Chapel: Striving for Productivity at Petascale, Sanity at Exascale

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I2PC Seminar, UIUC

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Sustained Performance Milestones

1 GF – 1988: Cray Y-MP; 8 Processors

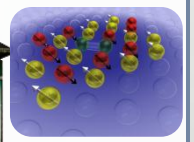
- Static finite element analysis

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

- Modeling of metallic magnet atoms

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

- Superconductive materials



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- TBD

Sustained Performance Milestones

1 GF – 1988: Cray Y-MP; 8 Processors

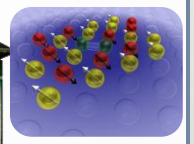
- Static finite element analysis
- Fortran77 + Cray autotasking + vectorization

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 + 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:

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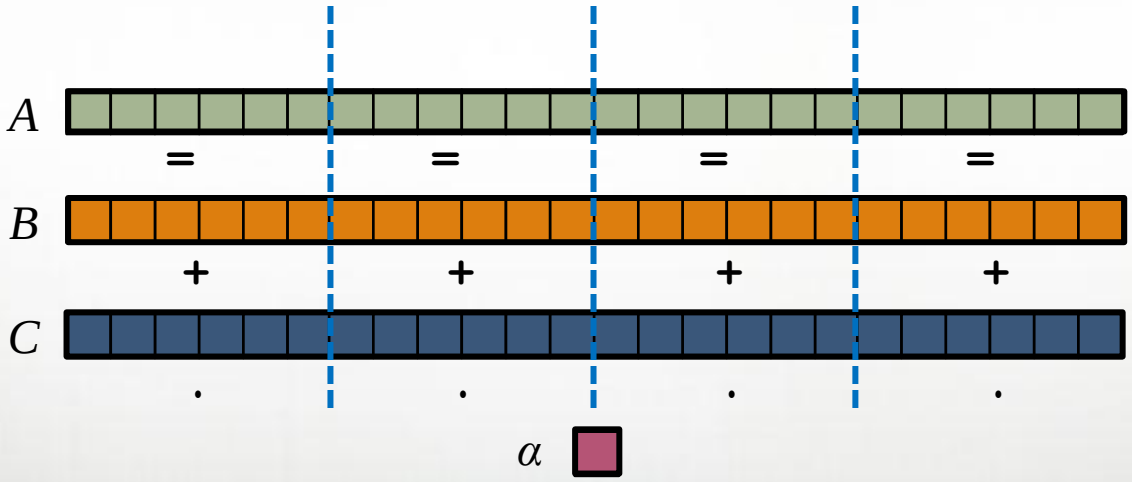

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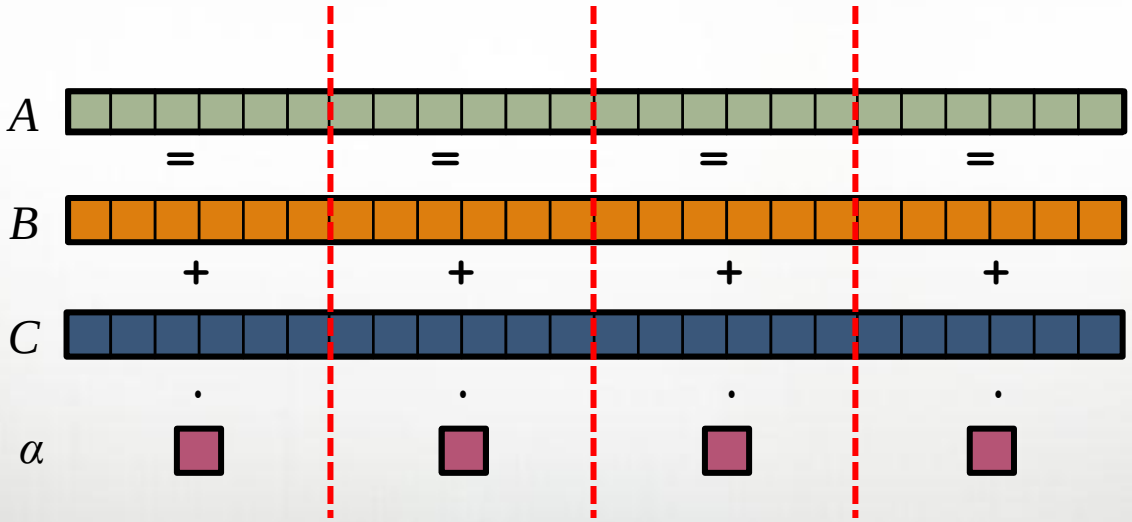

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Compute: $\forall i \in 1..m, A_i = B_i + \alpha \cdot C_i$

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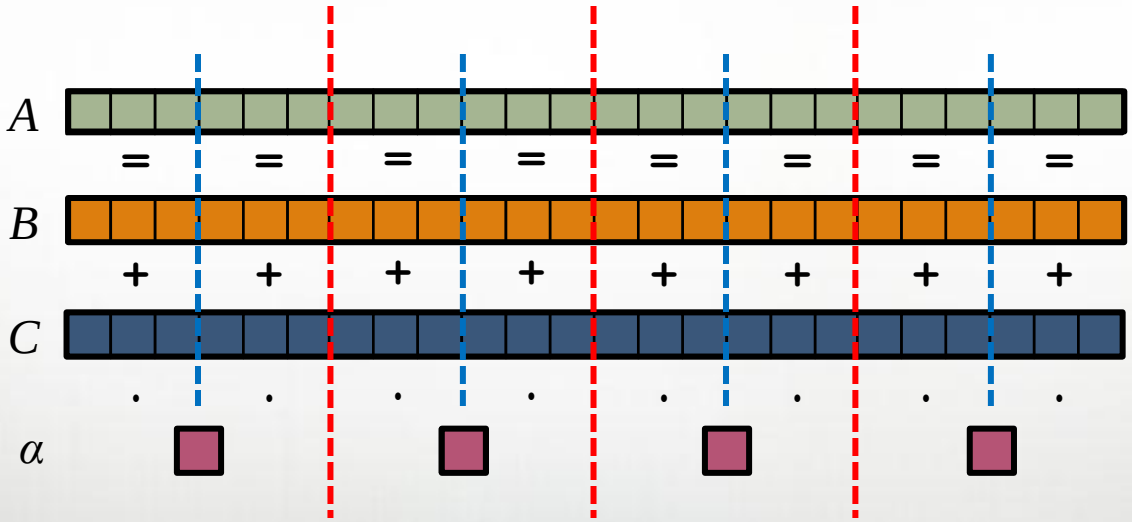
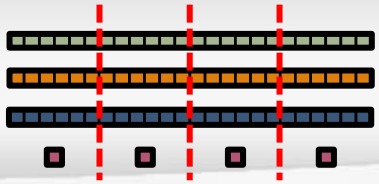


STREAM Triad: MPI



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;
  }

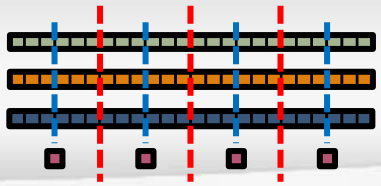
  scalar = 3.0;

  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) {
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  c = HPCC_XMALLOC( double, VectorSize );

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    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;

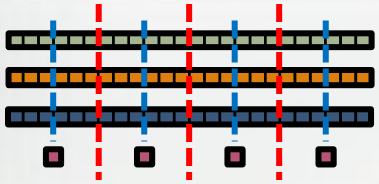
#ifdef _OPENMP
#pragma omp parallel for
#endif
  for (j=0; j<VectorSize; j++)
    a[j] = b[j]+scalar*c[j];

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

  return 0;
}
```

STREAM Triad: MPI+OpenMP vs. CUDA

MPI + OpenMP



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}

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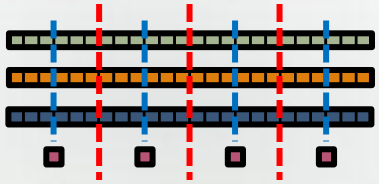
  return 0;
}
```

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:

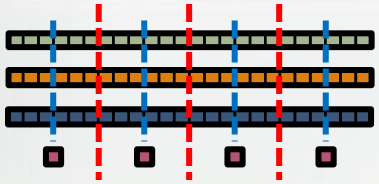
Type of HW Parallelism	Programming Model	Unit of Parallelism
Inter-node	MPI	executable
Intra-node/multicore	OpenMP/pthreads	iteration/task
Instruction-level vectors/threads	pragmas	iteration
GPU/accelerator	CUDA/OpenCL/OpenAcc	SIMD function/task

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

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

STREAM Triad: MPI+OpenMP vs. CUDA

MPI + OpenMP



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

int HPCC_Stream(HPCC_Params *params, int doIO) {
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    if (doIO) {
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    return 1;
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    a[j] = b[j]+scalar*c[j];

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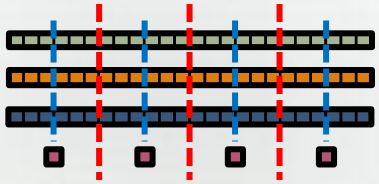
}
```

CUDA



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  scalar=3.0f;
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  cudaThreadSynchronize();

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

Chapel

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

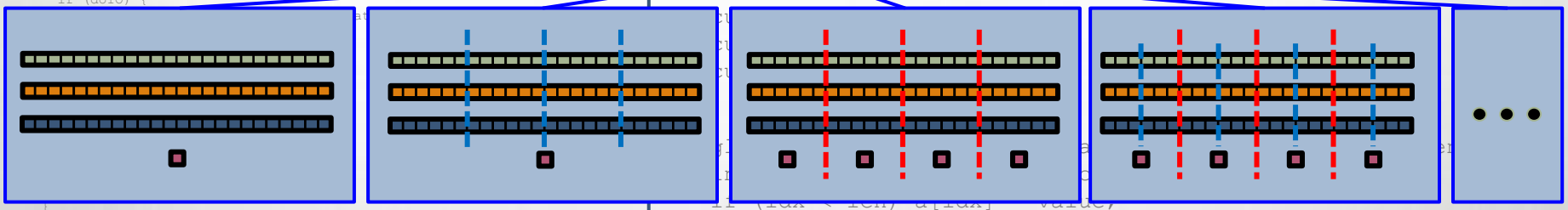
const ProblemSpace = [1..m] dmapped …;

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

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1) General Parallel Programming

With a unified set of concepts...

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

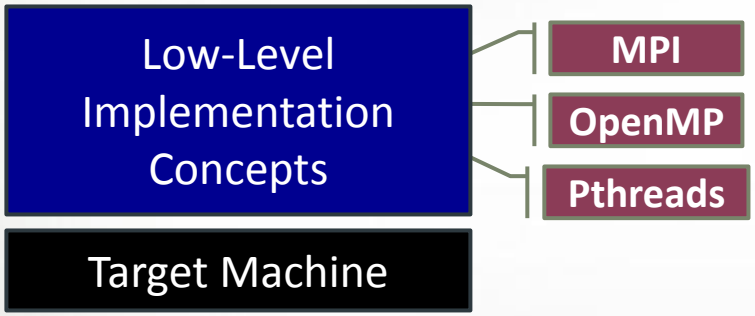
- **Styles:** data-parallel, task-parallel, concurrency, nested, …
- **Levels:** model, function, loop, statement, expression

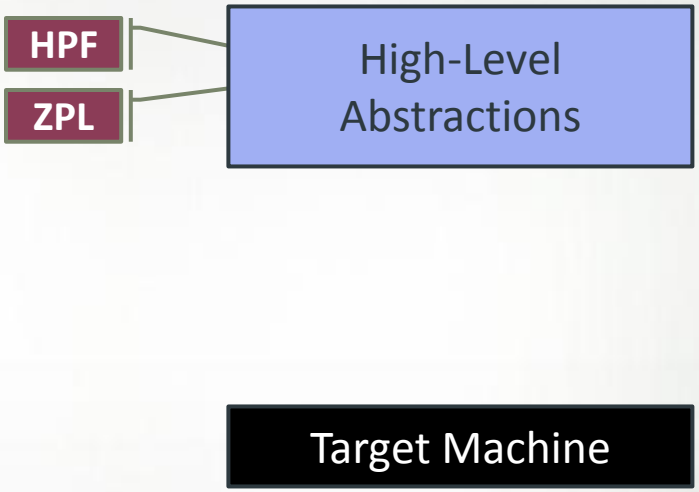
...target all parallelism available in the hardware

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

Style of HW Parallelism	Programming 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?"

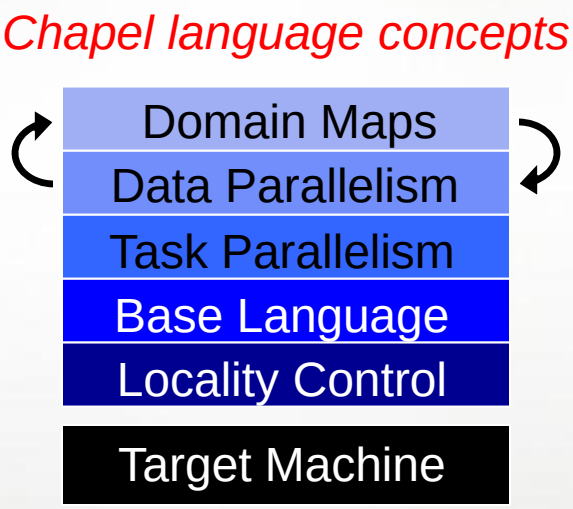
"Why don't my programs port trivially?"

"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



- 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

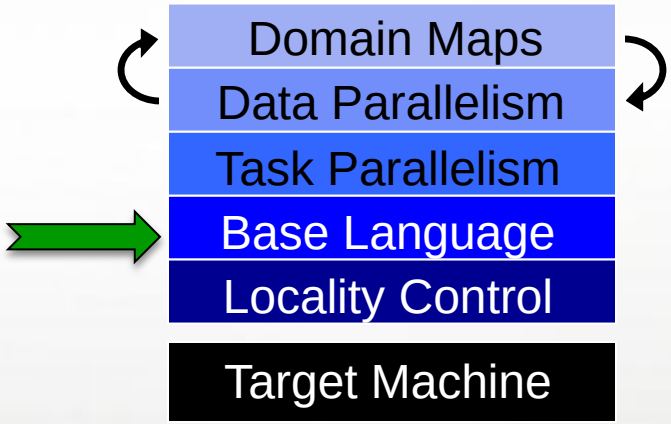
We'd like to narrow this gulf with Chapel:

- 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

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

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)
```

Range Types and Algebra

```
const r = 1..10;

printVals(r # 3);
printVals(r # -3);
printVals(r by 2);
printVals(r by 2 align 2);
printVals(r by -2);
printVals(r by 2 # 3);
printVals(r # 3 by 2);

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

```
1 2 3
8 9 10
1 3 5 7 9
2 4 6 8 10
10 8 6 4 2
1 3 5
1 3
```

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(D, 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

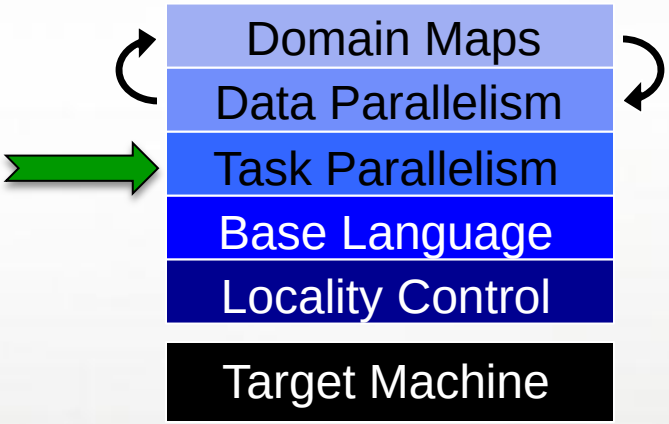
```
for (i,f) in (0..#n, fibonacci(n)) do
  writeln("fib #", i, " is ", f);
```

```
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
- 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
```

Bounded Buffer Producer/Consumer Example

```
cobegin {
  producer();
  consumer();
}

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

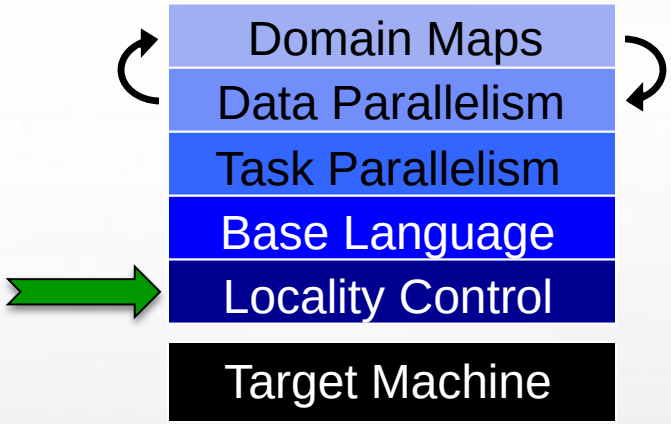
proc producer() {
  var i = 0;
  for … {
    i = (i+1) % buffersize;
    buff$[i] = …;    // reads block until empty, leave full
} }

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

Other Task Parallel Features

- *begin* statements for fire-and-forget tasks
- *atomic variables* for lock-free programming

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");

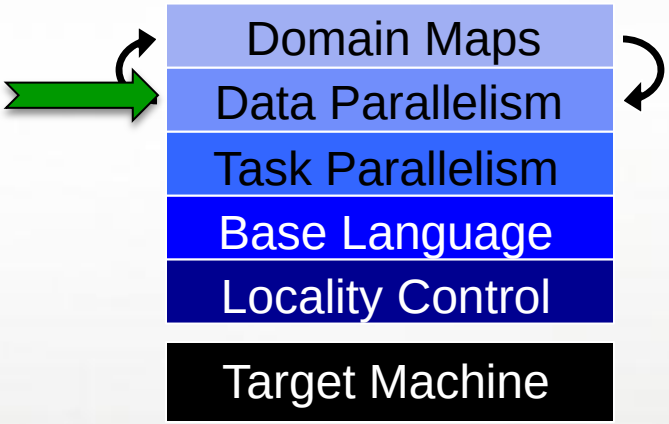
on Locales[1] do
  writeln("now on locale 1");

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

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

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

Data Parallel Features



Data Parallel Operations

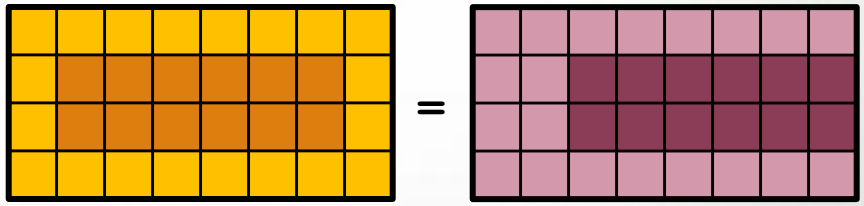
- Parallel Iteration via forall-loops

```
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

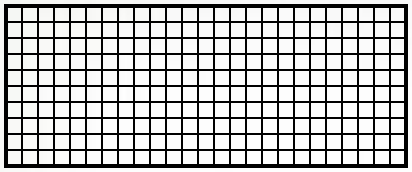
```
A = B + alpha * C;
```

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

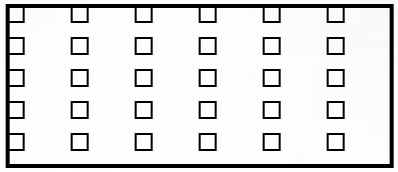
- And several others: indexing, reallocation, set operations, remapping, aliasing, queries, …

Chapel Domain Types

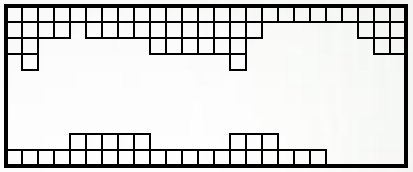
Chapel supports several types of domains (index sets) :



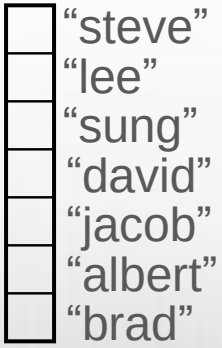
dense



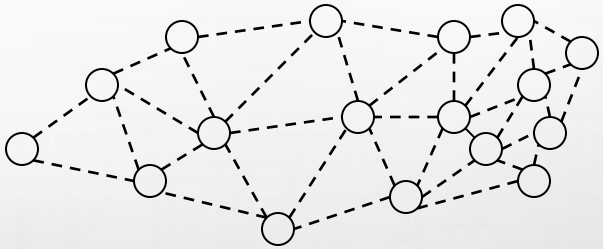
strided



sparse



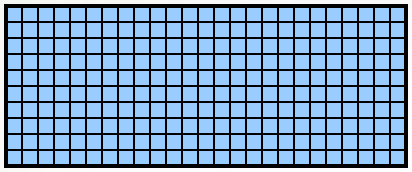
associative



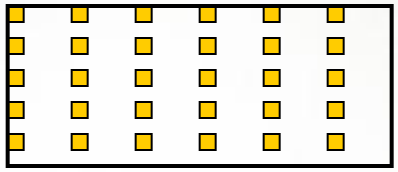
unstructured

Chapel Array Types

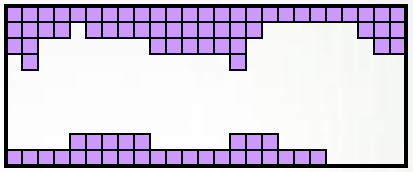
…each of which can be used to declare arrays, which in turn supports its data parallel operators:



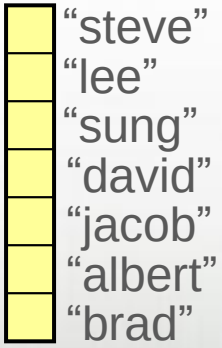
dense



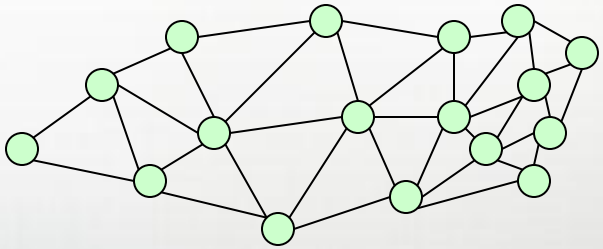
strided



sparse



associative



unstructured

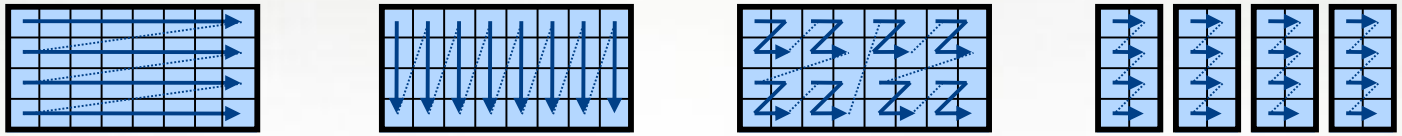
Outline

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

Data Parallelism Implementation Qs

Q1: How are arrays laid out in memory?

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

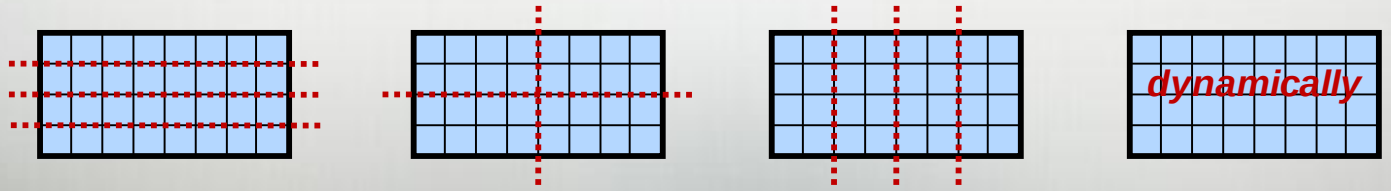


…?

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

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

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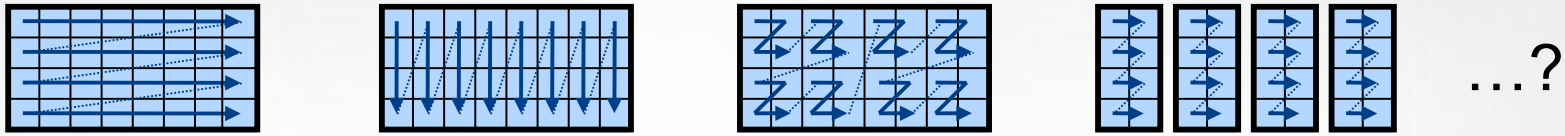

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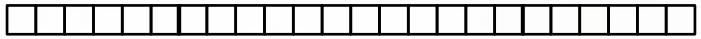
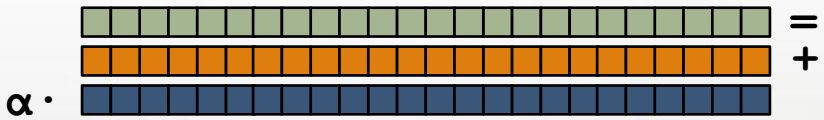
A: Chapel's *domain maps* are designed to give the user full control over such decisions

STREAM Triad: Chapel (multicore)

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



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




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

STREAM Triad: Chapel (multicore)

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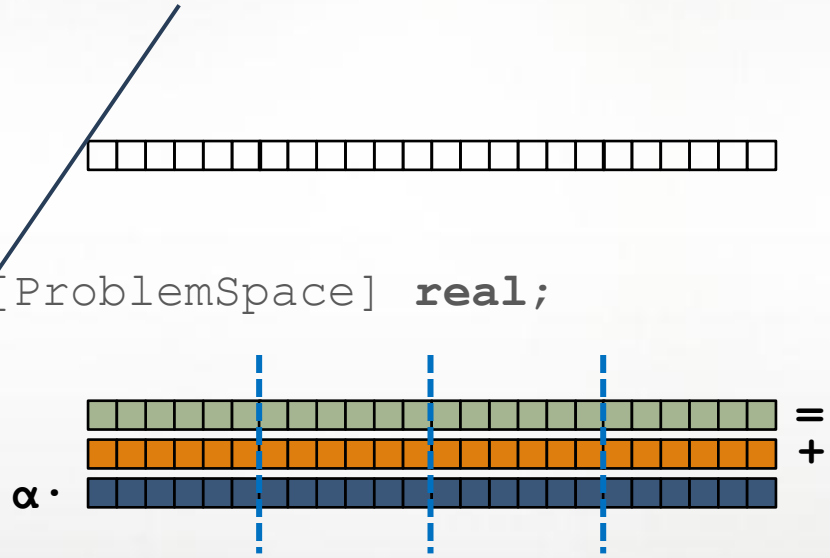
const ProblemSpace = [1..m];

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

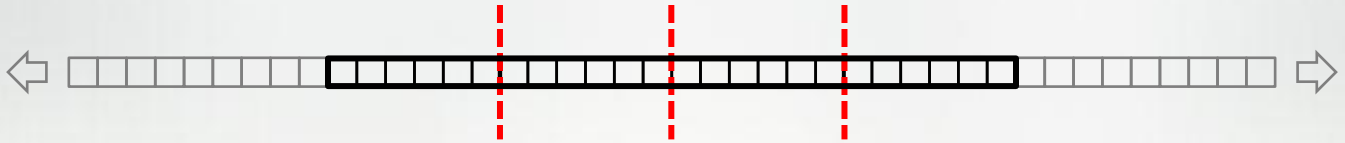
A = B + alpha * C;
```



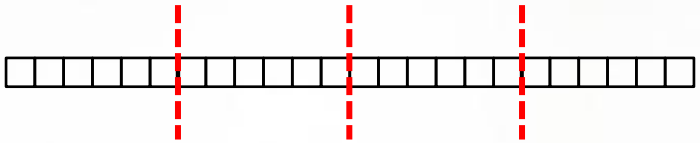
No domain map specified => use default layout

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

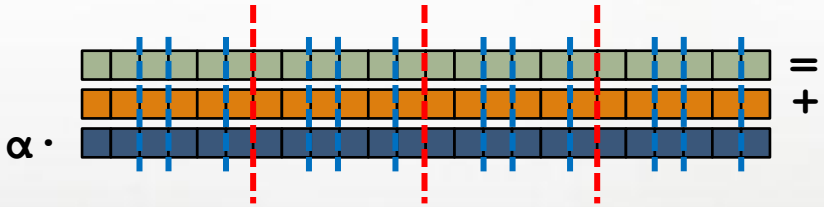
STREAM Triad: Chapel (multilocale, blocked)



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

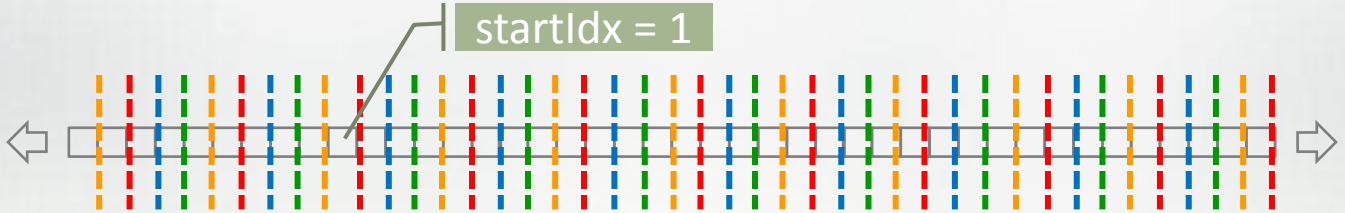


```
var A, B, C: [ProblemSpace] real;
```

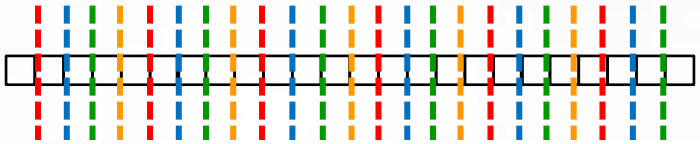



```
A = B + alpha * C;
```

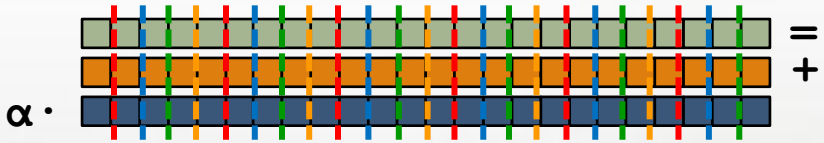
STREAM Triad: Chapel (multilocale, cyclic)




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



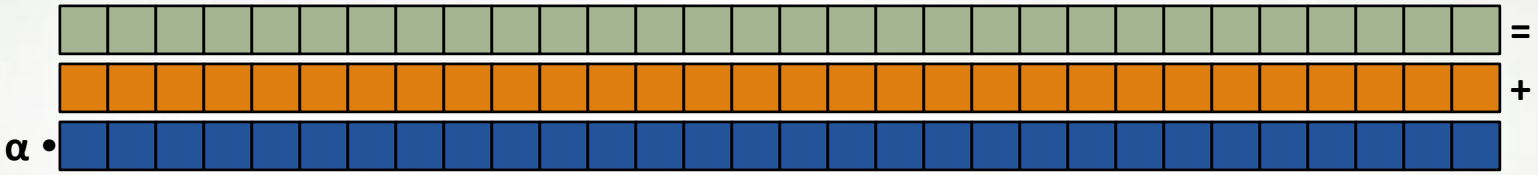
```
var A, B, C: [ProblemSpace] real;
```




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

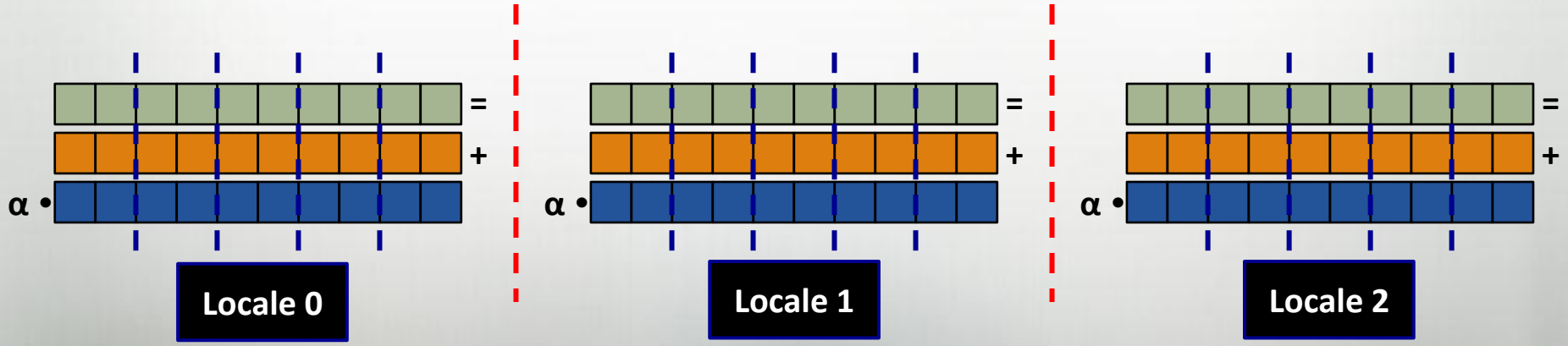
Domain Maps

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



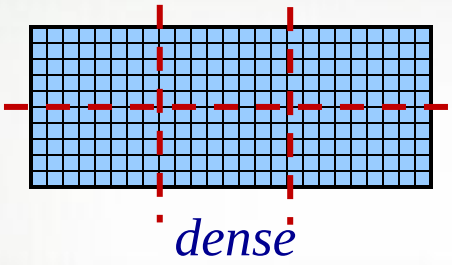

```
A = B + alpha * C;
```

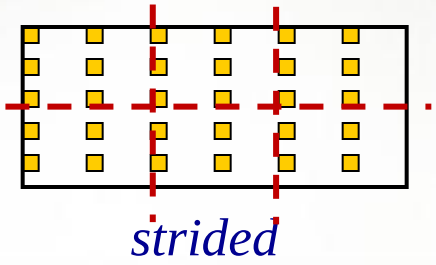
…to the target locales’ memory and processors:

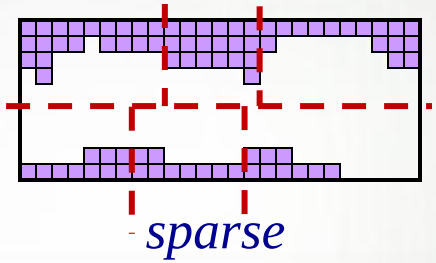


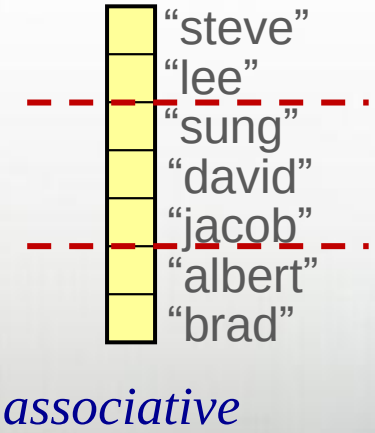
Domain Map Types

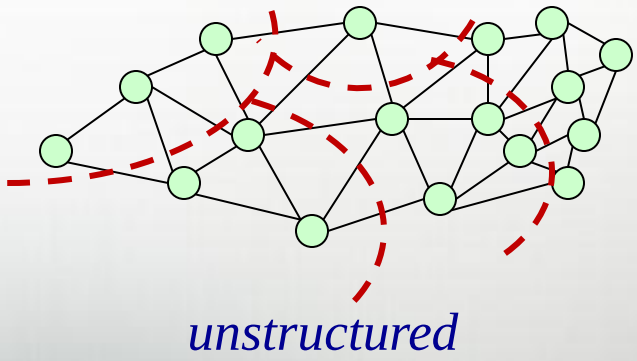
All Chapel domain types support domain maps





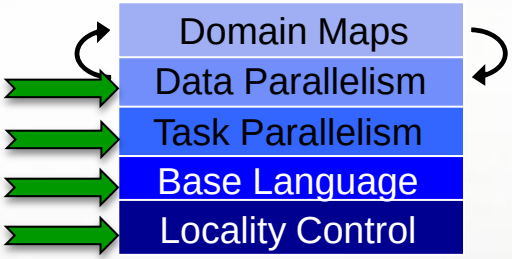






Chapel's Domain Map Philosophy

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 the 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 Map Descriptors

Domain Map

Represents: a domain map value

Generic w.r.t.: index type

State: the domain map's representation

Typical Size: Θ(1)

Required Interface:

- create new domains

Domain

Represents: a domain

Generic w.r.t.: index type

State: representation of index set

Typical Size: Θ(1) → Θ(*numIndices*)

Required Interface:

- create new arrays
- queries: size, members
- iterators: serial, parallel
- domain assignment
- index set operations

Array

Represents: an array

Generic w.r.t.: index type, element type

State: array elements

Typical Size: Θ(*numIndices*)

Required Interface:

- (re-)allocation of elements
- random access
- iterators: serial, parallel
- slicing, reindexing, aliases
- get/set of sparse "zero" values

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

Domain Maps: Next Steps

- More advanced uses of domain maps:
  - Dynamically load balanced domains/arrays
  - Resilient data structures
  - *in situ* interoperability with legacy codes
  - out-of-core computations

- Further compiler optimization via optional interfaces
  - particularly communication idioms (stencils, reductions, …)

Notes on Forall Loops

```
forall a in A do
  writeln("Here is an element of A: ", a);
```

Typically 1 ≤ #Tasks << #Iterations)

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

Forall-loops may be zippered, like for-loops
- Corresponding iterations will match up

More Data Parallelism Implementation Qs

Q1: How are forall loops implemented?

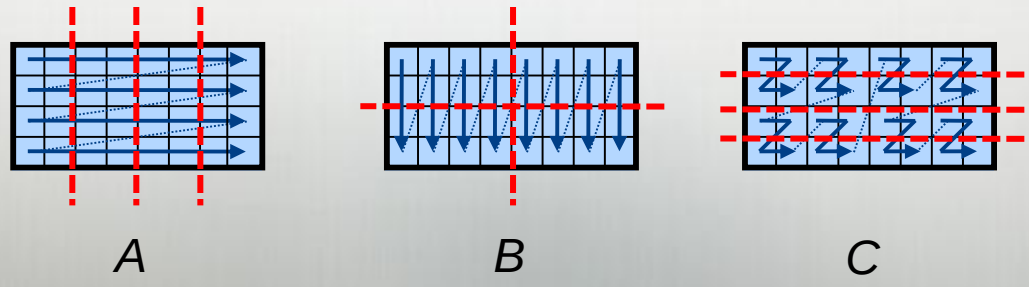
```
A = forall (i,j) in D do (i + j/10.0);
forall a in A do …
```

- How many tasks? Where do they execute?
- How is the iteration space divided between the tasks?

Q2: How are parallel zippered loops implemented?

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

- Particularly given that the iterands might have incompatible distributions, memory layouts, and parallelization strategies



More Data Parallelism Implementation Qs

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forall (a,b,c) in (A,B,C) do
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```

- Particularly given that the iterands might have incompatible distributions, memory layouts, and parallelization strategies

A: Chapel's *leader-follower* iterators are designed to give users full control over such decisions

Leader-Follower Iterators: Definition

- Chapel defines all forall loops in terms of leader-follower iterators:
  - *leader iterators:* create parallelism, assign iterations to tasks
  - *follower iterators:* serially execute work generated by leader

- Given…

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

…A is defined to be the *leader*

…*A, B,* and *C* are all defined to be *followers*

Leader-Follower Iterators: Rewriting

Conceptually, the Chapel compiler translates:

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

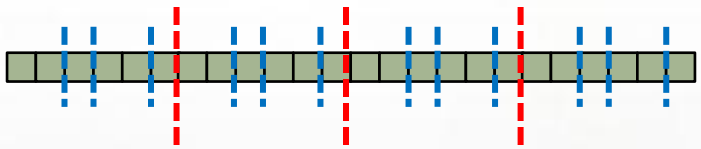
into:

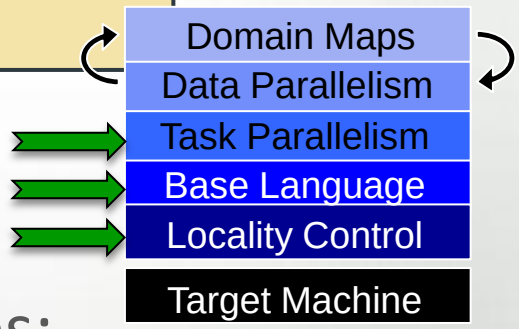
```
inlined A.lead() iterator, which yields work…
  for (a,b,c) in (A.follow(work),
                  B.follow(work)
                  C.follow(work)) do
    a = b + alpha * c;
```

Writing Leaders and Followers

Leader iterators are defined using task/locality features:

```
iter BlockArr.lead() {
  coforall loc in Locales do
    on loc do
      coforall tid in here.numCores do
        yield computeMyChunk(loc.id, tid);
}
```





Follower iterators simply use serial features:

```
iter BlockArr.follow(work) {
  for i in work do
    yield accessElement(i);
}
```

Controlling Data Parallelism

Q: *"What if I don't like the approach implemented by an array's leader iterator?"*

A: Several possibilities…

Controlling Data Parallelism

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

Make something else the leader.

Controlling Data Parallelism

```
const ProblemSize = [1..n] dmapped BlockCyclic(start=1,
                                               blocksize=64);

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

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

Change the array's default leader by changing its domain map (perhaps to one that you wrote yourself).

Controlling Data Parallelism

```
forall (a,b,c) in (dynamic(A, chunk=64), B, C) do
  a = b + alpha * c;
```

Invoke a standalone leader iterator explicitly (perhaps one that you wrote yourself).

For More Information on Leader-Follower Iterators

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

Chapel release:

- Primer example introducing leader-follower iterators:
  - examples/primers/leaderfollower.chpl
- Library of dynamic leader-follower range iterators:
  - *AdvancedIters* chapter of language specification

Summary of This Section

- Chapel avoids locking crucial implementation decisions into the language specification
  - local and distributed array implementations
  - parallel loop implementations
- Instead, these can be…

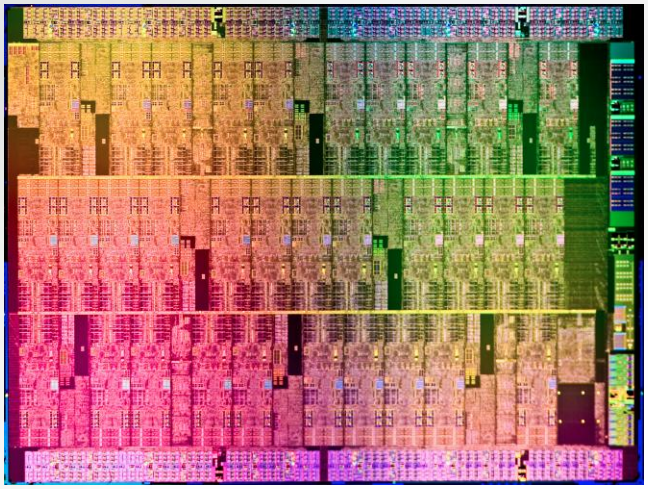
  …specified in the language by an advanced user

  …swapped in and out with minimal code changes
- The result cleanly separates the roles of domain scientist, parallel programmer, and implementation

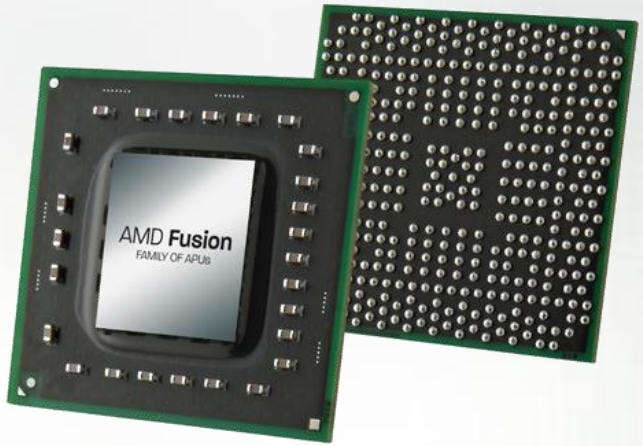
Outline

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

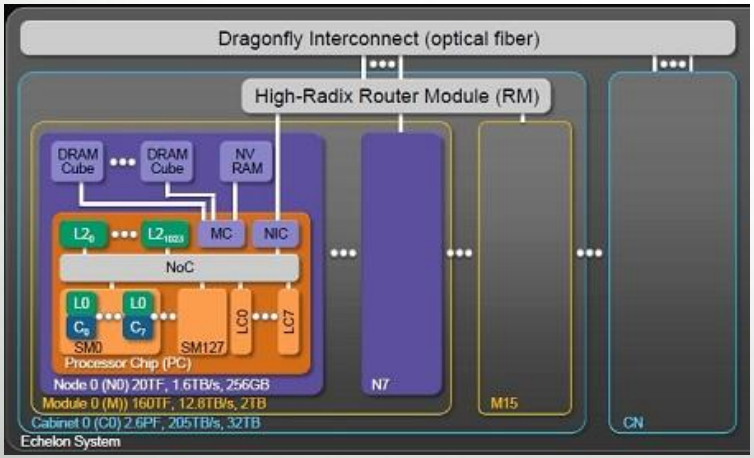
Candidate Next-Gen HPC Processor Technologies



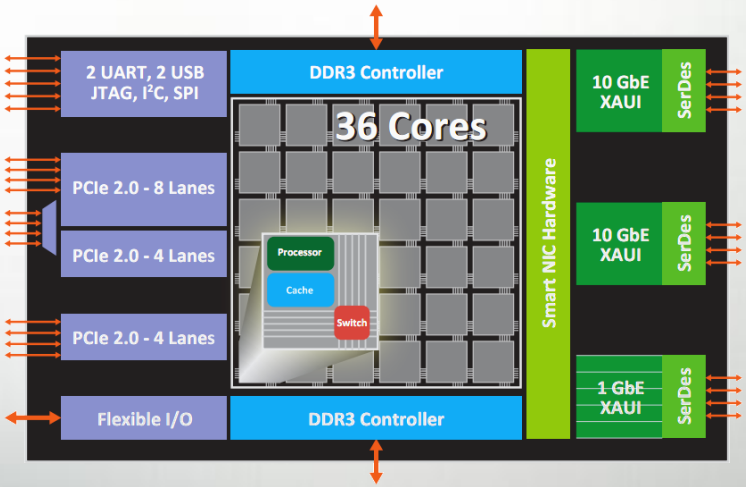
Intel MIC



AMD Fusion



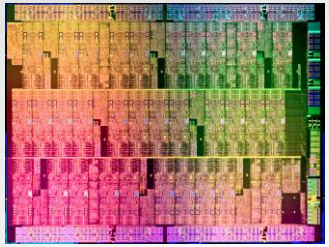
Nvidia Echelon

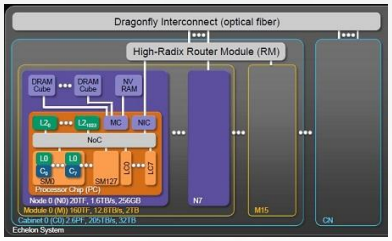


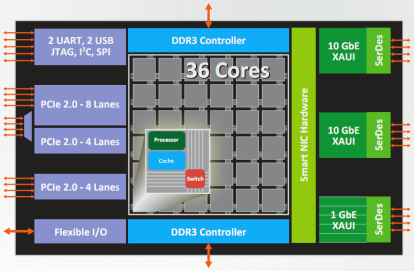
Tilera Tile-Gx

Sources: http://download.intel.com/pressroom/images/Aubrey_Isle_die.jpg, http://www.thinkcomputers.org/ces-2011-amds-fusion-apus/, 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

Additional Exascale Concerns

- limited memory bandwidth, memory::FLOP ratio
- resiliency concerns
- power efficiency concerns
- current programming models aren't a good fit
- diversity of abstract machine models
  - (at least initially)

A frightening time?

Or an opportunity to improve on past HPC programming models?

Chapel: Well-Positioned for Exascale

- distinct concepts for locality and parallelism
- not particularly tied to any HW architecture
- diverse styles of parallelism
  - task parallelism to fire off asynchronous sub-computations
  - data parallelism to match SIMD functional units
  - nested parallelism
- multiresolution approach
- plausibly adoptable

We believe these characteristics position Chapel well relative to current HPC programming models

Chapel: Limitations for Exascale

Chapel Limitations for Exascale, today:

- locales only support a single level of hierarchy
  - useful for horizontal (inter-node) locality
  - less so for describing additional hierarchy within a node
- lack of fault tolerance/error handling features

In Chapel's original design, these were both considered "version 2.0" features due to…

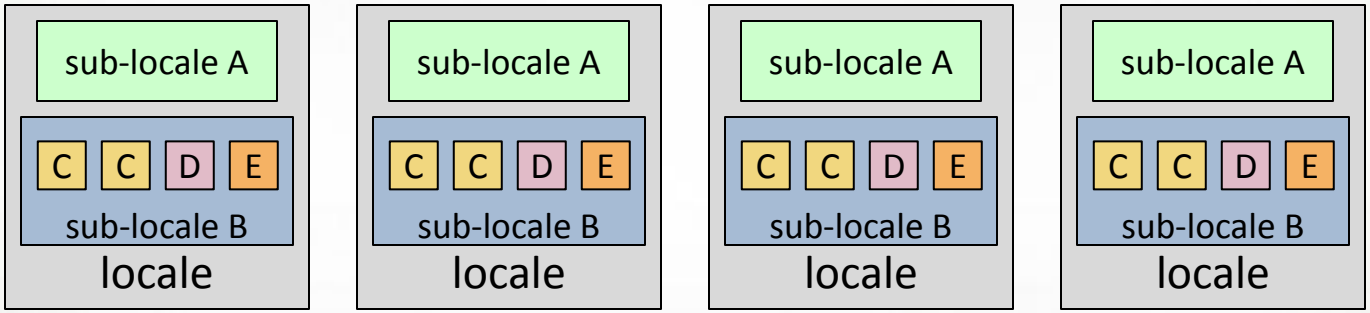
…our focus on petascale systems within HPCS

…the knowledge that our plate was already quite full

Current Work: Hierarchical Locales

Concept:

- Support locales within locales to describe architectural sub-structures within a node



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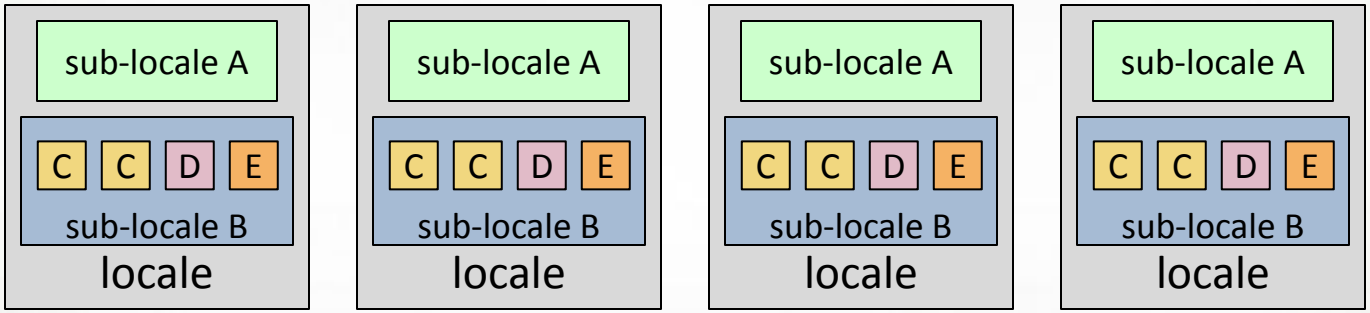

- As with current locales, on-clauses can be used to map tasks or variables to a sub-locale's memory/processors

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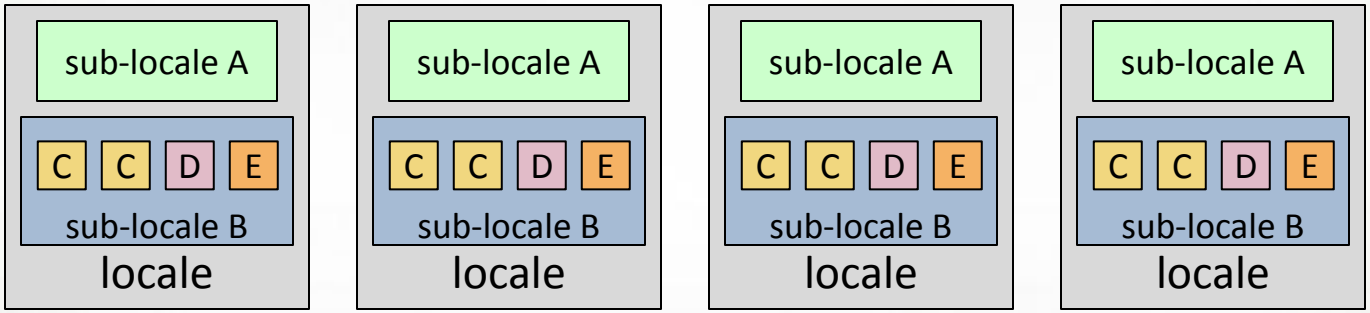
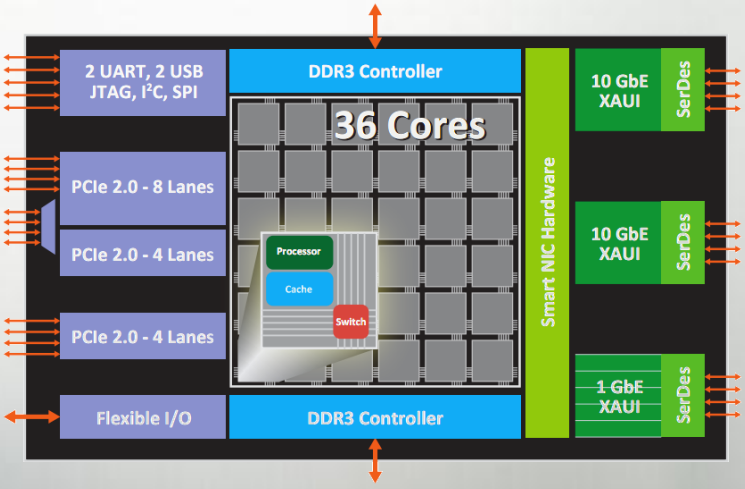


- As with current locales, on-clauses can be used to map tasks or variables to a sub-locale's memory/processors
- Locale structure is defined as Chapel code
  - introduces a new Chapel role: Architectural modeler

Sublocales: Tiled Processor Example

```
class locale: AbstractLocale {
  const xt = 6, yt = xTiles;
  const sublocGrid: [0..#xt, 0..#yt] tiledLoc = …;
  const allSublocs: [0..#xt*yt] tiledLoc = …;
  // tasking interface
  // memory interface
}

class tiledLoc: AbstractLocale {
  // tasking interface
  // memory interface
}
```



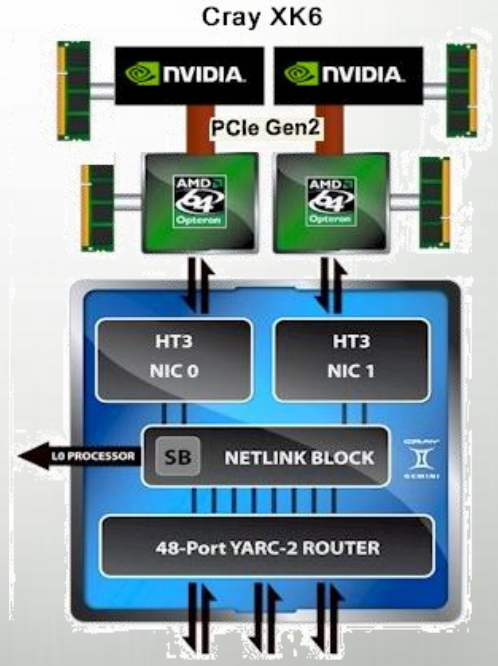
Tilera Tile-Gx

Sublocales: Hybrid Processor Example

```
class locale: AbstractLocale {
  const numCPUs = 2, numGPUs = 2;
  const cpus: [0..#numCPUs] cpuLoc = …;
  const gpus: [0..#numGPUs] gpuLoc = …;
  // tasking interface
  // memory interface
}

class cpuLoc: AbstractLocale { … }

class gpuLoc: AbstractLocale {
  // sublocales for different
  // memory types, thread blocks…?
  // tasking, memory interfaces
}
```



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 may help guard 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)

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Summary

Higher-level programming models can help insulate science from implementation

- yet, without necessarily abandoning 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 (Apr 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

Chapel and Education

- If I were teaching parallel programming, I'd want 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)

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)

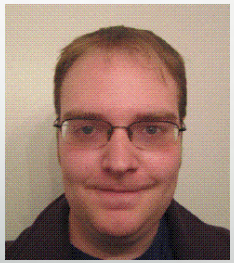

Kyle Wheeler (Sandia)

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 to appear at IPDPS 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, GMP:** 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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