Chapel: Locales

(Controlling Locality and Affinity)

Salt Lake City, Utah

The Locale Type

Definition:

- Abstract unit of target architecture
- Supports reasoning about locality
- Capable of running tasks and storing variables
  - i.e., has processors and memory

Properties:

- a locale's tasks have ~uniform access to local vars
- Other locale's vars are accessible, but at a price

In practice:

- Typically a compute node (multicore processor or SMP)

"Hello World" in Chapel: a Multi-Locale Version

- Multi-locale Hello World

```
coforall loc in Locales do
  on loc do
    writeln(“Hello, world! ”,
            “from node ”, loc.id, “ of ”, numLocales);
```

Locales and Program Startup

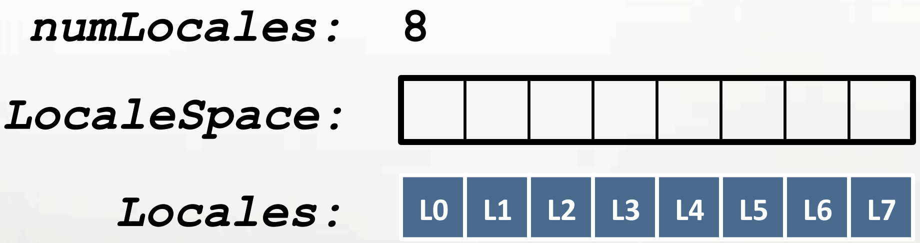
- Specify # of locales when running Chapel programs

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

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

- Chapel provides built-in locale variables

```
config const numLocales: int = …;
const LocaleSpace = {0..numLocales-1};
const Locales: [LocaleSpace] locale = …;
```



numLocales: 8

LocaleSpace:

Locales: L0 L1 L2 L3 L4 L5 L6 L7

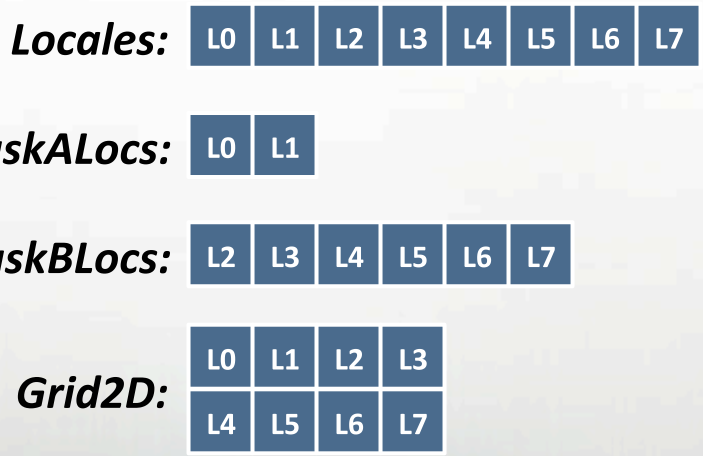
- main() begins as a single task on locale #0 (`Locales[0]`)

Rearranging Locales

Create locale views with standard array operations:

```
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

Locale Methods

- `proc locale.id: int { ... }`

  Returns locale’s index in LocaleSpace

- `proc locale.name: string { ... }`

  Returns name of locale, if available (like uname -a)

- `proc locale.numCores: int { ... }`

  Returns number of processor cores available to locale

- `proc locale.physicalMemory(...) { ... }`

  Returns physical memory available to user programs on locale

Example

```
const totalPhysicalMemory =
  + reduce Locales.physicalMemory();
```

The On Statement

- Syntax

```
on-stmt:
  on expr do stmt
  on expr { stmts }
```

- Semantics
  - Executes *stmt(s)* on the locale that stores *expr*
- Example

```
writeln("start executing on locale 0");
on Locales[1] do
  writeln("now we're on locale 1");
writeln("back on locale 0 again");
```

Locality and Parallelism are Orthogonal

- On-clauses do not introduce any parallelism

```
writeln("start executing on locale 0");
on Locales[1] do
  writeln("now we're on locale 1");
writeln("back on locale 0 again");
```

- But can be combined with constructs that do:

```
writeln("start executing on locale 0");
cobegin {
  on Locales[1] do
    writeln("this task runs on locale 1");
  on Locales[2] do
    writeln("while this one runs on locale 2");
}
writeln("back on locale 0 again");
```

- Orthogonal support for parallelism and locality is key

SPMD Programming in Chapel Revisited

- A language may support both global- and local-view programming — in particular, Chapel does

```
proc main() {
  coforall loc in Locales do
    on loc do
      MySPMDProgram(loc.id, Locales.numElements);
}

proc MySPMDProgram(me, p) {
  ...
}
```

Data-driven on-clauses

- On-clauses can also use a data-driven form…

```
cobegin {
  on node.left do
    search(node.left);
  on A[i,j] do
    bigComputation(A);
}
```

…supporting affinity between tasks and their data

(Note that even the ‘`on Locales[3]`*’ form can be considered data-driven, since each locale stores its respective locale value)*

Placement of data

Q: How does data get onto other locales to begin with?

A1: Lexical scoping

```
var x: int;                 // x is stored on locale 0
on Locales[1] {
  var y: int;               // y is stored on locale 1
  on Locales[2] {
    var z: int;             // z is stored on locale 2

    on y { y -= 1; }        // executes on locale 1
  }
}
```

Loc 0 *x*

Loc 1 *y*

Loc 2 *z*

Placement of data

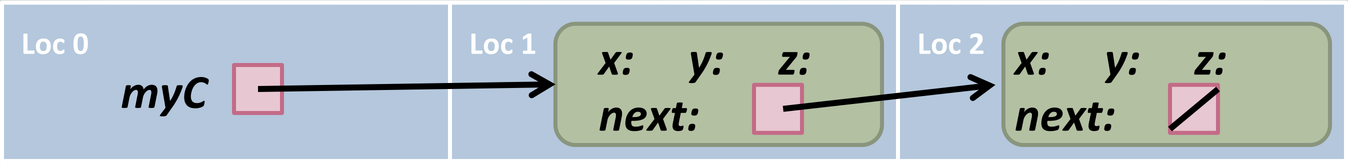
Q: How does data get onto other locales to begin with?

A2: Class instances

```
class C { var x, y, z: real;  var next: C;}

var myC: C;               // myC is stored on locale 0

on Locales[1] {
  myC = new C(…);         // myC's object lives on locale 1…
  on Locales[2] do
    myC.next = new C(…);   // and its next is on locale 2
}
on myC do …                // executes on locale 1
on myC.next do …           // executes on locale 2
```



Placement of data

Q: How does data get onto other locales to begin with?

A3: On-declarations (not yet implemented)

```
on Locales[1] var x: real;   // x is stored on locale 1
on Locales[2] var y: real;   // y is stored on locale 2

on x do …                    // executes on locale 1
on y do …                    // executes on locale 2
```

Loc 0

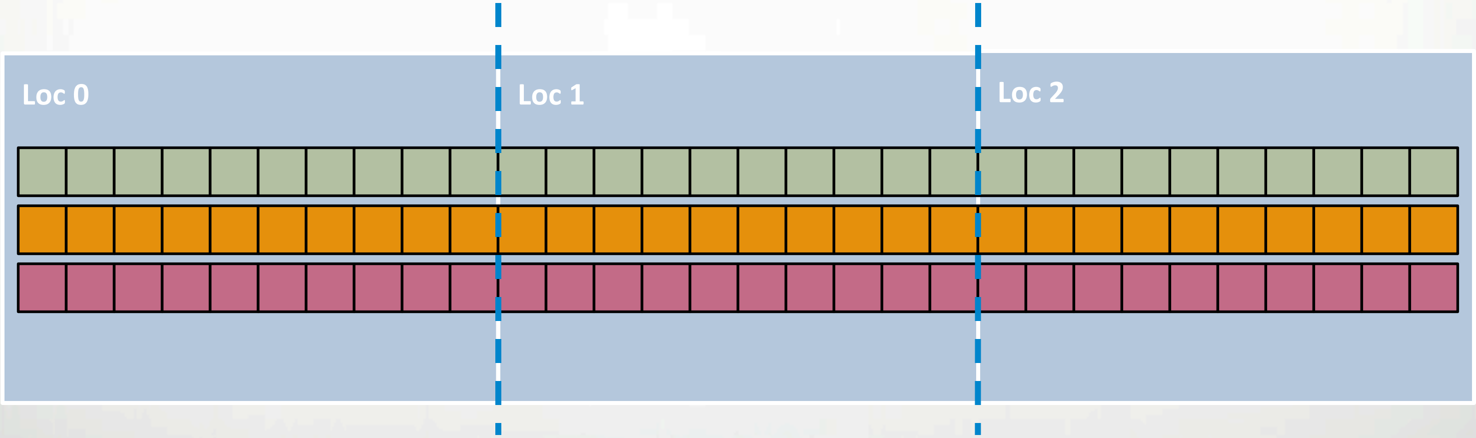
Loc 1 *x*

Loc 2 *y*

Placement of data

Q: How does data get onto other locales to begin with?

A4: Distributed domains and arrays (next slide deck)



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 …
```

Communication Implications

- Without optimizations, Chapel's global address space implies implicit communication

```
var x: int;

on Locales[1] {   // on-clause implies an active message
  var y: int;
  y = x;          // implies a remote get of x
  on x do
    y = x;        // implies a remote put to y
}
```

Optimized Communication

- The compiler can optimize communication subject to Chapel's memory consistency model

```
var x: int;

on Locales[1] {   // on-clause implies an active message
  var y: int;
  y = x;          // in practice, read-only values like x
}                 //  are bundled with the active message
```

Local statement

- Syntax

```
local-stmt:
  local { stmt };
```

- Semantics
  - Asserts to the compiler that all operations are local
- Example

```
on Locales[1] {
  var myC: C = …;
  …
  myC.x += 1; // is myC.x local?
}
```

```
on Locales[1] {
  var myC: C = …;
  …
  local { // assert it is
    myC.x += 1;
  }
}
```

- *Note:* Our current hope is to deprecate this feature, replacing it with data-centric concepts

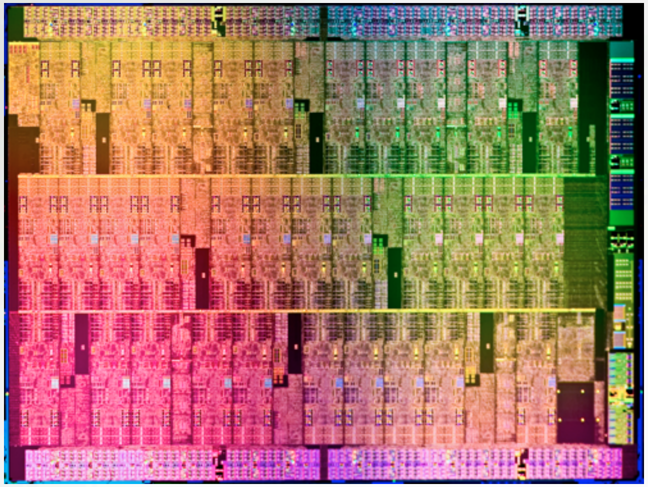
Status: Locales

- Most everything works correctly
  - exception: the on-declaration syntactic form
- The compiler is currently conservative about assuming variables may be remote
  - Impact: scalar performance overhead
- The compiler is currently lacking several important communication optimizations
  - Impact: scalability tends to be limited for programs with structured communication

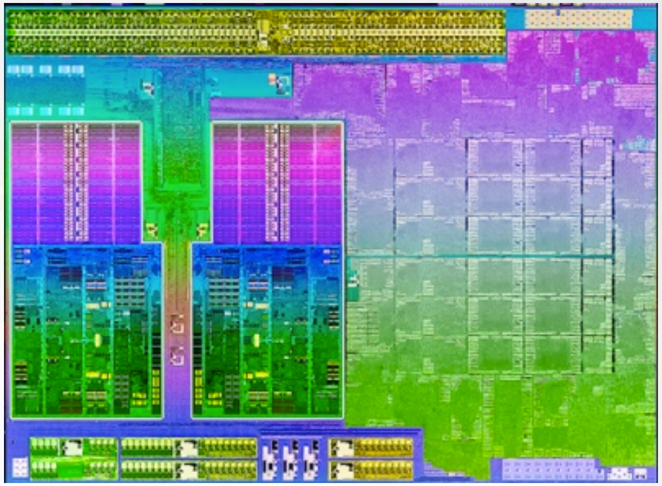
Future Directions

- Hierarchical Locales (currently being developed)
  - Support ability to expose hierarchy, heterogeneity within locales
  - Particularly important in next-generation nodes
    - CPU+GPU hybrids
    - tiled processors
    - manycore processors

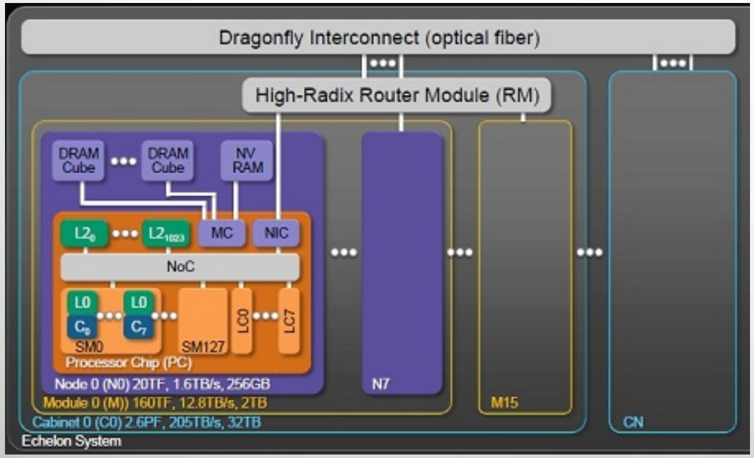
Prototypical Next-Gen Processor Technologies



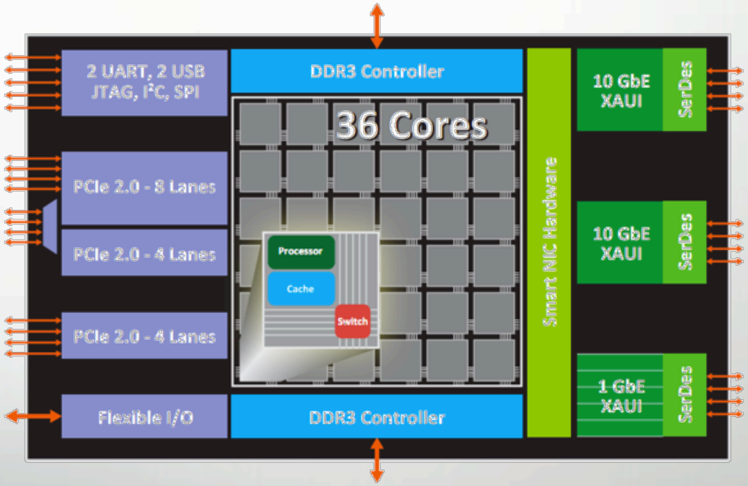
Intel MIC



AMD Trinity



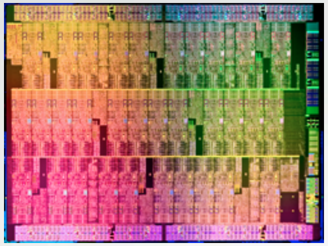
Nvidia Echelon

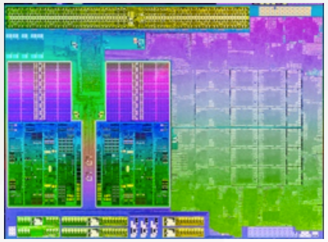


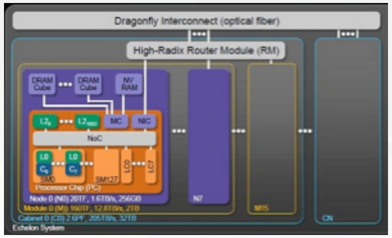
Tilera Tile-Gx

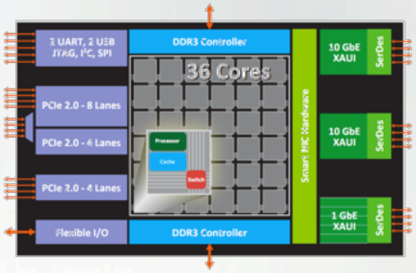
Sources: http://download.intel.com/pressroom/images/Aubrey_Isle_die.jpg, http://www.zdnet.com/amds-trinity-processors-take-on-intels-ivy-bridge-3040155225/, http://insidehpc.com/2010/11/26/nvidia-reveals-details-of-echelon-gpu-designs-for-exascale/, http://tilera.com/sites/default/files/productbriefs/Tile-Gx%203036%20SB012-01.pdf

General Characteristics of These Architectures









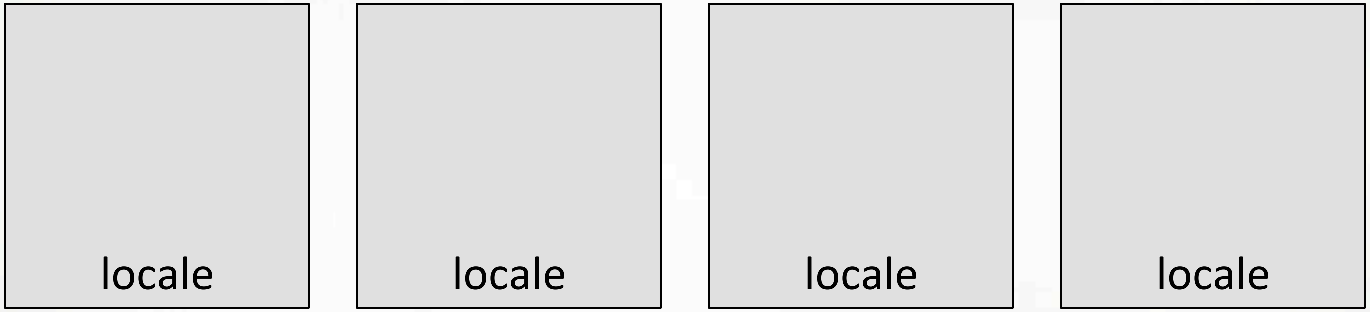
- Increased hierarchy and/or sensitivity to locality
- Potentially heterogeneous processor/memory types

⇒ Next-gen programmers will have a lot more to think about at the node level than in the past

Locales Today

Concept:

- Today, Chapel supports a 1D array of locales
  - users can reshape/slice to suit their computation's needs

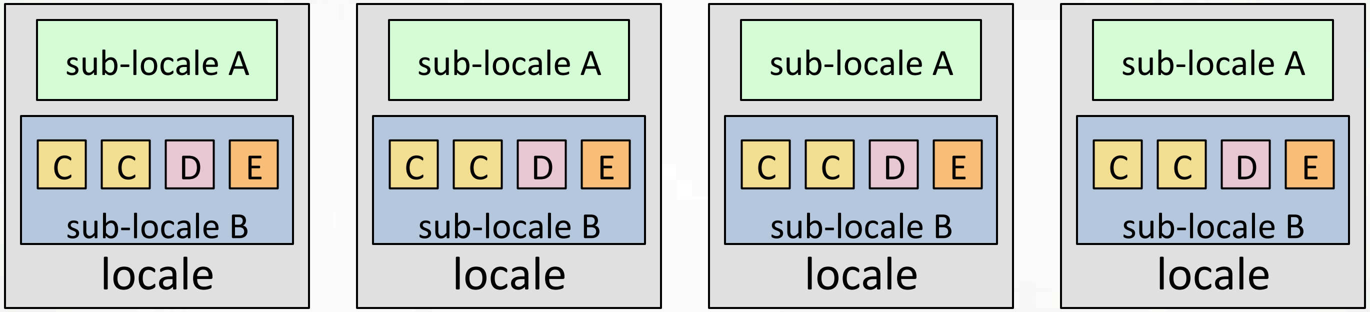


- Apart from queries, no further visibility into locale structure
  - no mechanism to refer to specific NUMA domains, processors, memories, …
  - assumption: compiler, runtime, OS, HW can handle intra-locale concerns

Current Work: Hierarchical Locales

Concept:

- Support locales within locales to describe architectural sub-structures within a node



- As with traditional locales, *on-clauses* and *domain maps* can be used to map tasks and variables to a sub-locale's memory and processors
- Locale structure is defined as Chapel code
  - permits implementation policies to be specified in-language
  - introduces a new Chapel role: *architectural modeler*