The Chapel Parallel Programming Language

Brad Chamberlain, Chapel Team, Cray Inc.

Pacific Northwest Numerical Analysis Seminar

October 19th, 2013

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Chapel: *The* Parallel Programming Language

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Chapel: The Parallel Programming Language of the Future!

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Chapel: The Parallel Programming Language of the Future! (?)

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YEEZUS

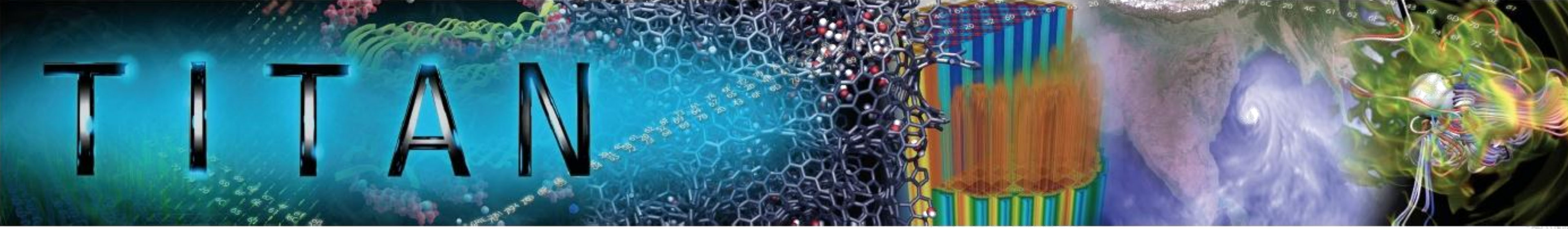
Kanye West's 1st Solo Tour in 5 Years

(kicks off in Seattle tonight)

Chapel: "That $#!^'s Cray"

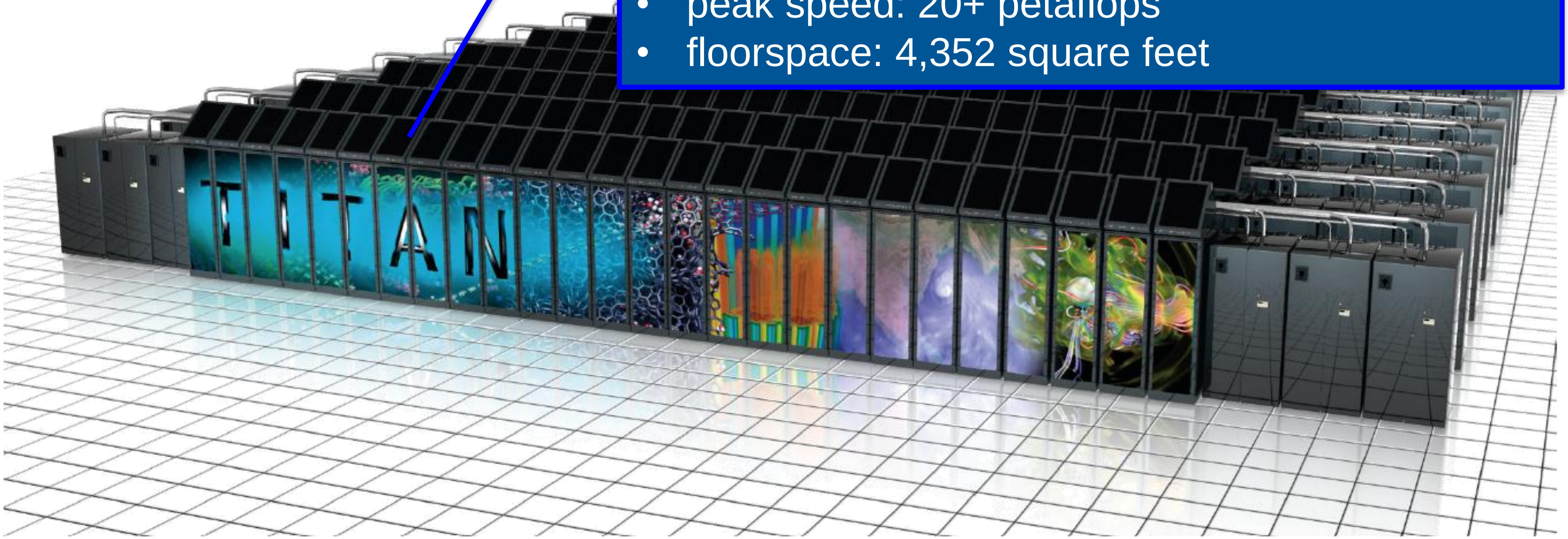
My Employer:

THE SUPERCOMPUTER COMPANY



Titan (ORNL)

- compute nodes: 18,688
- processors: 16-core AMD/node = 299,008 cores
- GPUs: 18,688 NVIDIA Tesla K20s
- memory: 32 + 6 GB/node = 710 TB total
- peak speed: 20+ petaflops
- floorspace: 4,352 square feet



For more information: http://www.olcf.ornl.gov/titan/

Blue Waters

Blue Waters (NCSA)

- compute nodes: 25,712
- processors: 386,816 AMD cores
- GPUs: 3,072 NVIDIA Kepler GPUs
- memory: 1.476 PB total
- peak speed: 11.61 petaflops

https://bluewaters.ncsa.illinois.edu/

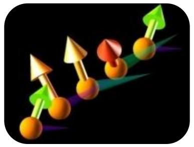
Sustained Performance Milestones

1 GF – 1988: Cray Y-MP; 8 Processors

- Static finite element analysis

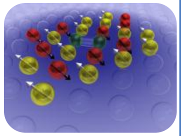
1 TF – 1998: Cray T3E; 1,024 Processors

- Modeling of metallic magnet atoms



1 PF – 2008: Cray XT5; 150,000 Processors

- Superconductive materials



1 EF – ~2018: Cray ____; ~10,000,000 Processors

- TBD

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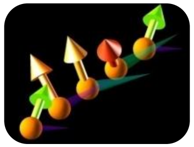

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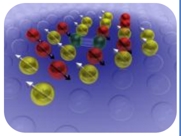

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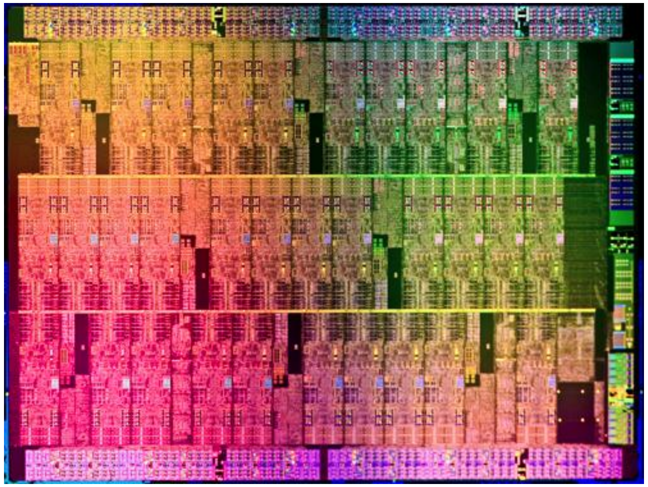
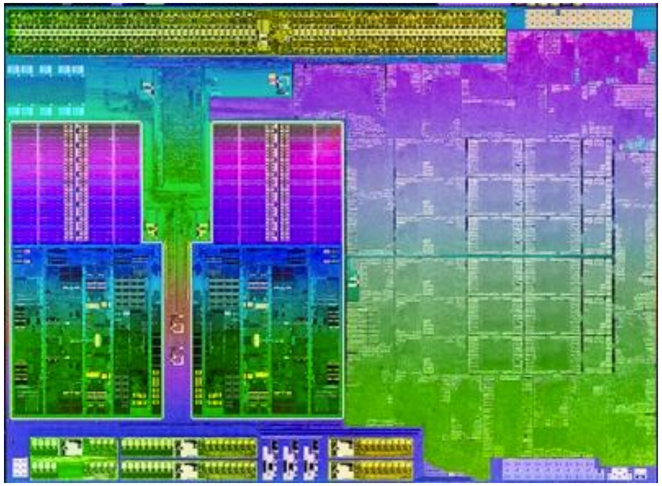
- TBD
- TBD: C/C++/Fortran + MPI + CUDA/OpenCL/OpenMP/OpenACC?

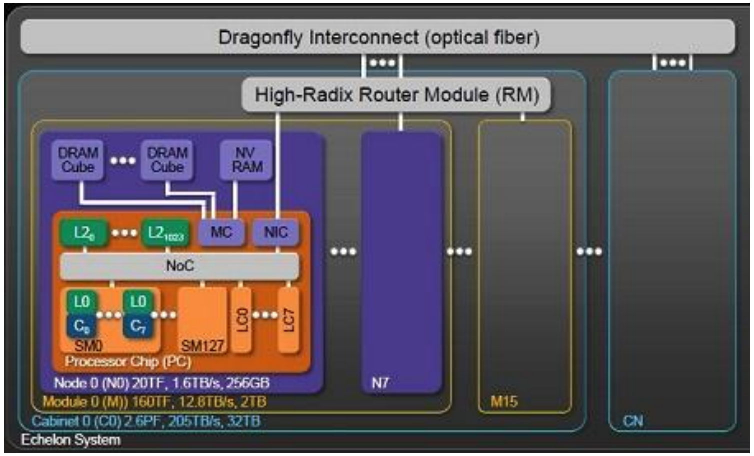
Prototypical Next-Gen Processor Technologies



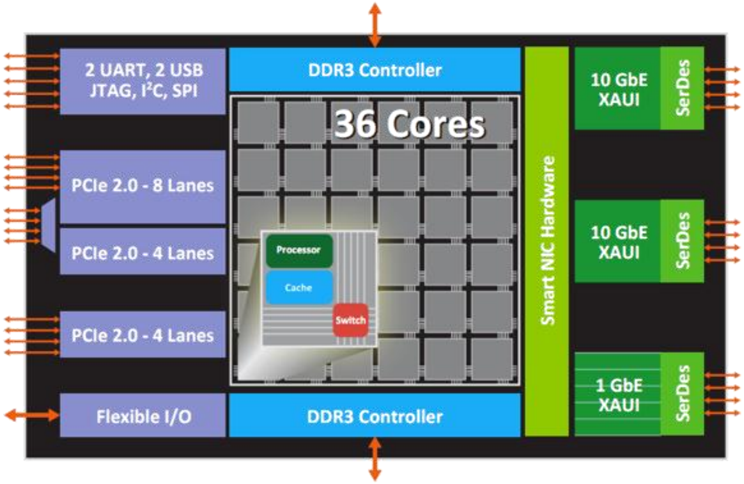
Intel MIC



AMD Trinity



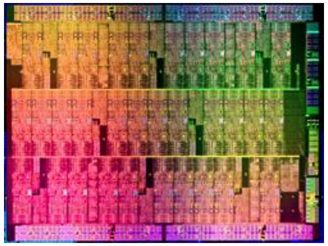
Nvidia Echelon

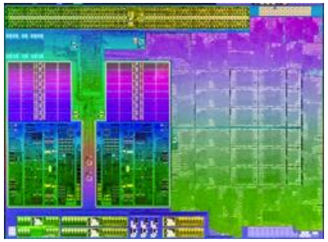


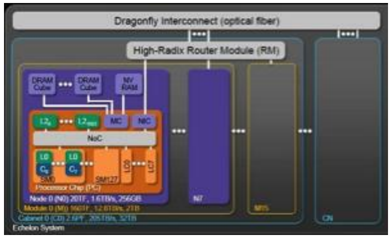
Tilera Tile-Gx

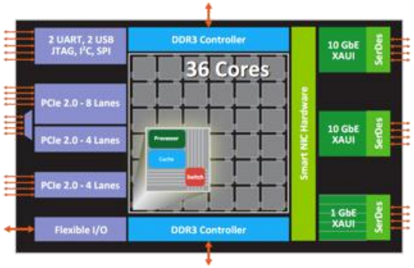
http://download.intel.com/pressroom/images/Aubrey_Isle_die.jpg http://www.zdnet.com/amds-trinity-processors-take-on-intels-ivy-bridge-3040155225/
http://insidehpc.com/2010/11/26/nvidia-reveals-details-of-echelon-gpu-designs-for-exascale/ http://tilera.com/sites/default/files/productbriefs/Tile-Gx%203036%20SB012-01.pdf

General Characteristics of These Architectures









- **Increased hierarchy and/or sensitivity to locality**
- **Potentially heterogeneous processor/memory types**

⇒ Next-gen programmers will have a lot more to think about at the node level than in the past

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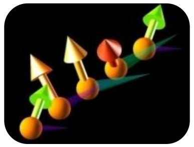

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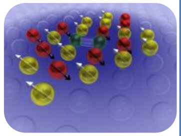


1 EF – ~2018: Cray ____; ~10,000,000 Processors

- TBD
- TBD: C/C++/Fortran + MPI + CUDA/OpenCL/OpenMP/OpenACC?

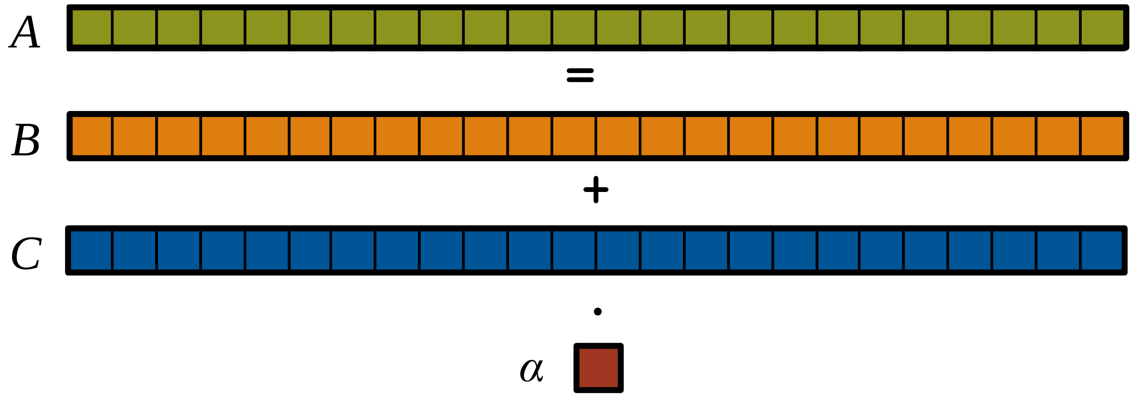
Or, perhaps something completely different?

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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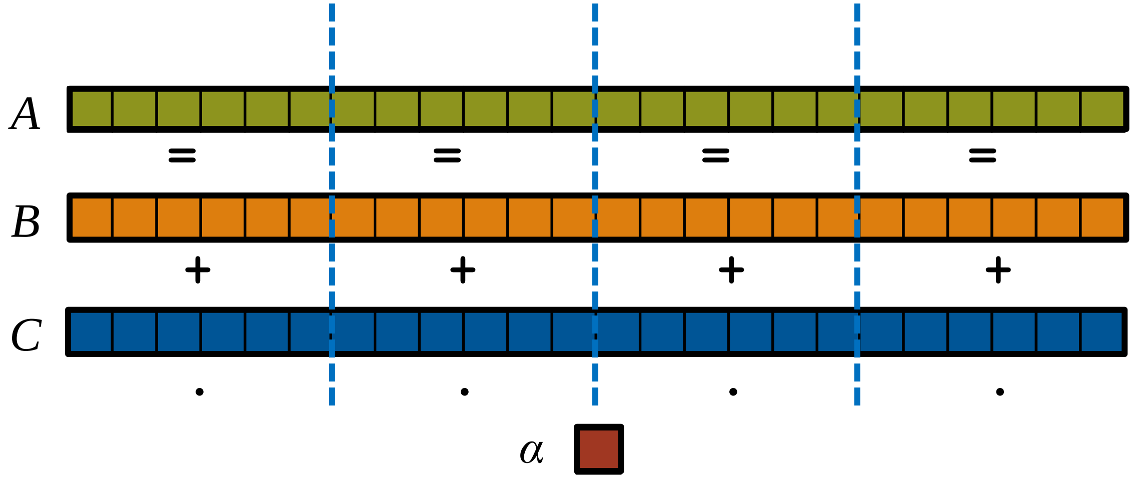
In pictures, in parallel:



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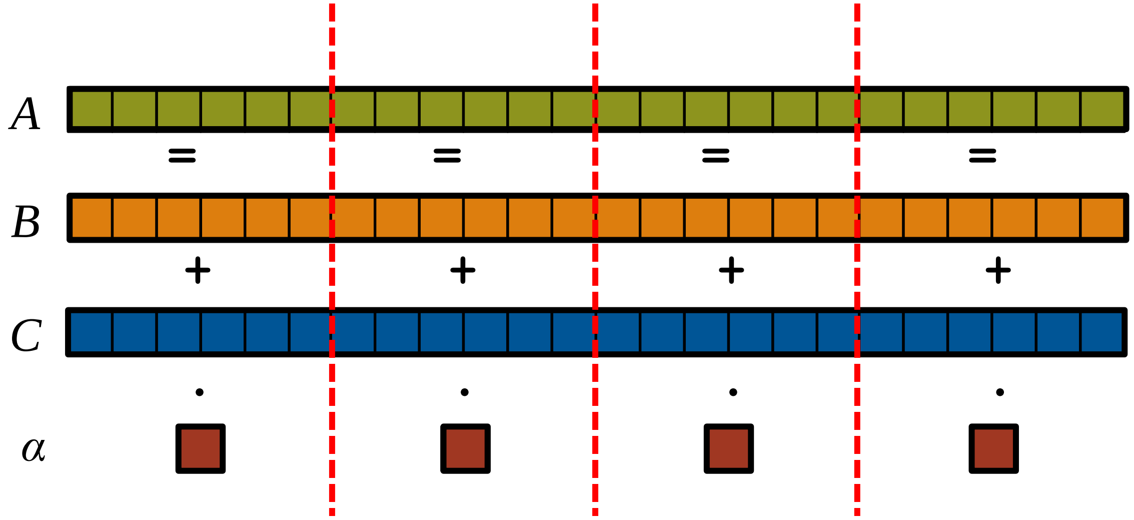
In pictures, in parallel (distributed memory):

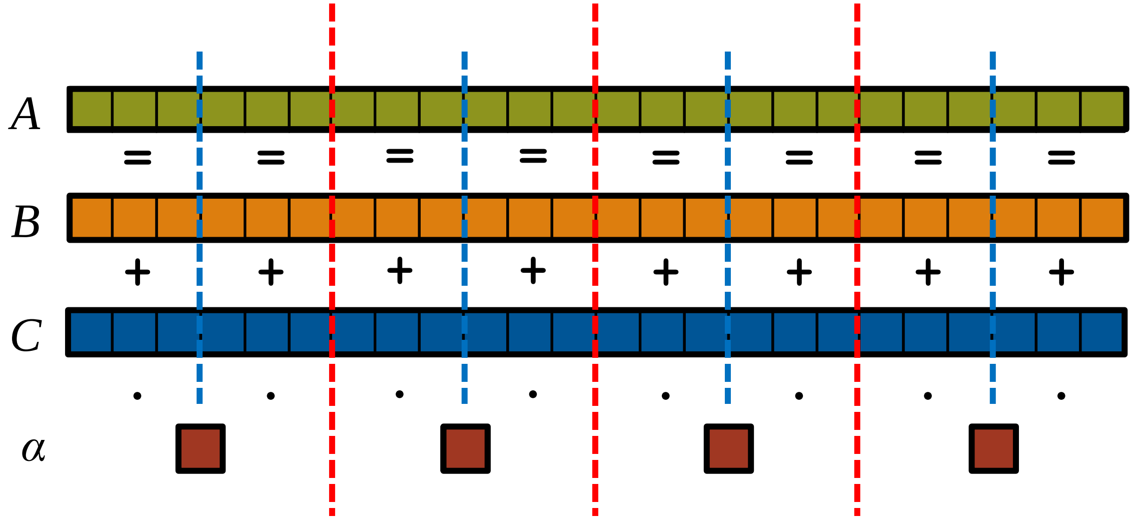


STREAM Triad: a trivial parallel computation

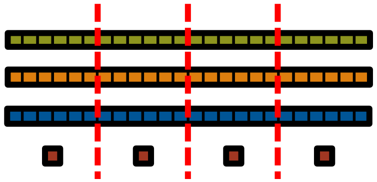
Given: m-element vectors A, B, C

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

In pictures, in parallel (distributed memory multicore):



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;
}

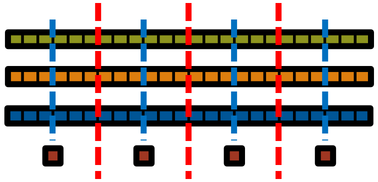
scalar = 3.0;



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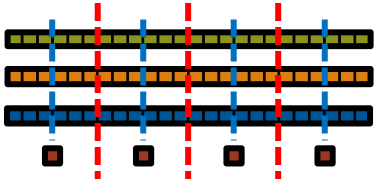
#endif
  for (j=0; j<VectorSize; j++)
    a[j] = b[j]+scalar*c[j];

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

STREAM Triad: MPI+OpenMP vs. CUDA

MPI + OpenMP



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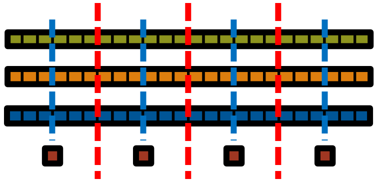
  for (j=0; j<VectorSize; j++)
    a[j] = b[j]+scalar*c[j];

  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];
```

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

Why so many programming models?

HPC has traditionally given users…

…low-level, *control-centric* programming models
…ones that are closely tied to the underlying hardware
…ones that support only a single type of parallelism

Examples:

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/OpenCL/OpenACC	SIMD function/task

benefits: lots of control; decent generality; easy to implement
downsides: lots of user-managed detail; brittle to changes

(“Glad I’m not an HPC Programmer!”)

A Possible Reaction:

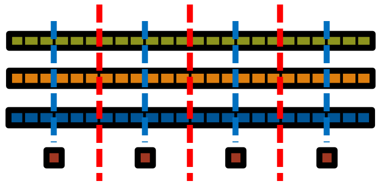
“This is all well and good for HPC users, but I’m a mainstream desktop programmer, so this is all academic for me.”

The Unfortunate Reality:

- Performance-minded mainstream programmers will increasingly deal with parallelism
- And, as chips become more complex, locality too

Rewinding a few slides…

MPI + OpenMP



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  if (!a || !b || !c) {
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    if (doIO) {
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    }
    return 1;
  }

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

  HPCC_free(c);
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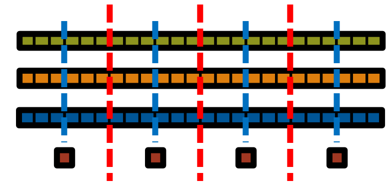
  HPCC_free(a);

  return 0;
}
```

CUDA



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  float scalar;

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  dim3 dimBlock(128);

  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);
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__global__ void set_array(float *a,  float value, int len) {
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  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

Chapel

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

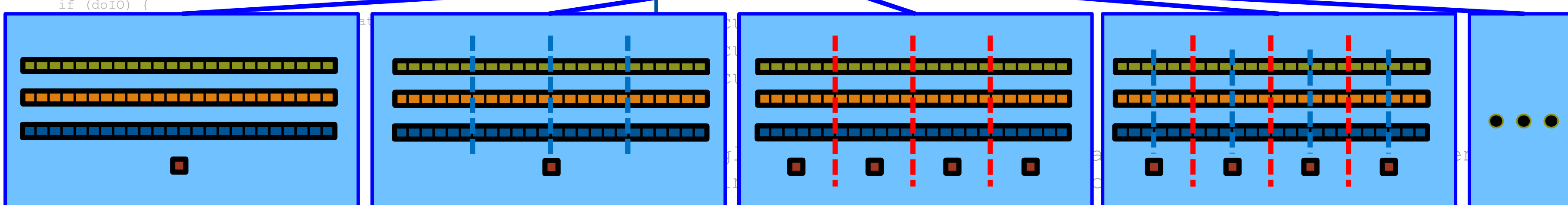
const ProblemSpace = {1..m} dmapped …;

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

B = 2.0;
C = 3.0;

A = B + alpha * C;
```

the special sauce



<u>Philosophy:</u> Good language design can tease details of locality and parallelism away from an algorithm, permitting the compiler, runtime, applied scientist, and HPC expert to each focus on their strengths.

Outline

- ✓ Motivation
- ➢ Chapel Background and Themes
- Survey of Chapel Concepts
- Project Status and Next Steps

What is Chapel?

- **An emerging parallel programming language**
  - Design and development led by Cray Inc.
    - in collaboration with academia, labs, industry
  - Initiated under the DARPA HPCS program
- **Overall goal: Improve programmer productivity**
  - Improve the programmability of parallel computers
  - Match or beat the performance of current programming models
  - Support better portability than current programming models
  - Improve the robustness of parallel codes
- **A work-in-progress**

Chapel's Implementation

- **Being developed as open source at SourceForge**
- **Licensed as BSD software**
- **Target Architectures:**
  - Cray architectures
  - multicore desktops and laptops
  - commodity clusters
  - systems from other vendors
  - *in-progress:* CPU+accelerator hybrids, manycore, …

Motivating Chapel Themes

1) General Parallel Programming
2) Global-View Abstractions
3) Multiresolution Design
4) Control over Locality/Affinity
5) Reduce HPC ↔ Mainstream Language Gap

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1) General Parallel Programming

With a unified set of concepts...

...express any parallelism desired in a user's program

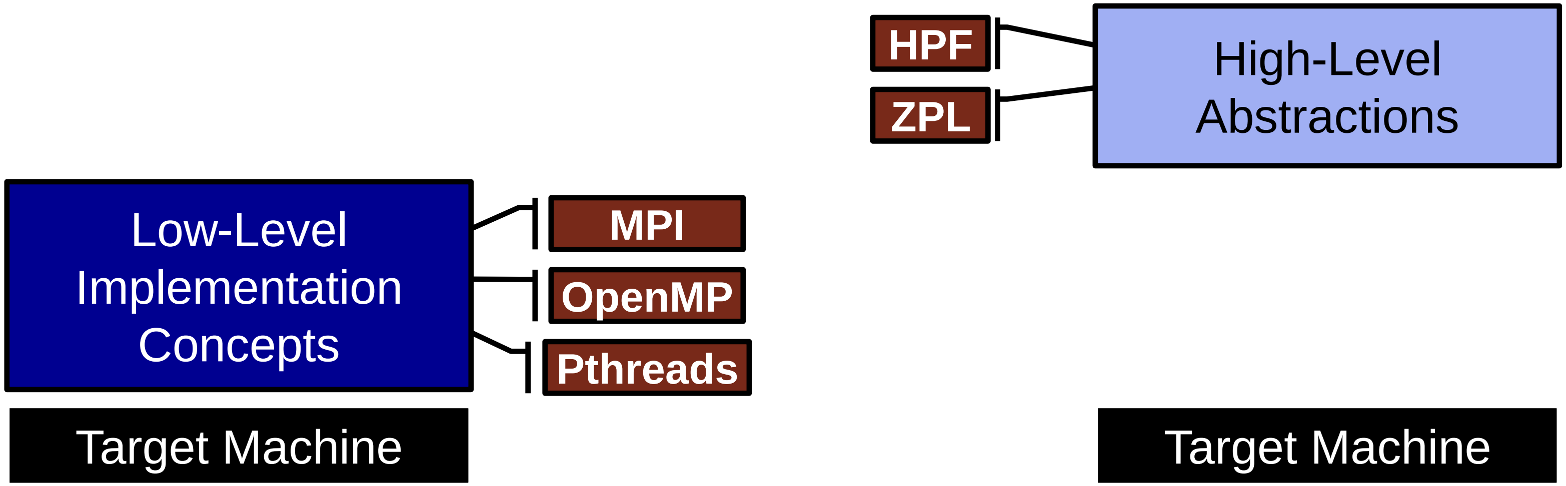
- **Styles:** data-parallel, task-parallel, concurrency, nested, …
- **Levels:** model, function, loop, statement, expression

...target any parallelism available in the hardware

- **Types:** machines, nodes, cores, instructions

Type of HW Parallelism	Programming Model	Unit of Parallelism
Inter-node	Chapel	executable/task
Intra-node/multicore	Chapel	iteration/task
Instruction-level vectors/threads	Chapel	iteration
GPU/accelerator	Chapel	SIMD function/task

3) Multiresolution Design: Motivation



"Why is everything so tedious/difficult?"

"Why don't my programs port trivially?"

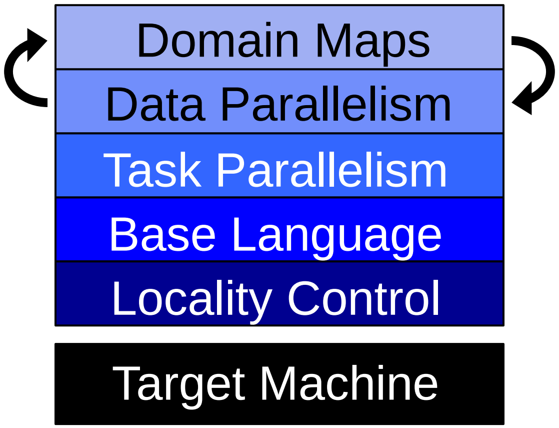
"Why don't I have more control?"

3) Multiresolution Design

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

5) Reduce HPC ↔ Mainstream Language Gap

Consider:

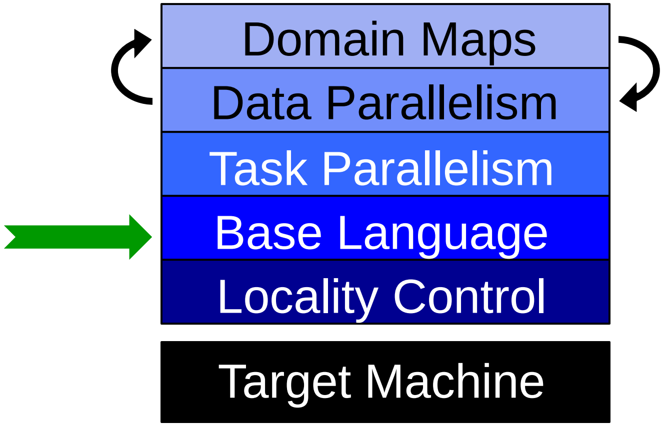
- Students graduate with training in Java, Matlab, Python, etc.
- Yet HPC programming is dominated by Fortran, C/C++, MPI

We'd like to narrow this gulf with Chapel:

- to leverage advances in modern language design
- to better utilize the skills of the entry-level workforce...
- ...while not alienating the traditional HPC programmer
  - e.g., support object-oriented programming, but make it optional

Outline

- ✓ Motivation
- ✓ Chapel Background and Themes
- ➢ Survey of Chapel Concepts



- Project Status and Next Steps

Static Type Inference

```
const pi = 3.14,                 // pi is a real
      coord = 1.2 + 3.4i,        // coord is a complex…
      coord2 = pi*coord,         // …as is coord2
      name = "brad",             // name is a string
      verbose = false;           // verbose is boolean

proc addem(x, y) {               // addem() has generic arguments
  return x + y;                  //   and an inferred return type
}

var sum = addem(1, pi),                    // sum is a real
    fullname = addem(name, "ford");        // fullname is a string

writeln((sum, fullname));
```

```
(4.14, bradford)
```

Range Types and Algebra

```
const r = 1..10;

printVals(r # 3);
printVals(r by 2);
printVals(r by -2);
printVals(r by 2 # 3);
printVals(r # 3 by 2);
printVals(0.. #n);

proc printVals(r) {
  for i in r do
    write(r, " ");
  writeln();
}
```

```
1 2 3
1 3 5 7 9
10 8 6 4 2
1 3 5
1 3
0 1 2 3 4 … n-1
```

Iterators

```
iter fibonacci(n) {
  var current = 0,
      next = 1;
  for 1..n {
    yield current;
    current += next;
    current <=> next;
  }
}
```

```
for f in fibonacci(7) do
  writeln(f);
```

```
0
1
1
2
3
5
8
```

```
iter tiledRMO(D, tilesize) {
  const tile = {0..#tilesize,
                0..#tilesize};
  for base in D by tilesize do
    for ij in D[tile + base] do
      yield ij;
}
```

```
for ij in tiledRMO({1..m, 1..n}, 2) do
  write(ij);
```

```
(1,1)(1,2)(2,1)(2,2)
(1,3)(1,4)(2,3)(2,4)
(1,5)(1,6)(2,5)(2,6)
…
(3,1)(3,2)(4,1)(4,2)
```

Zippered Iteration

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

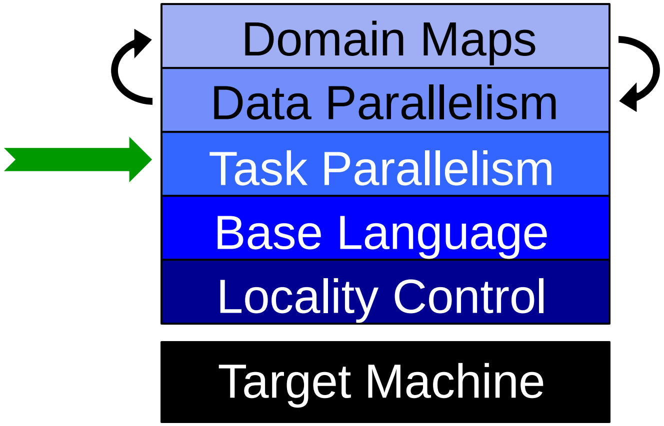
```
fib #0 is 0
fib #1 is 1
fib #2 is 1
fib #3 is 2
fib #4 is 3
fib #5 is 5
fib #6 is 8
…
```

Other Base Language Features

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

Outline

- ✓ Motivation
- ✓ Chapel Background and Themes
- ➢ Survey of Chapel Concepts



- Project Status and Next Steps

Task Parallelism: Begin Statements

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

Possible outputs:

```
hello world
good bye
```

```
good bye
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
```

Bounded Buffer Producer/Consumer Example

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

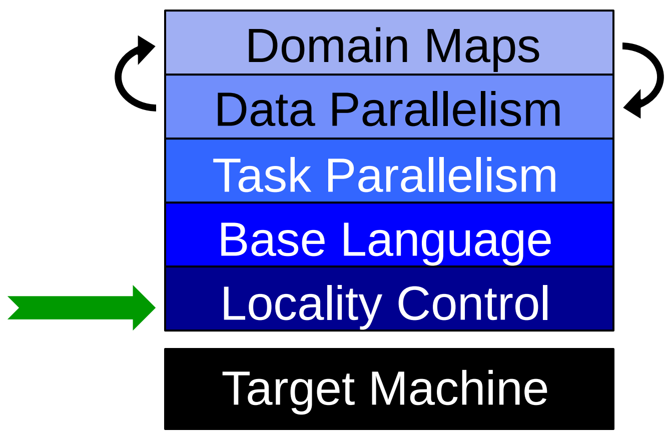
// 'sync' types store full/empty state along with value
var buff$: [0..#buffersize] sync real;

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
} }
```

Outline

- ✓ Motivation
- ✓ Chapel Background and Themes
- ➢ Survey of Chapel Concepts



Theme 4: Control over Locality/Affinity

- Project Status and Next Steps

The Locale Type

Definition:

- Abstract unit of target architecture
- Supports reasoning about locality
- Capable of running tasks and storing variables
  - i.e., has processors and memory

Typically: A compute node (multicore processor or SMP)

Defining 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

L0	L1	L2	L3	L4	L5	L6	L7

- User's `main()` begins executing 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");

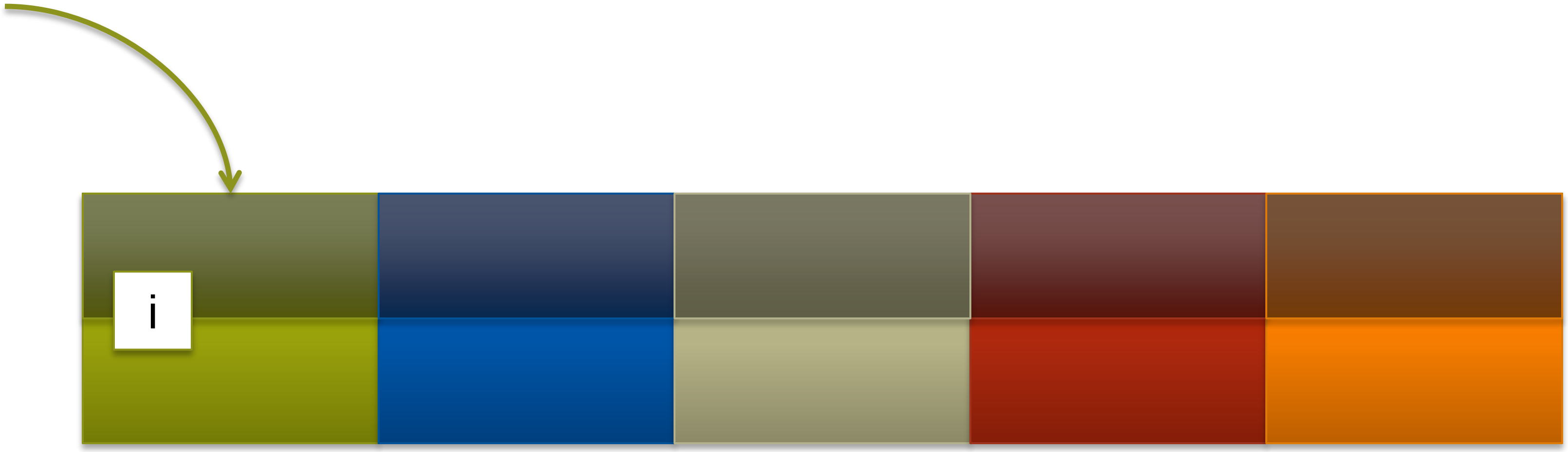
writeln("on locale 0 again");
```

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

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

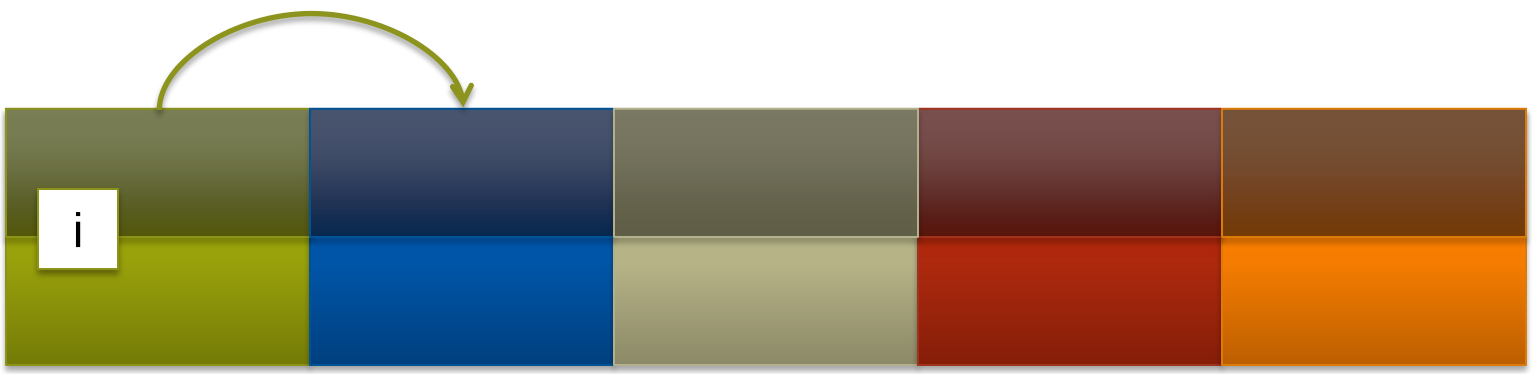
Chapel: Scoping and Locality

```
var i: int;
```



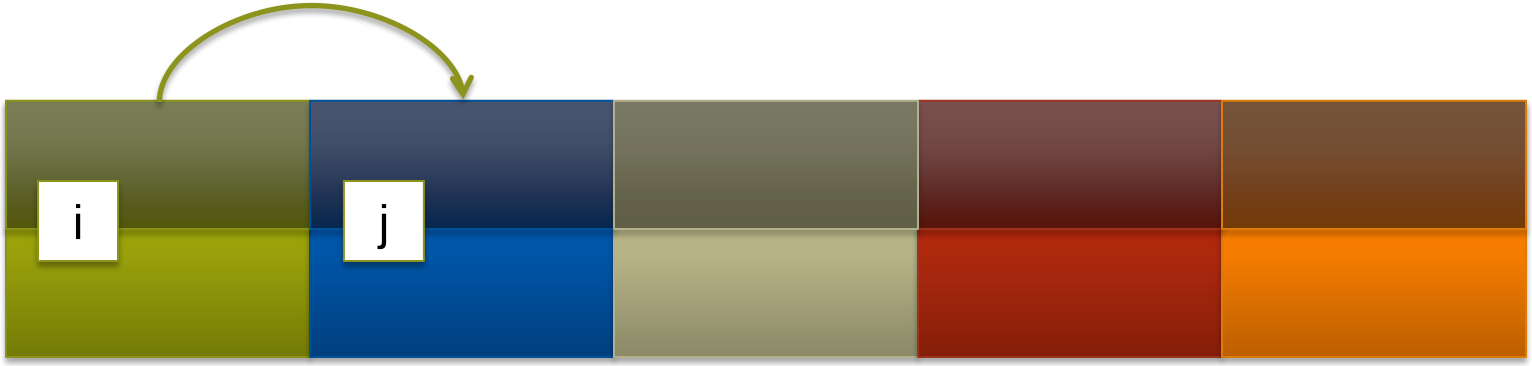
Chapel: Scoping and Locality

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



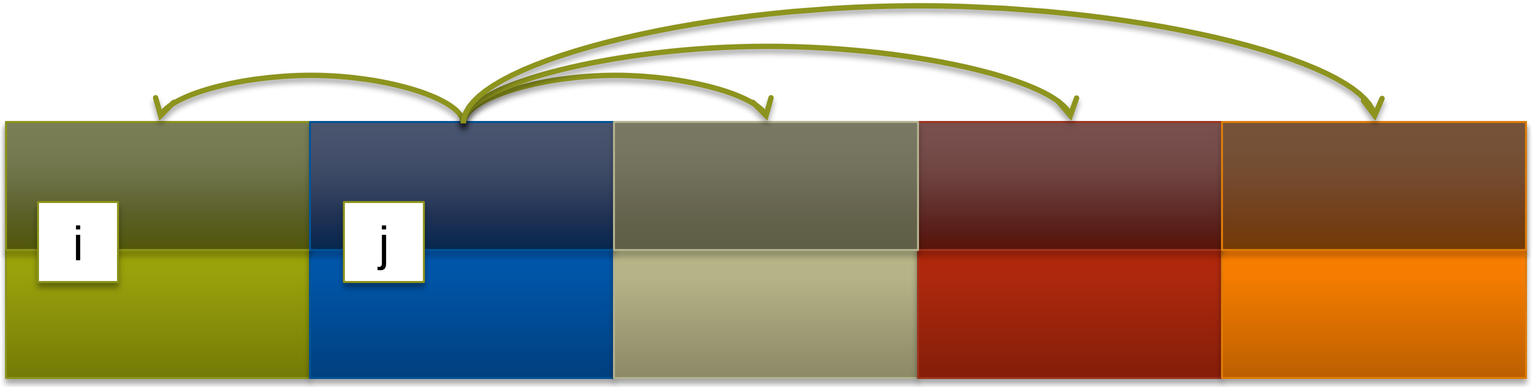
Chapel: Scoping and Locality

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



Chapel: Scoping and Locality

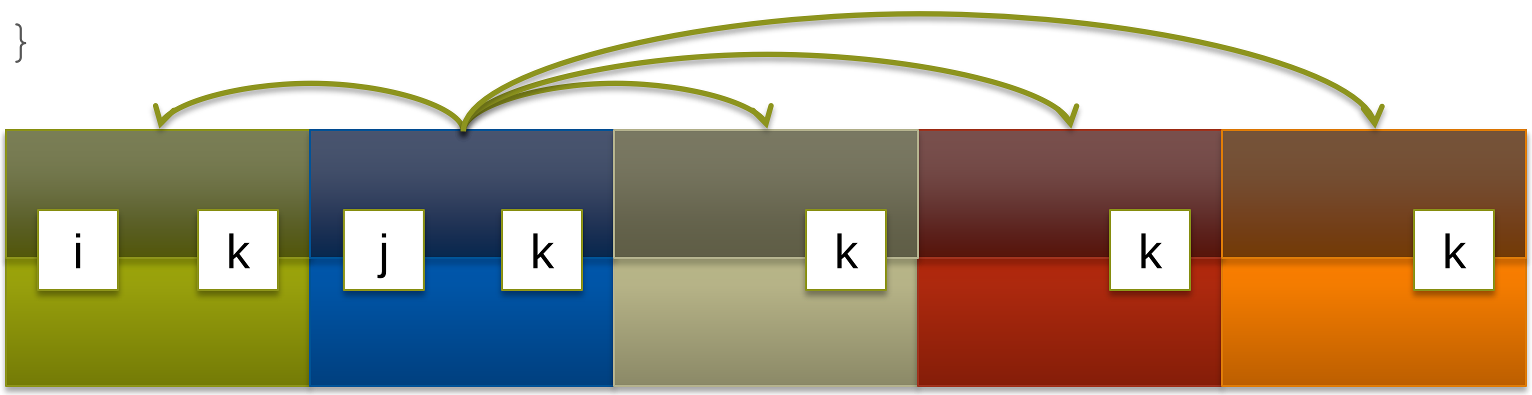
```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
```



Chapel: Scoping and Locality

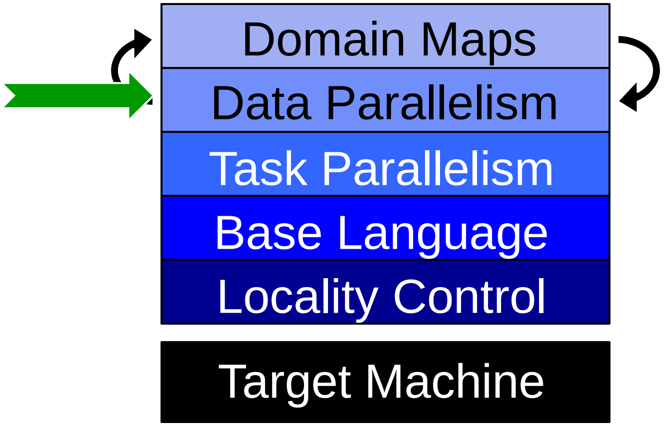
```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
      var k: int;

      // within this scope, i,j,k can be referenced;
      // the implementation manages the communication
    }
  }
}
```



Outline

✓ Motivation
✓ Chapel Background and Themes
➢ Survey of Chapel Concepts



- Project Status and Next Steps

Domains

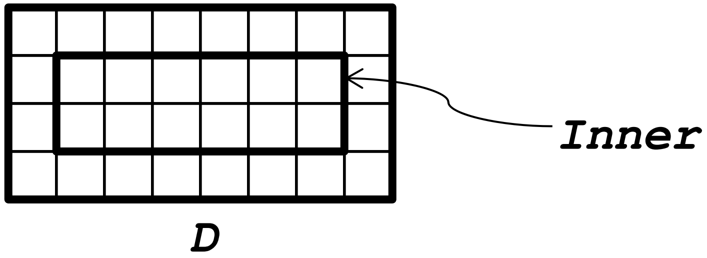
Domain:

- A first-class index set
- The fundamental Chapel concept for data parallelism

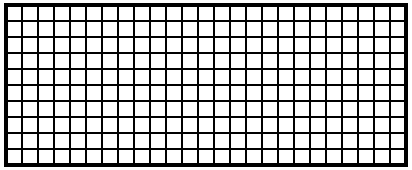
```
config const m = 4, n = 8;

var D: domain(2) = {1..m, 1..n};

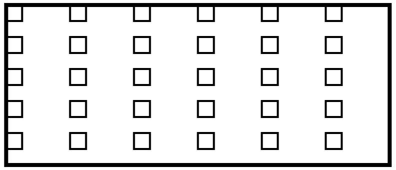
var Inner: subdomain(D) = {2..m-1, 2..n-1};
```



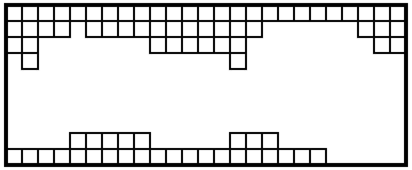
Chapel Domain Types



dense

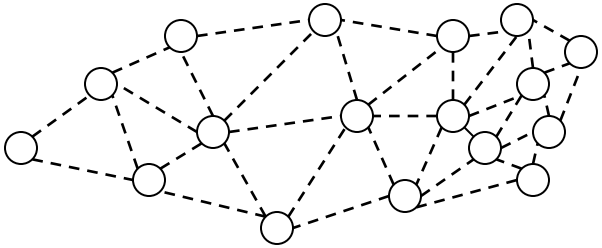


strided



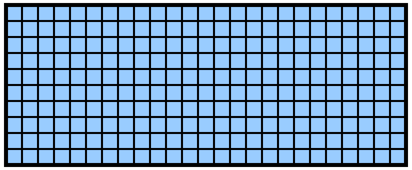
sparse

associative

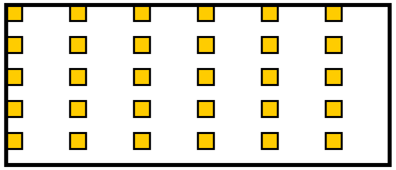


unstructured

Chapel Array Types



dense



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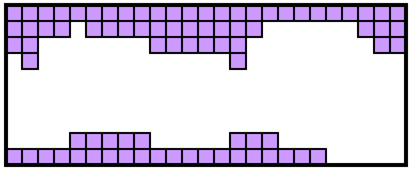
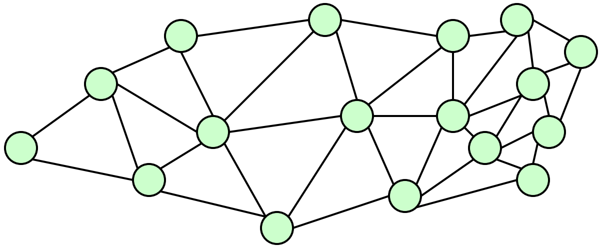


sparse

associative



unstructured

Chapel Domain/Array Operations

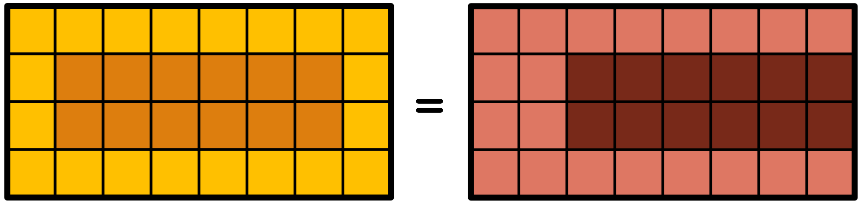
- Data Parallel Iteration (as well as serial and coforall)

```
A = forall (i,j) in D do (i + j/10.0);
```

1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8
3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8
4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8

- Array Slicing; Domain Algebra

```
A[InnerD] = B[InnerD+(0,1)];
```



- Promotion of Scalar Operators and Functions

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

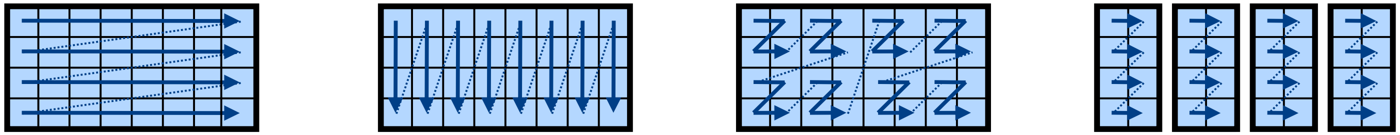
```
A = exp(B, C);
```

- And many others: indexing, reallocation, set operations, remapping, aliasing, queries, …

Data Parallelism Implementation Qs

Q1: How are arrays laid out in memory?

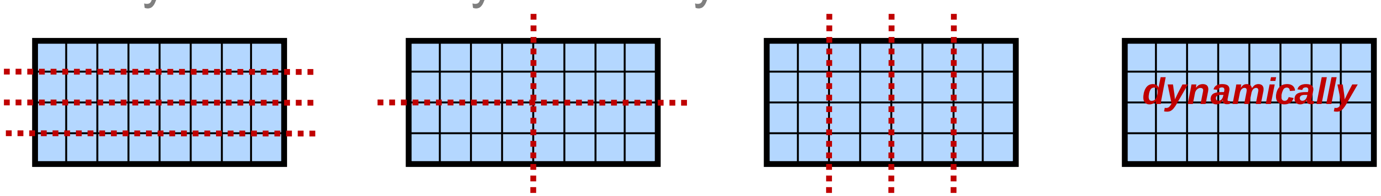
- Are regular arrays laid out in row- or column-major order? Or…?



- How are sparse arrays stored? (COO, CSR, CSC, block-structured, …?)

Q2: How are arrays stored by the locales?

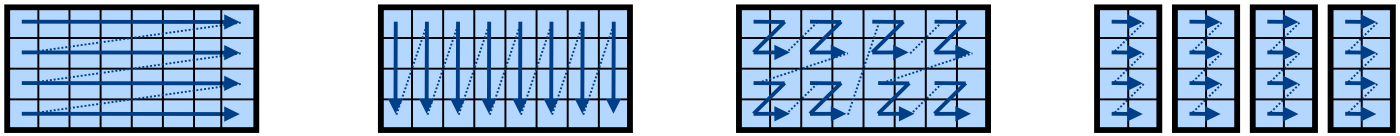
- Completely local to one locale? Or distributed?
- If distributed… In a blocked manner? cyclically? block-cyclically? recursively bisected? dynamically rebalanced? …?



Data Parallelism Implementation Qs

Q1: How are arrays laid out in memory?

- Are regular arrays laid out in row- or column-major order? Or…?



- How are sparse arrays stored? (COO, CSR, CSC, block-structured, …?)

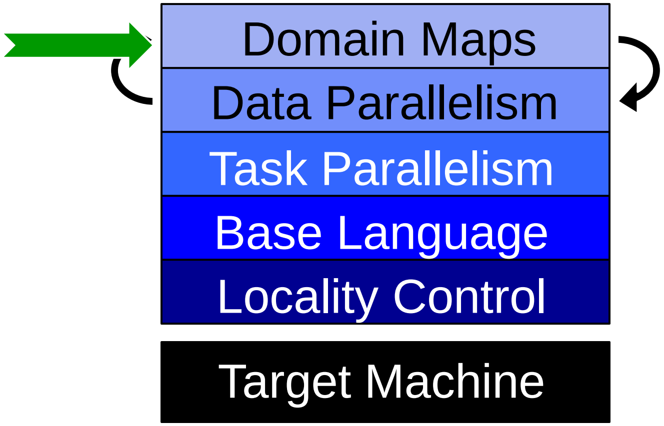
Q2: How are arrays mapped to the locales?

- Completely local to one locale? Or distributed?
- If distributed… In a blocked manner? cyclically? block-cyclically? recursively bisected? dynamically rebalanced? …?

A: Chapel's *domain maps* are designed to give the user full control over such decisions

Outline

- ✓ Motivation
- ✓ Chapel Background and Themes
- ➢ Survey of Chapel Concepts

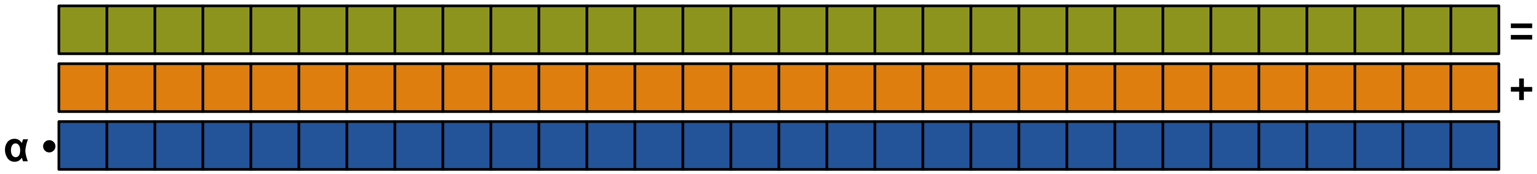


Theme 2: Global-view Abstractions

- Project Status and Next Steps

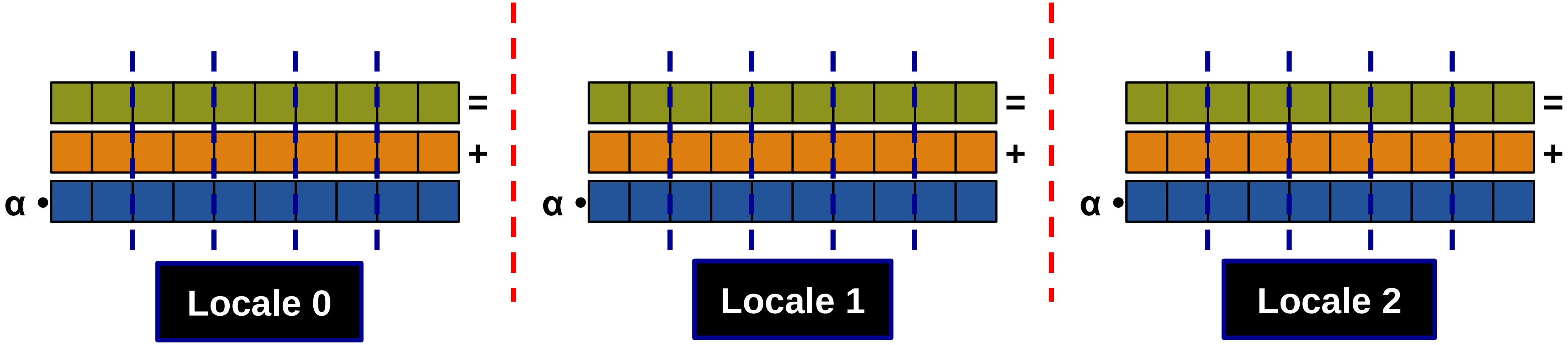
Domain Maps

Domain maps are "recipes" that instruct the compiler how to map the global view of a computation…



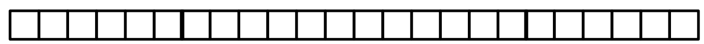

```
A = B + alpha * C;
```

…to the target locales' memory and processors:

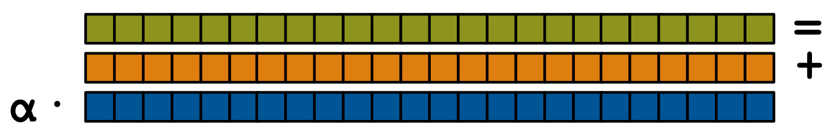


STREAM Triad: Chapel

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



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



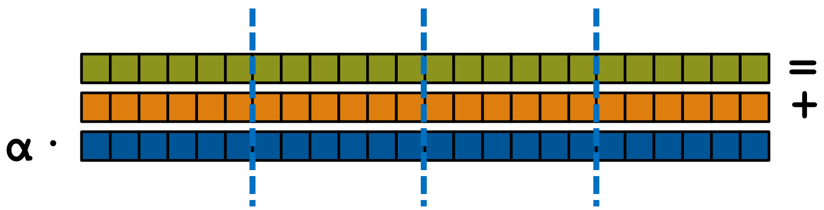

```
A = B + alpha * C;
```

STREAM Triad: Chapel (multicore)

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

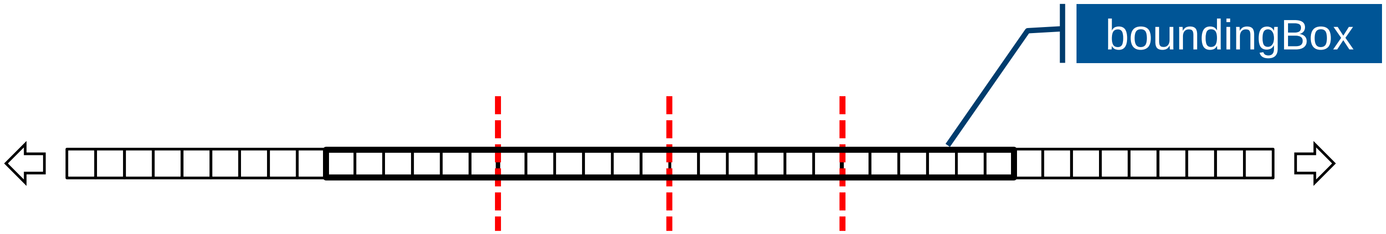
var A, B, C: [ProblemSpace] real;

A = B + alpha * C;
```

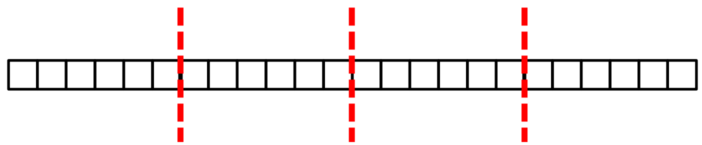


No domain map specified => use default layout
- current locale owns all indices and values
- computation will execute using local processors only

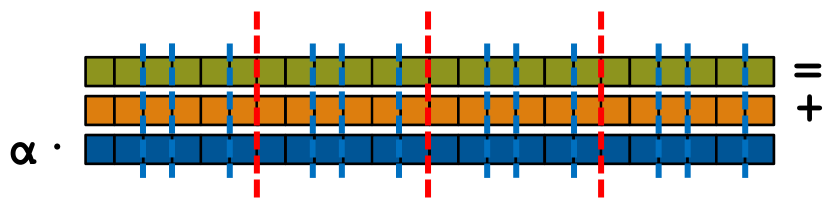
STREAM Triad: Chapel (multilocale, blocked)




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

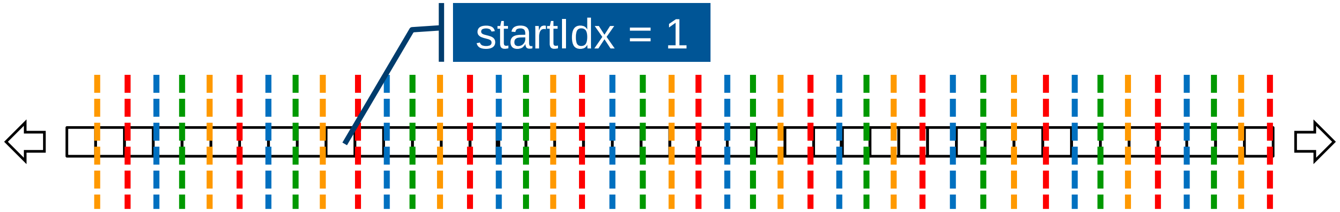


```
var A, B, C: [ProblemSpace] real;
```

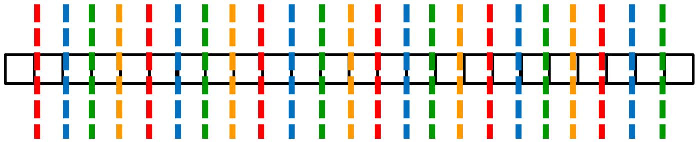



```
A = B + alpha * C;
```

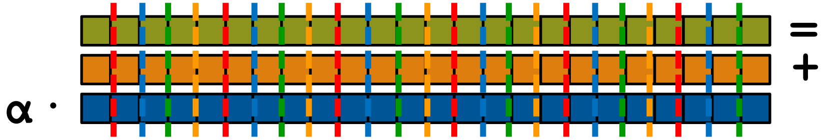
STREAM Triad: Chapel (multilocale, cyclic)




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

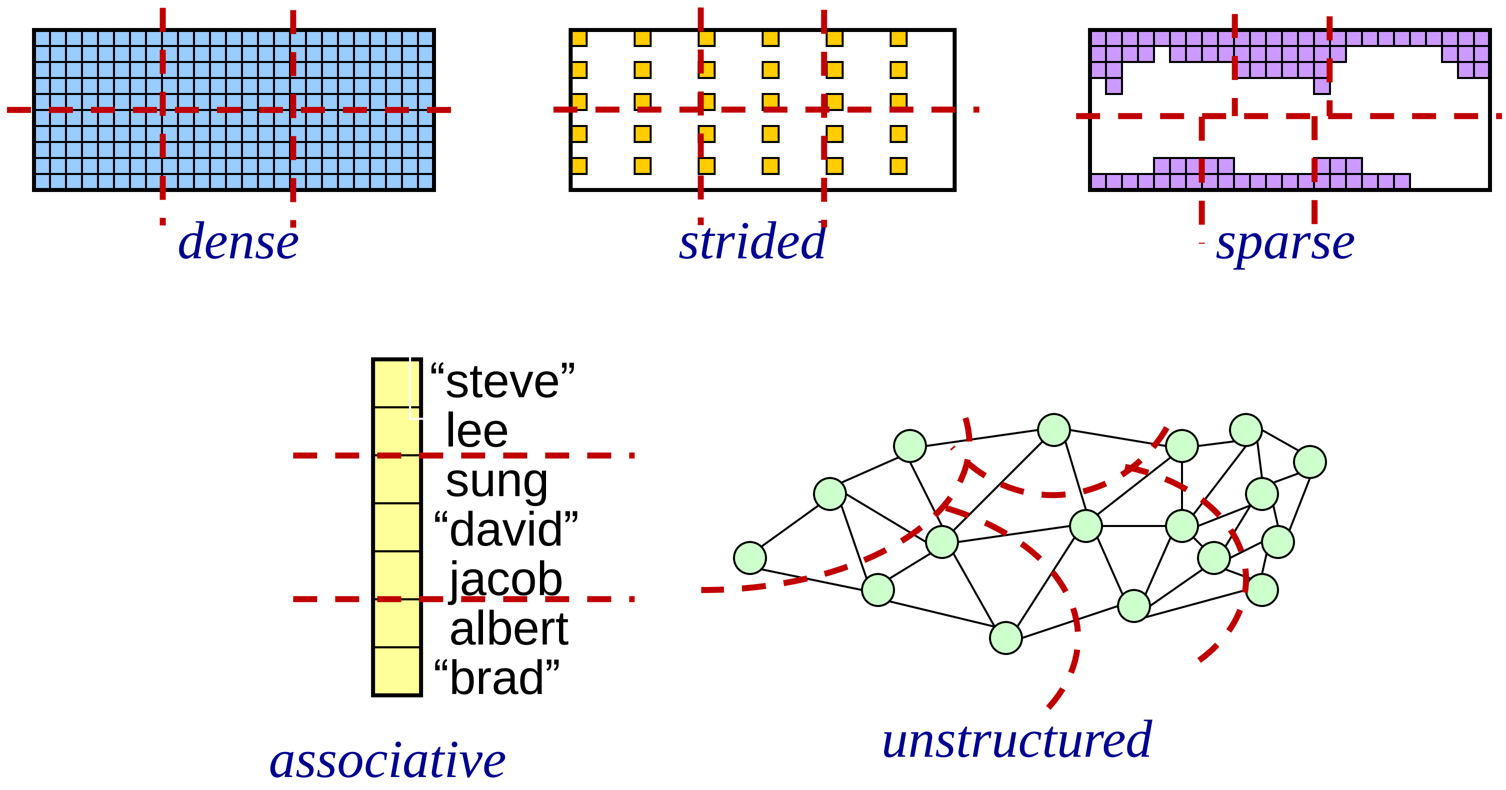


```
var A, B, C: [ProblemSpace] real;
```



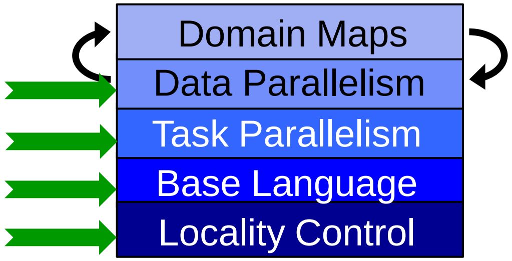

```
A = B + alpha * C;
```

Domain Map Types



Chapel's Domain Map Philosophy

1. **Chapel provides a library of standard domain maps**
   - to support common array implementations effortlessly
2. **Advanced users can write their own domain maps in Chapel**
   - to cope with shortcomings in our standard library



3. **Chapel's standard domain maps are written using the same end-user framework**
   - to avoid a performance cliff between "built-in" and user-defined cases

For More Information on Domain Maps

HotPAR'10: *User-Defined Distributions and Layouts in Chapel: Philosophy and Framework*
Chamberlain, Deitz, Iten, Choi; June 2010

CUG 2011: *Authoring User-Defined Domain Maps in Chapel*
Chamberlain, Choi, Deitz, Iten, Litvinov; May 2011

Chapel release:

- Technical notes detailing domain map interface for programmers:
  $CHPL_HOME/doc/technotes/README.dsi
- Current domain maps:
  $CHPL_HOME/modules/dists/*.chpl
  layouts/*.chpl
  internal/Default*.chpl

Summary of this Domain Maps Section

- **Chapel avoids locking crucial implementation decisions into the language specification**
  - local and distributed array implementations
  - parallel loop implementations

- **Instead, these can be…**

  …specified in the language by an advanced user

  …swapped in and out with minimal code changes

- **The result separates the roles of domain scientist, parallel programmer, and implementation cleanly**

Outline

- ✓ Motivation
- ✓ Chapel Background and Themes
- ✓ Survey of Chapel Concepts
- ➢ **Project Status and Next Steps**

Implementation Status -- Version 1.8.0 (Oct 2013)

Overall Status:

- Most features work at a functional level
  - some features need to be improved or re-implemented (e.g., OOP)
- Many performance optimizations remain
  - particularly for distributed memory (multi-locale) execution

This is a good time to:

- Try out the language and compiler
- Use Chapel for non-performance-critical projects
- Give us feedback to improve Chapel
- Use Chapel for parallel programming education

Chapel and Education

- **When teaching parallel programming, I like to cover:**
  - data parallelism
  - task parallelism
  - concurrency
  - synchronization
  - locality/affinity
  - deadlock, livelock, and other pitfalls
  - performance tuning
  - …
- **I don't think there's been a good language out there…**
  - for teaching *all* of these things
  - for teaching some of these things well at all
  - ***until now:*** We believe Chapel can potentially play a crucial role here

    (see http://chapel.cray.com/education.html for more information and http://cs.washington.edu/education/courses/csep524/13wi/ for my use of Chapel in class)

The Cray Chapel Team (Summer 2013)

Chapel Community

(see chapel.cray.com/collaborations.html for further details and possible collaboration areas)

- **Lightweight Tasking using Qthreads:** Sandia (Dylan Stark, et al.)
  - paper at CUG, May 2011
- **Lightweight Tasking using MassiveThreads:** U Tokyo (Kenjiro Taura, Jun Nakashima)
- **I/O, regexp, LLVM back-end, etc.:** LTS/UMD (Michael Ferguson, et al.)
- **Application Studies:** LLNL (Rob Neely, Bert Still, Jeff Keasler), Sandia (Richard Barrett, et al.)
- **Chapel-MPI-3 Compatibility:** Argonne (Pavan Balaji, Rajeev Thakur, Rusty Lusk)
- **Futures/Task-based Parallelism:** Rice (Vivek Sarkar, Shams Imam, Sagnak Tasirlar, et al.)
- **Parallel File I/O, Bulk-Copy Opt:** U Malaga (Rafael Asenjo, Maria Angeles Navarro, et al.)
  - papers at ParCo, Aug 2011; SBAC-PAD, Oct 2012
- **Interoperability via Babel/BRAID:** LLNL/Rice (Tom Epperly, Shams Imam, et al.)
  - paper at PGAS, Oct 2011
- **Runtime Communication Optimization:** LBNL (Costin Iancu, et al.)
- **Energy and Resilience:** ORNL (David Bernholdt, et al.)
- **Interfaces/Generics/OOP:** CU Boulder (Jeremy Siek, et al.)
- **Model Checking and Verification:** U Delaware (Stephen Siegel, T. Zirkel, T. McClory)

(and several others as well…)

Chapel: the next five years

- **Harden Prototype to Production-grade**
  - Performance Optimizations
  - Add/Improve Lacking Features
- **Target more complex/modern compute node types**
  - e.g., CPU+GPU, Intel MIC, …
- **Continue to grow the user and developer communities**
  - including nontraditional circles: desktop parallelism, “big data”
  - transition Chapel from Cray-controlled to community-governed
- **Grow the team at Cray**
  - four positions open at present (manager, SW eng, build/test/release)

Summary

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

- yet, without necessarily abdicating control
- Chapel does this via its multiresolution design
  - Here, we saw it in domain maps and leader-follower iterators
  - These avoid locking crucial performance decisions into the language

We believe Chapel can greatly improve productivity

…for current and emerging HPC architectures

…and for the growing need for parallel programming in the mainstream

For More Information: Online Resources

Chapel project page: http://chapel.cray.com

- overview, papers, presentations, language spec, …

Chapel SourceForge page: https://sourceforge.net/projects/chapel/

- release downloads, public mailing lists, code repository, …

Mailing Aliases:

- chapel_info@cray.com: contact the team at Cray
- chapel-users@lists.sourceforge.net: user-oriented discussion list
- chapel-developers@lists.sourceforge.net: developer discussion
- chapel-education@lists.sourceforge.net: educator discussion
- chapel-bugs@lists.sourceforge.net: public bug forum

For More Information: Suggested Reading

Overview Papers:

- *The State of the Chapel Union* [slides], Chamberlain, Choi, Dumler, Hildebrandt, Iten, Litvinov, Titus. CUG 2013, May 2013.
  - *a high-level overview of the project summarizing the HPCS period*

- *A Brief Overview of Chapel*, Chamberlain (pre-print of a chapter for *A Brief Overview of Parallel Programming Models*, edited by Pavan Balaji, to be published by MIT Press in 2014).
  - *a more detailed overview of Chapel's history, motivating themes, features*

Blog Articles:

- *[Ten] Myths About Scalable Programming Languages*, Chamberlain. IEEE Technical Committee on Scalable Computing (TCSC) Blog, (https://www.ieeetcsc.org/activities/blog/), April-November 2012.
  - *a series of technical opinion pieces designed to combat standard arguments against the development of high-level parallel languages*

http://chapel.cray.com   chapel_info@cray.com   http://sourceforge.net/projects/chapel/