Locality/Affinity Features
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What is a Locale?

**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:

  ```pascal
  proc locale.physicalMemory(...) { ... }
  proc locale.numPUs() { ... }
  proc locale.id { ... }
  proc locale.name { ... }
  ```

- On- clauses support placement of computations:

  ```pascal
  writeln("on locale 0");
  on Locales[1] do
    writeln("now on locale 1");
  writeln("on locale 0 again");
  ```

  ```pascal
  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:

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

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

```
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:

```
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

<table>
<thead>
<tr>
<th>partitioned shared name-/address space</th>
</tr>
</thead>
<tbody>
<tr>
<td>private space 0</td>
</tr>
<tr>
<td>private space 1</td>
</tr>
<tr>
<td>private space 2</td>
</tr>
<tr>
<td>private space 3</td>
</tr>
<tr>
<td>private space 4</td>
</tr>
</tbody>
</table>
SPMD PGAS Languages (using a pseudo-language, not Chapel)

```plaintext
shared var i(*): int;  // declare a shared variable i
```

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

var j: int;                  // declare a private variable j

```
i=  
  0  2  4  6  8
  j  j  j  j  j
```
SPMD PGAS Languages (using a pseudo-language, not Chapel)

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

    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)
```

```
i=
0 — 2 — 4 — 6 — 8

j=
2 — 4 — 6 — 8 — 0
```
Chapel and PGAS

- 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

```plaintext
var i: int;
```
Chapel: Scoping and Locality

```chapel
var i: int;
on Locales[1] {

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

```chapel
var i: int;
on Locales[1] {
  var j: int;
}
```

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

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

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;
            ...
        }
    }
}
```

```
Locales (think: “compute nodes”)
```

```
i  k  j  k  k  k  k
0  1  2  3  4
```
Chapel: Scoping and Locality

```chapel
var i: int;
on Locales[1] {
    var j: int;
    coforall loc in Locales {
        on loc {
            var k: int;
            k = 2*i + j;
        }
    }
}
```

OK to access $i$, $j$, and $k$ wherever they live

$\text{Locales}$ (think: “compute nodes”)

$$k = 2*i + j;$$
Chapel: Scoping and Locality

```chapel
var i: int;
on Locales[1] {
    var j: int;
    coforall loc in Locales {
        on loc {
            var k: int;
            k = 2*i + j;
        }
    }
}
```

Here, `i` and `j` are remote, so the compiler + runtime will transfer their values.

`Locales` (think: “compute nodes”)
Chapel: Locality queries

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

            ...here...
            // query the locale on which this task is running
            ...j.locale...
            // query the locale on which j is stored
        }
    }
}
```

Locales (think: “compute nodes”)
Querying a Variable's Locale

- **Syntax**
  
  ```
  locale-query-expr:
  expr . locale
  ```

- **Semantics**
  - Returns the locale on which `expr` is stored

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

**Built-in locale variable**
- `const here: locale;`

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

**Example**

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

on myC do
  if (here == Locales[0]) then ...
```
Reasoning about Communication

● Though implicit, users can reason about communication
  ● semantic model is explicit about where data is placed / tasks execute
  ● execution-time queries support reasoning about locality
    ● e.g., here, x.locale
  ● tools should also play a role here
    ● e.g., chplvis, contained in the release (developed by Phil Nelson, WWU)
Rearranging Locales

Create locale views with standard array operations:

```plaintext
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
```
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