Chapel: Domain Maps

(Layouts and Distributions)

Salt Lake City, Utah

"Hello World" in Chapel: a Domain-Map Version

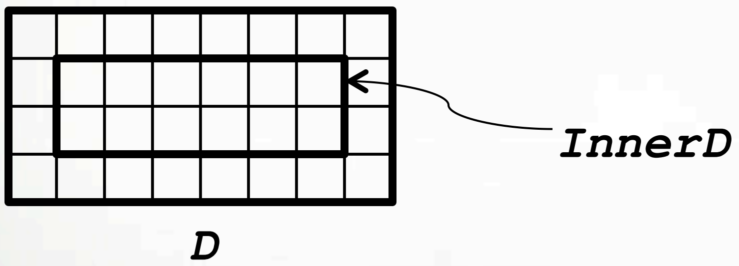
- Multi-locale Data Parallel Hello World

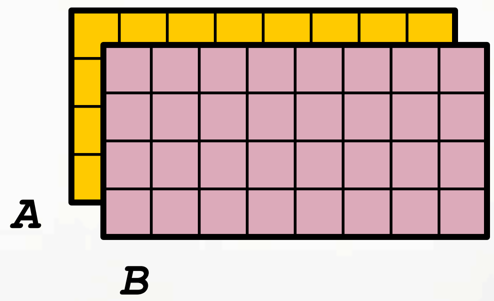
```
config const numIters = 100000;
const WorkSpace = {1..numIters} dmapped Block(…);

forall i in WorkSpace do
  writeln("Hello, world! ",
          "from iteration ", i, " of ", numIters,
          " on locale ", here.id, " of ", numLocales);
```

Review: Data Parallelism

- Domains are first-class index sets
  - Specify the size and shape of arrays
  - Support iteration, array operations, etc.

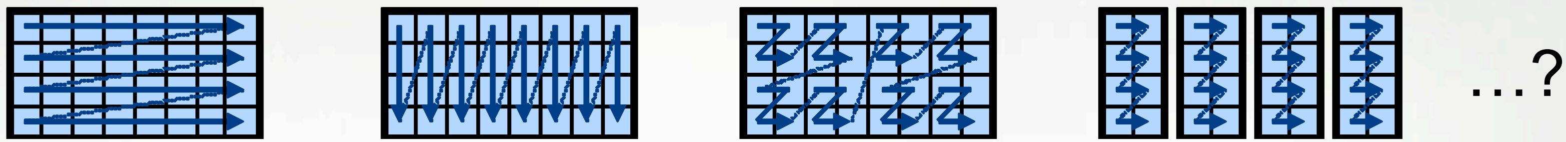




Data Parallelism: Implementation Qs

Q1: How are arrays laid out in memory?

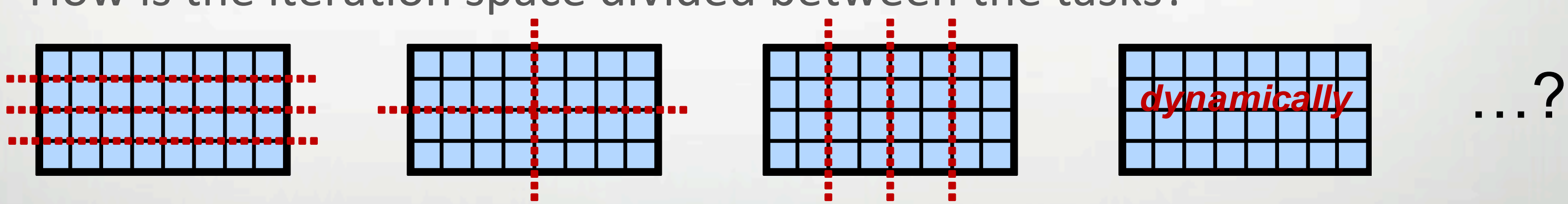
- Are regular arrays laid out in row- or column-major order? Or…?



- What data structure is used to store sparse arrays? (COO, CSR, …?)

Q2: How are data parallel operators implemented?

- How many tasks?
- How is the iteration space divided between the tasks?



Data Parallelism: Implementation Qs

Q3: How are arrays distributed between locales?

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

Q4: What architectural features will be used?

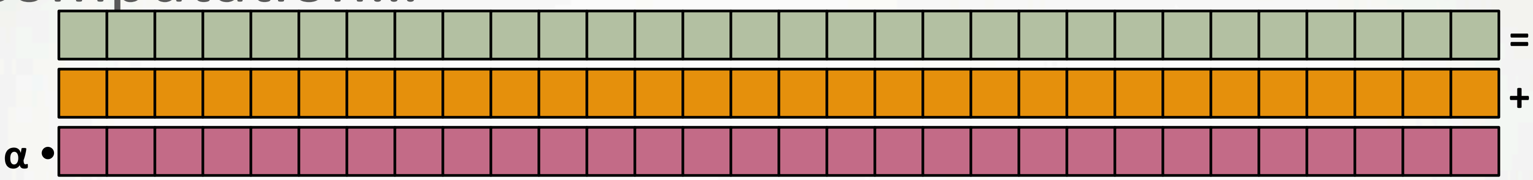
- Can/Will the computation be executed using CPUs? GPUs? both?
- What memory type(s) is the array stored in? CPU? GPU? texture? …?

A1: In Chapel, any of these could be the correct answer

A2: Chapel's *domain maps* are designed to give the user full control over such decisions

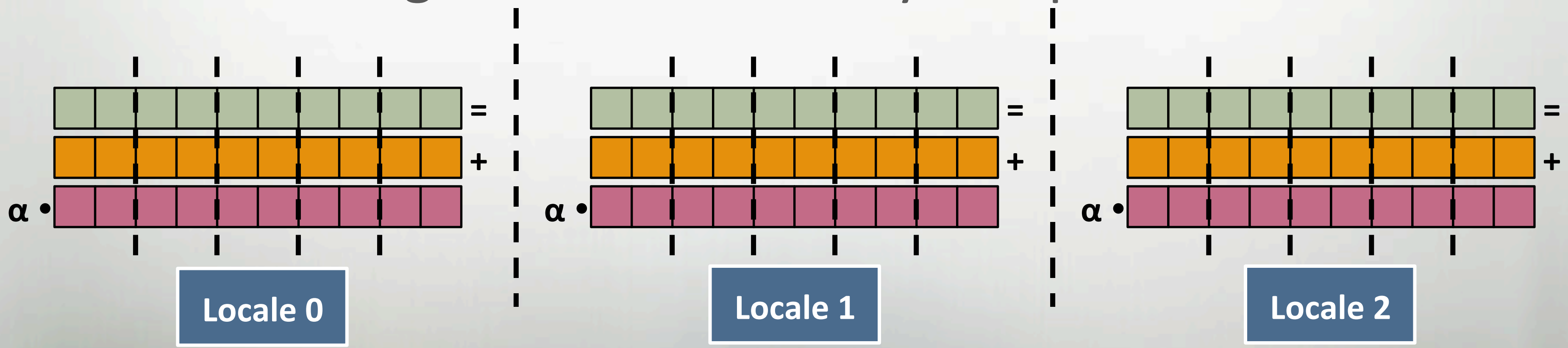
Domain Maps

Domain maps are "recipes" (written in Chapel) 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 Maps

Domain Maps: "recipes for implementing parallel/ distributed arrays and domains"

They define data storage:

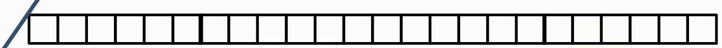
- Mapping of domain indices and array elements to locales
- Layout of arrays and index sets in each locale's memory

…as well as operations:

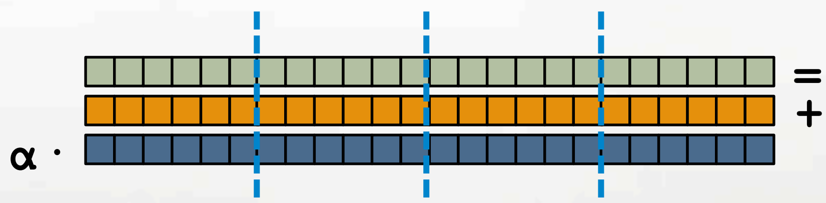
- random access, iteration, slicing, reindexing, rank change, …
- the Chapel compiler generates calls to these methods to implement the user's array operations

STREAM Triad: Chapel (multicore)

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



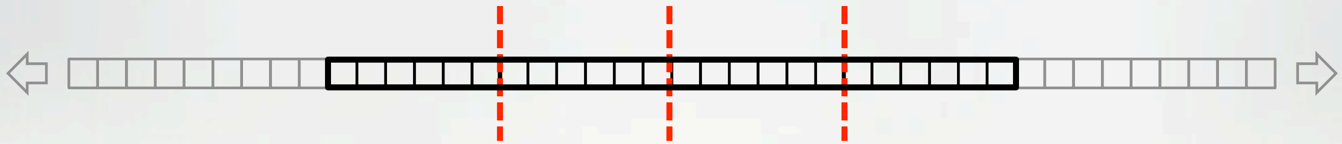
```
var A, B, C: [ProblemSpace] real;
```



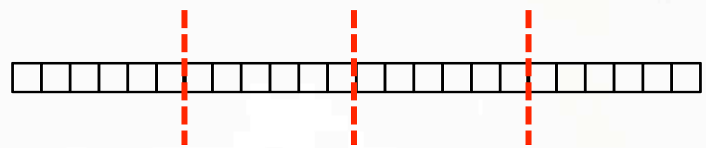

```
A = B + alpha * C;
```

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

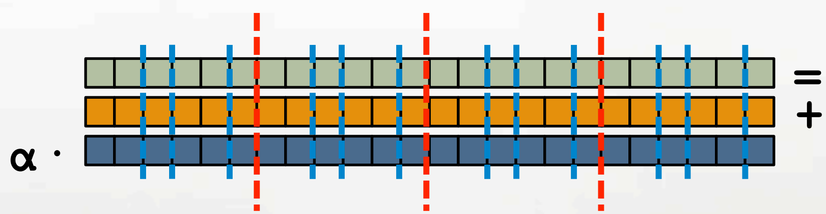
STREAM Triad: Chapel (multinode, blocked)



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

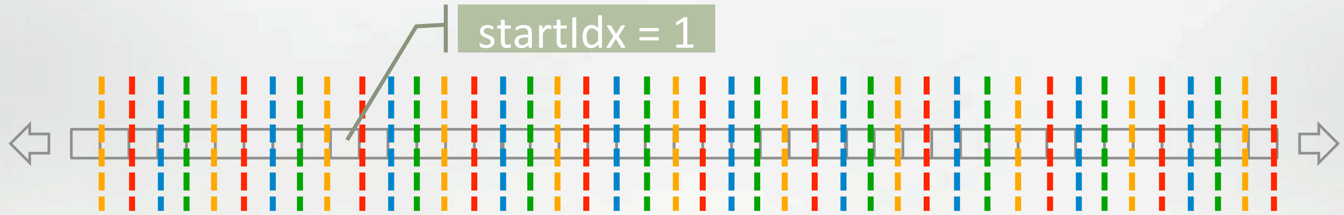


```
var A, B, C: [ProblemSpace] real;
```

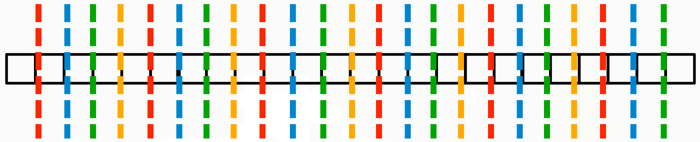



```
A = B + alpha * C;
```

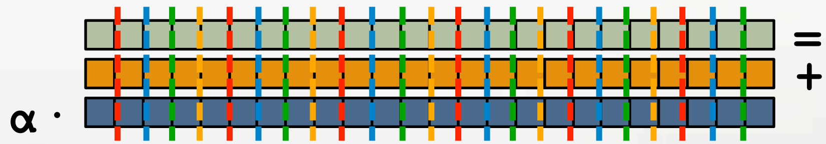
STREAM Triad: Chapel (multinode, cyclic)




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



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




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

Domain Maps: Layouts and Distributions

Domain Maps fall into two major categories:

layouts: target a single locale

- (that is, a desktop machine or multicore node)
- **examples:** row- and column-major order, tilings, compressed sparse row

distributions: target multiple locales

- (that is, a distributed memory cluster or supercomputer)
- **examples:** Block, Cyclic, Block-Cyclic, Recursive Bisection, …

Declaring a Distributed Domain

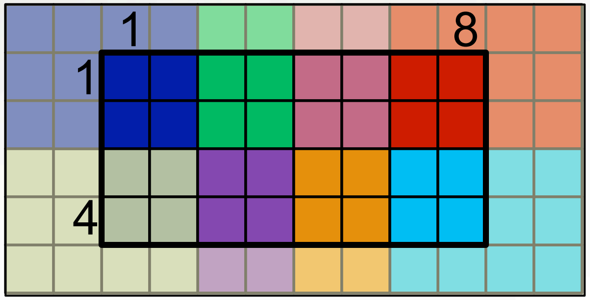
- Domain types and literals may be domain mapped
  - In practice, this tends to be a great place to rely on type inference to avoid repetition:

```
const Dom = {1..m, 1..n} dmapped myDMap(…);
```

- Domain maps can also be declared independently of a domain value (not covered here)
  - Useful for declaring several domains using the same map

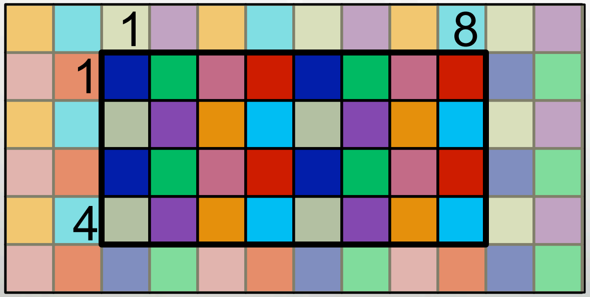
Some Standard Distributions: Block and Cyclic

```
var Dom = {1..4, 1..8} dmapped Block(boundingBox={1..4, 1..8});
```



distributed to

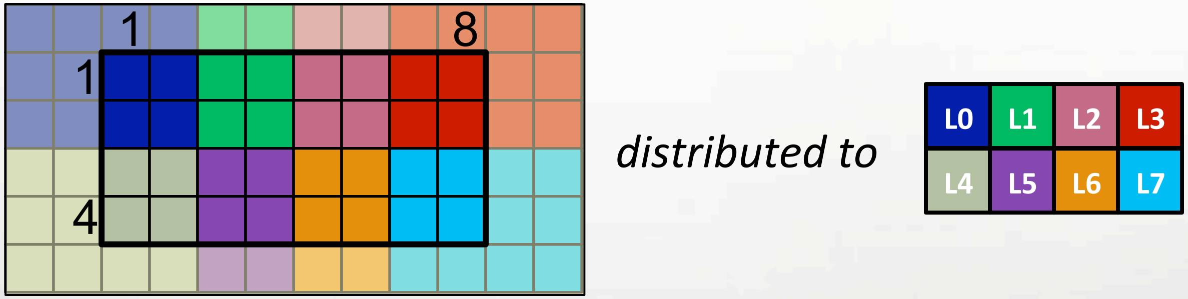

```
var Dom = {1..4, 1..8} dmapped Cyclic(startIdx=(1,1));
```



distributed to

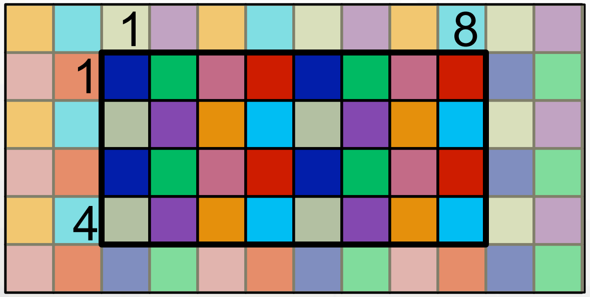
The Block class constructor

```
proc Block(boundingBox: domain,
           targetLocales: [] locale = Locales,
           dataParTasksPerLocale = ...,
           dataParIgnoreRunningTasks = ...,
           dataParMinGranularity = ...)
```



The Cyclic class constructor

```
proc Cyclic(startIdx,
            targetLocales: [] locale = Locales,
            dataParTasksPerLocale = ...,
            dataParIgnoreRunningTasks = ...,
            dataParMinGranularity = ...)
```



distributed to

Domain Maps and forall loops

- Having applied a domain map to a domain/array…

```
const Dom = {1..m, 1..n} dmapped Block(…);
var A, B: [Dom] real;
```

…forall loops over that domain and array will be distributed according to the domain map

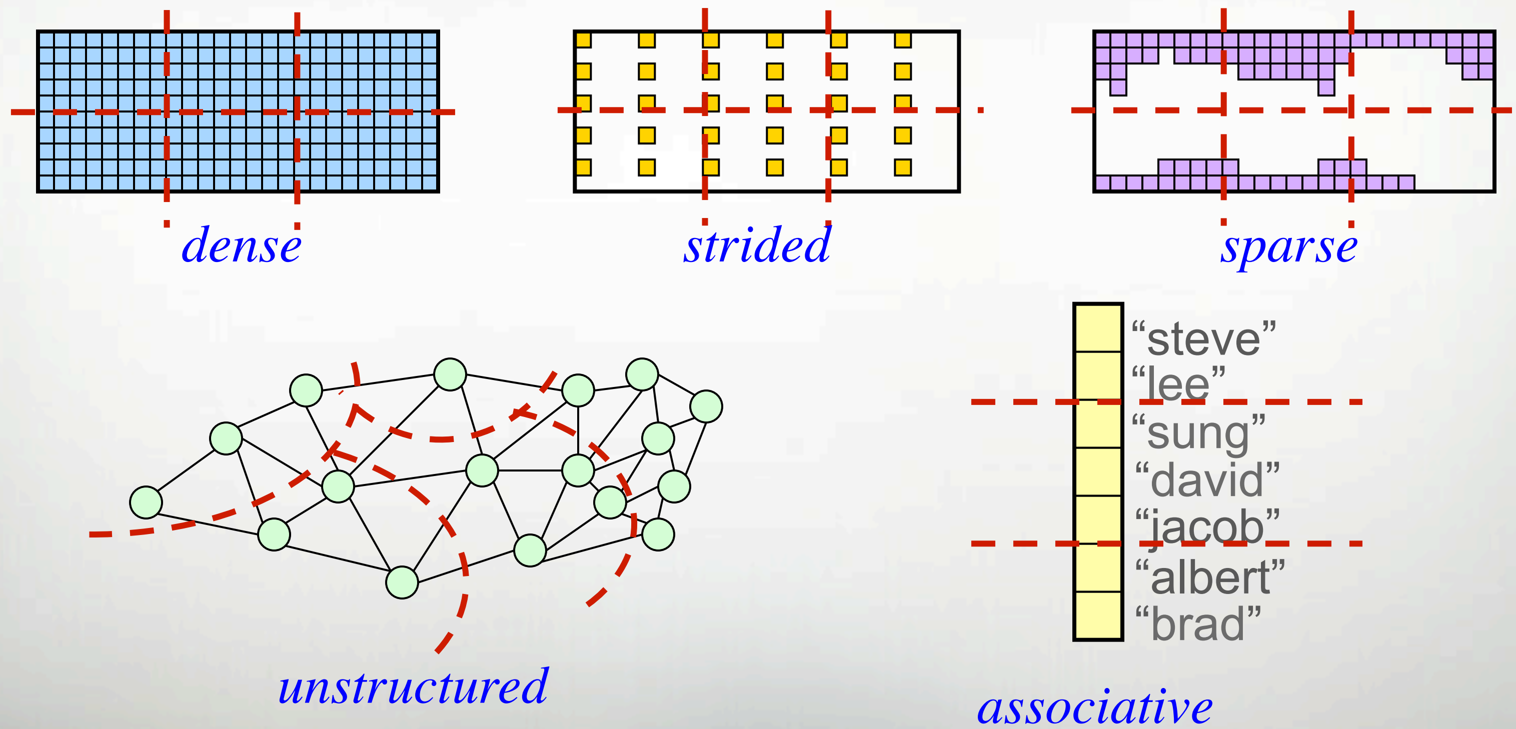
- i.e., data parallel expressions like:

```
forall ij in Dom do …;
forall a in A do …;
B = sin(A);
```

- result in code like:

```
coforall loc in <Dom's domainMap>.targetLocales do
  on loc do
    forall ij in <local portion of Dom, A, B>, … do
      …;
```

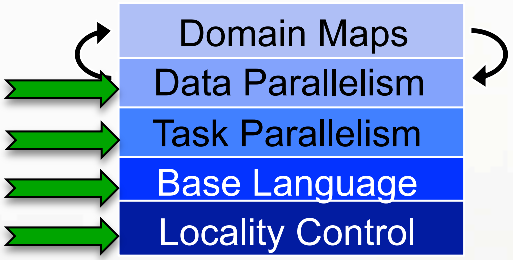
All Domain Types Support Domain Maps



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

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: Status

- All Chapel arrays implemented using domain maps
  - Full-featured Block, Cyclic, Replicated distributions
  - COO and CSR Sparse layouts supported
  - Quadratic probing Associative layout supported
  - Prototype Block-Cyclic and 2D Dimensional distribution available
- Associative distributions underway
- User-defined domain map interface still evolving
- Memory currently leaked for distributed arrays

Future Directions

- Advanced uses of domain maps:
  - GPU programming
  - Dynamic load balancing
  - Resilient computation
  - *in situ* interoperability
  - Out-of-core computations
- Improved syntax for declared domain maps