Productive Programming in Chapel: A Computation-Driven Introduction

Short Introduction to Locality

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Outline

✓ Motivation
✓ Chapel Background and Themes
✓ Learning the Base Language with n-body
✓ Short Introduction to Task Par
✓ Hands-On 1: Hello World
➢ Short Introduction to Locality
   ● Data Parallelism with Jacobi
   ● Hands-On 2: Mandelbrot
   ● Project Status, Next Steps

Theme 4: Control over Locality/Affinity

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The Locale Type

Definition:

- Abstract unit of target architecture
- Supports reasoning about locality
  - defines “here vs. there” / “local vs. remote”
- Capable of running tasks and storing variables
  - i.e., has processors and memory

Typically: A compute node (multicore processor or SMP)
Getting started with 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 = ...;
  ```

- User’s `main()` begins executing on locale #0
Locale Operations

● Locale methods support queries about the target system:

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

● **On-clauses** support placement of computations:

```chapel
writeln("on locale 0");
on Locales[1] do
    writeln("now on locale 1");
writeln("on locale 0 again");
on A[i,j] do
    bigComputation(A);
on node.left do
    search(node.left);
```
Parallelism and Locality: Orthogonal in Chapel

- This is a **parallel**, but local program:

```chapel
begin writeln("Hello world!");
writeln("Goodbye!");
```

- This is a **distributed**, but serial program:

```chapel
writeln("Hello from locale 0!");
on Locales[1] do writeln("Hello from locale 1!");
writeln("Goodbye from locale 0!");
```

- This is a **distributed** and **parallel** program:

```chapel
begin on Locales[1] do writeln("Hello from locale 1!");
on Locales[2] do begin writeln("Hello from locale 2!");
writeln("Goodbye from locale 0!");
```
Partitioned Global Address Space (PGAS) Languages

(Or perhaps: partitioned global namespace languages)

- **abstract concept:**
  - support a shared namespace on distributed memory
    - permit parallel tasks to access remote variables by naming them
  - establish a strong sense of ownership
    - every variable has a well-defined location
    - local variables are cheaper to access than remote ones

- **traditional PGAS languages have been SPMD in nature**
  - best-known examples: Co-Array Fortran, UPC
proc main() {
    var i(*): int;       // declare a shared variable i
proc main() {
    var i(*): int;     // declare a shared variable i
    i = 2*this_image(); // each image initializes its copy
SPMD PGAS Languages (using a pseudo-language, not Chapel)

```plaintext
proc main() {
    var i(*): int;     // declare a shared variable i
    i = 2*this_image(); // each image initializes its copy
    var j: int;        // declare a private variable j
```

0 2 4 6 8

j j j j j
proc main() {
    var i(*): int;  // declare a shared variable i
    i = 2*this_image();  // each image initializes its copy

    var j: int;  // declare a private variable j
    j = i( (this_image()+1) % num_images() );  // ^ access our neighbor’s copy of i
    // communication implemented by compiler + runtime

    // How did we know our neighbor had an i?
    // Because it’s SPMD – we’re all running the same
    // program. (Simple, but restrictive)
Chapel and PGAS

● **PGAS: Partitioned Global Address Space**
  ● support a shared namespace on distributed memory
  ● but allow reasoning about locality

● **Chapel is PGAS, but unlike most, it’s not inherently SPMD**

  ⇒ never think about “the other copies of the program”
  ⇒ “global name/address space” comes from lexical scoping

  ● as in traditional languages, each declaration yields one variable
  ● variables are stored on the locale where the task declaring it is executing

---

Locales (think: “compute nodes”)
Chapel: Scoping and Locality

var i: int;

Locales (think: “compute nodes”)
var i: int;
on Locales[1] {

Locales (think: “compute nodes”)
var i: int;
on Locales[1] {
    var j: int;

Locales (think: “compute nodes”)
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {

    }
  }
}
Chapel: Scoping and Locality

var i: int;
on Locales[1] {
    var j: int;
    coforall loc in Locales {
        on loc {
            var k: int;
            // within this scope, i, j, and k can be referenced;
            // the implementation manages the communication for i and j
        }
    }
}
Chapel: Scoping and Locality

```chapel
var i: int;
on Locales[1] {
    var j: int;
    coforall loc in Locales {
        on loc {
            var k: int;
            // within this scope, i, j, and k can be referenced;
            // the implementation manages the communication for i and j
            k = i + j;
        }
    }
}
```

Locales (think: “compute nodes”)
Chapel: Scoping and Locality

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

Images / Threads / Locales / Places / etc. (think: “compute nodes”)
Chapel: Scoping and Locality

\[
\begin{align*}
\text{var } i & \text{: int; } \\
\text{on Locales[1] } & \{ \\
& \text{var } j \text{: int; } \\
& \text{coforall loc in Locales } \{ \\
& \text{on loc } \{ \\
& \text{var } k \text{: int; } \\
& k = i + j; \\
& \}
& \}
& \}
\end{align*}
\]

Images / Threads / Locales / Places / etc. (think: “compute nodes”)
Chapel and PGAS: Public vs. Private

How public a variable is depends only on scoping

- who can see it?
- who actually bothers to refer to it non-locally?

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

```
0 | 1 | 2 | 3 | 4
k | k | k | k | k
```
Querying a Variable's Locale

● **Syntax**

```plaintext
locale-query-expr:
  expr . locale
```

● **Semantics**

  ● Returns the locale on which `expr` is stored

● **Example**

```plaintext
var i: int;
on Locales[1] {
  var j: int;
  writeln((i.locale.id, j.locale.id));  // outputs (0,1)
}
```

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Here

● **Built-in locale variable**

```chapel
class const here: locale;
```

● **Semantics**
- Refers to the locale on which the task is executing

● **Example**

```chapel
writeln(here.id); // outputs 0
on Locales[1] do
  writeln(here.id); // outputs 1

on myC do
  if (here == Locales[0]) then ...
```
Rearranging Locales

Create locale views with standard array operations:

```chapel
var TaskALocs = Locales[0..1];
var TaskBLocs = Locales[2..];
var Grid2D = reshape(Locales, {1..2, 1..4});
```

Locales: L0 L1 L2 L3 L4 L5 L6 L7

TaskALocs: L0 L1

TaskBLocs: L2 L3 L4 L5 L6 L7

Grid2D: L0 L1 L2 L3
        L4 L5 L6 L7
Distributed Smith-Waterman

Now, what about distributed memory?

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**COMPUTE | STORE | ANALYZE**
Distributed Smith-Waterman

Now, what about distributed memory?

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Distributed Smith-Waterman

Now, what about distributed memory?

Advantages:

• Good cache behavior: Nice fat blocks of data touchable in memory order
• Pipeline parallelism: Good utilization once pipeline is filled
Distributed Smith-Waterman

Distributed Chunked Data-Driven Task-Parallel Approach:

const Hspace = {0..n, 0..n};
const LocaleGrid = Locales.reshape({0..#numLocales, 0..0});
const DistHSpace = Hspace dmapped Block(Hspace, LocaleGrid);
var H: [DistHSpace] int;

proc computeH(H: [] int) {
    const ProbSpace = H.domain.translate(1,1);
    const StrProbSpace = ProbSpace by (rowsPerChunk, colsPerChunk);
    var NeighborsDone: [StrProbSpace] atomic int;
    ...
    proc computeHHelp(x,y) {
        on H[x,y] {
            for (i,j) in ProbSpace[x..#rowsPerChunk, y..#colsPerChunk] do
                H[i,j] = f(H[i-1,j-1], H[i-1,j], H[i,j-1]);
            const eastReady = NeighborsDone[x, y+colsPerChunk].fetchAdd(1);
            ...etc...
            if (eastReady == 2) then begin computeHHelp(x, y+colsPerChunk);
            ...etc...
        } }
    }

Reshape the 1D Locales array into a 2D column
Block-distribute the data space across the column of locales
Compute each chunk on the locale that owns its initial element
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