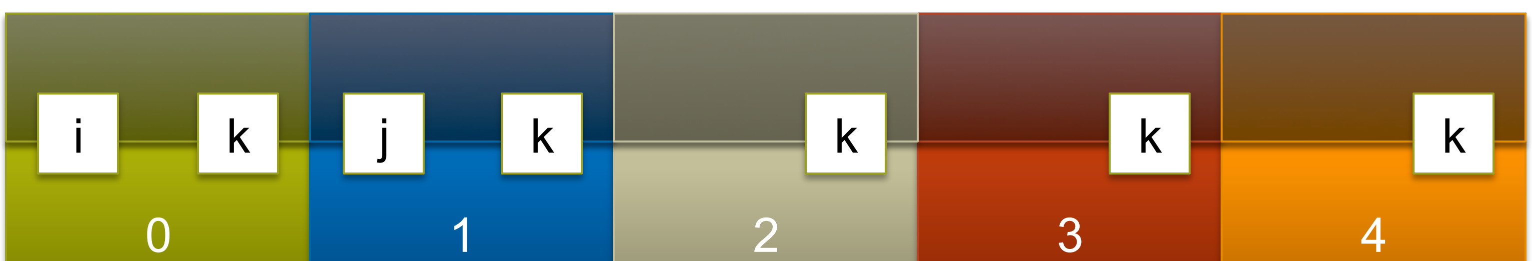
here, *i* and *j* are remote, so the compiler + runtime will transfer their values




*Locales* (think: “compute nodes”)

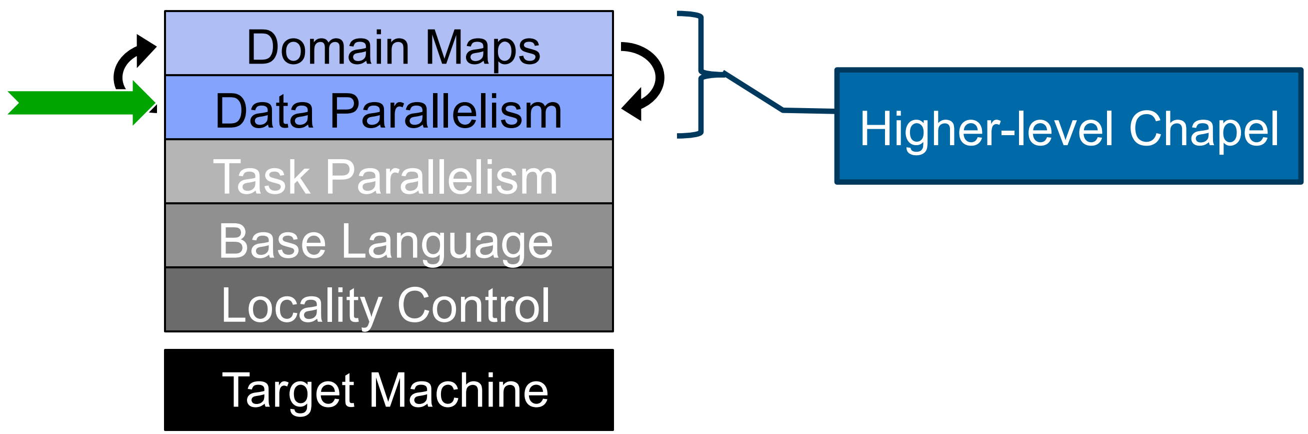
# Chapel: Locality queries

```
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
    }
  }
}
```



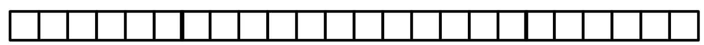

*Locales* (think: “compute nodes”)

# Data Parallelism

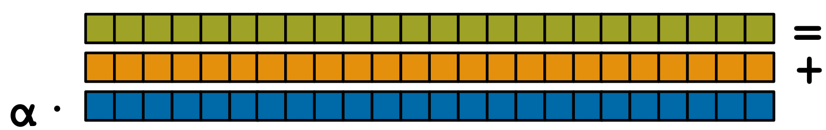


# Data Parallelism By Example: STREAM Triad

```
const ProblemSpace = {1..m};
```



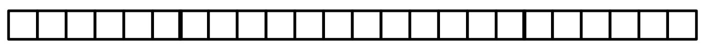
```
var A, B, C: [ProblemSpace] real;
```



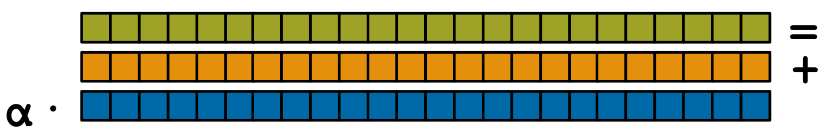

```
forall (a,b,c) in zip(A,B,C) do
  a = b + alpha*c;
```

# Data Parallelism By Example: STREAM Triad

```
const ProblemSpace = {1..m};
```



```
var A, B, C: [ProblemSpace] real;
```




```
A = B + alpha * C;   // equivalent to the zippered forall
```

# Other Data Parallel Features

- **Rich Domain/Array Types:**
  - multidimensional
  - strided
  - sparse
  - associative
- **Slicing:** Refer to subarrays using ranges/domains

```
… A[2..n-1, lo..#b] …
… A[ElementsOfInterest] …
```

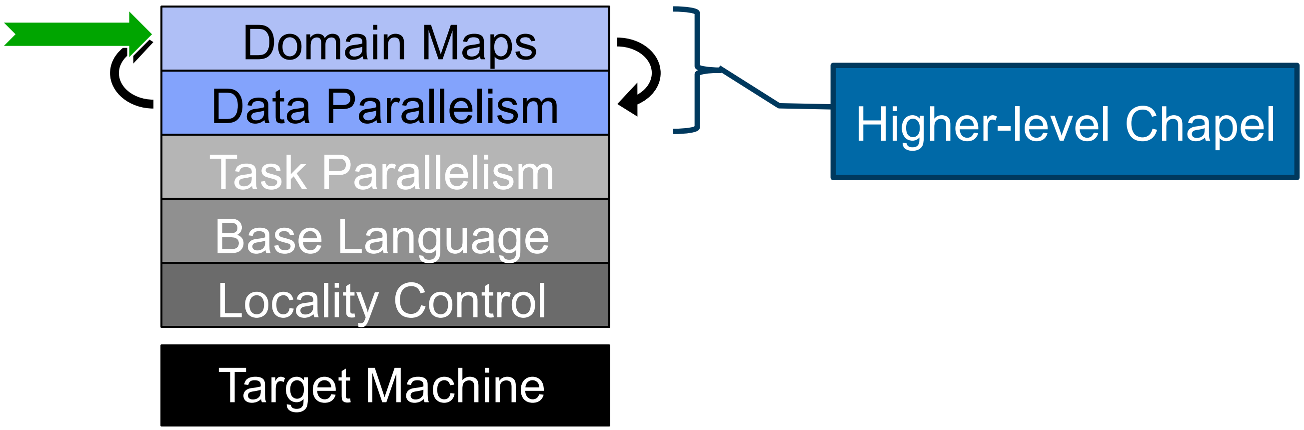
- **Promotion:** Call scalar functions with array arguments

```
… pow(A, B)…   // equivalent to: forall (a,b) in zip(A,B) do pow(a,b)
```

- **Reductions/Scans:** Apply operations across collections

```
… + reduce A …
… myReduceOp reduce A …
```

# Domain Maps

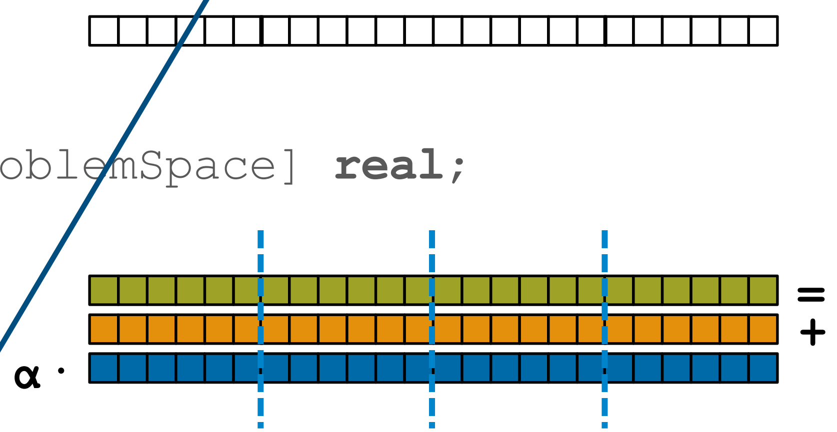


Domain Maps
Data Parallelism
Task Parallelism
Base Language
Locality Control
Target Machine
Higher-level Chapel

# STREAM Triad: Chapel (multicore)

```
const ProblemSpace = {1..m};
```

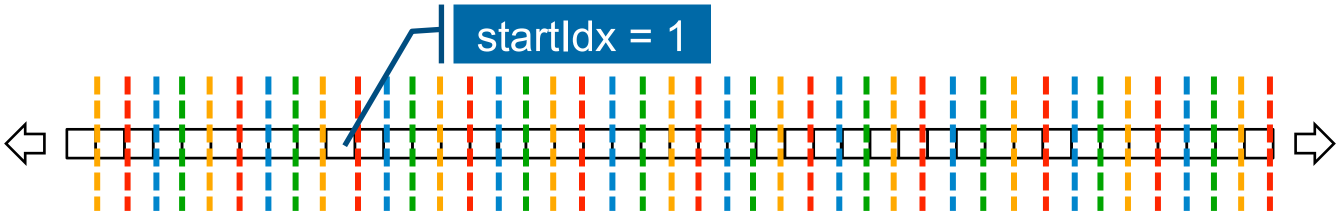
```
var A, B, C: [ProblemSpace] real;
```



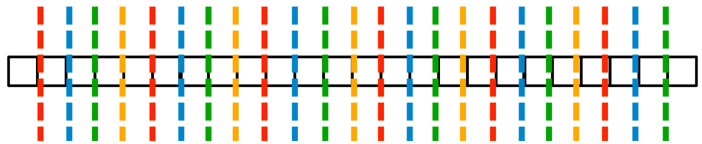

```
A = B + alpha * C;
```

No domain map specified ⇒ use default layout
- current locale owns all domain indices and array values
- computation will execute using local processors only

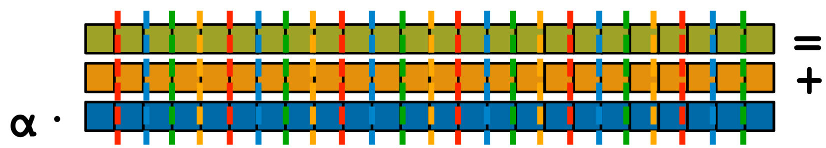
# STREAM Triad: Chapel (multilocale, cyclic)




```
const ProblemSpace = {1..m}
                     dmapped Cyclic(startIdx=1);
```

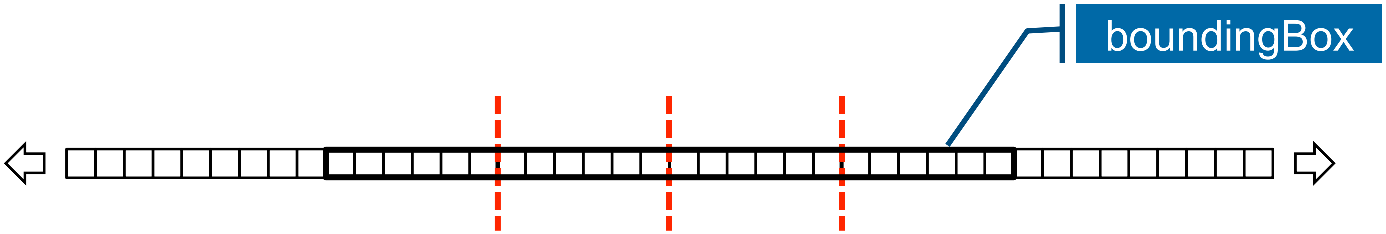


```
var A, B, C: [ProblemSpace] real;
```

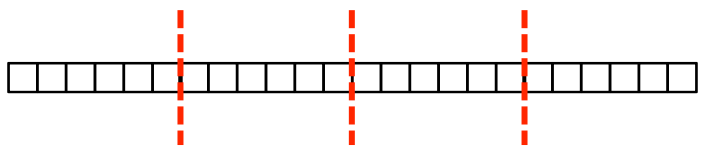



```
A = B + alpha * C;
```

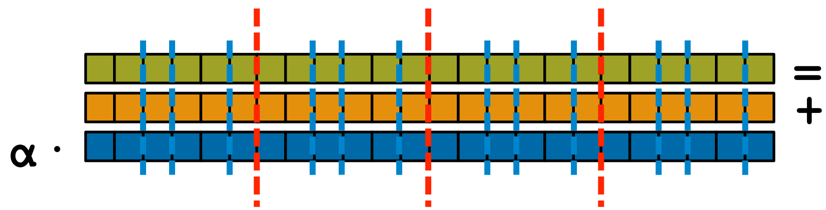
# STREAM Triad: Chapel (multilocale, blocked)




```
const ProblemSpace = {1..m}
                        dmapped Block(boundingBox={1..m});
```



```
var A, B, C: [ProblemSpace] real;
```




```
A = B + alpha * C;
```

# STREAM Triad: Chapel

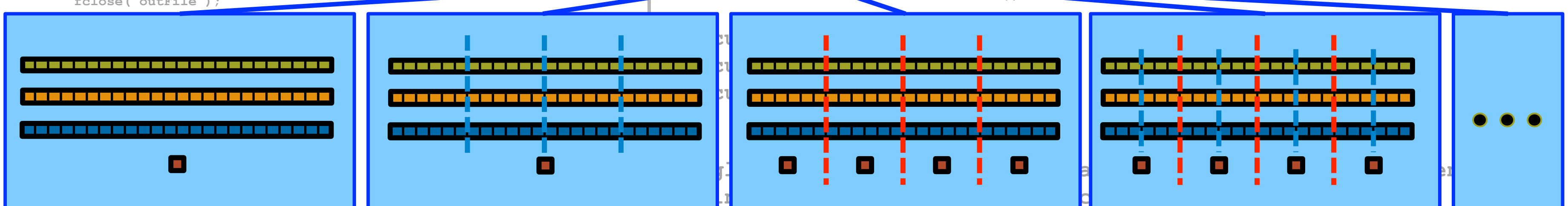
MPI + OpenMP

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

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

int HPCC_StarStream(HPCC_Params *par
  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 == myR
  MPI_Reduce( &rv, &errCount, 1, MPI

  return errCount;
}

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

  VectorSize = HPCC_LocalVectorSize(

  a = HPCC_XMALLOC( double, VectorSi
  b = HPCC_XMALLOC( double, VectorSi
  c = HPCC_XMALLOC( double, VectorSi

  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 );
```

**Chapel**

```
config const m = 1000,
             alpha = 3.0;

const ProblemSpace = {1..m} dmapped …;

var A, B, C: [ProblemSpace] real;

B = 2.0;
C = 3.0;

A = B + alpha * C;
```

the special sauce



<u>Philosophy:</u> 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.

# Chapel is Extensible

**Advanced users can create their own…**

…domain maps (array layouts and distributions)…

…parallel loop schedules…

…models of the target architecture…

**…as Chapel code, without modifying the compiler.**

**Why?** To create a future-proof language.

**This has been our main R&D challenge:** How to create a language that does not lock these policies into the implementation without sacrificing performance?

# Language Summary

***Parallel programmers deserve better programming models***

***Higher-level programming models can help insulate algorithms from parallel implementation details***

- yet, without necessarily abdicating control
- Chapel does this via its multiresolution design

***We believe Chapel can greatly improve productivity***

…for current and emerging parallel architectures

…for HPC users as well as mainstream uses of parallelism

# Outline

- ✓ Motivation for Chapel
- ✓ Survey of Chapel Concepts
- ➢ Chapel Project and Characterizations
- Chapel Resources

# Chapel is Portable

- **Chapel is designed to be hardware-independent**

- **The current release requires:**
  - a C/C++ compiler
  - a *NIX environment (Linux, OS X, BSD, Cygwin, …)
  - POSIX threads
  - RDMA, MPI, or UDP (for distributed memory execution)

- **Chapel can run on…**

  …laptops and workstations
  …commodity clusters
  …the cloud
  …HPC systems from Cray and other vendors
  …modern processors like Intel Xeon Phi, GPUs*, etc.

* = academic work only; not yet supported in the official release

# Chapel is Open-Source

- **Chapel's development is hosted at GitHub**
  - https://github.com/chapel-lang
- **Chapel is licensed as Apache v2.0 software**
- **Instructions for download + install are online**
  - see http://chapel.cray.com/download.html to get started

# The Chapel Team at Cray (Summer 2016)

# Chapel is a Collaborative Effort

HERIOT WATT UNIVERSITY

AMD

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

WESTERN
WASHINGTON UNIVERSITY

東京大学
THE UNIVERSITY OF TOKYO

Colorado State University

RICE

UNIVERSITY OF MARYLAND

BERKELEY LAB
Lawrence Berkeley National Laboratory

Lawrence Livermore National Laboratory

Sandia National Laboratories

HAVERFORD COLLEGE

(and several others…)

http://chapel.cray.com/collaborations.html

# Chapel is a Work-in-Progress

- **Currently being picked up by early adopters**
  - over two releases, 3000+ downloads per year
  - Users who try it generally like what they see

# A notable early adopter

## Chapel in the (Cosmological) Wild 1:00 – 2:00

**Nikhil Padmanabhan**, *Yale University Professor, Physics & Astronomy*

**Abstract:** This talk aims to present my personal experiences using Chapel in my research. My research interests are in observational cosmology; more specifically, I use large surveys of galaxies to constrain the evolution of the

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**CHIUW 2016 keynote: "Chapel in the (Cosmological) Wild", Nikhil Padmanabhan**

Chapel Parallel Programming Language

1 month ago • 86 views

This is Nikhil Padmanabhan's keynote talk from CHIUW 2016: the 3rd Annual Chapel Implementers and Users workshop. The slides are availabl...

# Chapel is a Work-in-Progress

- Currently being picked up by early adopters
  - Last two releases got ~3500 downloads total in a year
  - Users who try it generally like what they see
- Most current features are functional and working well
  - some areas need improvements, e.g., error-handling, constructors
- Performance varies, but is continually improving
  - shared memory performance is typically competitive with C+OpenMP
  - distributed memory performance tends to be more hit-and-miss
- We are actively working to address these lacks

# Outline

- ✓ Motivation for Chapel
- ✓ Survey of Chapel Concepts
- ✓ Chapel Project and Characterizations
- ➢ Chapel Resources

# Chapel Websites

**Project page:** http://chapel.cray.com

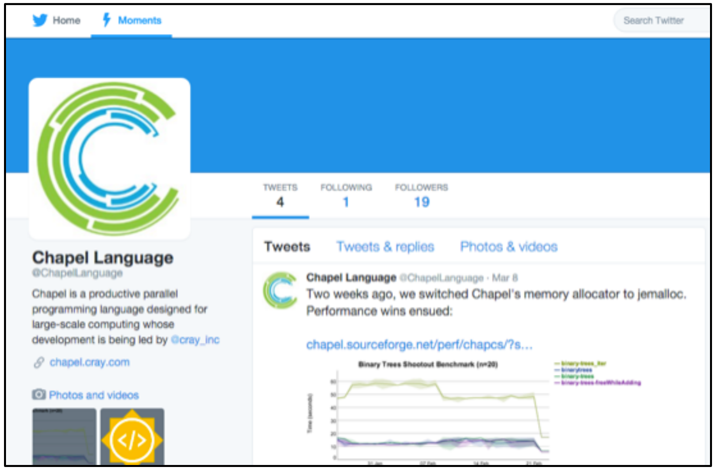
- overview, papers, presentations, language spec, …

**GitHub:** https://github.com/chapel-lang

- download Chapel; browse source repository; contribute code

**Facebook:** https://www.facebook.com/ChapelLanguage

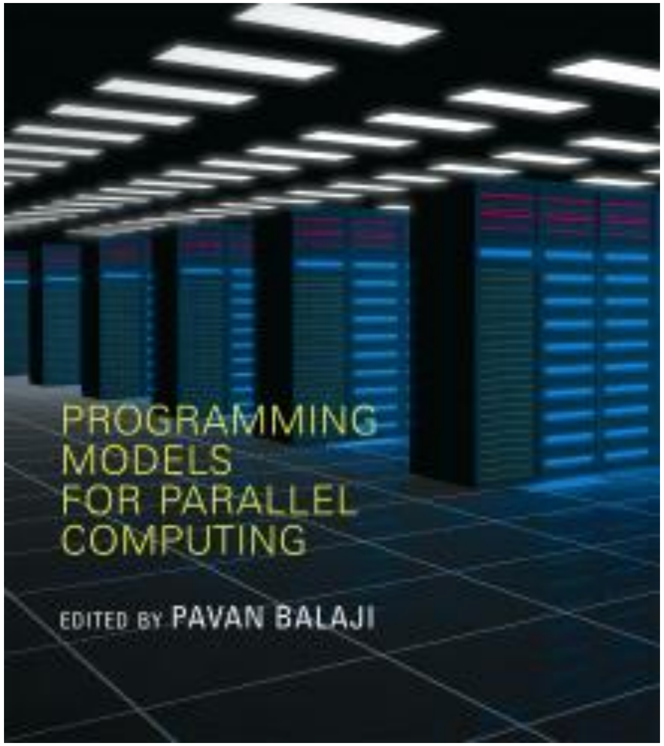
**Twitter:** https://twitter.com/ChapelLanguage

# Suggested Reading

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 **http://chapel.cray.com/papers.html**

# Chapel Blog Articles

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

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

***Chapel Springs into a Summer of Code***, Cray Blog, April 2016.

- *coverage of recent events*

***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.cray.com "blog articles" 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 Mailing Lists

**low-traffic / read-only:**

chapel-announce@lists.sourceforge.net: announcements about Chapel

**community lists:**

chapel-users@lists.sourceforge.net: user-oriented discussion list
chapel-developers@lists.sourceforge.net: developer discussions
chapel-education@lists.sourceforge.net: educator discussions
chapel-bugs@lists.sourceforge.net: public bug forum

**(subscribe at SourceForge:** http://sourceforge.net/p/chapel/mailman/**)**

**To mail the Cray team:**

chapel_info@cray.com: contact the team at Cray
chapel_bugs@cray.com: for reporting non-public bugs

**or use IRC (#chapel on chat.freenode.net) or StackOverflow**

# Current Events:
# Computer Language Benchmark Game

# Computer Language Benchmarks Game

## Chapel was recently added to the game:

## As of Oct 17th:

- **for performance:**
  - **1 top entries:** pidigits
  - **2 top-5 entries:** meteor, thread-ring
  - **2 top-10 entries:** fannkuch-redux, chameneos-redux
  - **3 top-20 entries:** n-body, spectral-norm, binary-trees
- **for code compactness:**
  - **2 top entries:** n-body, thread-ring
  - **2 top-5 entries:** spectral-norm, pidigits
  - **4 top-20 entries:** mandelbrot, regex-dna, chameneos-redux, meteor

**The Computer Language Benchmarks Game**

64-bit quad core data set

Will your toy benchmark program be faster if you write it in a different programming language? It depends how you write it!

**Which programs are fast?**

Which are succinct? Which are efficient?

Ada C Chapel Clojure C# C++
Dart Erlang F# Fortran Go Hack
Haskell Java JavaScript Lisp Lua
OCaml Pascal Perl PHP Python
Racket Ruby JRuby Rust Scala
Smalltalk Swift TypeScript

# Computer Language Benchmarks Game

## Chapel was recently added to the game:

### As of Oct 17th:

- fo…
- fo…

4 top-20 entries: mandelbrot, regex-dna, chameneos-redux, meteor

The Computer Language Benchmarks Game

64-bit quad core data set

**We want easy answers**, but easy answers are often incomplete or wrong. You and I know, there's more we should understand:

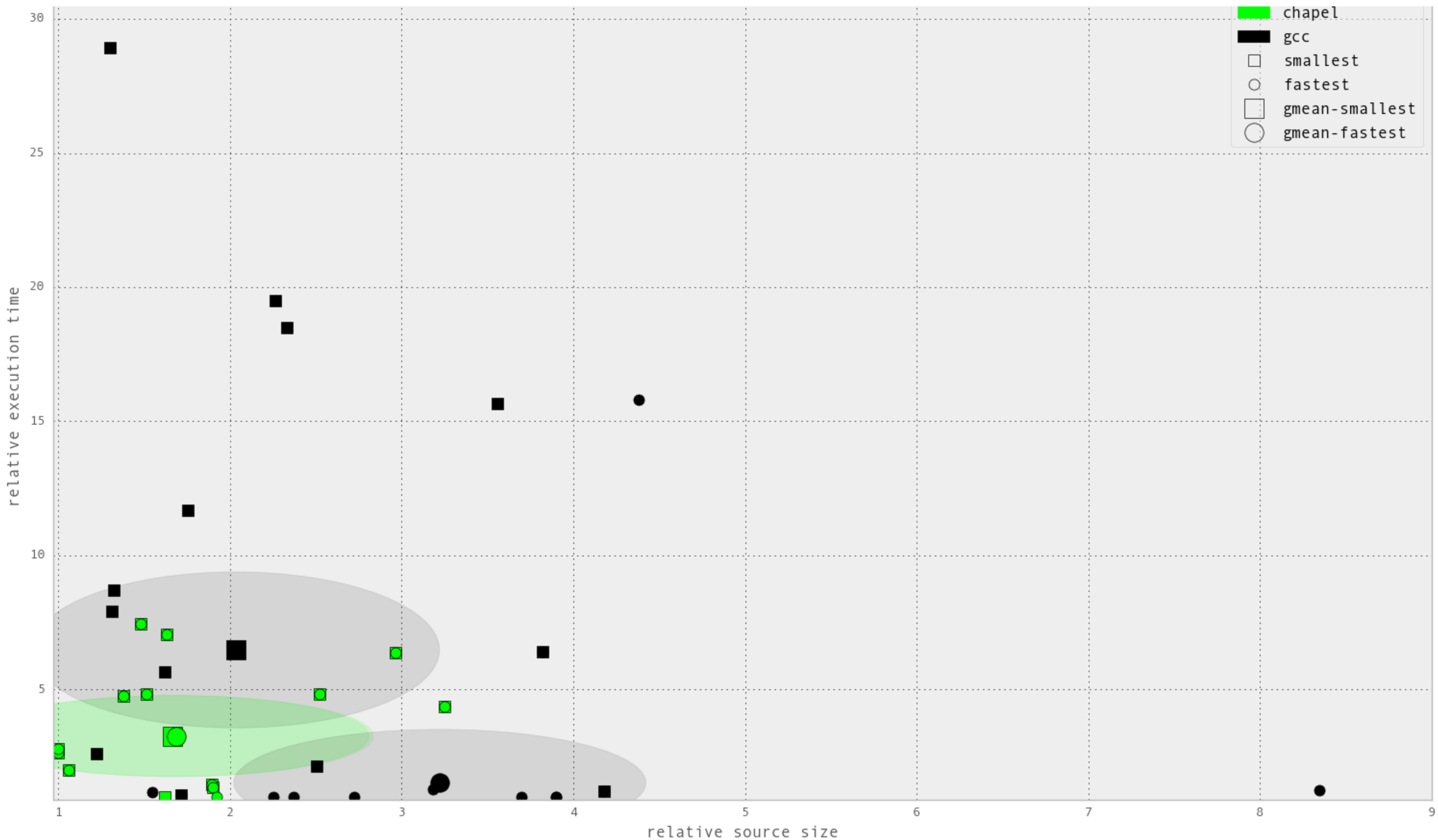
stories details fast? conclusions

{ for researchers }

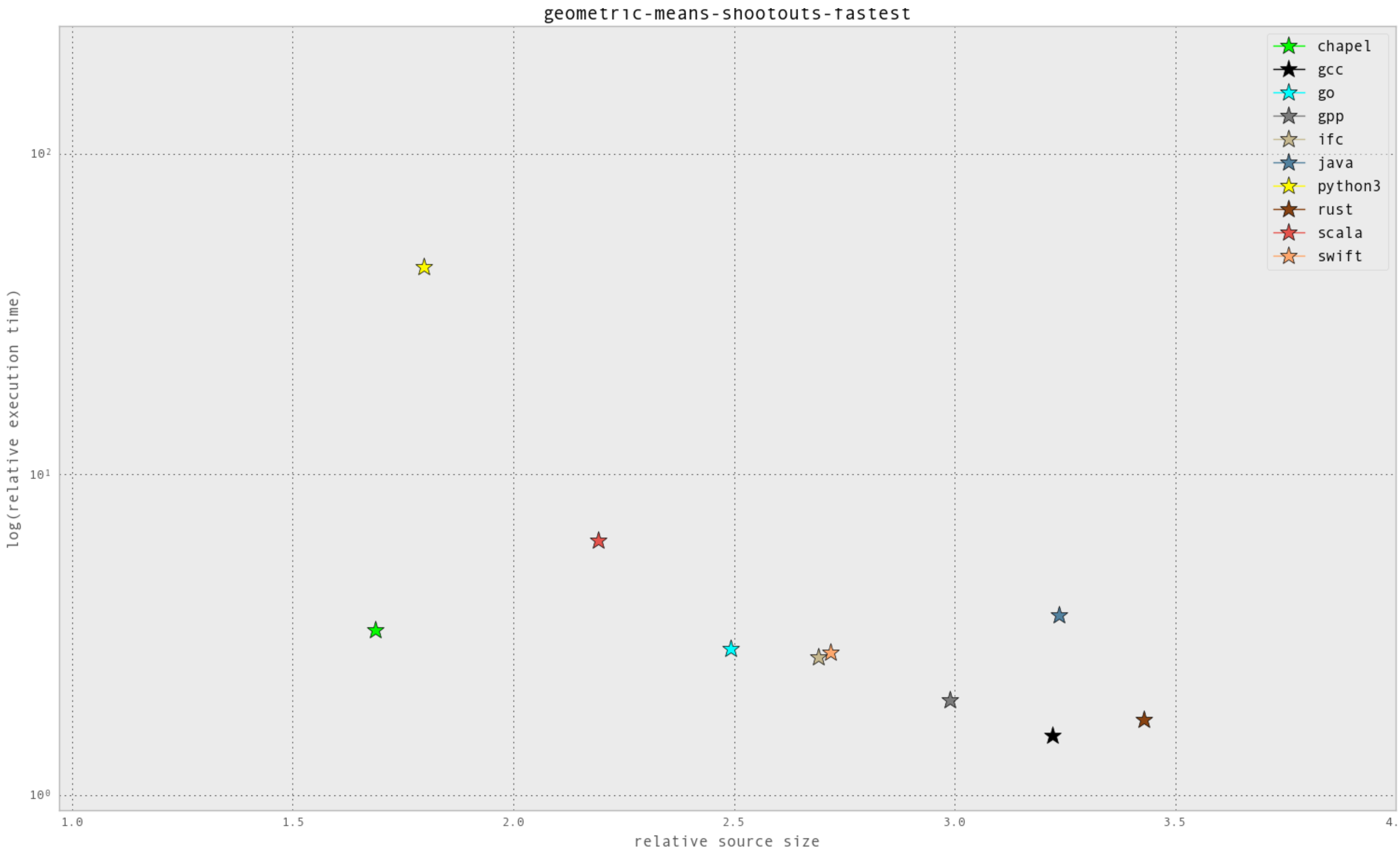
Racket Ruby JRuby Rust Scala

Smalltalk Swift TypeScript

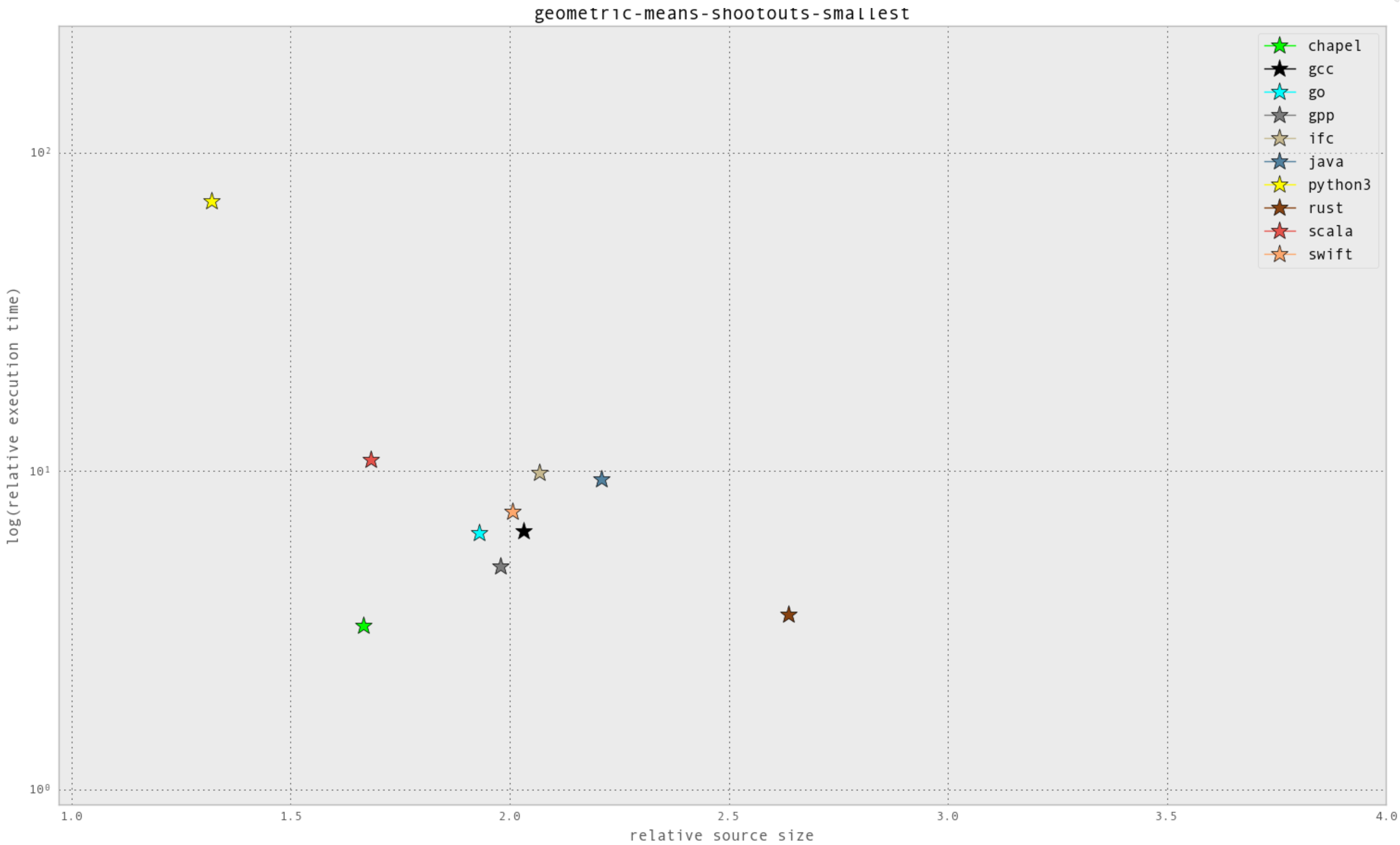
# Chapel vs GCC



# Fastest benchmark in various languages



# Smallest benchmark in various languages



# Chapel:
## Productive Parallel Programming at Scale

## Questions?