Chapel: Task Parallelism

Sung-Eun Choi and Steve Deitz

Cray Inc.

Outline

- Primitive Task-Parallel Constructs
  - The **begin** statement
  - The **sync** types
- Structured Task-Parallel Constructs
- Atomic Transactions and Memory Consistency
- Implementation Notes and Examples

Unstructured Task Creation: Begin

- Syntax

```
begin-stmt:
  begin stmt
```

- Semantics
  - Creates a concurrent task to execute *stmt*
  - Control continues immediately (no join)
- Example

```
begin writeln("hello world");
writeln("good bye");
```

- Possible output

```
hello world
good bye
```

```
good bye
hello world
```

Synchronization via Sync-Types

- Syntax

```
sync-type:
  sync type
```

- Semantics
  - Default read blocks until written (until “full”)
  - Default write blocks until read (until “empty”)
- Examples: Critical sections and futures

```
var lock$: sync bool;

lock$ = true;
critical();
lock$;
```

```
var future$: sync real;

begin future$ = compute();
computeSomethingElse();
useComputeResults(future$);
```

Synchronization via Single-Types

- Syntax

```
single-type:
  single type
```

- Semantics
  - Default read blocks until written (until “full”)
  - Write once
- Example: Multiple consumers

```
var future$: single real;
begin { computeTaskA(); useResult1(future$); }
begin { computeTaskB(); useResult2(future$); }
future$ = computeResult();
```

Sync-Type Methods

`readFE():t`	wait until full, leave empty, return value
`readFF():t`	wait until full, leave full, return value
`readXX():t`	non-blocking, return value
`writeEF(v:t)`	wait until empty, leave full, set value to `v`
`writeFF(v:t)`	wait until full, leave full, set value to `v`
`writeXF(v:t)`	non-blocking, leave full, set value to `v`
`reset()`	non-blocking, leave empty, reset value
`isFull: bool`	non-blocking, return true if full else false

- Defaults – read: **`readFE`**, write: **`writeEF`**

Single-Type Methods

~~`readFE():t`~~	~~wait until full, leave empty, return value~~
`readFF():t`	wait until full, leave full, return value
`readXX():t`	non-blocking, return value
`writeEF(v:t)`	wait until empty, leave full, set value to `v`
~~`writeFF(v:t)`~~	~~wait until full, leave full, set value to `v`~~
~~`writeXF(v:t)`~~	~~non-blocking, leave full, set value to `v`~~
~~`reset()`~~	~~non-blocking, leave empty, reset value~~
`isFull: bool`	non-blocking, return true if full else false

- Defaults – read: **`readFF`**, write: **`writeEF`**

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- Structured Task-Parallel Constructs
  - The **cobegin** statement
  - The **coforall** loop
  - The **sync** statement
  - The **serial** statement
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Block-Structured Task Invocation: Cobegin

- Syntax

```
cobegin-stmt:
  cobegin { stmt-list }
```

- Semantics
  - Invokes a concurrent task for each listed *stmt*
  - Control waits to continue – implicit join
- Example

```
cobegin {
  consumer(1);
  consumer(2);
  producer();
}
```

Cobegin is Unnecessary

Any cobegin statement

```
cobegin {
  stmt1();
  stmt2();
  stmt3();
}
```

can be rewritten in terms of begin statements

```
var s1$, s2$, s3$: sync bool;
begin { stmt1(); s1$ = true; }
begin { stmt2(); s2$ = true; }
begin { stmt3(); s3$ = true; }
s1$; s2$; s3$;
```

but the compiler may miss out on optimizations.

Loop-Structured Task Invocation: Coforall

- Syntax

```
coforall-loop:
  coforall index-expr in iteratable-expr { stmt }
```

- Semantics
  - Loop over *iteratable-expr* invoking concurrent tasks
  - Control waits to continue – implicit join
- Example

```
begin producer();
coforall i in 1..numConsumers {
  consumer(i);
}
```

Like Cobegin, Coforall is also Unnecessary

```
coforall i in 1..n do stmt();
```

```
var count$: sync int = 0, flag$: sync bool = true;

for i in 1..n {
  const count = count$;
  if count == 0 then flag$;
  count$ = count + 1;
  begin {
    stmt();
    const count = count$;
    if count == 1 then flag$ = true;
    count$ = count - 1;
  }
}

flag$;
```

Usage of Begin, Cobegin, and Coforall

- Use begin when
  - Creating tasks with unbounded lifetimes
  - Load balancing requires dynamic task creation
  - Cobegin and coforall are insufficient for task structuring
- Use cobegin when
  - Invoking a fixed # of tasks (potentially heterogeneous)
  - The tasks have bounded lifetimes
- Use coforall when
  - Invoking a fixed or dynamic # of homogeneous task
  - The tasks have bounded lifetimes

Structuring Sub-Tasks: Sync-Statements

- Syntax

```
sync-statement:
  sync stmt
```

- Semantics
  - Executes *stmt*
  - Waits on all *dynamically-encountered* begins
- Example

```
sync {
  for i in 1..numConsumers {
    begin consumer(i);
  }
  producer();
}
```

Program Termination and Sync-Statements

Where the cobegin statement is static,

```
cobegin {
  functionWithBegin();
  functionWithoutBegin();
}
```

the sync statement is dynamic.

```
sync {
  begin functionWithBegin();
  begin functionWithoutBegin();
}
```

Program termination is defined by an implicit sync.

```
sync main();
```

Limiting Concurrency: Serial

- Syntax

```
serial-statement:
  serial expr { stmt }
```

- Semantics
  - Evaluates *expr* and then executes *stmt*
  - Squelches dynamically-encountered concurrency
- Example

```
def search(i: int) {
  // search node i
  serial i > 8 do cobegin {
    search(i*2);
    search(i*2+1);
  }
}
```

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  - The **atomic** statement
  - Races and memory consistency
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Atomic Transactions (Unimplemented)

- Syntax

```
atomic-statement:
  atomic stmt
```

- Semantics
  - Executes stmt so it appears as a single operation
  - No other task sees a partial result
- Example

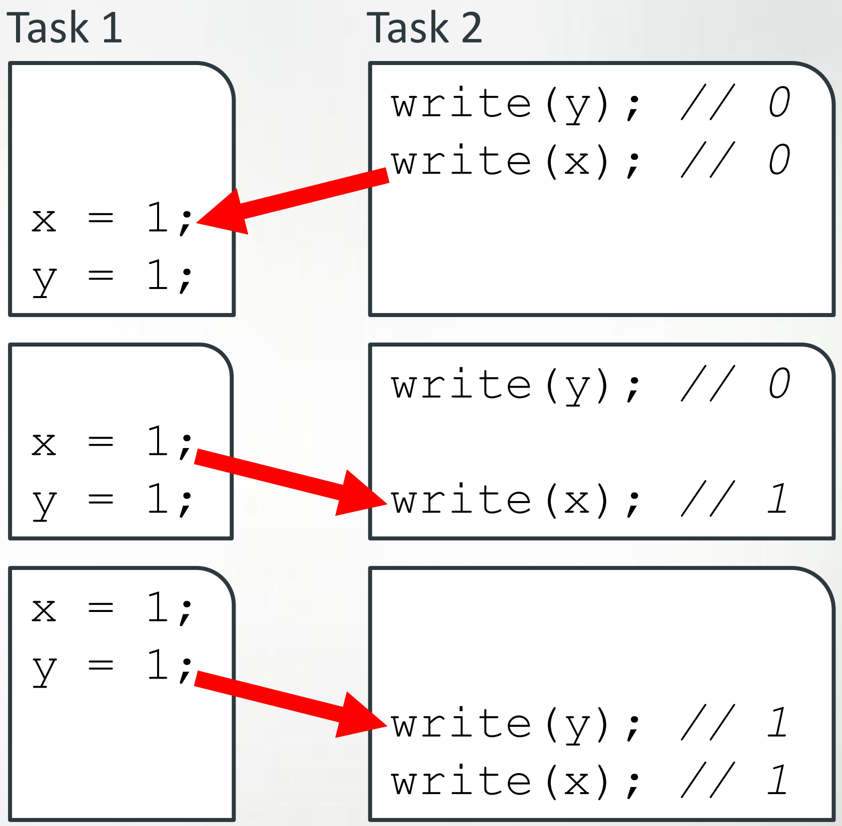
```
atomic A(i) = A(i) + 1;
```

```
atomic {
  newNode.next = node;
  newNode.prev = node.prev;
  node.prev.next = newNode;
  node.prev = newNode;
}
```

Races and Memory Consistency

- Example

```
var x = 0, y = 0;
cobegin {
  {
    x = 1;
    y = 1;
  }
  {
    write(y);
    write(x);
  }
}
```



```
x = 1;
y = 1;
```

```
write(y); // 0
write(x); // 0
```

```
x = 1;
y = 1;
```

```
write(y); // 0
write(x); // 1
```

```
x = 1;
y = 1;
```

```
write(y); // 1
write(x); // 1
```

- Could the output be 10? Or 42?

Data-Race-Free Programs (The Fine Print)

A program without races is sequentially consistent.

> A multi-processing system has sequential consistency if "*the results of any execution is the same as if the operations of all the processors were executed in some sequential order, and the operations of each individual processor appear in this sequence in the order specified by its program.*" – Leslie Lamport

The behavior of a program with races is undefined.

Synchronization is achieved in two ways:

- By reading or writing sync (or single) variables
- By executing atomic statements

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  - Using Chapel version 1.1
  - Quicksort example

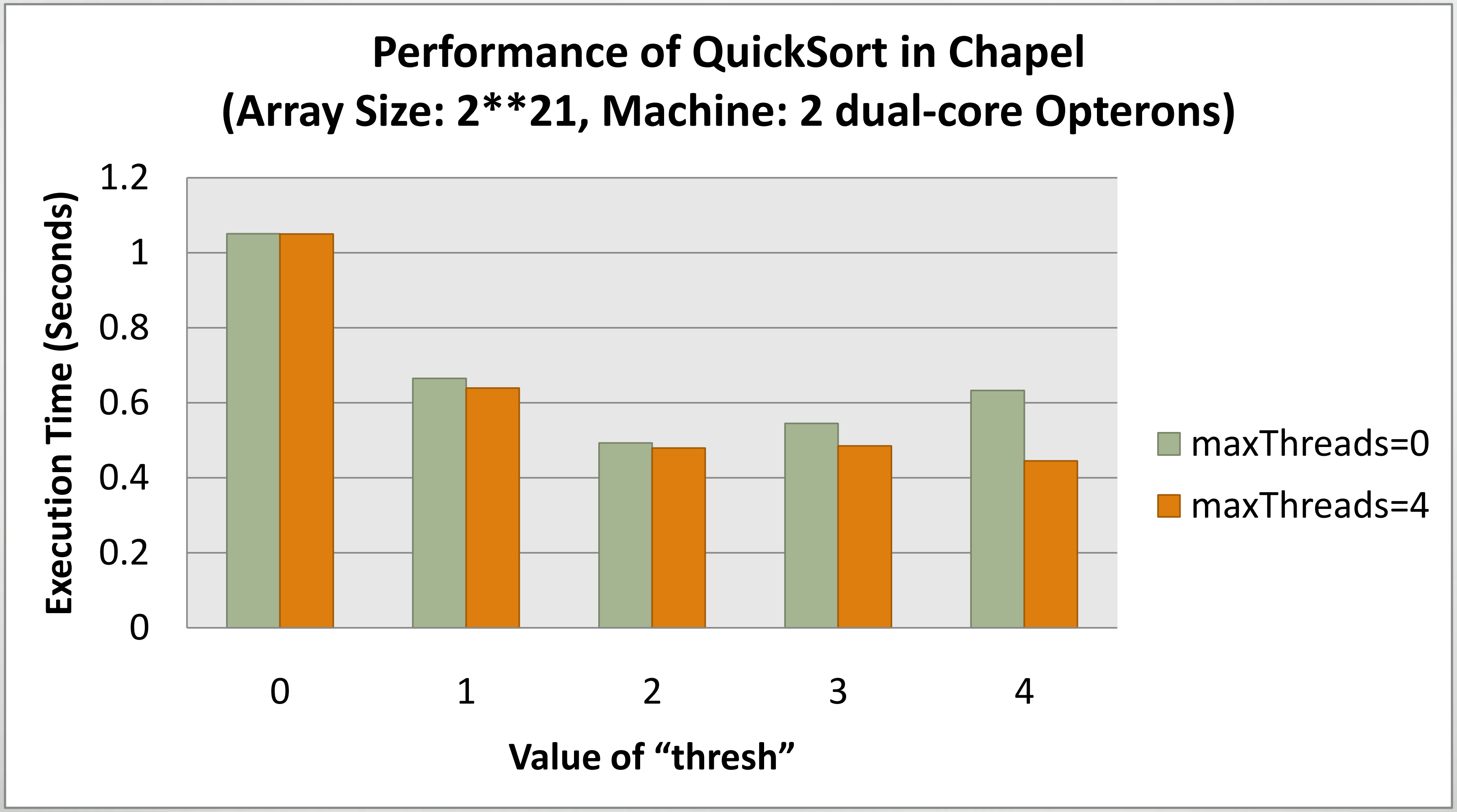
Using Chapel Version 1.1

- Concurrency limiter: **maxThreadsPerLocale**
  - Use **--maxThreadsPerLocale=<i>** for at most i threads
  - Use **--maxThreadsPerLocale=0** for a system limit *(default)*
- Current task-to-thread scheduling policy
  - Once a thread gets a task, it runs to completion
  - Cobegin/coforall parent threads execute subtasks
  - If an execution runs out of threads, it may deadlock

Quick Sort in Chapel

```
def quickSort(arr: [],
              thresh: int,
              low: int = arr.domain.low,
              high: int = arr.domain.high) {
  if high - low < 8 {
    bubbleSort(arr, low, high);
  } else {
    const pivotVal = findPivot(arr, low, high);
    const pivotLoc = partition(arr, low, high, pivotVal);
    serial thresh <= 0 do cobegin {
      quickSort(arr, thresh-1, low, pivotLoc-1);
      quickSort(arr, thresh-1, pivotLoc+1, high);
    }
  }
}
```

Performance of Multi-Threaded Chapel



Future Directions

- Task teams
- Suspendable tasks
- Work stealing, load balancing
- Eurekas
- Task-private variables

Questions?

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