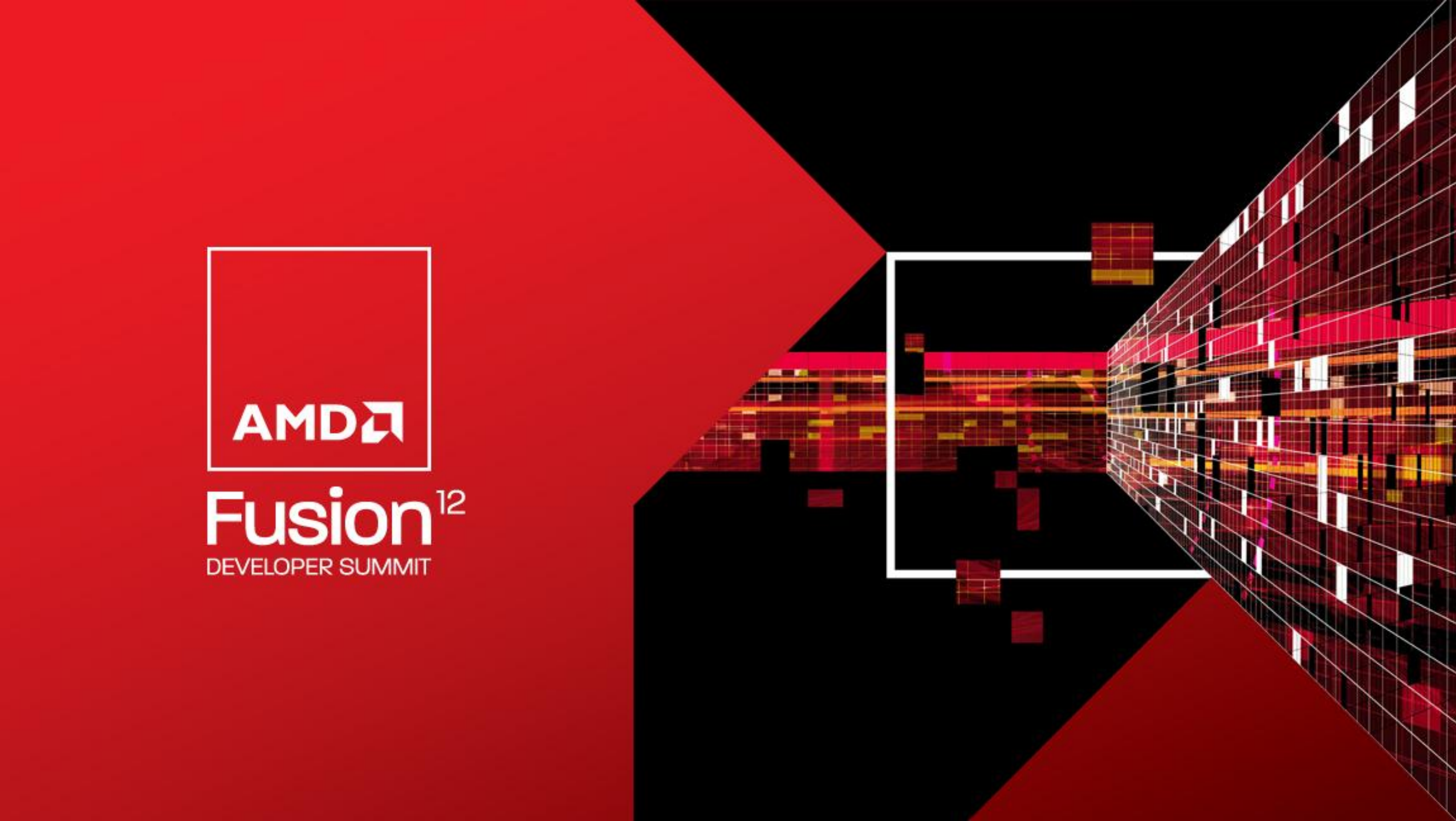
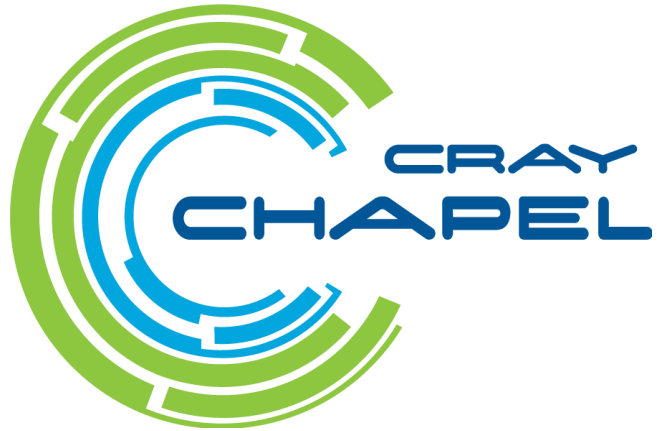

AMD
Fusion 12
DEVELOPER SUMMIT

AMD Fusion 12 DEVELOPER SUMMIT

CHAPEL

Multiresolution Parallel Programming

Brad Chamberlain
Cray Inc.
Principal Engineer



CRAY®
THE SUPERCOMPUTER COMPANY

Sustained Performance Milestones

1 GF – 1988: Cray Y-MP; 8 Processors

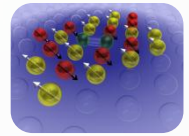
- Static finite element analysis

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

Sustained Performance Milestones w/ Programming Models

1 GF – 1988: Cray Y-MP; 8 Processors

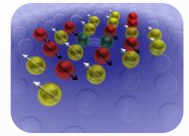
- Static finite element analysis
- Fortran77 + Cray autotasking + vectorization

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

- Modeling of metallic magnet atoms
- Fortran + MPI (Message Passing Interface)

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

- Superconductive materials
- C++/Fortran + MPI + vectorization



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

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

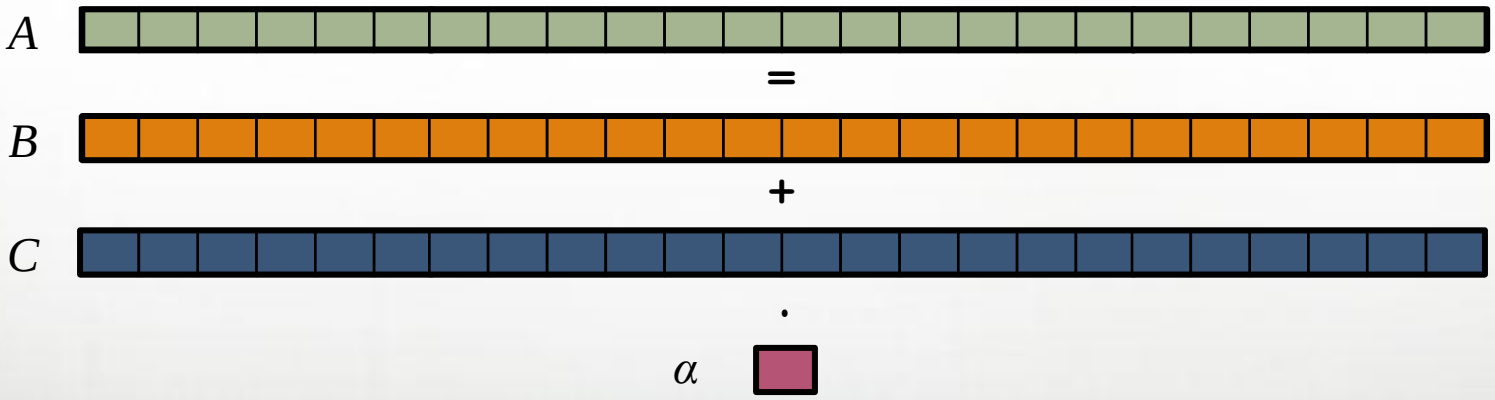
Or Perhaps Something Completely Different?

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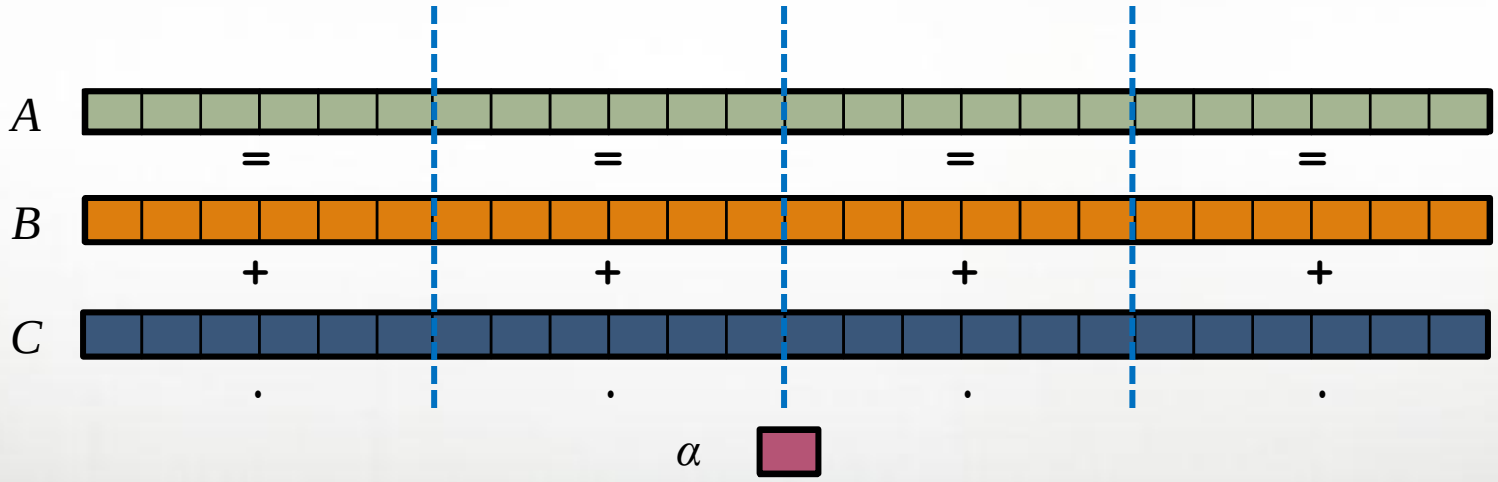
Compute: $\forall i \in 1..m, A_i = B_i + \alpha \cdot C_i$

In pictures, in parallel:

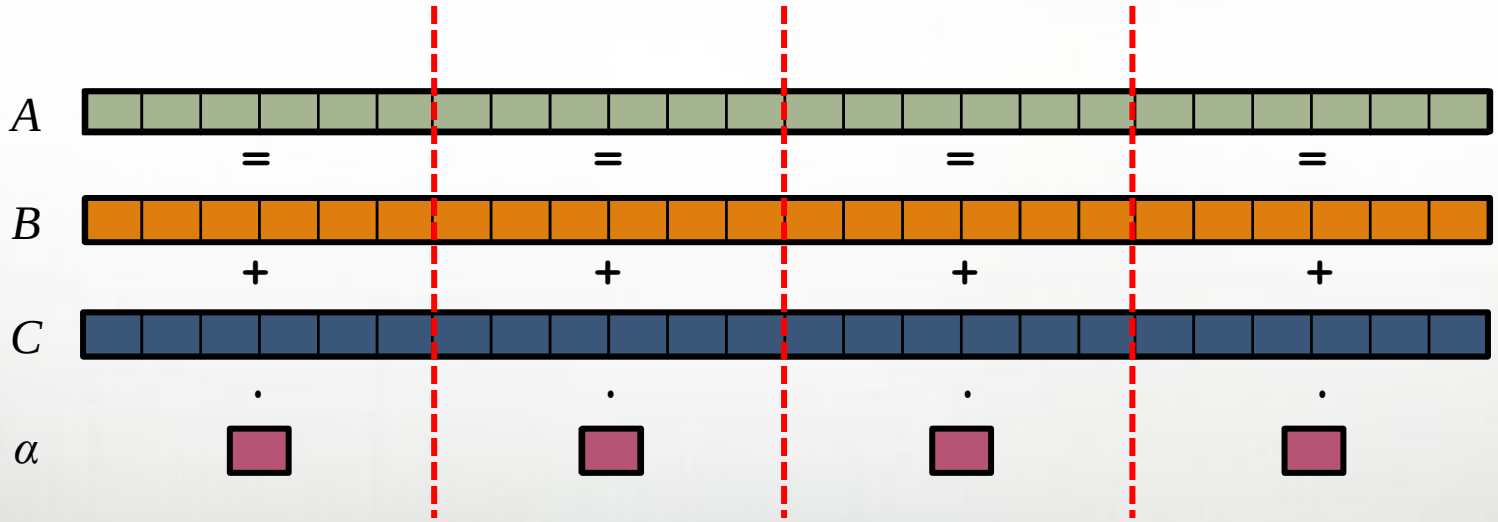


STREAM Triad: a trivial parallel computation

Given: m-element vectors A, B, C

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

In pictures, in parallel (distributed memory):

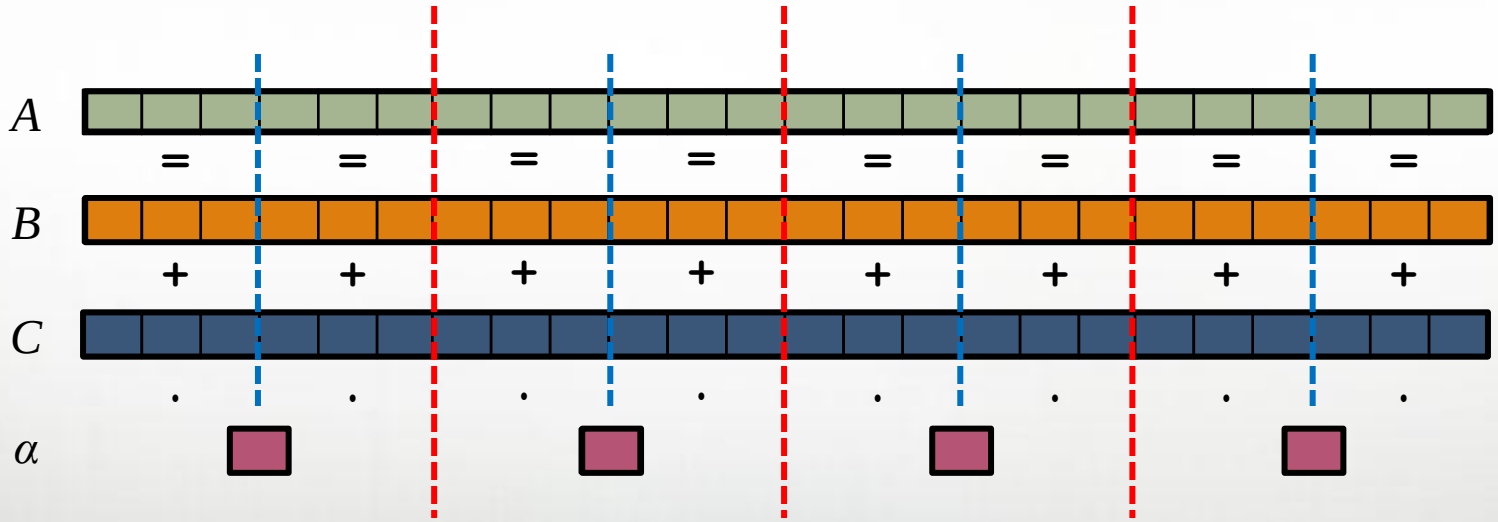


STREAM Triad: a trivial parallel computation

Given: m-element vectors A, B, C

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

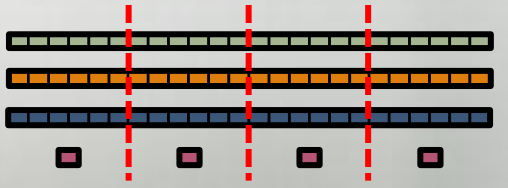
In pictures, in parallel (distributed memory multicore):



STREAM Triad: MPI

MPI

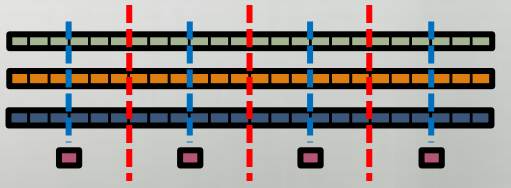
```
#include <hpcc.h>

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);

  return 0;
}
```



STREAM Triad: MPI+OpenMP

MPI + OpenMP

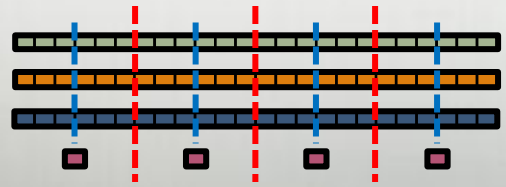
```
#include <hpcc.h>
#ifdef _OPENMP
#include <omp.h>
#endif

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;
}

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] = 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;
}
```



STREAM Triad: MPI+OpenMP vs. CUDA

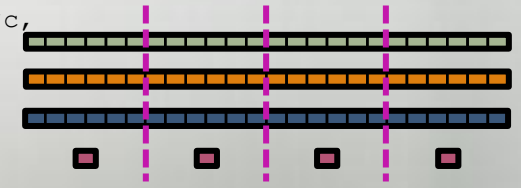
MPI + OpenMP

```
#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;
}

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] = 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.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];
}
```



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 Models	Unit of Parallelism
Inter-node	MPI/UPC/CAF	executable
Intra-node/multicore	OpenMP/pthreads	iteration/task
Instruction-level vectors/multi-threading	vendor-specific pragmas	iteration
GPU/accelerator	CUDA/OpenCL/OpenAcc	SIMD function/task

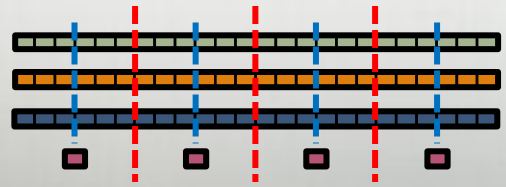
benefits: lots of control; decent generality; relatively easy to implement

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

Rewinding a few slides…

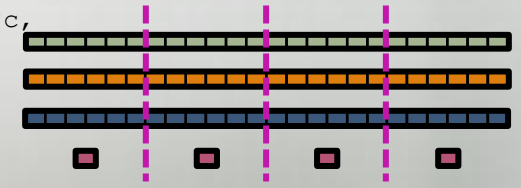
MPI + OpenMP

```
#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;
}

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] = 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.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];
}
```



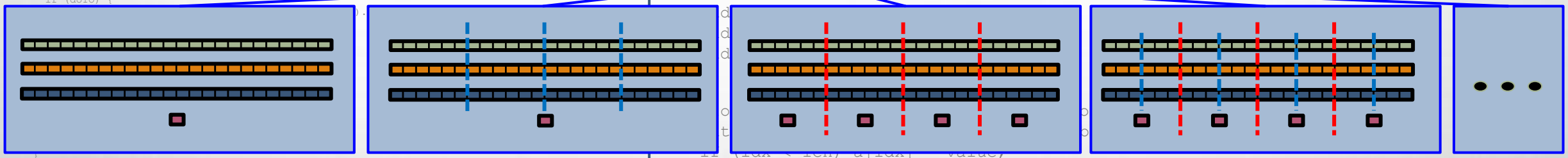
HPC suffers from too many distinct notations for expressing parallelism and locality

STREAM Triad: Chapel

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



Philosophy: 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
- Tour of Chapel Concepts
- Chapel and Exascale
- Wrap-up

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

Motivating Chapel Themes

1) General Parallel Programming
2) Global-View Abstractions
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1) General Parallel Programming

With a unified set of concepts...

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

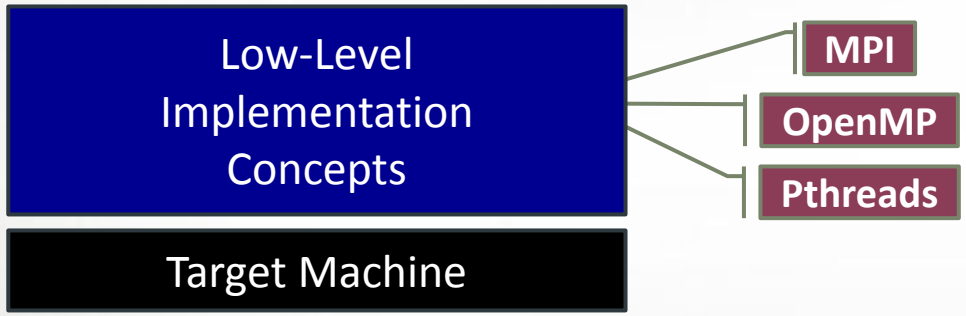
- **Styles:** data-parallel, task-parallel, concurrency, nested, …
- **Levels:** model, function, loop, statement, expression

...target all parallelism available in the hardware

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

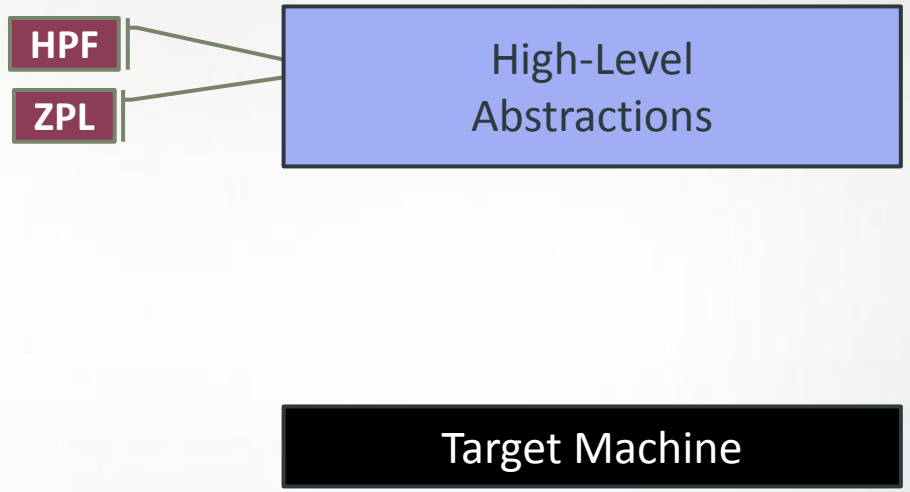
Style of HW Parallelism	Programming Models	Unit of Parallelism
Inter-node	Chapel	executable
Intra-node/multicore	Chapel	iteration/task
Instruction-level vectors/multi-threading	Chapel	iteration
GPU/accelerator	Chapel	SIMD function/task

3) Multiresolution Design: Motivation



"Why is everything so tedious/difficult?"

"Why don't my programs port trivially?"

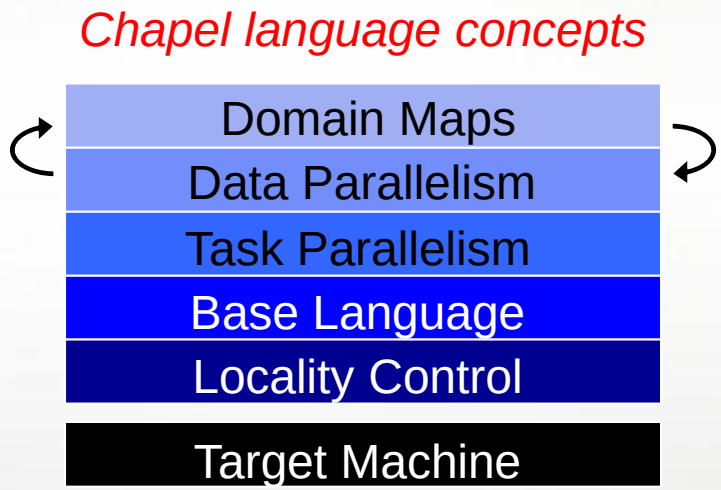


"Why don't I have more control?"

3) Multiresolution Design

Multiresolution Design: Support multiple tiers of features

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



- 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, Perl, Python
- 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

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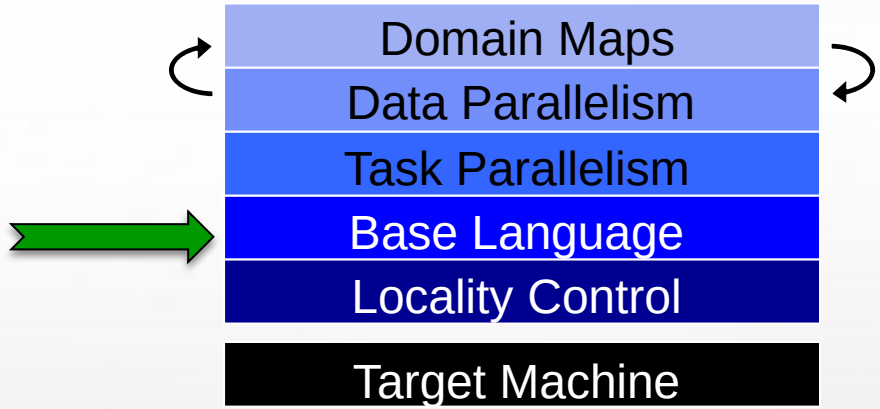
Base Language Features



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)
```

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

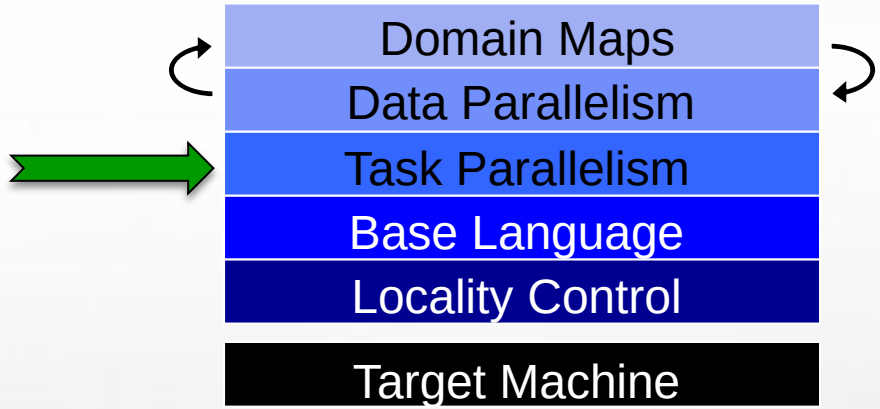
```
for ij in tiledRMO([1..n, 1..n], 2) do
  write(ij);
```

```
(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)
```

Other Base Language Features

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

Task Parallel Features



Coforall Loops

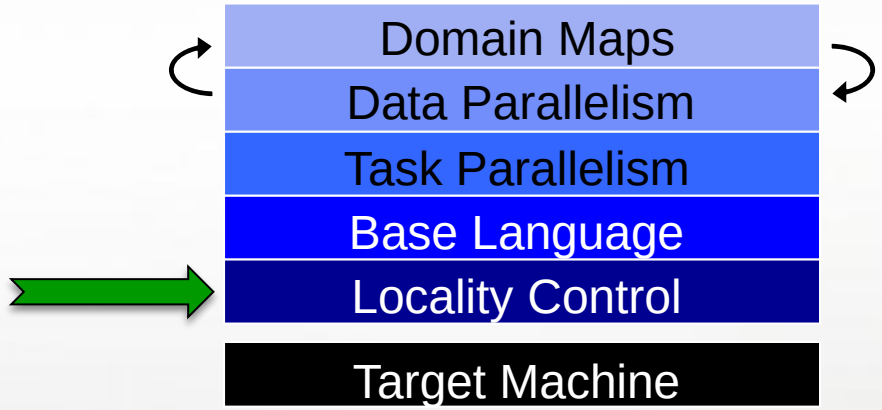
```
coforall t in 0..#numTasks do
  writeln("Hello from task ", t, " of ", numTasks);

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

```
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
```

Other Task Parallel Features

- *begin* statements for fire-and-forget tasks
- *cobegin* statements for heterogeneous tasks
- *sync* and *atomic variables* for data-centric synchronization

Locality Features



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 multi-core processor or SMP node

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 = …;
```

Locale Operations

- Locale methods support queries about target system:

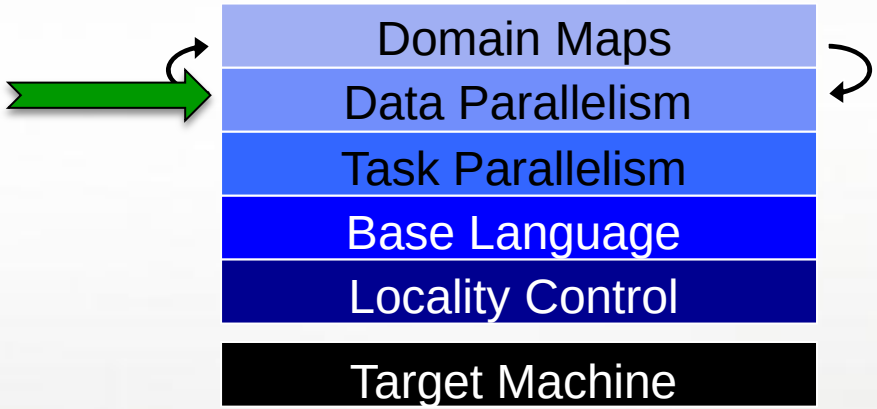
```
proc locale.physicalMemory(…) { … }
proc locale.numCores { … }
proc locale.id { … }
proc locale.name { … }
```

- *On-clauses* support placement of computations:

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

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

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

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

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

Data Parallel Features



Chapel Data Parallel Operations

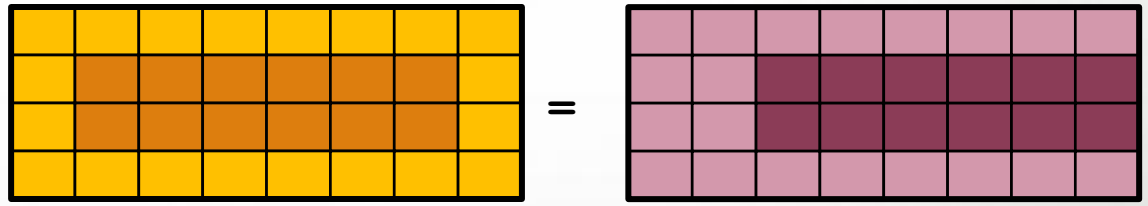
- Parallel Iteration

```
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

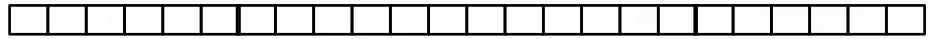
```
A = B + alpha * C;
```

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

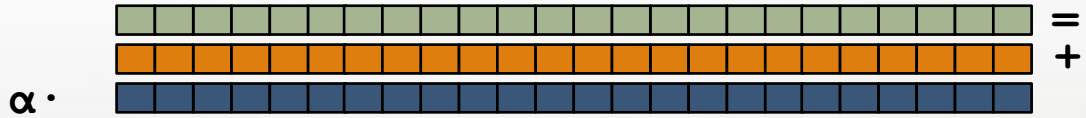
- And several others…

STREAM Triad: Chapel

```
const ProblemSpace = [1..m];
```



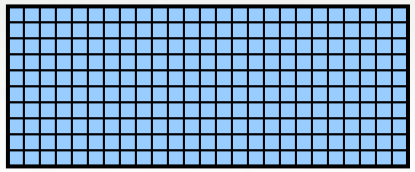
```
var A, B, C: [ProblemSpace] real;
```



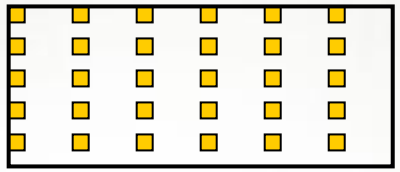

```
A = B + alpha * C;
```

Chapel Array Types

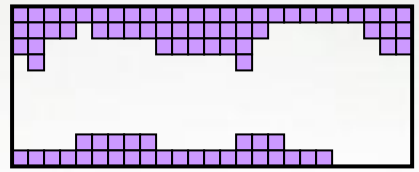
Chapel supports several types of arrays…



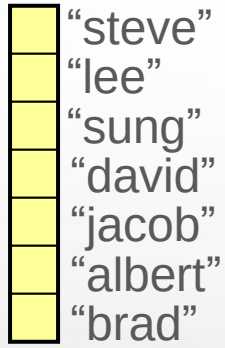
dense



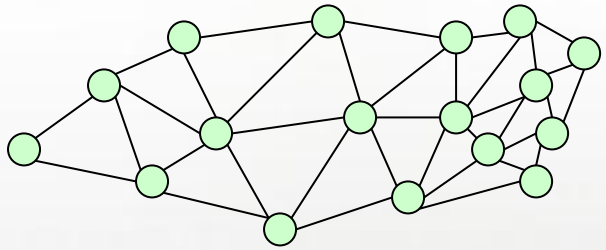
strided



sparse



associative



unstructured

…each of which supports Chapel’s data parallel operators

Data Parallelism Implementation Qs

Q1: How are arrays laid out in memory?

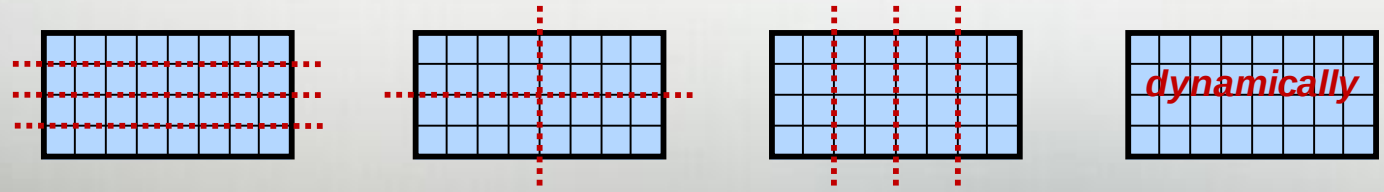
- Are regular arrays laid out in row- or column-major order? Or…?

…?

- How are sparse arrays stored? (COO, CSR, CSC, block-structured, …?)
- What about associative and unstructured?

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? …?

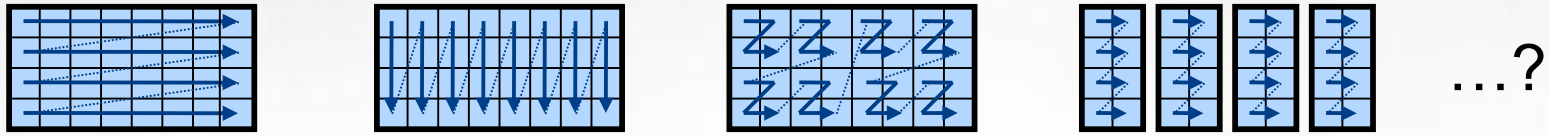


…?

Data Parallelism Implementation Qs

Q1: How are arrays laid out in memory?

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



…?

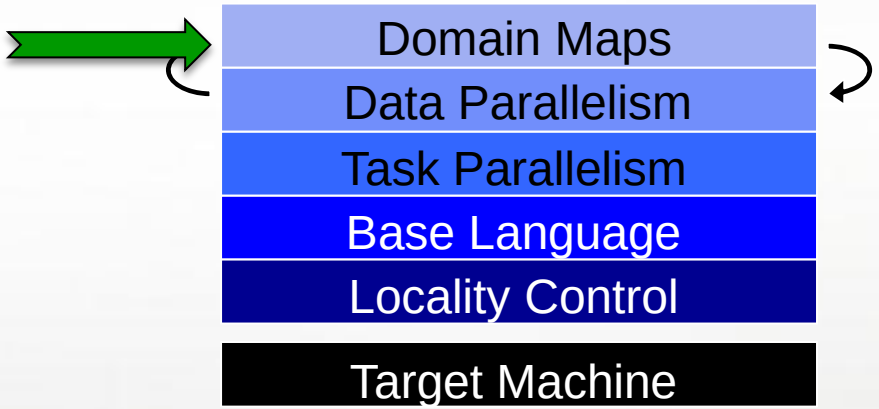
- How are sparse arrays stored? (COO, CSR, CSC, block-structured, …?)
- What about associative and unstructured?

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? …?

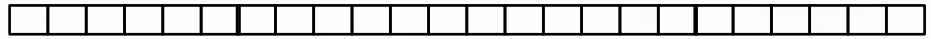
A: Chapel's *domain maps* are designed to give the user full control over such decisions

Domain Maps

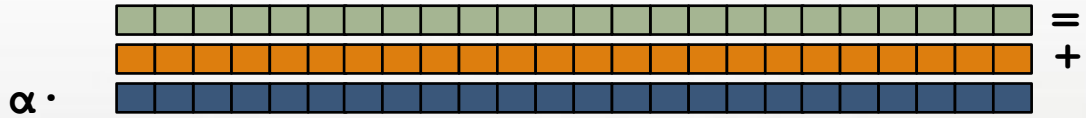

Domain Maps
Data Parallelism
Task Parallelism
Base Language
Locality Control
Target Machine

STREAM Triad: Chapel (multicore)

```
const ProblemSpace = [1..m];
```



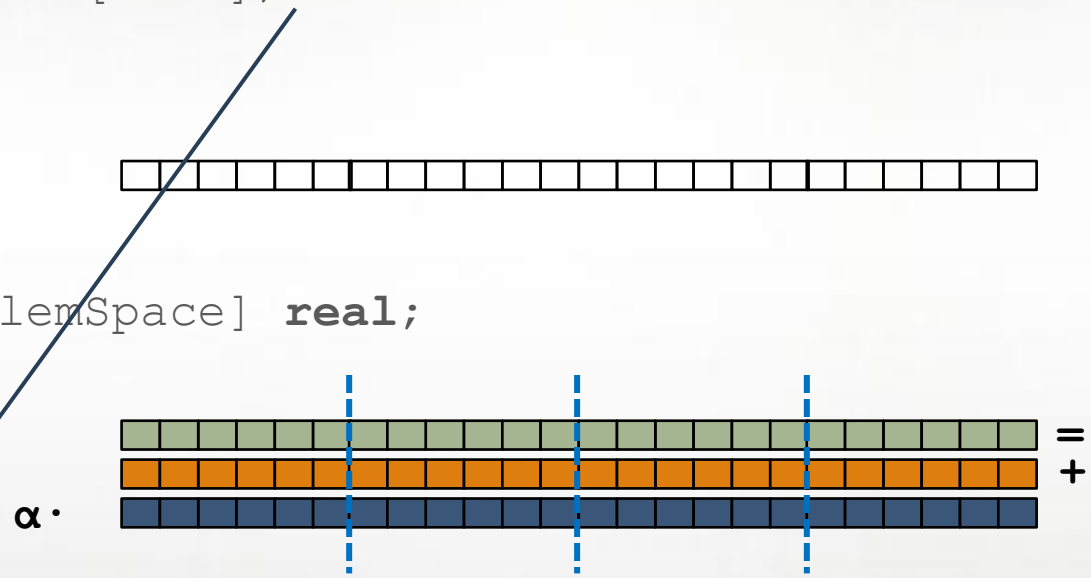
```
var A, B, C: [ProblemSpace] real;
```




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

STREAM Triad: Chapel (multicore)

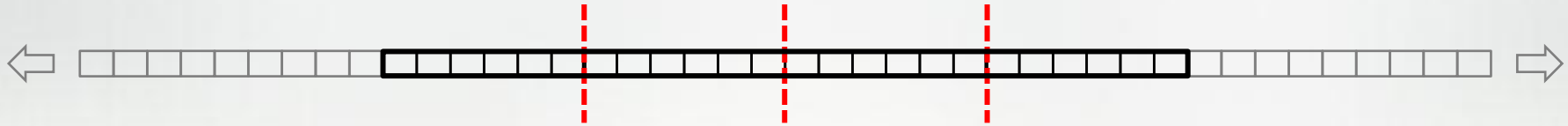
```
const ProblemSpace = [1..m];

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

A = B + alpha * C;
```



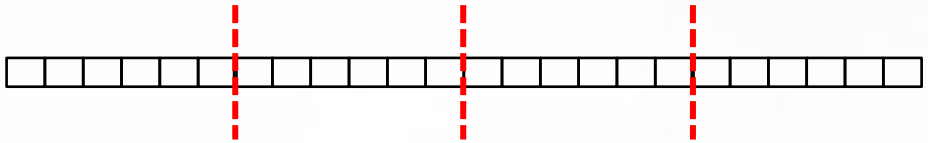
No domain map specified => use default layout

- current locale owns all indices and values
- computation will execute using local processors only

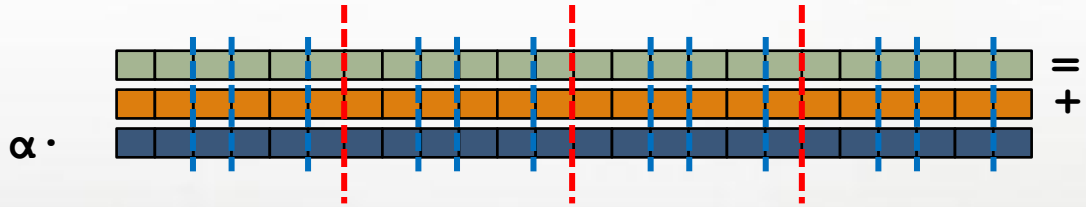
STREAM Triad: Chapel (multilocale, blocked)



```
const ProblemSpace = [1..m]
                     dmapped Block(boundingBox=[1..m], targetLocales=Locales);
```

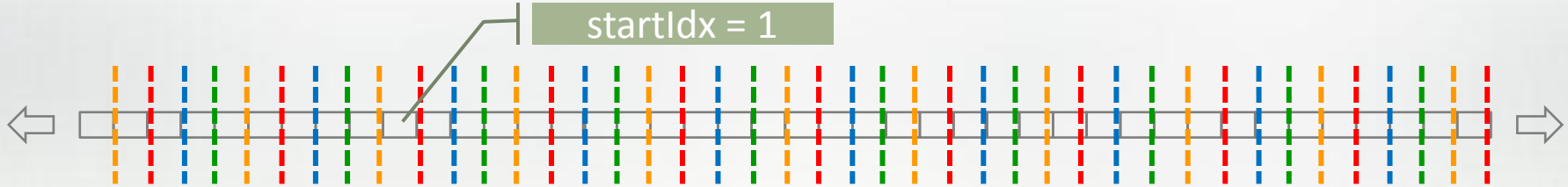


```
var A, B, C: [ProblemSpace] real;
```

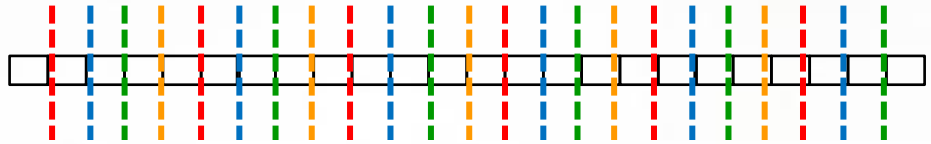



```
A = B + alpha * C;
```

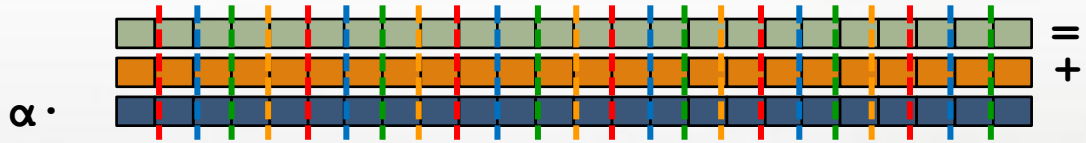
STREAM Triad: Chapel (multilocale, cyclic)




```
const ProblemSpace = [1..m]
                     dmapped Cyclic(startIdx=1, targetLocales=Locales);
```



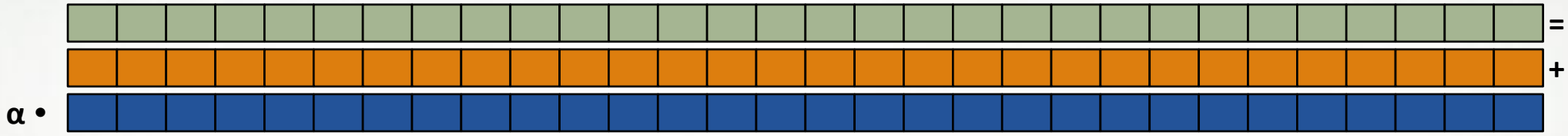
```
var A, B, C: [ProblemSpace] real;
```




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

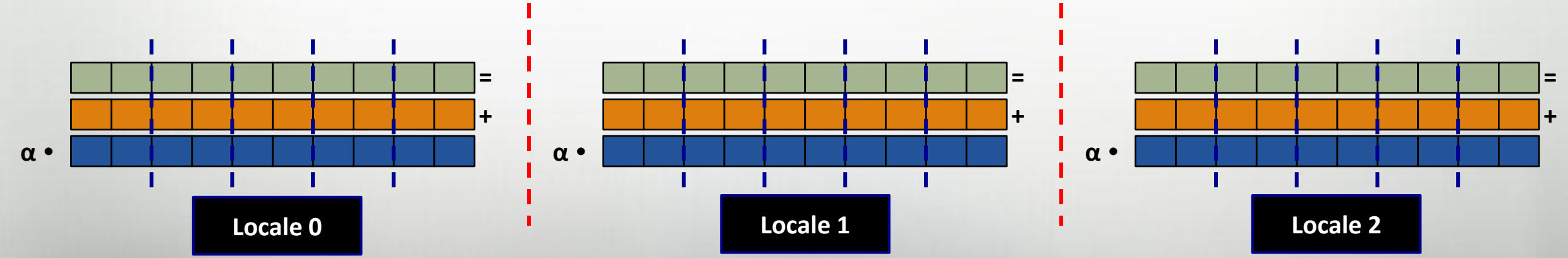
Domain Maps

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



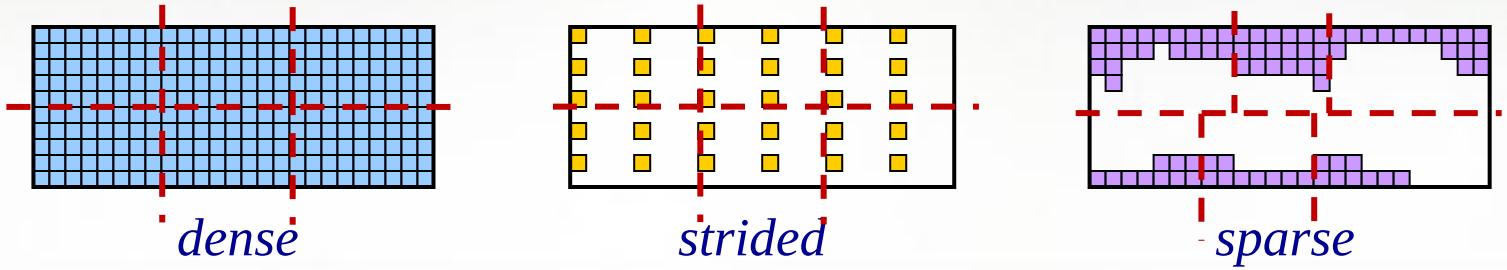

```
A = B + alpha * C;
```

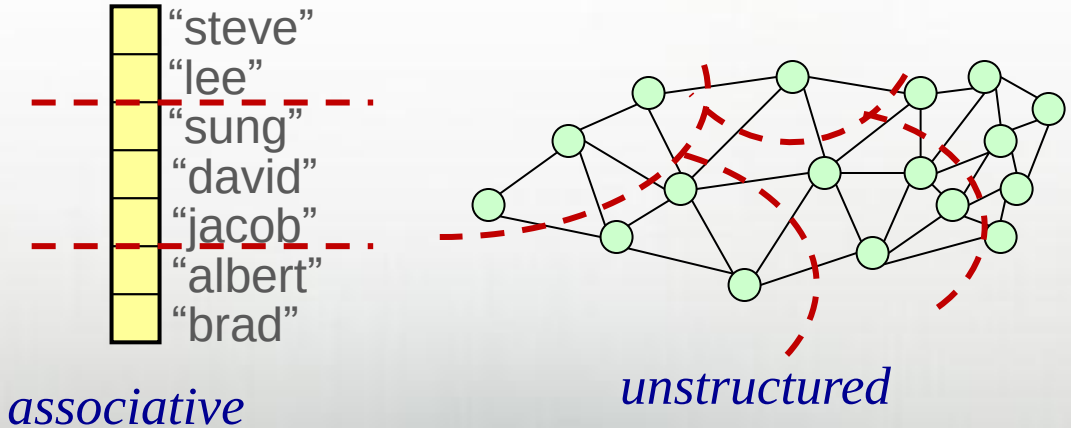
…to the target locales’ memory and processors:



Domain Map Types

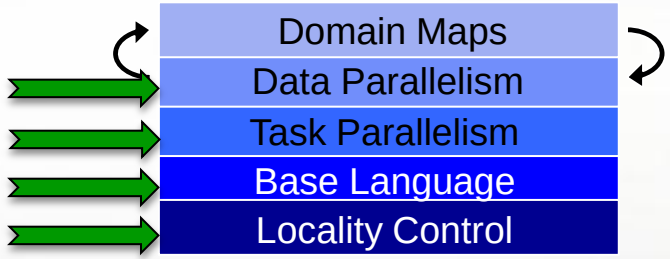
All Chapel arrays support domain maps





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

Domain Maps: Summary

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

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

PGAS 2011: *User-Defined Parallel Zippered Iterators in Chapel,* Chamberlain, Choi, Deitz, Navarro; October 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

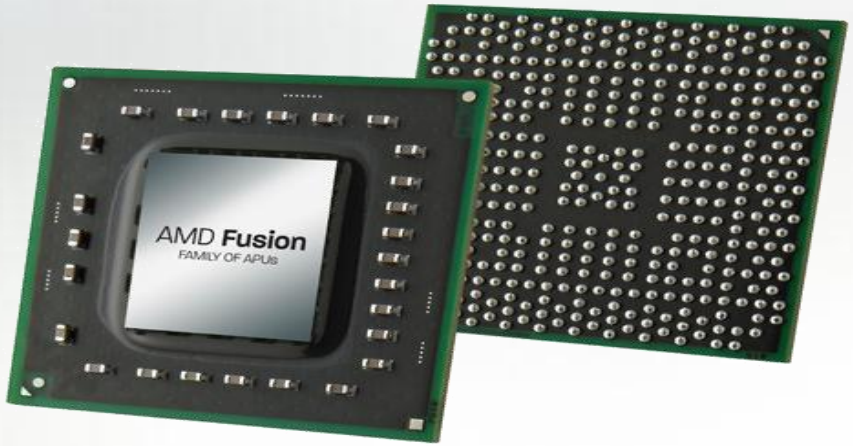
  layouts/*.chpl

  internal/Default*.chpl

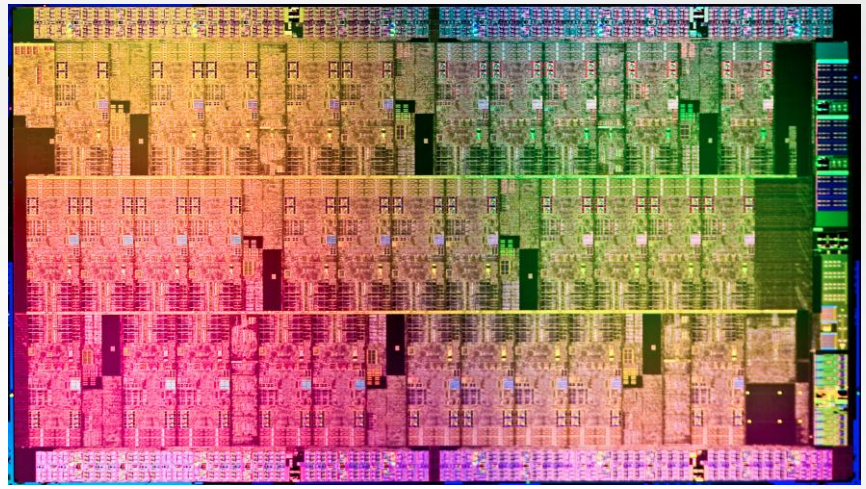
Outline

- ✓ Motivation
- ✓ Chapel Background and Themes
- ✓ Tour of Chapel Concepts
- ➢ Chapel and Exascale
- Wrap-up

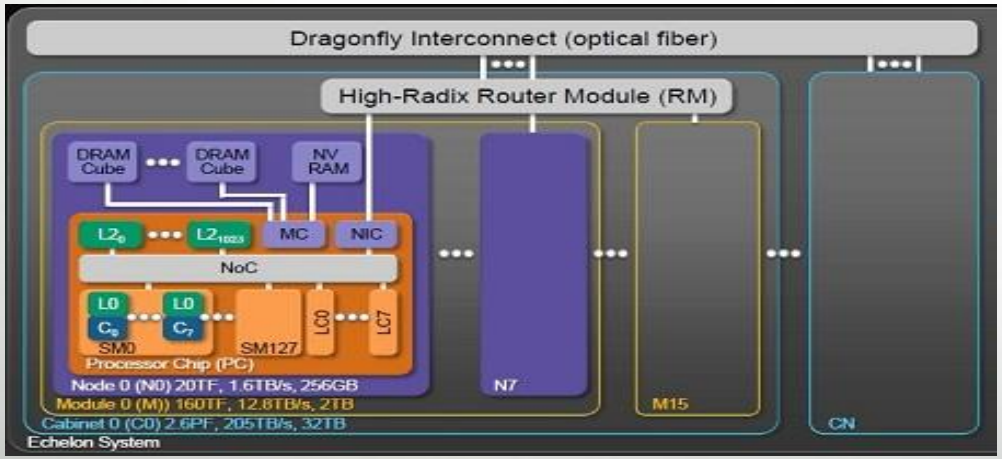
Candidate Next-Generation Processor Technologies



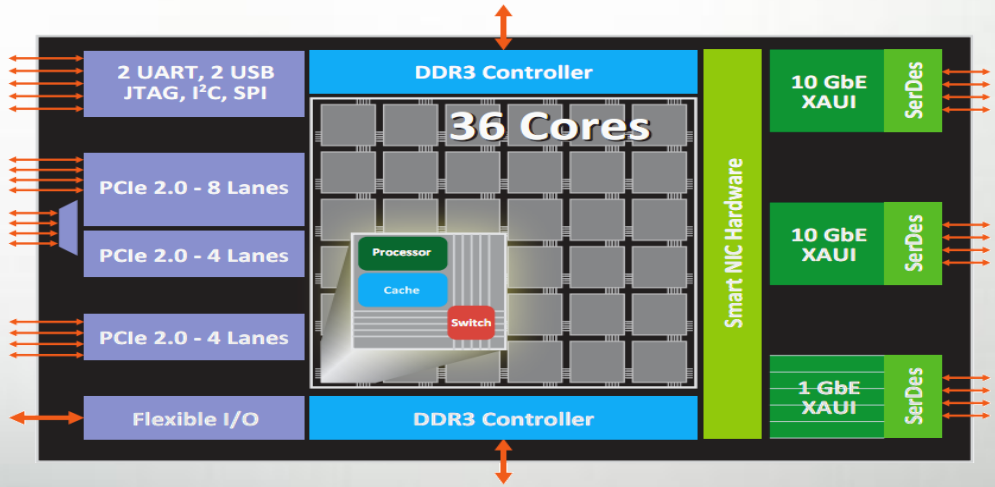
AMD Fusion



Intel MIC



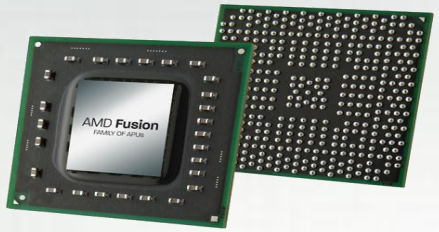
Nvidia Echelon

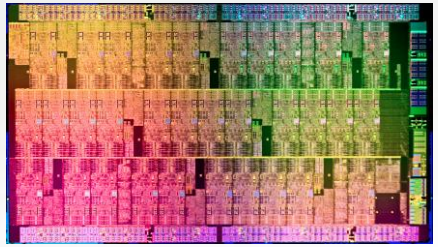


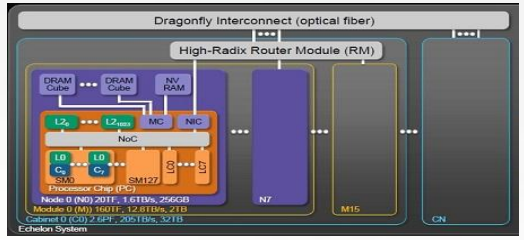
Tilera Tile-Gx

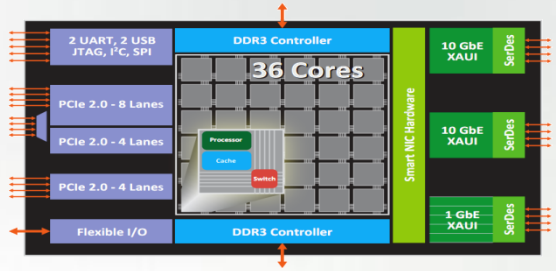
Sources: http://www.thinkcomputers.org/ces-2011-amds-fusion-apus/, http://download.intel.com/pressroom/images/Aubrey_Isle_die.jpg, http://insidehpc.com/2010/11/26/nvidia-reveals-details-of-echelon-gpu-designs-for-exascale/, http://tilera.com/sites/default/files/productbriefs/Tile-Gx%203036%20SB012-01.pdf

General Characteristics of These Architectures









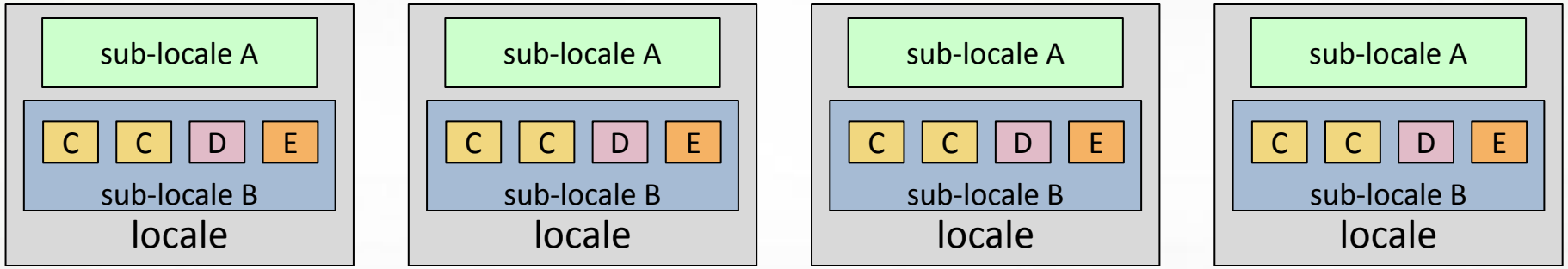
- Increased hierarchy and/or sensitivity to locality
- Heterogeneous processor and memory types

⇒ HPC (and mainstream) programmers will have a lot more to think about at the processor level

Current Work: Hierarchical Locales

Concept:

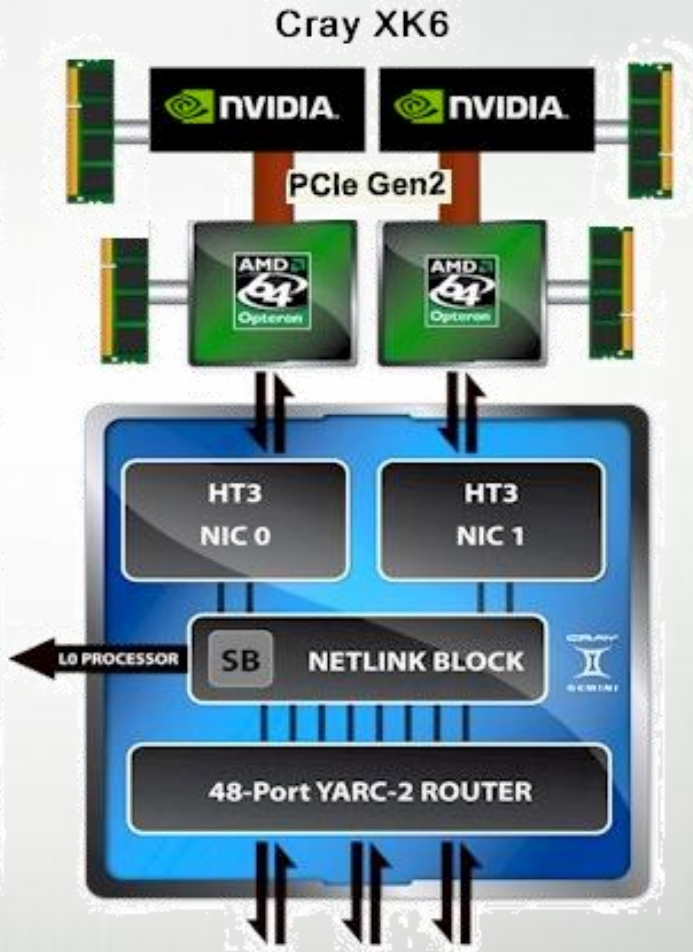
- Support sub-locales within locales to describe node architecture sub-structures



- As with current locales, on-clauses and domain maps can be used to map tasks or variables to a sub-locale's memory/processors
- Locale structures are defined as Chapel code
  - introduces a new Chapel programmer role: Architectural modeler

Sublocales: Hybrid Processor Example

```
class locale: AbstractLocale {
  const numCPUs = 2, numGPUs = 2;
  const cpu: [0..#numCPUs] cpuLoc = …;
  const gpu: [0..#numGPUs] gpuLoc = …;
  // tasking interface for node-level
  // memory interface for node-level
}
class cpuLoc: AbstractLocale {
  // sub-locales for different NUMA domains
  // tasking, memory interfaces for CPU
}
class gpuLoc: AbstractLocale {
  // sub-locales for memories, processors
  // tasking, memory interfaces for GPU
}
```



Hierarchical Locales: Challenges

Portability: Chapel code that refers to sub-locales causes problems for locales with different structure

Mitigation Strategies

- Well-designed domain maps should buffer the data parallel user from many of these challenges
- More advanced runtime designs and compiler work could help save most task parallel users from this level of detail
- Not a Chapel-specific challenge, fortunately

Communication Generation: A function of two locale types, not one

(and they may not be known at compile-time)

Outline

- ✓ Motivation
- ✓ Chapel Background and Themes
- ✓ Tour of Chapel Concepts
- ✓ Chapel and Exascale
- ➢ Wrap-up

Summary

Higher-level programming models can help insulate algorithms from implementation

- yet, without necessarily abandoning finer-grain control
- Chapel does this via its multiresolution design

Exascale represents an opportunity to move to architecture-independent programming models

- ones that support general styles of parallel programming
- ones that separate issues of locality from parallelism

Some Next Steps

- Hierarchical Locales
- Resilience Features
- Performance Optimizations
- Lock down post-HPCS Funding
- Evolve from Prototype- to Production-grade
- Evolve from Cray- to community-language
- and much more…

Implementation Status -- Version 1.5.0 (April 19, 2012)

In a nutshell:

- Most features work at a functional level
- 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

Join Our Growing Community

- Cray:


Brad Chamberlain


Sung-Eun Choi


Greg Titus


Vass Litvinov


Tom Hildebrandt

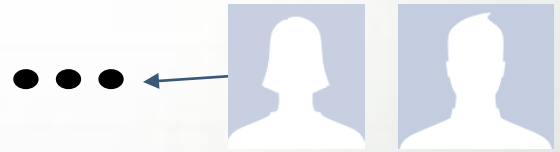
(open positions)

- External Collaborators:


Albert Sidelnik
(UIUC)


Jonathan Turner
(CU Boulder)

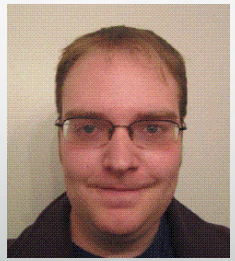

Kyle Wheeler
(Sandia)


You? Your Friend/Student/ Colleague?

- Interns:


Jonathan Claridge
(UW)


Hannah Hemmaplardh
(UW)


Andy Stone
(Colorado State)


Jim Dinan
(OSU)


Rob Bocchino
(UIUC)


Mackale Joyner
(Rice)

Featured Collaborations (see chapel.cray.com/collaborations.html for details)

- **CPU-GPU Computing:** UIUC (David Padua, Albert Sidelnik, Maria Garzarán)
  - **paper at IPDPS, May 2012**
- **Tasking using Qthreads:** Sandia (Rich Murphy, Kyle Wheeler, Dylan Stark)
  - **paper at CUG, May 2011**
- **Interoperability using Babel/BRAID:** LLNL (Tom Epperly, Adrian Prantl, et al.)
  - **paper at PGAS, Oct 2011**
- **Dynamic Iterators:**
- **Bulk-Copy Opt:**
- **Parallel File I/O:**

  U Malaga (Rafael Asenjo, Maria Angeles Navarro, et al.)
  - **paper at ParCo, Aug 2011**
- **Improved I/O & Data Channels:** LTS (Michael Ferguson)
- **Interfaces/Generics/OOP:** CU Boulder (Jeremy Siek, Jonathan Turner)
- **Tasking over Nanos++:** BSC/UPC (Alex Duran)
- **Tuning/Portability/Enhancements:** ORNL (Matt Baker, Jeff Kuehn, Steve Poole)
- **Chapel-MPI Compatibility:** Argonne (Rusty Lusk, Pavan Balaji, Jim Dinan, et al.)

For More Information

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 Lists:

- chapel_info@cray.com: contact the team
- chapel-users@lists.sourceforge.net: user-oriented discussion list
- chapel-developers@lists.sourceforge.net: dev.-oriented discussion
- chapel-education@lists.sourceforge.net: educator-oriented discussion
- chapel-bugs@lists.sourceforge.net: public bug forum
- chapel_bugs@cray.com: private bug mailing list

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

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