Chapel & X10

CS315B
Lecture 13

What is Chapel?

"Chapel is a modern parallel programming language designed for productivity at scale."

What Does That Mean?

- Pay attention to the issues in large-scale parallel programming
  - Control
  - Memory
- But have features that look like a "real" programming language
  - Types, type inference, objects, …

History

- Main paper in 2007
  - Read the intro to this paper!
- Preceded by Cascade
  - ~2004
  - And by ZPL before that …
- Still an active project today

Model of Control

- In a word: threads

A Few Words About Threads

- A thread is a sequential program

- Multiple threads can execute in parallel
  - All statements in a single thread execute in the specified order
  - There is no specified ordering of instructions in different threads
  - Instructions from different threads may be interleaved in any order

- And threads share state
  - One thread can write a value another thread reads

Example 1

Thread 1

x = 0
y = 0
x = x + 1

Thread 2

x = 0
y = 0
y = y + 1

Example 2

Thread 1

x = 0
y = 0
x = y + 1

Thread 2

x = 0
y = 0
y = y + 1

Example 3

Thread 1

initially y = 0

y = y + 1

Thread 2

y = y + 1

Example 3: Machine Level

Thread 1

initially y = 0

r1 = load y
r1 = r1 + 1
y = store r1

Thread 2

r2 = load y
r2 = r2 + 1
y = store r2

Example 3: Atomics

Thread 1	Thread 2
initially y = 0	
atomic{ y = y + 1 }	atomic{ y = y + 1 }

Thread Synchronization

- Threading systems often have a wide array of synchronization primitives
  - Ways to restrict the interleavings of threads
- General philosophy
  - Allow any interleavings by default
  - Add enough synchronization to eliminate undesirable interleavings

Data Parallelism in Chapel

- Index domains, both structured and unstructured
- Parallel for loops

  forall i in I do …

- Legion/Regent use Chapel-style domains

Task Parallelism

- cobegin {s1; s2}
- Statements s1 and s2 may run in parallel
- Structured future-like variables for inter-thread communication
  - Variables can be either *full* or *empty*
  - A write fills the variable
  - A read empties it
  - Producer-consumer style parallelism

Nested Parallelism

- Constructs can be arbitrarily nested
- Fine to have
  - Task parallelism inside of data parallelism
  - Or vice versa

Reductions

- Built-in support for reductions and scans.
- Not integrated directly with other features
  - Really a separate facility
  - But can be used in combination with other kinds of parallelism

Locales

- *Locales* name places where computation can happen and values can be stored

- Locales are an abstract concept
  - In practice, a node would be a locale

- Note: The set of all locales is just … a set
  - No structure
  - No topological relationships between set elements
  - Combines processors and memories in one

Data Model: Distributions

- A domain can be *distributed* among a set of locales

- Chapel supports standard distributions
  - Blocked, cyclic, blocked cyclic
  - And user-defined distributions

Alignment

- A new Chapel distribution can be defined as an *alignment* with an existing distribution
- E.g., "Layout index set B the same was as A"
- Allows distributions to be derived from existing distributions
  - Compare with Legion/Regent's dependent partitioning

Owner Computes

- Consider forall i in I do …
- Default execution uses the *owner computes* rule:
  - Iteration i is executed on the locale that owns it
- Programmer can override:

  forall i in I do on A[i+1] do …

User-Defined Distributions

- Additional distributions can be defined
- Implement distribution interface
  - A lower-level API for defining distributions
- The standard distributions are also written this way
  - But there is a difference in compiler knowledge!

Example

```
const indices = {1..1000} dmapped Cyclic(startIdx = 1)

forall i in indices do
        writeln("iteration ", i, "on locale ", here.id)
```

Object-Oriented Features

- Chapel strives to look and feel like a modern object-oriented language
  - E.g., Java
- But not fully OO
  - Emphasis on arrays and pass-by-value
  - Because of importance in high-performance computing

Chapel Critique

- Machine Model
- Memory/Data
- Control
- Latency hiding

Machine Model

- Designed for a world of clusters
- Locales are essentially a flat collection
  - Fine if the locales are nodes that are peers on a network
  - Reality is now more complex due to accelerators and other heterogeneity within a node
    - e.g., NUMA

Memory/Data Model

- Model of machine memory is very simple
- Unified with computation
  - No mechanism for talking about different memories accessible from the same processor
  - No mechanism for talking about hierarchy

Data Model

- Lots of support for manipulating, partitioning index spaces
  - A good idea, widely adopted
  - Can also define and use subspaces
  - Sparse index space support is not fully worked out
- Note: The index space itself is mapped, not the data
  - Allows multiple arrays with the same index space to be trivially partitioned the same way

Data Model (Cont.)

- Emphasis on where the data is placed
  - And can only have one placement
- No (?) facilities for expressing movement of data
  - Data movement is implicit, in that if a thread on a locale needs a value from another locale the needed messages are generated automatically
  - Data movement at the granularity of individual requests

Control

- Locales are virtualized processors
  - And memories
- Fine to have multiple threads per processor
  - No guarantee of exclusive access
- Ability to run multiple threads/locale is also the latency hiding mechanism
- Various synchronization mechanisms we didn't discuss
  - Present in all threading models

X10

- Surprisingly similar to Chapel!
- Not really fair …
  - There are real differences in the designs
  - But not so much at the level of today's lecture
- X10 is
  - Thread-based
  - Provides data parallel and task parallel constructs
  - Has a flat model of compute/memory locations called *places*

X10: What's Different

- Java-based
  - More emphasis on integration into an existing language
  - More emphasis on being object-oriented
- Garbage-collected
  - A huge difference
  - Only serious HPC effort that uses GC
  - Every local JVM collects its own heap on a node
  - Make sure inter-node references are tracked
    - So that data pointed to on remote nodes isn't collected!