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” / ”cheap vs. $$$”
- 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

- Users specify # of locales when running Chapel programs

```
% a.out --numLocales=8
% a.out -nl 8
```

- Chapel provides built-in locale variables

```chapel
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:

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

- On-clauses support placement of computations:

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

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

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

```plaintext
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!".GetKey());
  ```

- 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: Fortran Co-Arrays, UPC
SPMD PGAS Languages (using a pseudo-language, not Chapel)

shared int i(*);   // declare a shared variable i
SPMD PGAS Languages (using a pseudo-language, not Chapel)

shared int i(*); // declare a shared variable i

function main() {
    i = 2*this_image(); // each image initializes its copy
}

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

shared int i(*); // declare a shared variable i

function main() {
    i = 2*this_image(); // each image initializes its copy

    private int j; // declare a private variable j

    // Initial values:
    i = 0, 2, 4, 6, 8
    j = j, j, j, j, j
}
SPMD PGAS Languages (using a pseudo-language, not Chapel)

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

    private int j;  // declare a private variable j
    j = i( (this_image() + 1) % num_images() );
    // ^^^ access our neighbor’s copy of i
    // communication is implemented by the compiler + runtime
    // Q: How did we know our neighbor had an i?  A: Because it’s SPMD – we’re
    // all running the same program. (Simple, but restrictive)
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

```chapel
var i: int;
```

**Locales** (think: “compute nodes”)

- `i`
- 0
- 1
- 2
- 3
- 4
```
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

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

**Locales** (think: “compute nodes”)

OK to access `i`, `j`, and `k` wherever they live.

$k = 2i + j$;
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”)

k = 2*i + j;
Chapel: Locality queries

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

            ...
            // 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**
  ```
  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
Questions about (low-level) locality in Chapel?
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