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

<table>
<thead>
<tr>
<th>Thread 1</th>
<th>Thread 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x = 0 )</td>
<td>( x = 0 )</td>
</tr>
<tr>
<td>( y = 0 )</td>
<td>( y = 0 )</td>
</tr>
<tr>
<td>( x = x + 1 )</td>
<td>( y = y + 1 )</td>
</tr>
</tbody>
</table>

### Example 2

<table>
<thead>
<tr>
<th>Thread 1</th>
<th>Thread 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x = 0 )</td>
<td>( x = 0 )</td>
</tr>
<tr>
<td>( y = 0 )</td>
<td>( y = 0 )</td>
</tr>
<tr>
<td>( x = y + 1 )</td>
<td>( y = y + 1 )</td>
</tr>
</tbody>
</table>
Example 3

Thread 1  
initially \( y = 0 \)

\( y = y + 1 \)

Thread 2

\( y = y + 1 \)

Example 3: Machine Level

Thread 1  
initially \( y = 0 \)

\[ r1 = \text{load } y \]
\[ r1 = r1 + 1 \]
\[ y = \text{store } r1 \]

Thread 2

\[ r2 = \text{load } y \]
\[ r2 = r2 + 1 \]
\[ y = \text{store } r2 \]
Example 3: Atomics

Thread 1
initially y = 0

atomic{ y = y + 1 }

Thread 2

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
  \[
  \text{forall } i \in I \text{ do } ...
  \]
- Legion/Regent use Chapel-style domains

Task Parallelism

- \textit{cobegin \{s1; s2\}}
- Statements \textit{s1} and \textit{s2} may run in parallel
- Structured future-like variables for inter-thread communication
  - Variables can be either \textit{full} or \textit{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 \texttt{forall} \texttt{i in I do} ...

- Default execution uses the \textit{owner computes} rule:
  - Iteration \texttt{i} is executed on the locale that owns it

- Programmer can override:
  \texttt{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!

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**Example**

```plaintext
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!