Actors that Unify Threads and Events

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Implementing Concurrent Processes

1. Thread-based
   - Behavior = body of designated method
   - Execution state = thread stack
   - *Examples:* Java threads, POSIX threads
2. Event-based
   - Behavior = set of event handlers
   - Execution state = object shared by handlers
   - *Examples:* Java Swing, TinyOS

Threads

[Ousterhout96]

- Support multiple hardware cores (Good)
- Behavior = sequential program (Good)
- Heavyweight (Bad)
  - High memory consumption
    - Pre-allocated stacks
  - Lock contention bottleneck
- Synchronization using locks error-prone, not composable (Bad)

Events: Remedy?
[vonBehren03]

- Lightweight (Good)
  - Multiple events interleaved on single thread
  - Low memory consumption
- Automatic synchronization (Good)
- No hardware support (Bad)
- Inversion of control (Bad)
  - Behavior != sequential program

Rest of this Talk

- Programming with Actors in Scala
- Unifying Threads and Events
  - Programming Model
  - Lightweight Execution Environment
- Composing Actors
- Selective Communication
- Experimental Results

Actors

- Model of concurrent processes introduced by Hewitt and Agha
- Upon reception of a message, an actor may
  - send messages to other actors
  - create new actors
  - change its behavior/state
- Most popular implementation: Erlang
- But: No widespread adoption in languages for standard VMs (e.g. JVM, CLR)

Actors in Scala

- Two principle operations (adopted from Erlang)

```
actor ! message                     // message send

receive {                           // message receive
  case msgpat_1 => action_1
  ...
  case msgpat_n => action_n
}
```

- Send is asynchronous; messages are buffered in actor's *mailbox*
- `receive` waits for message that matches any of the patterns `msgpat_i`

Example: Producers

- Producers act like iterators, generate values *concurrently* with consumer:

```
class InOrder(n: IntTree) extends Producer[Int] {
  def produceValues = traverse(n)
  def traverse(n: IntTree) = if (n != null) {
    traverse(n.left)
    produce(n.elem)
    traverse(n.right) } }
```

- Methods `produceValues` (abstract) and `produce` inherited from class `Producer`

Implementing Producers

Producers are implemented in terms of two actors.

1. The *producer* actor runs `produceValues`:

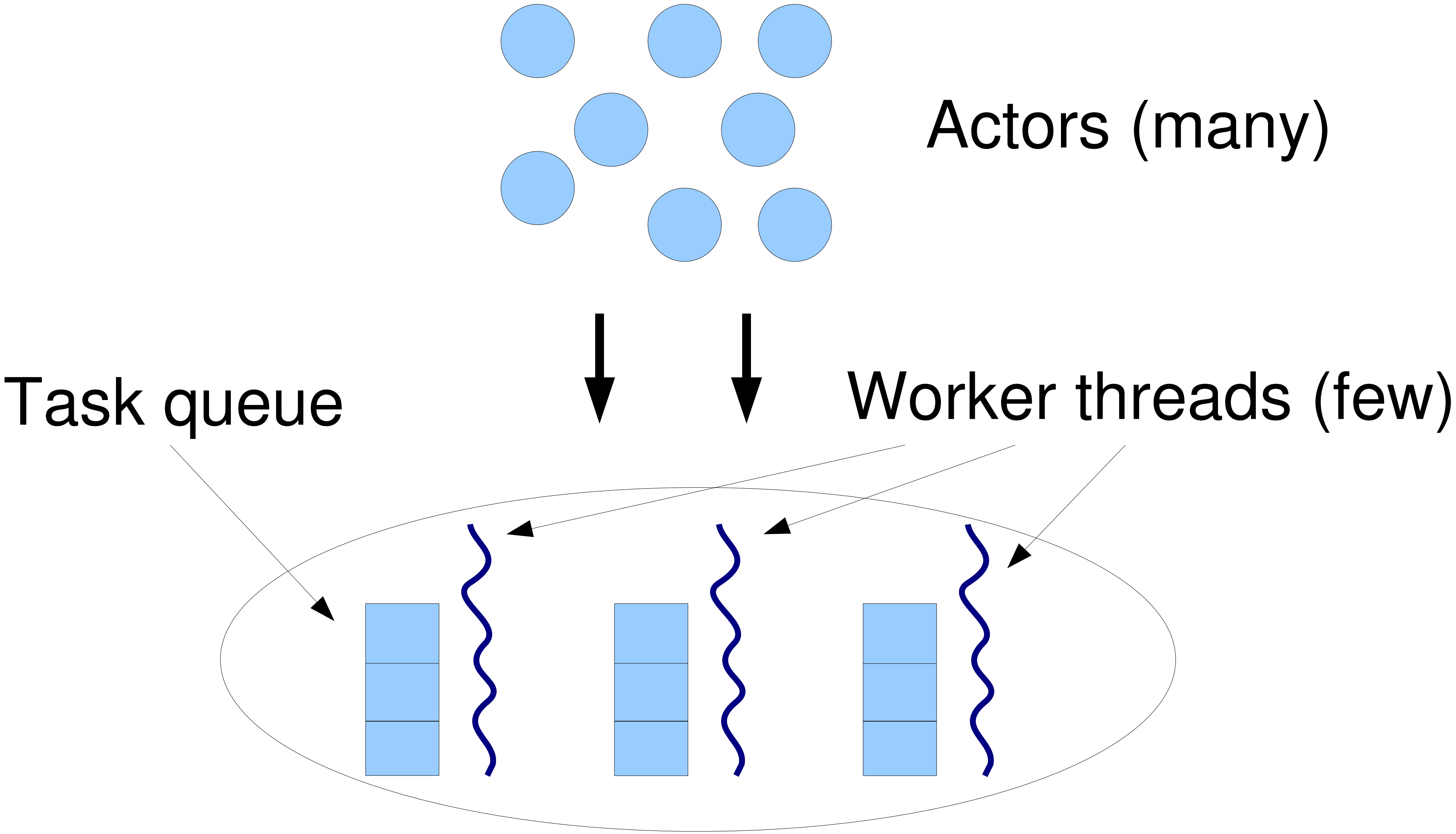
```
abstract class Producer[T] extends Iterator[T] {
  def produceValues: Unit
  def produce(x: T) {
    coordinator ! Some(x)
  }
  private val producer = actor {
    produceValues; coordinator ! None
  }
}
```

Implementing Producers (2)

2. The *coordinator* actor synchronizes requests from clients and values from the producer

```
val coordinator = actor {
  while (true) {
    receive {
      case Next =>
        receive {
          case x: Option[_] => client ! x
        }
    }
  }
}
```

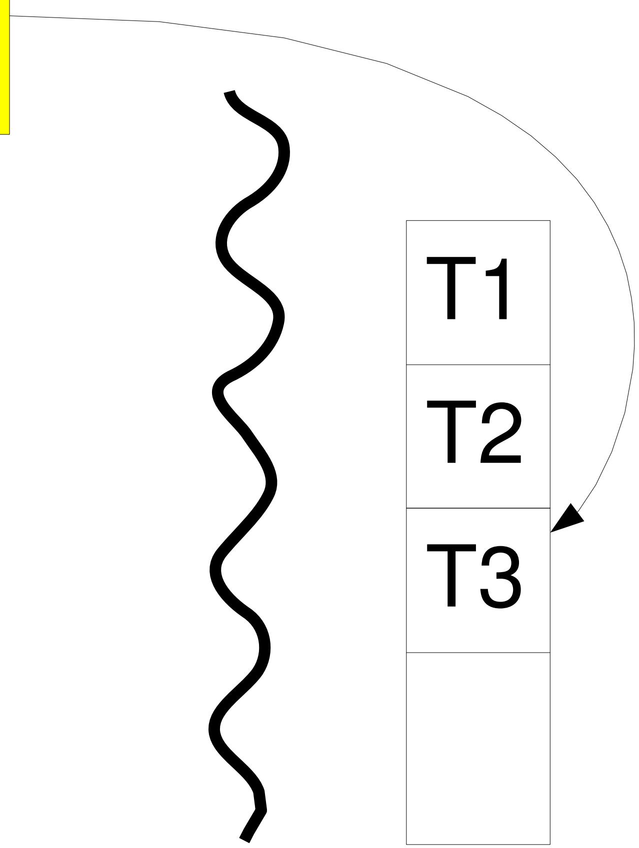
Lightweight Execution Environment



Creating Actors

```
actor
{
  // body
}
```

closure => T3



Thread Mode: `receive`

```
...
receive
{
  case Msg(x) =>
    // handle msg
}
...
```

1. Scan messages in mailbox
2. If no message matches any of the patterns, *suspend worker thread*
3. Otherwise, process first matching message

Actor remains active

Event Mode: **`react`**

```
...
react
{
  case Msg(x) =>
    // handle msg
}
```

1. Register message handler
2. Become passive (temporarily)

Actor becomes inactive

Suspend in Event Mode

Task Ti:

```
...
react
{
  case Msg(x) =>
    // handle msg
}
```

Exception:

1. Unwinds stack of actor/worker thread
2. Finishes current task

```
        // do nothing
      }
```

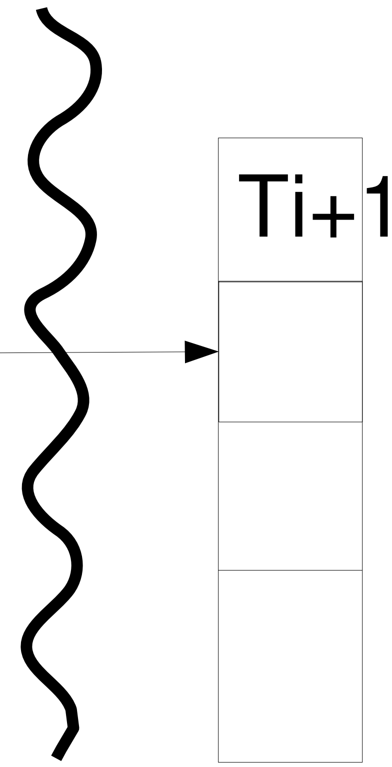
```
def react(f: PartialFunction[Any, Unit]): Nothing = {
  mailbox.dequeueFirst(f.isDefinedAt) match {
    case None => continuation = f; suspended = true
    case Some(msg) => ...
  }
  throw new SuspendActorException
}
```

Resume in Event Mode

Actor *a* waits for

```
{
  case Msg(x) =>
    // handle msg
}
```

wt executes Ti



Task Ti:

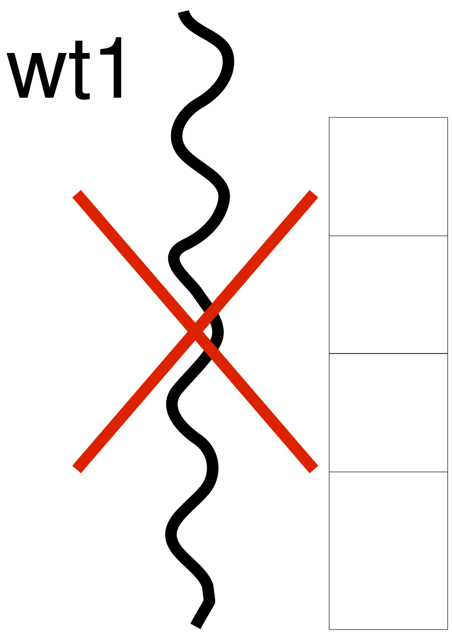
Ti+2

```
...
a ! Msg(42)
...
```

Ti+2: [yellow box] `.apply(Msg(42))`

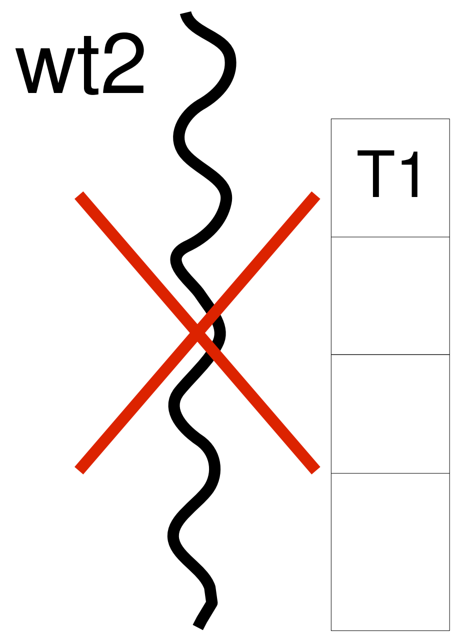
Thread Pool Resizing

A suspended in
`receive`
`{ case Msg(x) =>... }`



T1:
```
...
A ! Msg(x)
...
```

B suspended
in library (e.g. wait())



Executing T1 would unblock wt1!

Implementing Producers (3)

Economize one thread in Producer by changing `receive` in the coordinator actor to `react`

```
val coordinator = actor {
  loop {
    react {
      case Next =>
        react {
          case x: Option[_] => client ! x
        }
    }
  }
}
```

Composing Actors

- Composing event-driven code non-trivial
  - `react` may *unwind stack* at any point
  - Normal sequencing does not work
- Composition operators for common uses
  - `a andThen b` runs `a` followed by `b`
  - `def loop(body: => Unit) = body andThen loop(body)`

Channels

```
trait OutputChannel[-Msg] {
  def !(msg: Msg): Unit
  def forward(msg: Msg): Unit
}
trait InputChannel[+Msg] {
  receive[R](f: PartialFunction[Msg, R]): R
  react(f: PartialFunction[Msg, Unit]): Nothing
  ...
}

class Channel[Msg] extends InputChannel[Msg]
                   with OutputChannel[Msg]

trait Actor extends OutputChannel[Any] {
  ...
}
```

Selective Communication

- Generalize `receive`/`react`:

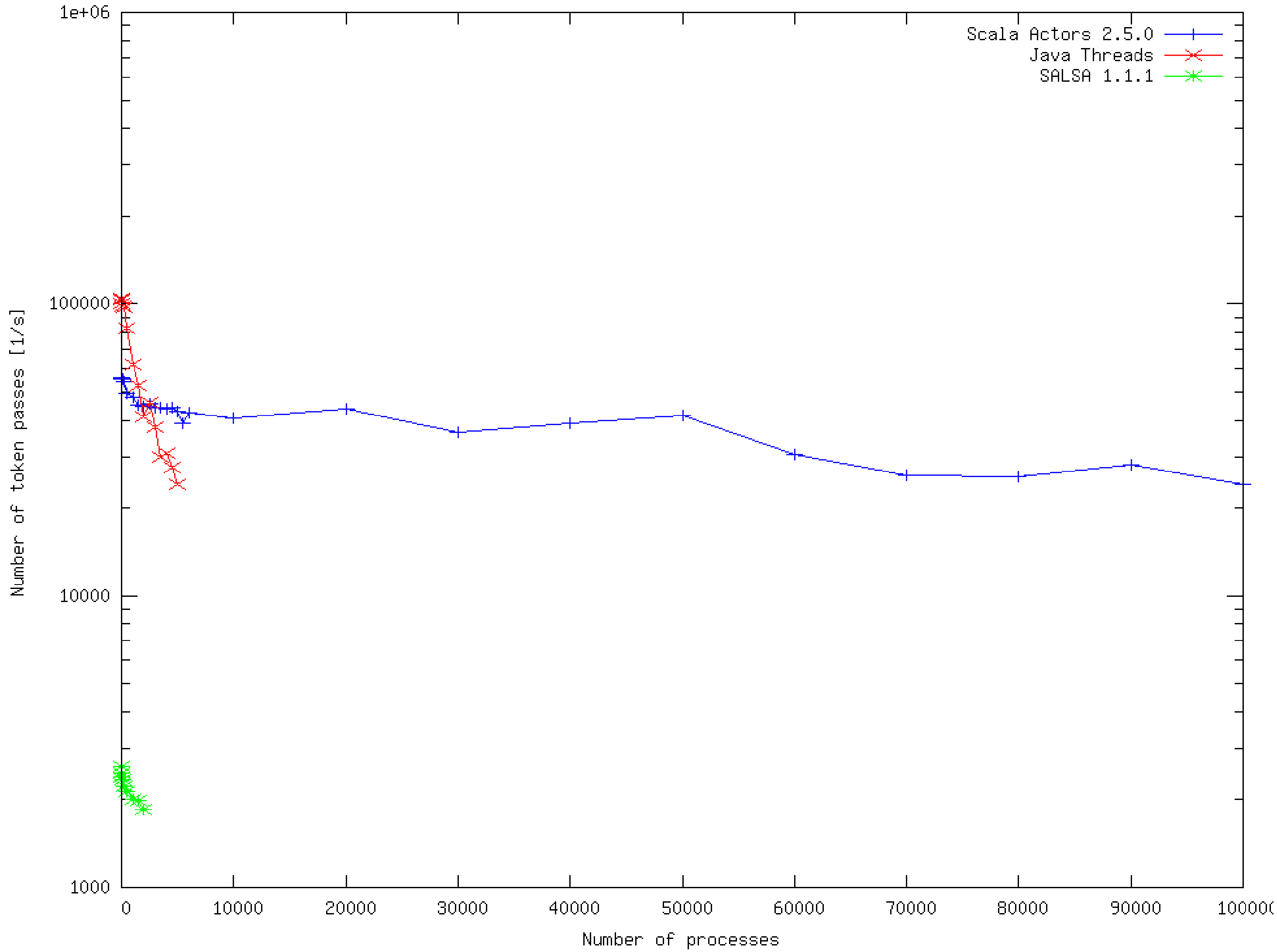
```
receive {
  case DataCh ! data => ...
  case CtrlCh ! cmd => ...
}
```

- Composing alternatives using `orElse`:

```
receive {
  case DataCh ! data => ...
  case CtrlCh ! cmd => ...
} orElse super.reactions
```

Experimental Results

Number of token passes per second in ring of processes.



Conclusion

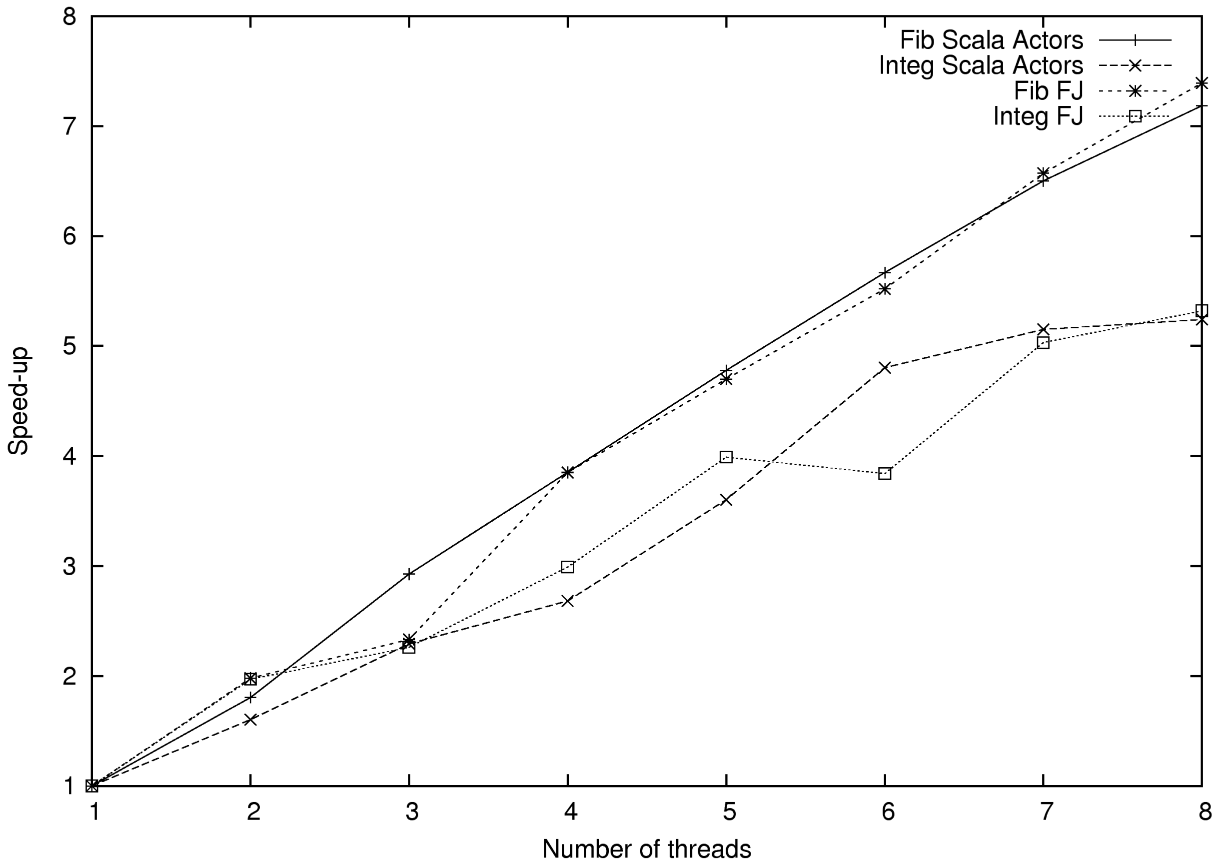
- Threads and events can be unified under an abstraction of actors
- `receive`/`react` allows programmers to trade-off efficiency for flexibility
- Implemented in **Scala Actors** library (`http://www.scala-lang.org/`)
- Real-world usage: *lift* web framework

Thread Pool Resizing (2)

(cf. SEDA [Welsh01])

- Sample task queue
- Add thread when queue length exceeds threshold (up to max. number of threads)
- Remove thread when idle for specified period of time

Experimental Results (2)



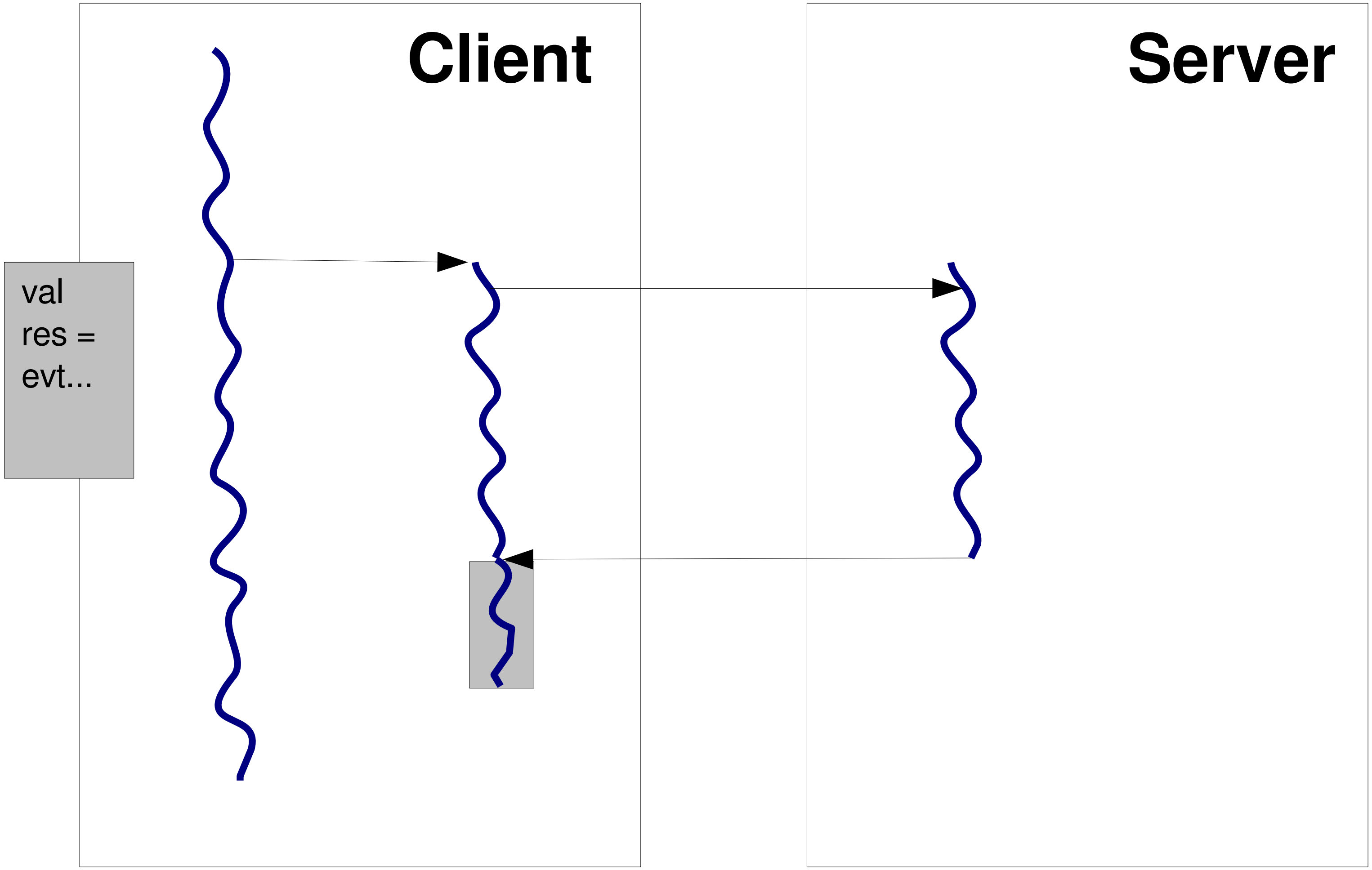
- Micro benchmarks run on 4-way dual-core Opteron machine (8 cores total)
- Compared to Doug Lea's FJTask framework for Java

Programming with Events

```
def httpFetch(queryURL: String) = {
  val req = new XmlHttpRequest
  req.addOnReadyStateChangedListener(new PropertyChangeListener() {
    override def propertyChange(evt: PropertyChangeEvent) {
      if (evt.getNewValue() == ReadyState.LOADED) {
        val response = req.getResponseText()
        httpParseResponse(response)
      }
    }
  })
  try {
    req.open(Method.GET, new URL(queryURL))
    req.send()
  } catch {
    case e: Throwable => ...
  }
}
```

Typical asynchronous HTTP document fetch

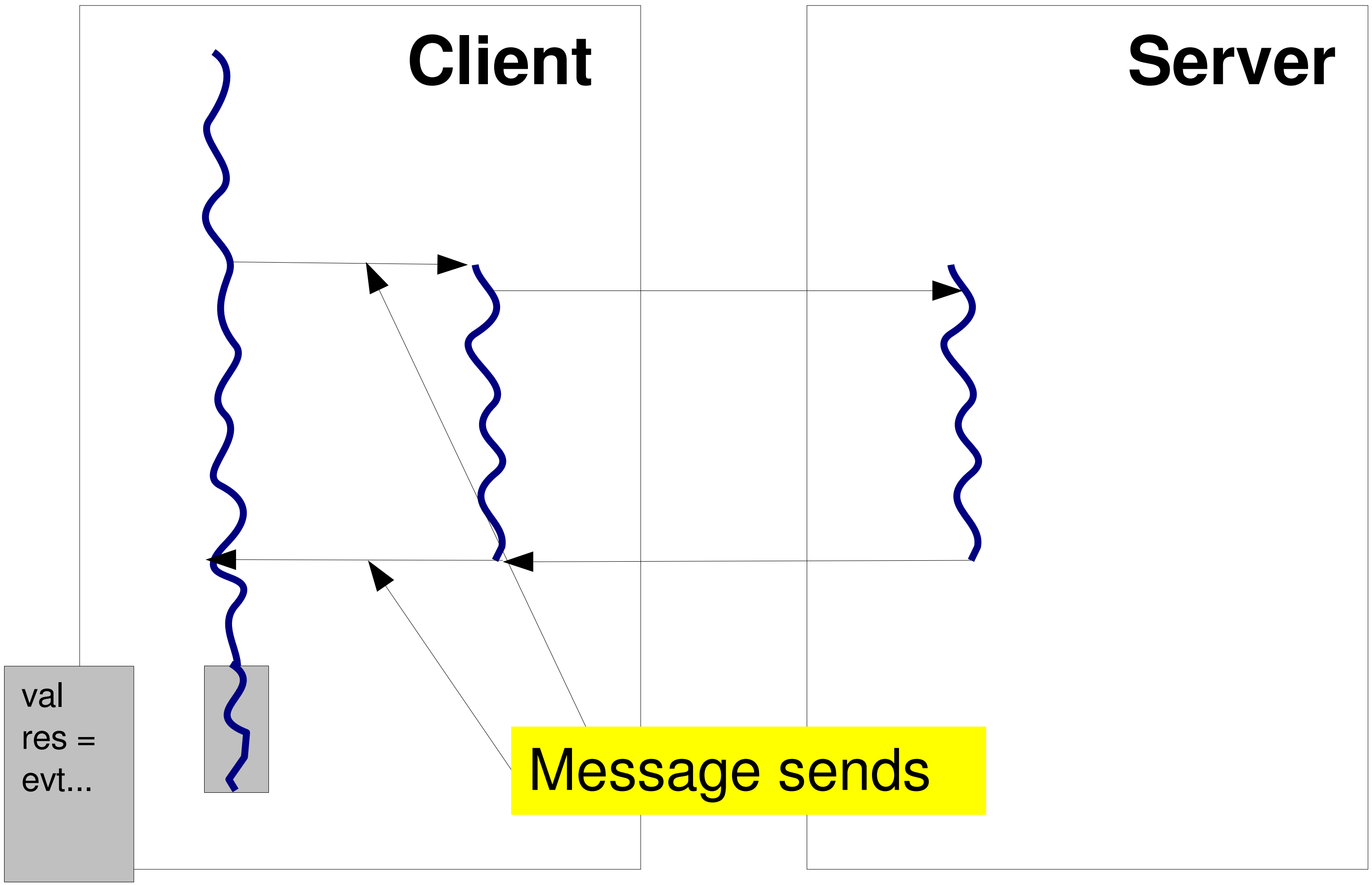
Inversion of Control



Problems of Inversion of Control

- Hard to understand control-flow
  - reconstruct entire call-graph
- Manual stack management
  - handler code *not* defined where event is handled
  - local variables, parameters etc. not accessible
- Managing resources (files, sockets) becomes *even harder*
  - often long-lived, used in several event handlers
  - when is a missing close() a leak?

Blocking-style Code



Concurrency is Indispensable

- Software is concurrent
  - Interactive applications
  - Web services
  - Distributed software
- Hardware is concurrent
  - Hyper-threading
  - Multi-cores, Many-cores
  - Grid computing