# Chapel: Features

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CSEP 524
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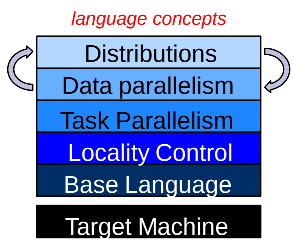
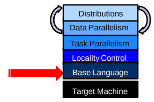
## Outline

- Language Overview
  - Base Language
  - Task Parallelism
  - Data Parallelism
  - Locality
  - Distributions

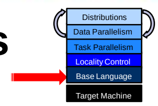


# Base Language: Design




- Block-structured, imperative programming
- Intentionally not an extension to an existing language
- Instead, select attractive features from others:
  **ZPL, HPF:** data parallelism, index sets, distributed arrays
  (see also APL, NESL, Fortran90)
  **Cray MTA C/Fortran:** task parallelism, lightweight synchronization
  **CLU:** iterators (see also Ruby, Python, C#)
  **ML:** latent types (see also Scala, Matlab, Perl, Python, C#)
  **Java, C#:** OOP, type safety
  **C++:** generic programming/templates (without adopting its syntax)
  **C, Modula, Ada:** syntax
- Follow lead of C family of languages when useful
  (C, Java, C#, Perl, …)

# Base Language: My Favorite Features

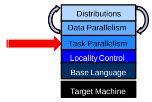



- **Rich compile-time language**
  - parameter values (compile-time constants)
  - folded conditionals, unrolled for loops, tuple expansions
  - type and parameter functions – evaluated at compile-time
- **Latent types**
  - ability to omit type specifications for convenience or code reuse
  - type specifications can be omitted from…
    …variables (inferred from initializers)
    …class members (inferred from constructors)
    …function arguments (inferred from callsite)
    …function return types (inferred from return statements)
- **Configuration variables** (and parameters)

```
config const n = 100;  // override with ./a.out --n=100000
```

- **Tuples**
- **Iterators** (in the CLU, Ruby sense, not C++/Java-style)
- **Declaration Syntax**: more like Pascal/Modula/Scala than C

# Task Parallelism: Task Creation



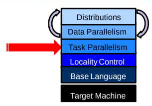

*begin:* creates a task for future evaluation

```
begin DoThisTask();
WhileContinuing();
TheOriginalThread();
```

*sync:* waits on all begins created within its dynamic scope

```
sync {
  begin treeSearch(root);
}

def treeSearch(node) {
  if node == nil then return;
  begin treeSearch(node.right);
  begin treeSearch(node.left);
}
```

# Task Parallelism: Structured Tasks




*cobegin:* creates a task per component statement:

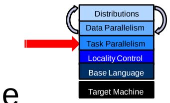
```
computePivot(lo, hi, data);
cobegin {
  Quicksort(lo, pivot, data);
  Quicksort(pivot, hi, data);
} // implicit join here
```

```
cobegin {
  computeTaskA(…);
  computeTaskB(…);
  computeTaskC(…);
} // implicit join
```

*coforall:* creates a task per loop iteration

```
coforall e in Edges {
  exploreEdge(e);
} // implicit join here
```

# Task Parallelism: Task Coordination




*sync variables:* store full/empty state along with value

```
var result$: sync real;    // result is initially empty
sync {
  begin … = result$;       // block until full, leave empty
  begin result$ = …;       // block until empty, leave full
}
result$.readXX();          // read value, leave state unchanged;
                           // other variations also supported
```

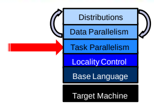
*single-assignment variables:* writeable once only

```
var result$: single real = begin f(); // result initially empty
…                     // do some other things
total += result$;     // block until f() has completed
```

*atomic sections:* support transactions against memory

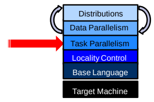
```
atomic {
  newnode.next = insertpt;
  newnode.prev = insertpt.prev;
  insertpt.prev.next = newnode;
  insertpt.prev = newnode;
}
```

# Producer/Consumer example



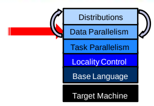

```
var buff$: [0..buffersize-1] sync int;

cobegin {
  producer();
  consumer();
}

def producer() {
  var i = 0;
  for … {
    i = (i+1) % buffersize;
    buff$(i) = …;
  }
}

def consumer() {
  var i = 0;
  while {
    i = (i+1) % buffersize;
    …buff$(i)…;
  }
}
```

# QuickSort in Chapel



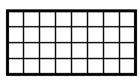

```
def quickSort(arr: [],
              thresh: int,
              low: int = arr.domain.low,
              high: int = arr.domain.high) {
  if high - low < 8 {
    bubbleSort(arr, low, high);
  } else {
    const pivotVal = findPivot(arr, low, high);
    const pivotLoc = partition(arr, low, high, pivotVal);
    serial thresh <= 0 do cobegin {
      quickSort(arr, thresh-1, low, pivotLoc-1);
      quickSort(arr, thresh-1, pivotLoc+1, high);
    }
  }
}
```

# Data Parallelism: Domains



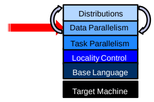

*domain:* a first-class index set

```
var m = 4, n = 8;

var D: domain(2) = [1..m, 1..n];
```



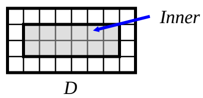
*D*

# Data Parallelism: Domains

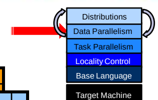



*domain:* a first-class index set

```
var m = 4, n = 8;

var D: domain(2) = [1..m, 1..n];
var Inner: subdomain(D) = [2..m-1, 2..n-1];
```

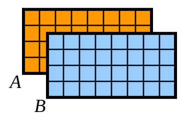



# Domains: Some Uses



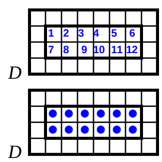

- Declaring arrays:

```
var A, B: [D] real;
```



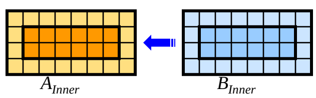

- Iteration (sequential or parallel):

```
    for    ij in Inner { … }
or: forall ij in Inner { … }
or: …
```



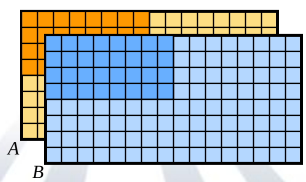

- Array Slicing:

```
A[Inner] = B[Inner];
```




- Array reallocation:

```
D = [1..2*m, 1..2*n];
```



## Forall vs. For vs. Coforall

**for loops:**

- Use the current task to execute the loop serially

**coforall loops:**

- Execute the loop using a distinct task per iteration
- Can have synchronization between iterations

**forall loops:**

- Use some number of tasks between these two extremes
- Must be legally executable by a single task
- How many tasks are used in practice?

## Data Parallelism Throttles

**--dataParTasksPerLocale=#**

- Specify # of tasks to execute forall loops
- Default: number of cores *(in current implementation)*

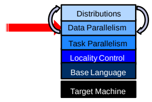
**--dataParIgnoreRunningTasks=[true|false]**

- If false, reduce # of forall tasks by # of running tasks
- Default: true *(in current implementation)*

**--dataParMinGranularity=#**

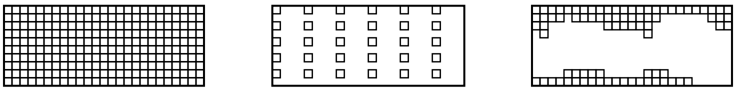
- reduce # of tasks if any task has fewer iterations
- Default: 1 *(in current implementation)*

# Data Parallelism: Domain Types



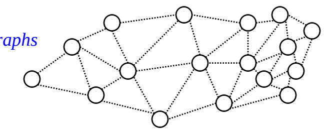

Chapel supports several domain types…

```
var OceanSpace = [0..#lat, 0..#long],
    AirSpace = OceanSpace by (2,4),
    IceSpace: sparse subdomain(OceanSpace) = genCaps();
```



*dense* *strided* *sparse*

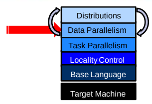
*graphs*



*associative*

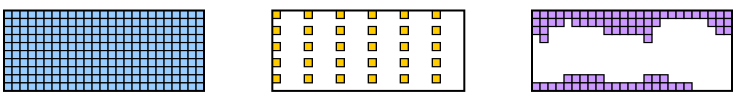

```
var Vertices: domain(opaque) = …,  People: domain(string) = …;
```

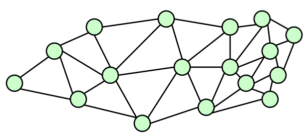
# Data Parallelism: Domain Uses

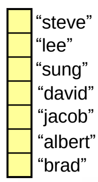



All domain types can be used to declare arrays…

```
var Ocean: [OceanSpace] real,
    Air: [AirSpace] real,
    IceCaps[IceSpace] real;
```

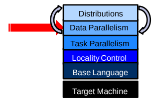






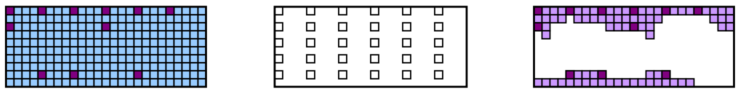

```
var Weight: [Vertices] real,      Age: [People] int;
```

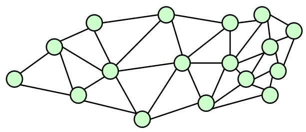
# Data Parallelism: Domain Uses




…to iterate over index sets…

```
forall ij in AirSpace do
  Ocean(ij) += IceCaps(ij);
```

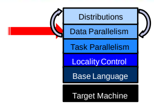





```
forall v in Vertices do
  Weight(v) = numEdges(v);
```

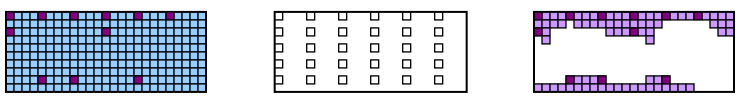
```
forall p in People do
  Age(p) += 1;
```

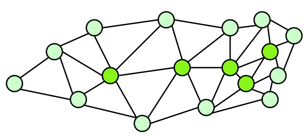
# Data Parallelism: Domain Uses




…to slice arrays…

```
Ocean[AirSpace] += IceCaps[AirSpace];
```

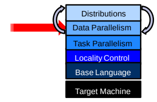





…Vertices[Interior]…

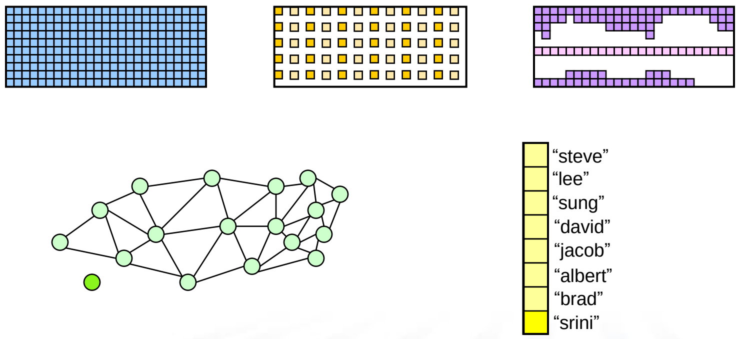
…People[Interns]…

# Data Parallelism: Domain Uses



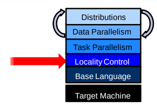

…and to reallocate arrays

```
AirSpace = OceanSpace by (2,2);
IceSpace += genEquator();
```



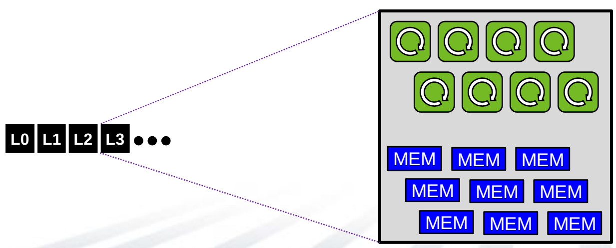

```
newnode = Vertices.create();    People += "srini";
```

# Locality: Locales

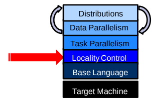



*locale:* An abstract unit of the target architecture

- supports reasoning about locality
- has capacity for processing and storage
- two threads in a given locale have similar access to a given address
  - addresses in that locale are ~uniformly accessible
  - addresses in other locales are also accessible, but at a price
- locales are defined for a given architecture by a Chapel compiler
  - e.g., a multicore processor or SMP node could be a locale



# Locales and Program Startup




- Chapel users specify # locales on executable command-line

```
prompt> myChapelProg -nl=8      # run using 8 locales
```

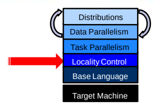
L0 L1 L2 L3 L4 L5 L6 L7

- Chapel launcher bootstraps program execution:
  - obtains necessary machine resources
    - *e.g.*, requests 8 nodes from the job scheduler
  - loads a copy of the executable onto the machine resources
  - starts running the program. *Conceptually…*

    …locale #0 starts running program's entry point (`main()`)

    …other locales wait for work to arrive

# Locale Variables

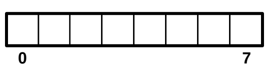



Built-in variables represent a program's locale set:

```
config const numLocales: int;            // number of locales
const LocaleSpace = [0..numLocales-1],   // locale indices
      Locales: [LocaleSpace] locale;     // locale values
```

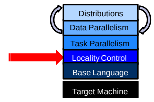
*numLocales:* **8**

*LocaleSpace:*




*Locales:* L0 L1 L2 L3 L4 L5 L6 L7

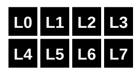
# Locale Views



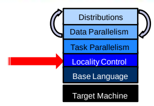

Using standard array operations, users can create their own locale views:

```
var TaskALocs = Locales[..numTaskALocs];
var TaskBLocs = Locales[numTaskALocs+1..];
```


```
var CompGrid = Locales.reshape([1..gridRows,
                                1..gridCols]);
```




# Locale Methods



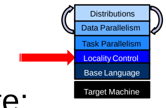

- The locale type supports built-in methods:

```
def locale.id: int;                   // index in LocaleSpace
def locale.name: string;              // similar to uname -n
def locale.numCores: int;             // # of processor cores
def locale.physicalMemory(…): …;      // amount of memory
…
```

- Locale queries can also be made:

```
…myvar.locale…   // query the locale where myvar is stored
…here…           // query where the current task is running
```

# Locality: Task Placement



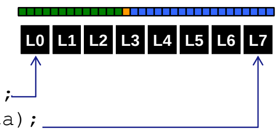

*on clauses:* indicate where statements should execute:

Either by naming locales explicitly…

```
cobegin {
  on TaskALocs do computeTaskA(…);
  on TaskBLocs do computeTaskB(…);
  on Locales(0) do computeTaskC(…);
}
```

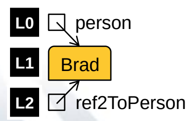

…or in a data-driven manner:

```
const pivot = computePivot(lo, hi, data);
cobegin {
  on data[lo] do Quicksort(lo, pivot, data);
  on data[hi] do Quicksort(pivot+1, hi, data);
}
```

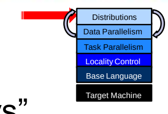



They can also control where data is allocated:

```
var person: Employee;
on Locales(1) do person = new Employee("Brad");
on Locales(2) do var ref2ToPerson = person;
```

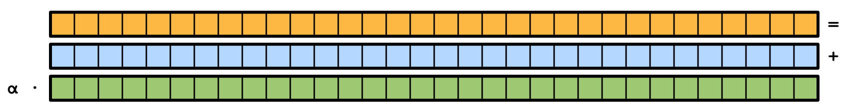



# Chapel Distributions

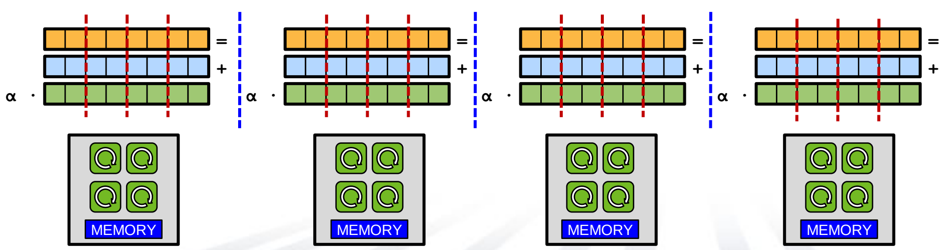



***Distributions:*** "Recipes for parallel, distributed arrays"

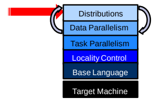
- help the compiler map from the computation's global view…




…down to the *fragmented*, per-processor implementation

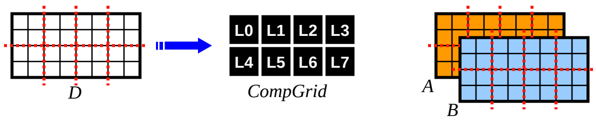


# Domain Distribution




Domains may be distributed across locales

```
var D: domain(2) dmapped Block(CompGrid, …) = …;
```




A distribution defines…

…ownership of the domain's indices (and its arrays' elements)

…default work ownership for operations on the domains/arrays

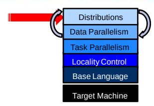
- e.g., forall loops or promoted operations

…memory layout/representation of array elements/domain indices

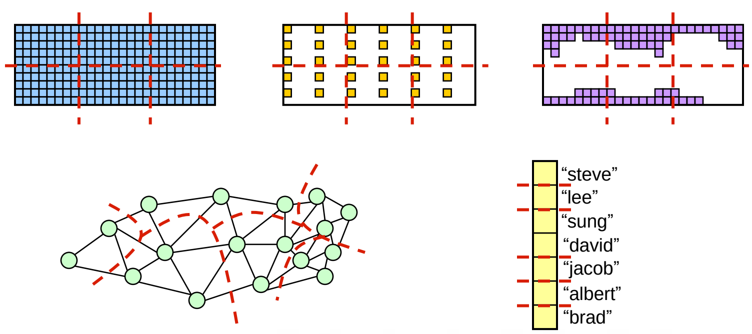
…implementation of operations on its domains and arrays

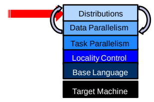
- e.g., accessors, iterators, communication patterns, …

# Domain Distributions




- Any domain type may be distributed
- Distributions do not affect program semantics
  - only implementation details and therefore performance






# Domain Distributions

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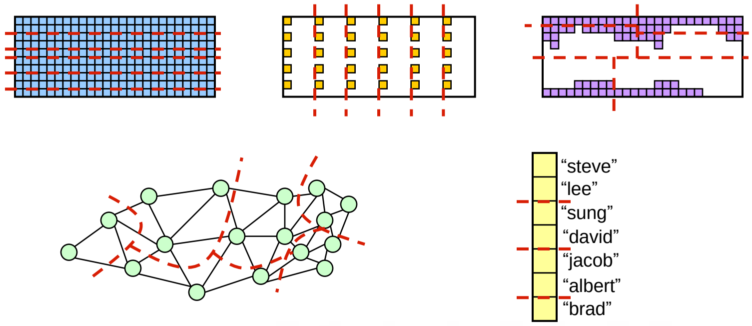
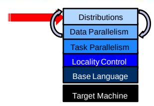



# Distributions: Goals & Research

- Advanced users can write their own distributions
  - specified in Chapel using lower-level language features
- Chapel will provide a standard library of distributions
  - written using the same user-defined distribution mechanism

*(Draft paper describing user-defined distribution strategy available by request)*

# The Block Distribution

The Block Distribution maps the indices of a domain in a dense fashion across the target Locales according to the `boundingBox` argument

```
const Dist = new dmap(new Block(boundingBox=[1..4, 1..8]));

var Dom: domain(2) dmapped Dist = [1..4, 1..8];
```

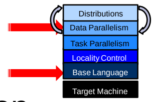

# The Cyclic Distribution

The Cyclic Distribution maps the indices of a domain in a round-robin fashion across the target Locales according to the `startIdx` argument

```
const Dist = new dmap(new Cyclic(startIdx=(1,1)));

var Dom: domain(2) dmapped Dist = [1..4, 1..8];
```

# Other Features




- zippered and tensor flavors of iteration and promotion
- *subdomains* and *index types* to help reason about indices
- reductions and scans (standard or user-defined operators)