COMP 311
Functional Programming

Coroutines

Guest Lecture, Oct 27, 2015.

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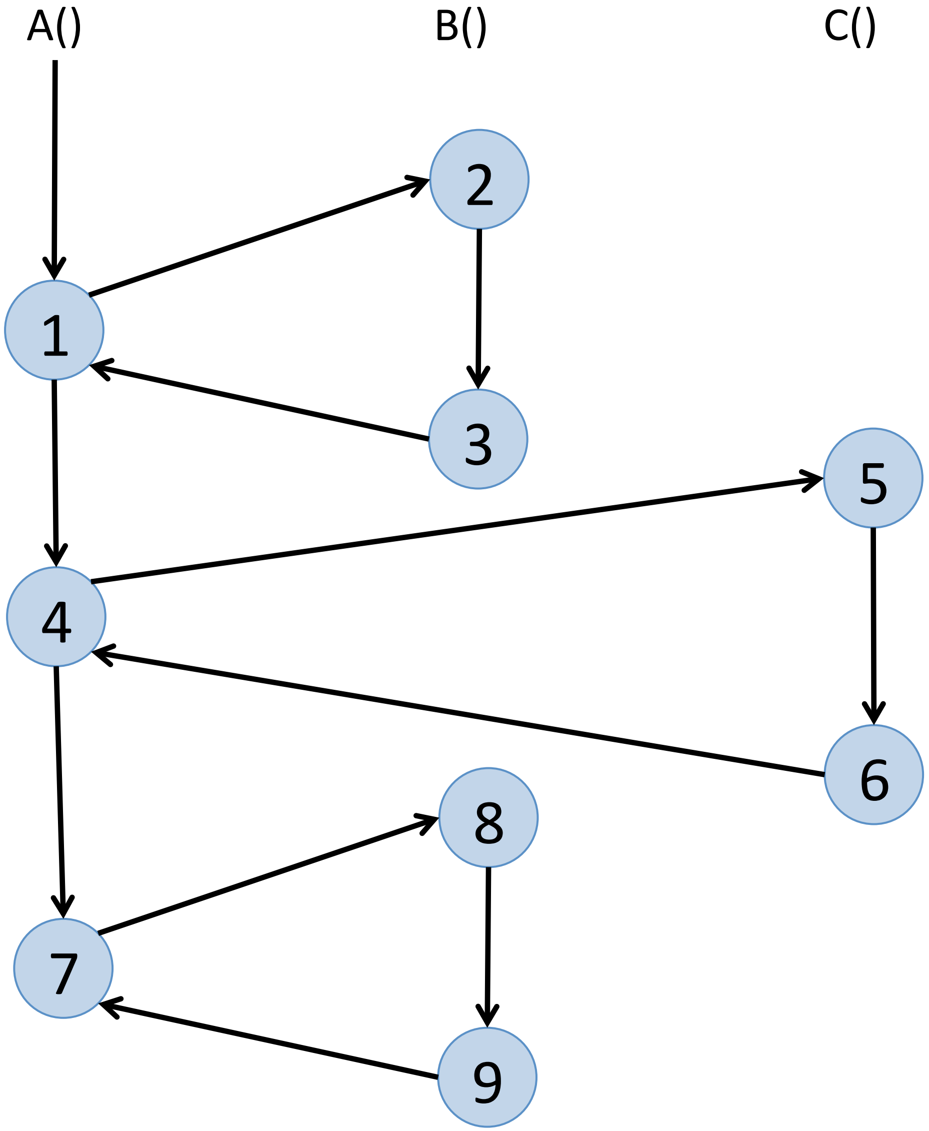
Review: Subroutines (aka Functions)

- A block of executable code
- Exactly one point of entry
- Once a subroutine exits, it is done

Review: Subroutines relationships

- A subroutine may call another subroutine
- Starts a caller-callee relationship
  - Control transferred to the entry point of callee
  - Callee local data created from scratch
  - Callee runs to completion and returns
  - Caller resume computation from call site

Review: Subroutines control flow



Review: Subroutines Example

```scala
object ProducerConsumerSubroutine {
  def main(args: Array[String]) {
    var (itemsConsumed, consumerResult) = (0, 0L)
    val numItems: Int = 10
    val queue = new util.LinkedList[Long]()
    for (i <- 1 to numItems) {
      producer(numItems, i, queue)

      val (a, b) = consumer(queue)
      itemsConsumed = a
      result = b
    }
    println("Items Consumed = " + itemsConsumed)
    println("Sum = " + consumerResult)
  }
  ...
}
```

Review: Subroutines Example

```
object ProducerConsumerSubroutine {
  ...
  def producer(numItems, itemIndex, queue) = {
    if (itemIndex >= numItems)
      queue.offer(-1)
    val item = 1L * itemIndex
    queue.offer(item)
  }
  def consumer(queue) = {
    val item = queue.poll()
    var (itemsConsumed, itemsSum) = (0, 0L)
    if (item != -1) {
      itemsConsumed += 1
      itemsSum += item
    }
    (itemsConsumed, itemsSum)
  }
}
```

Review: Subroutines relationships

- Caller-callee relationship
  - Control transferred to the entry point of callee
  - Callee local data created from scratch
  - Callee runs to completion and returns
  - Callee local data is destroyed
  - Caller resume computation from call site
- If Caller calls Callee again, whole process is repeated

Review: Subroutines Example

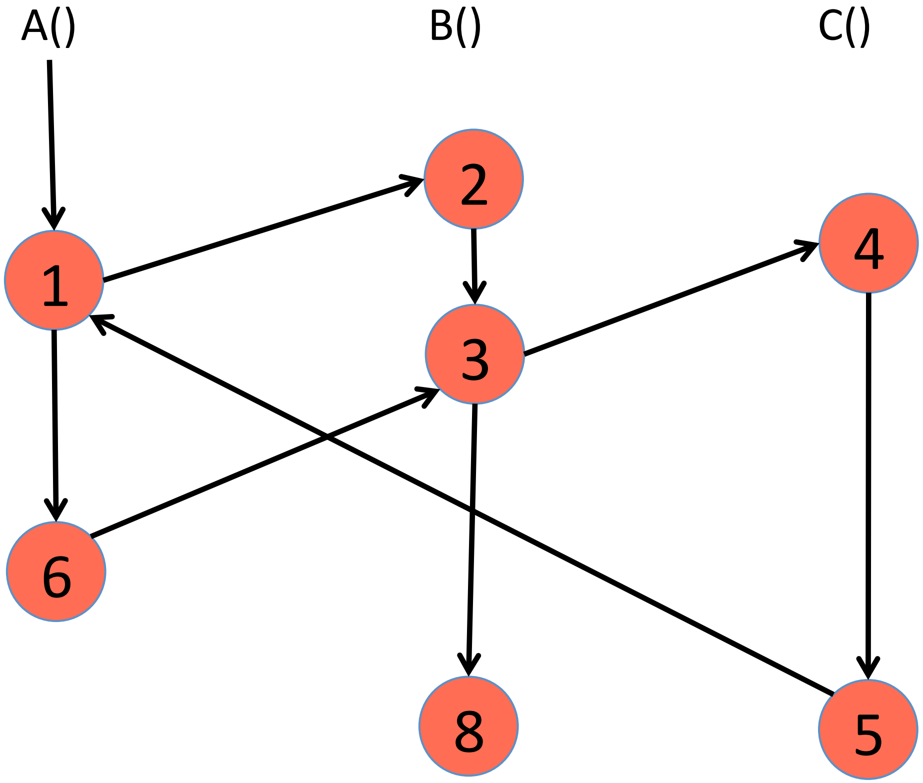
```
object ProducerConsumerSubroutine {
  ...
  private var (itemsConsumed, itemsSum) = (0, 0L)
  def producer(numItems, itemIndex, queue) = {
    if (itemIndex >= numItems)
      queue.offer(-1)
    val item = 1L * itemIndex
    queue.offer(item)
  }
  def consumer(queue) = {
    val item = queue.poll()
    if (item != -1) {
      itemsConsumed += 1
      itemsSum += item
    }
    (itemsConsumed, itemsSum)
  }
}
```

Imagine a procedure that

"remembers"

its state across calls

Example control flow



Coroutines

- A block of executable code
- Exactly one point of entry
- Coroutines can exit by calling other coroutines
    - Typically using the **yield** statement
    - Yield indicates that the routine is done executing for now
    - Coroutine may be resumed from the yield point
- **One or more** points of **re-entry**

Coroutines (contd)

- Allow for **suspending** and **resuming** execution at yield points
- Coroutines hold state between invocations
  - parameters and local variables are preserved between invocations
  - Nested call chains

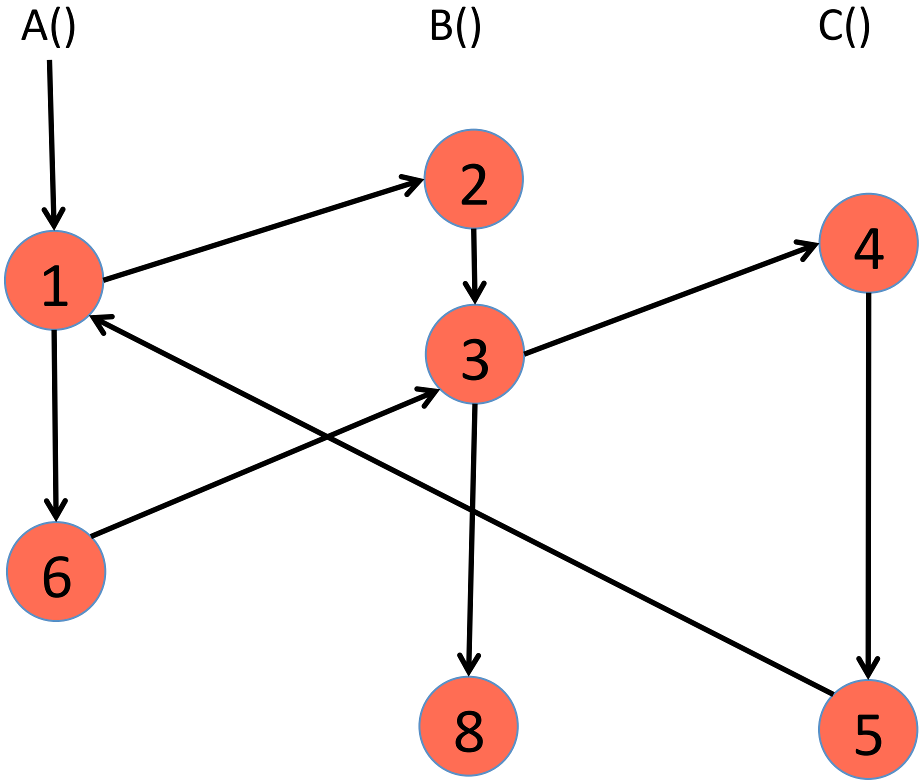
Coroutines Example

```
object ProducerConsumerCoroutine {
  def main(args: Array[String]) {
    val numItems: Int = 10
    val queue = new util.LinkedList[Long]()

    runCoroutines("producer", () => {
      coroutine("producer", () => producer(numItems, queue))
      coroutine("consumer", () => consumer(queue))
    })
    // wait for one of the registered coroutines to return
    val (itemsConsumed, result) = coroutineResult("consumer")

    println("Items Consumed = " + itemsConsumed)
    println("Sum = " + result)
  }
  ...
}
```

Coroutines Example

```
object ProducerConsumerCoroutine {
  ...
  def producer(numItems: Int, queue: util.Queue[Long]) = {
    var itemIndex = 1
    while (itemIndex <= numItems) {
      queue.offer(itemIndex); yieldTo("consumer")
      itemIndex += 1
    }
    queue.offer(-1); yieldTo("consumer")
  }
  def consumer(queue: util.Queue[Long]): (Int, Long) = {
    var (itemsConsumed, itemsSum) = (0, 0L)
    var item = queue.poll()
    while (item != -1) {
      itemsConsumed += 1; itemsSum += item
      yieldTo("producer")
      item = queue.poll()
    }
    (itemsConsumed, itemsSum)
} }
```

Class Exercise:
Write Code for Example control flow



Iterator Example

```
object FibonacciGeneratorCoroutine {
  def printFib(numItems: Int) = {
    var itemIndex = 1
    while (itemIndex <= numItems) {
      yieldTo("fib")
      itemIndex += 1
    }
  }
  def fib() = {
    var f1 = 1; println(f1); yieldToCaller()
    var f2 = 1; println(f2); yieldToCaller()
    while (true) {
      val f3 = f1 + f2; f1 = f2; f2 = f3
      println(f3); yieldToCaller()
    }
  }
  ...
}
```

Observation

- Any subroutine can be translated to a coroutine which does not call *yield*.
- Coroutines are more general than subroutines!

Implementation Details

- Rely on Scala's support for Delimited Continuations using `shift/reset` (http://infoscience.epfl.ch/record/149136/files/icfp113-rompf.pdf)
- Taught in COMP 411: Continuations and Continuation-passing style transforms

Current motivations for Coroutines

- Mainly in the Concurrency/Parallelism world
  - Use coroutines to build efficient runtimes
- Overcoming the limitations of a single-threaded process
- Achieve better computational performance

Concurrent/Parallel Programming

- Most current runtimes rely on O/S-level threads to execute work in parallel
- Ideally execute one-thread (worker) per core
- No overheads from thread context switches

Issues with OS Threads
Blocking Operations

- When worker encounters blocking operation =>
  - Spawn another worker to maintain parallelism
- E.g. One thread each for the producer and consumer
- Not scalable when we have hundreds of interacting producers and consumers!

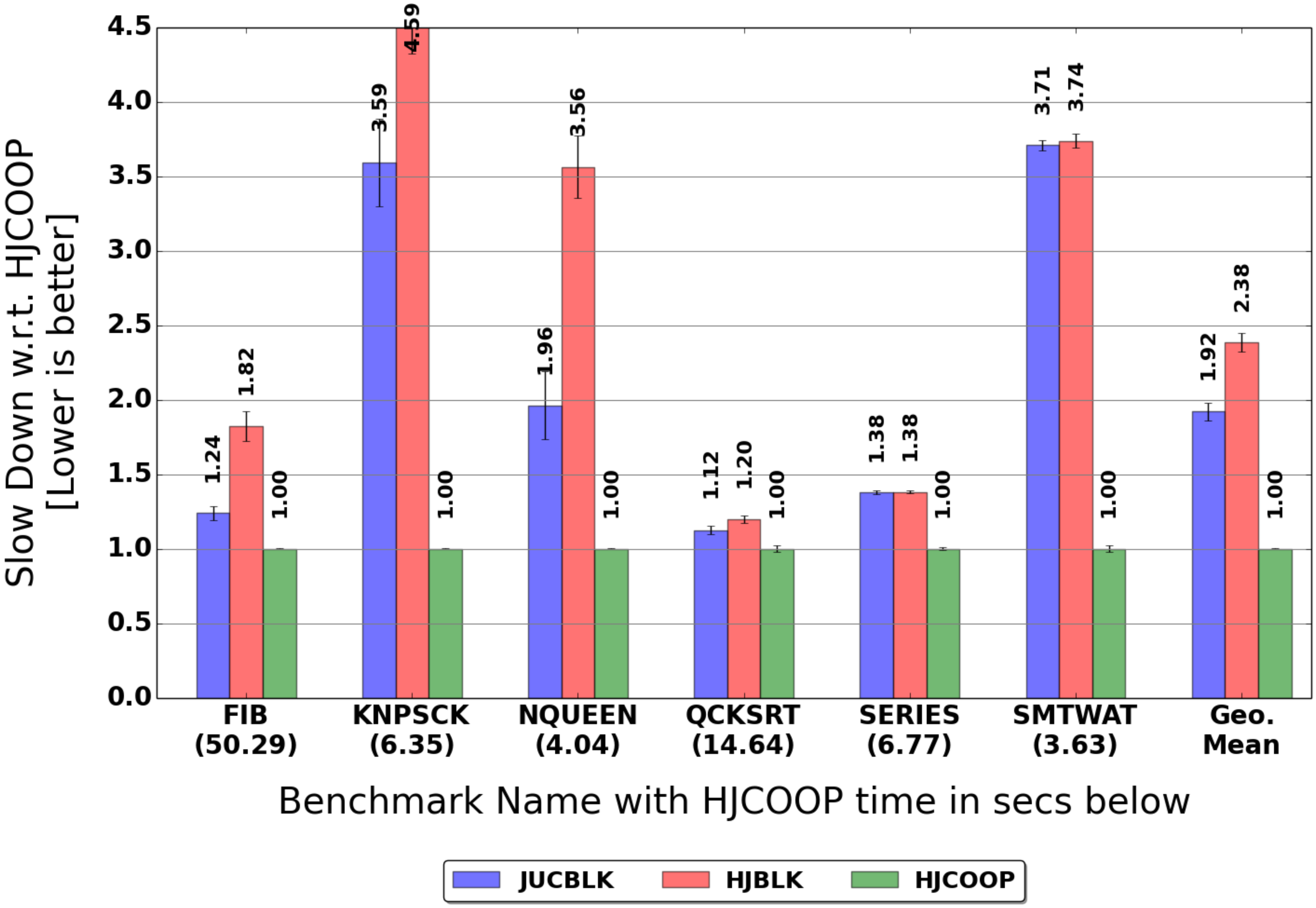
Concurrent Programming

- Coroutines as user-level threads
  - Another level of abstraction
  - Process => OS Threads => User-level threads
  - Context switch of coroutines is much cheaper
- Concurrent Scheduler
  - Manages interactions between coroutines
  - Determines when to resume coroutines

Learn more about use of Coroutines in COMP 322

- Habanero-Java library uses Coroutines to implement its Cooperative runtime
- Users write programs unaware of presence of Coroutines
  - Compiler and runtime uses Coroutines behind the scenes

Coroutines Performance Gains



Acknowledgments

- http://stackoverflow.com/questions/24780935/difference-between-subroutine-co-routine-function-and-thread
- https://en.wikipedia.org/wiki/Coroutine#Comparison_with_subroutines
- http://jim-mcbeath.blogspot.com/2010/09/scala-coroutines.html
- https://www.cs.purdue.edu/homes/suresh/390C-Spring2012/lectures/Lecture-2.pdf