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DFScala: High Level Dataflow Support for Scala

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Workshop on Data-Flow Execution Models for Extreme Scala Computing
23 September 2012
Minneapolis

TERAFLUX

EPSRC
Engineering and Physical Sciences Research Council

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Context

- Processors with thousands cores
- Simplifying the architecture by minimising cache coherency
- Teraflux is looking at hardware architectures combining dataflow and transactional memory
- This work is looking at implementing the programming model for non-specialist, industrial programmers

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Why Dataflow?

- Simple programming model
- Implicit parallelism
- Deterministic by default
- No shared-state
- No need for cache coherency

Basics of Scala

- Martin Odersky, EPFL, 2003
- JVM language – similar look and feel, semantics, object model, concurrency model to Java
- Adds anonymous functions, pattern matching, type inference
- Data structures are immutable by default
- Several parallelism models – threads, actors, parallel collections

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Why Scala?

- Pragmatic, high-productivity
- Strong static typing, but dynamic feel through type inference
- Existing Java infrastructure and libraries
- Motivates and facilitates a functional approach, but doesn't enforce it
- A familiar language for many programmers

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DFScala Model

- Data-driven
- Coarse-grained
- Nodes are functions
- Graph is dynamic
- Graph is statically checked for type correctness
- Graphs can be nested
- Avoid pitfalls of parallelism, make dataflow simpler

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DFScala Library

- Dataflow nodes are Scala functions
- Type-safety using inference
- Nodes are runnable when the function's arguments are available
- Java thread pool
- Shared-state scheduler using software transactional memory

```
def fib(n : Int) : Int =
  if (n <= 2)
    1
  else
    fib(n-1) + fib(n-2)
```

```
def fib(n : Int, out: Token[Int]) {
  if (n <= 2)
    out(1)
  else {
    val adder = thread(
      (a: Int, b: Int, out: Token[Int]) =>
        out(a + b)
    )

    adder(Blank, Blank, out)

    thread(fib _, n - 1, adder.token1)
    thread(fib _, n - 2, adder.token2)
  }
}
```

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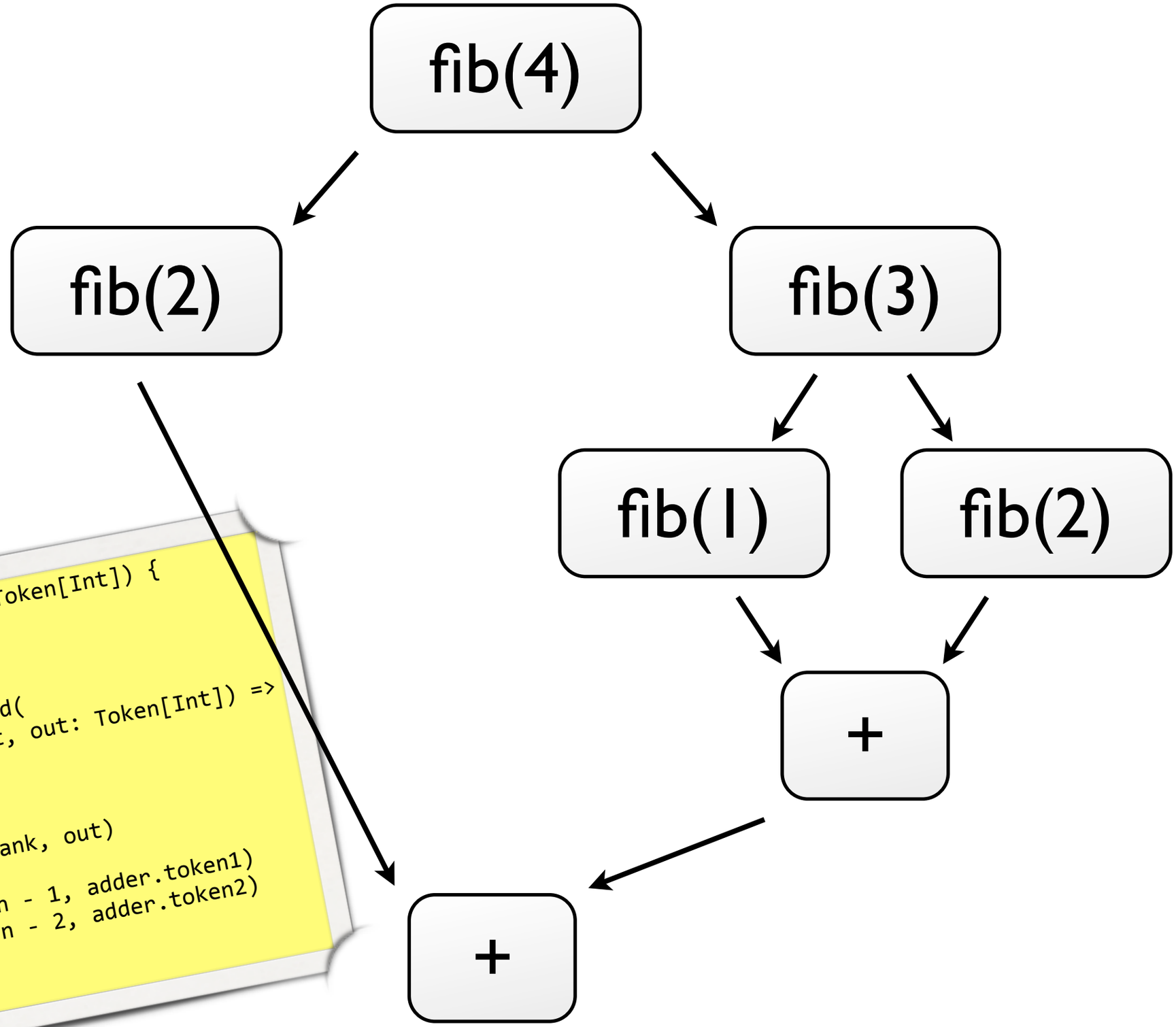
  }
}
```

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  if (n <= 2)
    out(1)
  else {
    val adder = thread(
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    )

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    thread(fib _, n - 1, adder.token1)
    thread(fib _, n - 2, adder.token2)
  }
}
```

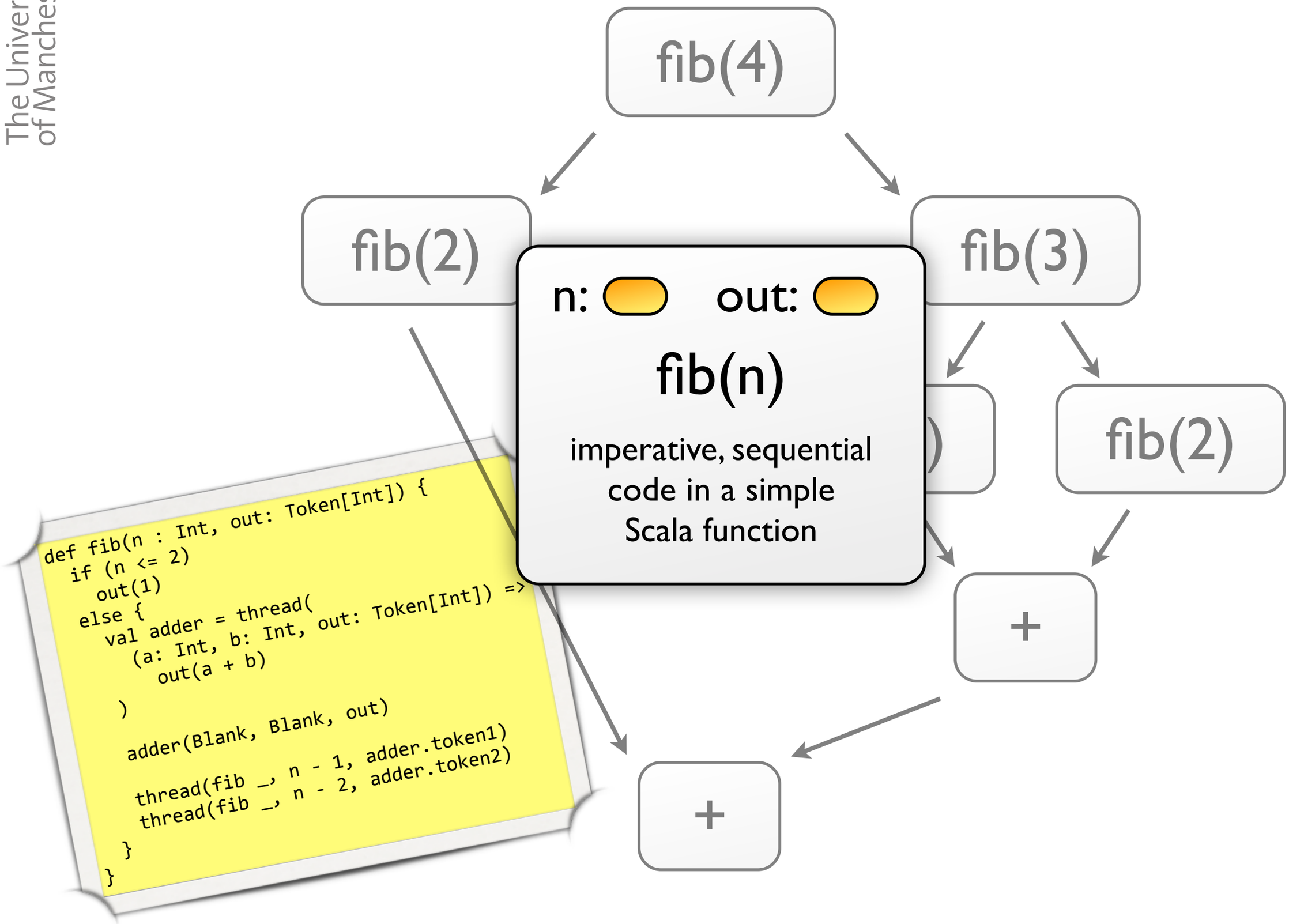

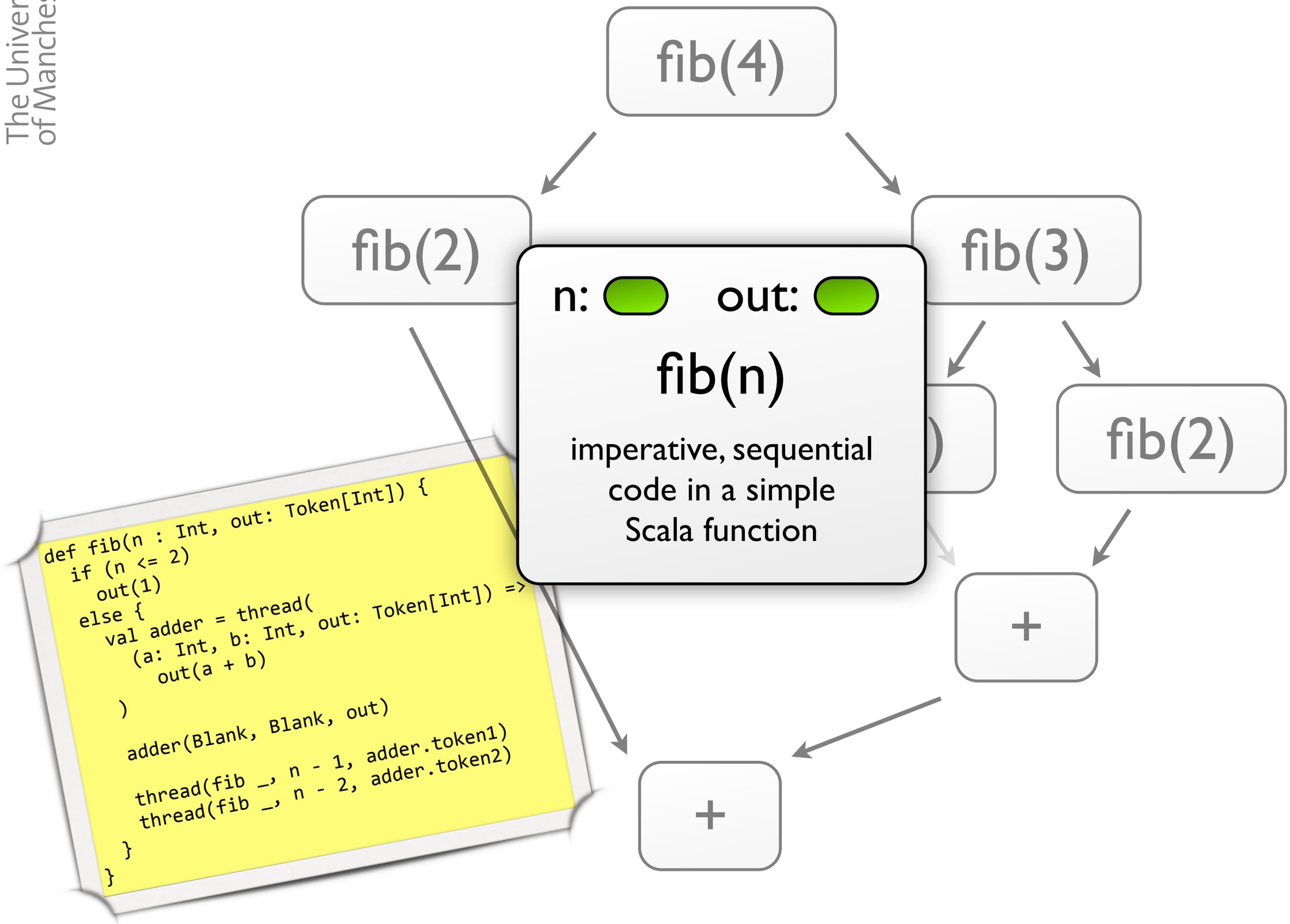
fib(4)
fib(2)
fib(3)
n:
out:
fib(n)
imperative, sequential code in a simple Scala function
fib(2)
+
+
def fib(n : Int, out: Token[Int]) {
if (n <= 2)
out(1)
else {
val adder = thread(
(a: Int, b: Int, out: Token[Int]) =>
out(a + b)
)
adder(Blank, Blank, out)
thread(fib _, n - 1, adder.token1)
thread(fib _, n - 2, adder.token2)
}
}

Benefits

- Programmers only need to worry about functions and the usual function boundaries
- Use existing arguments instead of I-structures
- No mutable state
- Graph is statically checked for type safety
- Can be used with existing code and libraries

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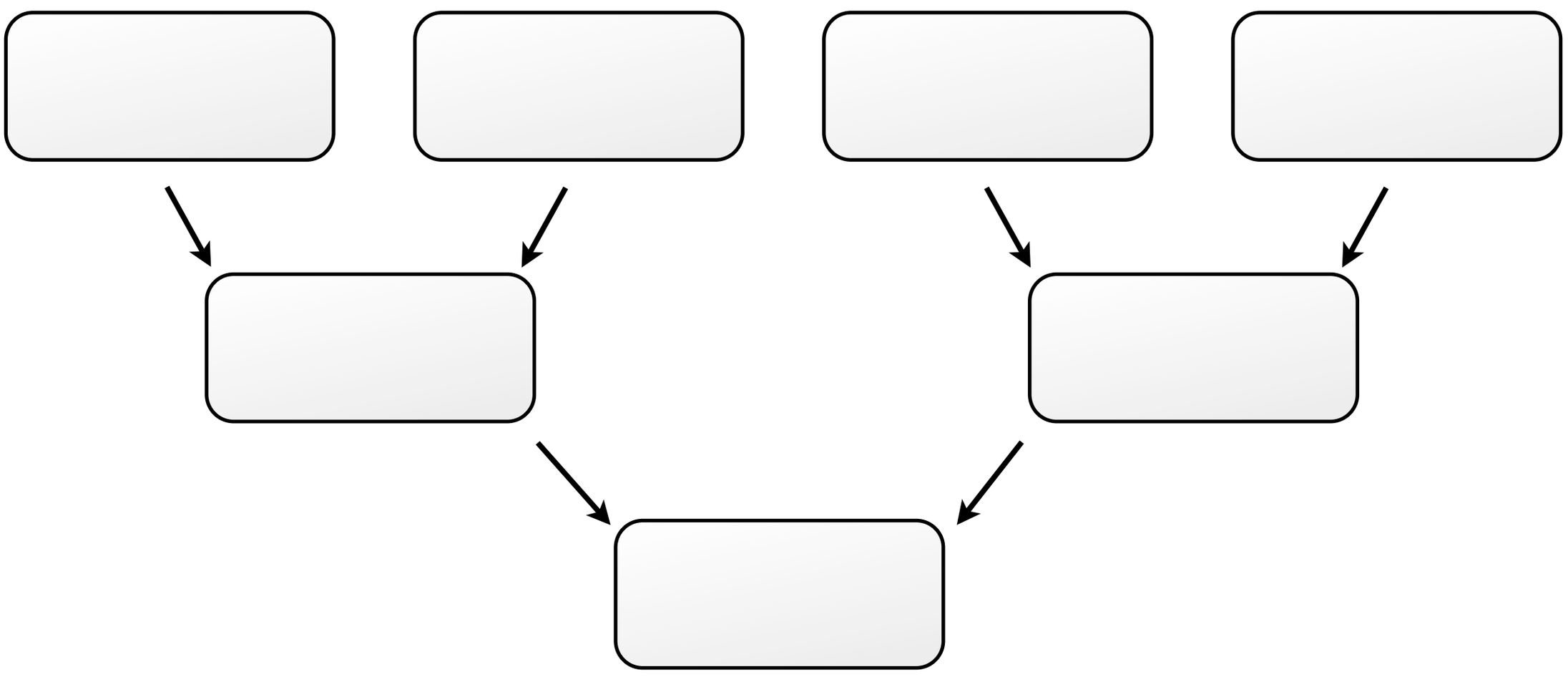
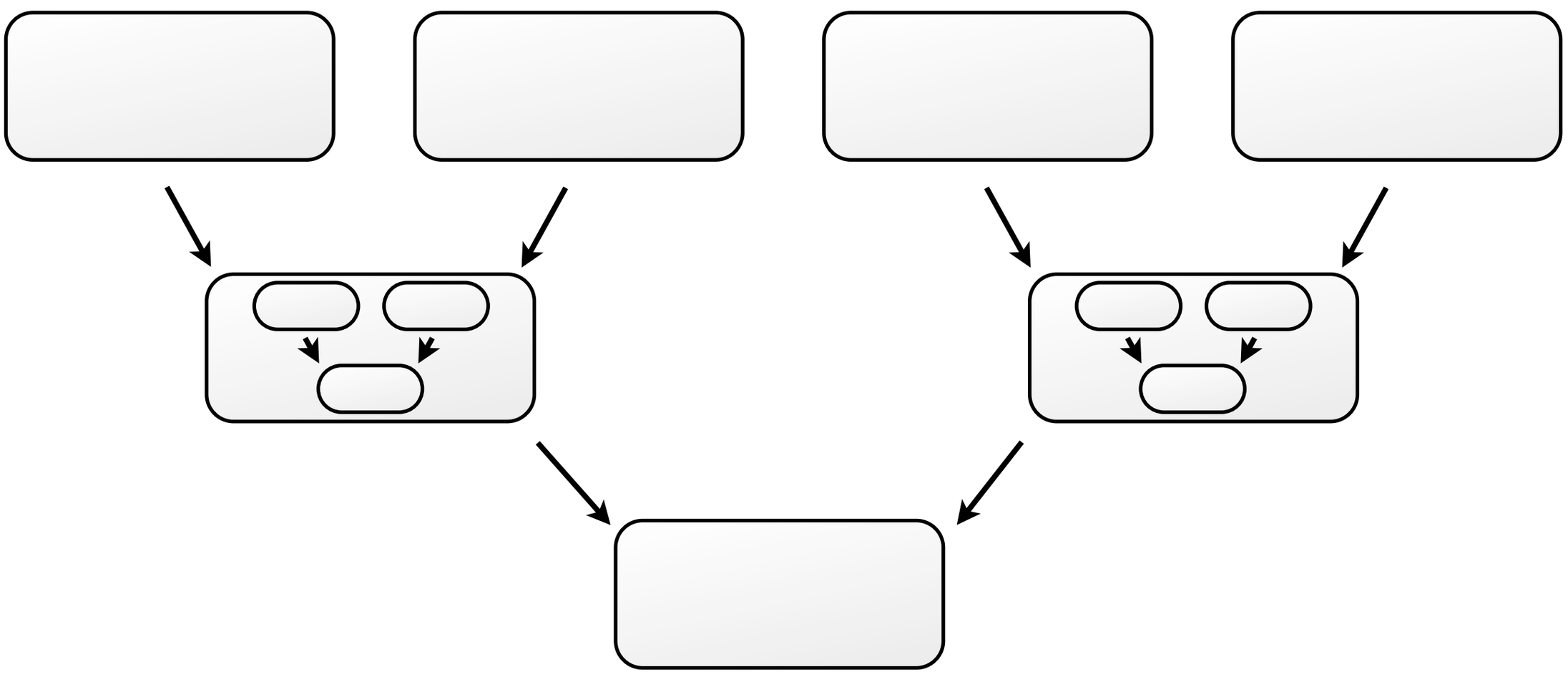
Nested Graphs

- DFScala by default does not allow for any parallelism within nodes
- Each function forming a node is entirely sequential and runs from start to finish without pauses
- As an explicit exception, dataflow graphs can be nested within nodes

Nested Graphs



Nested Graphs



Compare to Akka

- Dataflow library for Scala
- Part of a framework for large, distributed, concurrent applications (think Erlang)
- Released after we started work
- Based on the Oz model
- New concepts – dataflow variables (I-structures)
- Concurrency within functions using continuations

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Compare to Akka

```
def fib(n: Int): Int = {
  val r, a, b = Promise[Int]()
  flow { r << a() + b() }
  flow { a << fib(n - 1) }
  flow { b << fib(n - 2) }

  return r()
}
```

Compare to CNC-Scala

- Port of C++ Intel Concurrent Collections to Scala
- Also have a focus on 'parallelism oblivious developers' and productivity
- Parallelism is within collections
- Each collection element is an I-structure, dependencies between them form the dataflow graph
- Also concurrency in functions using continuations

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Comparisons

	DFScala	Akka	CNC
Dataflow	✓	✓	✓
Scala	✓	✓	✓
Dynamic	✓	✓	✓
Task parallel	✓	✓	✓
Pure Scala	✓	✓	
Special dataflow variables		✓	✓

Summary

- Focus on programmability
- Coarse-grained
- Nodes are written as Scala functions
- Edges are normal function arguments
- Real software, plus tooling, available today

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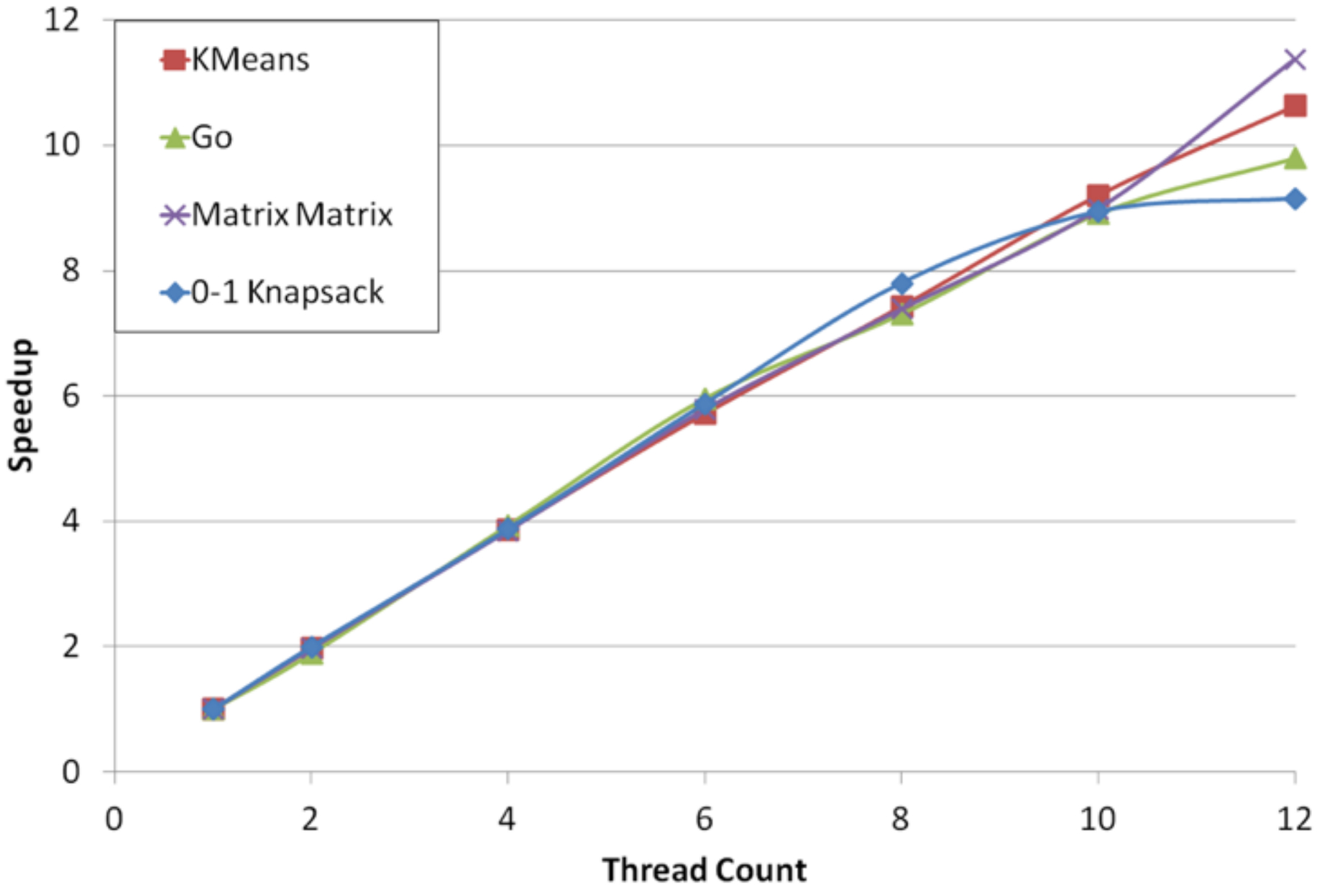
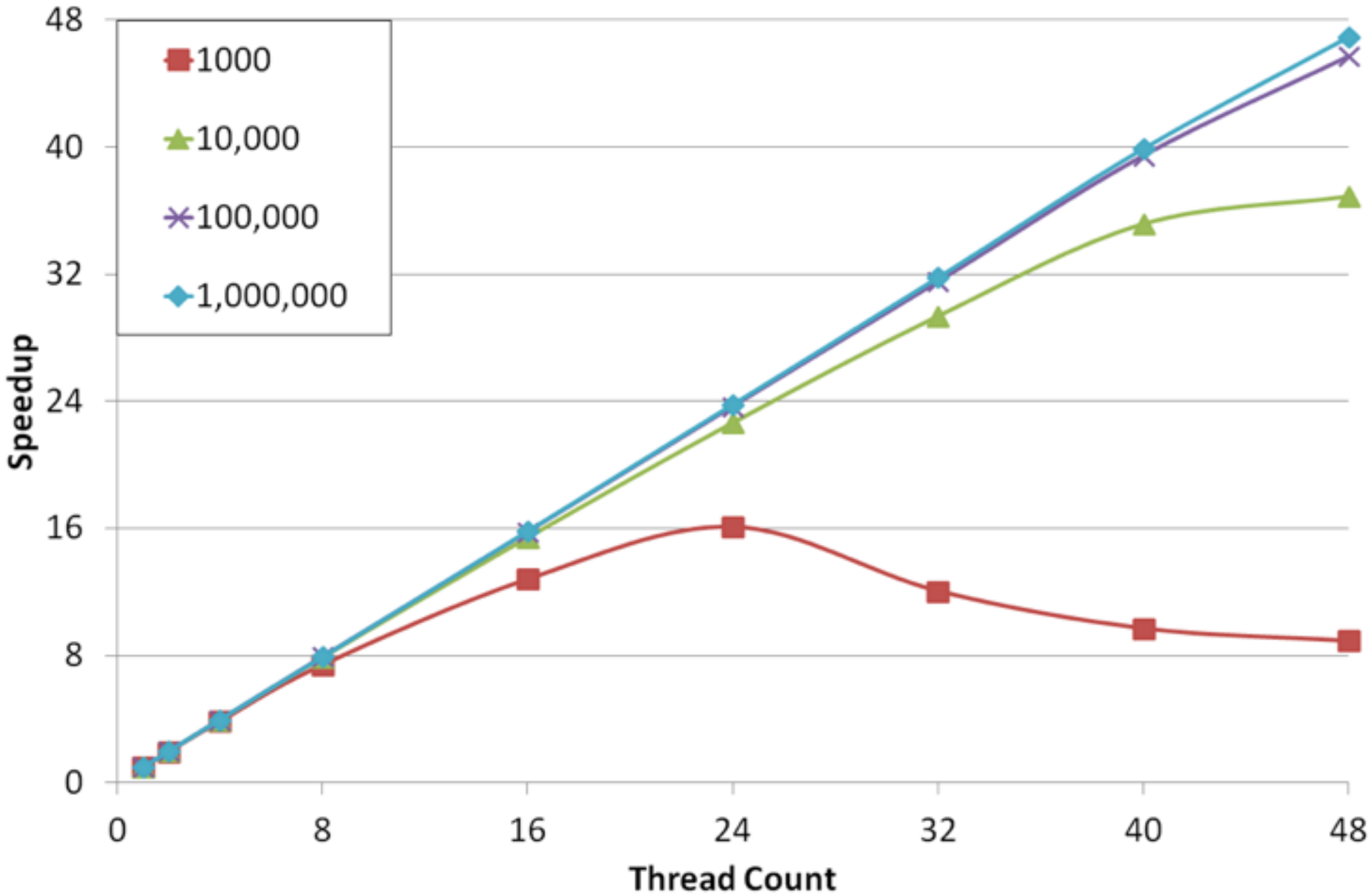
Benchmarks

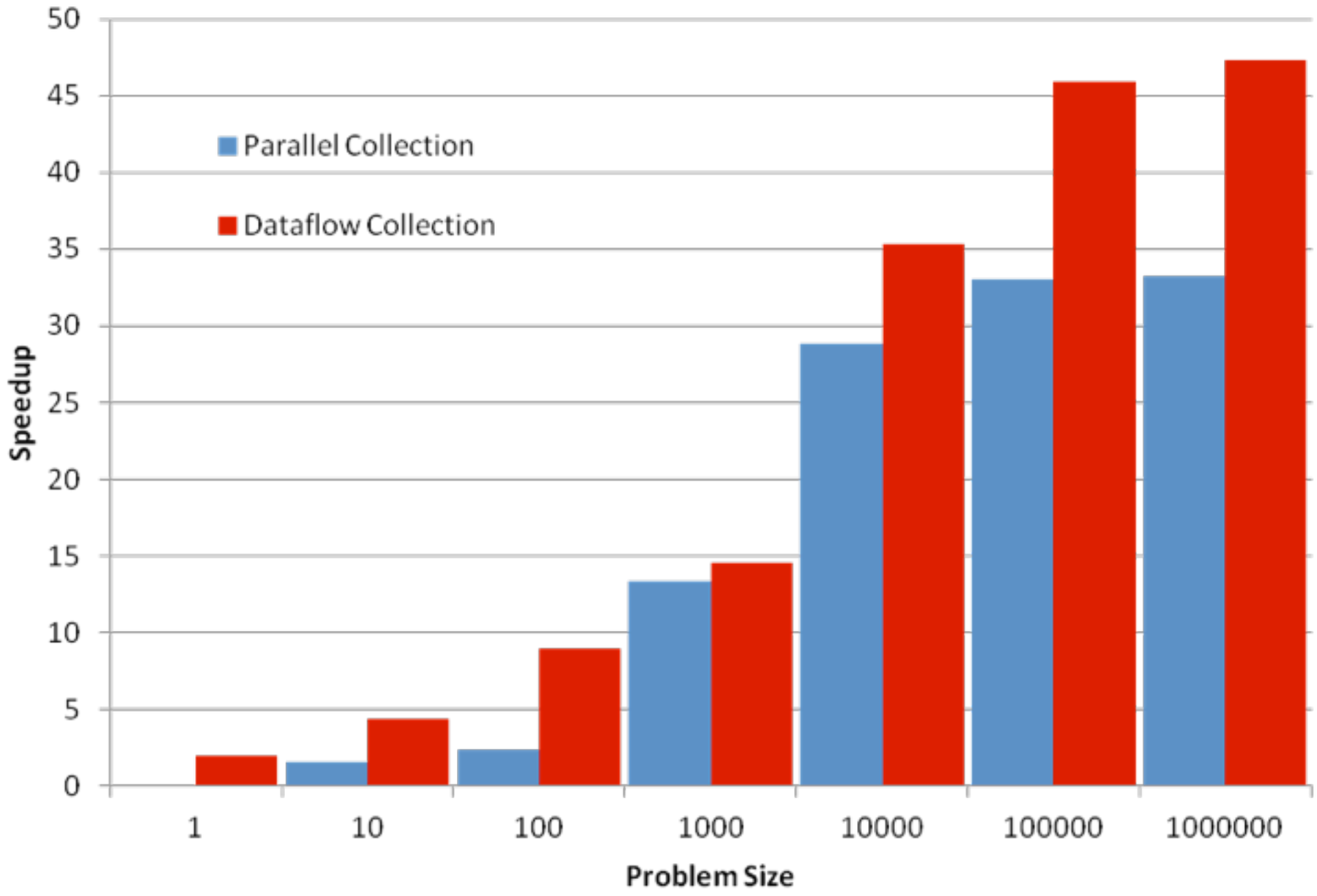
- Matrix Multiplication
- KMeans
- 0-1 Knapsack
- Go
- Parallel collections



Benchmark Speedup, 2x 6-core AMD Opteron



Collections Speedup, 4x 12-core AMD Opteron



Collections Compared to Scala Parallel Collections, 4x 12-core AMD Opteron

Tooling

- Pure Scala library
- Loggers for analysing runtime performance
- Graphical debugger

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DFScala Scope

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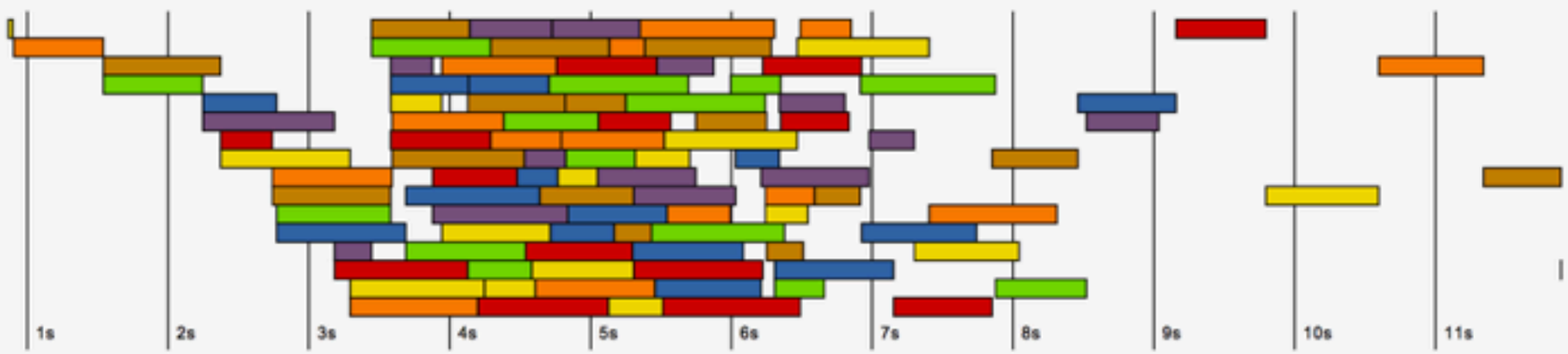
Util 34.54%

dataflow program finished
11.83s #2 finished
11.83s #2 started
11.83s #4 finished
11.83s #4 to #2 arg 1
11.28s #4 started
11.28s #10 finished
11.28s #10 to #4 arg 1
10.54s #10 started
10.54s #13 finished
10.54s #13 to #10 arg 1
9.74s #13 started
9.74s #34 finished
9.74s #34 to #13 arg 1

Thread	Parent	Received	Sent	Children	Created	Started	Finished	Duration	State
#1	root	root	#3	#2 #3	0.74s	0.81s	0.84s	0.03s	finished
#2	#1	#4			0.81s	11.83s	11.83s	0.00s	finished
#3	#1	#1	#5 #6	#4 #5 #6	0.81s	0.84s	1.48s	0.64s	finished
#4	#3	#7 #10	#2		1.48s	11.28s	11.83s	0.55s	finished
#5	#3	#3	#11 #12	#10 #11 #12	1.48s	1.48s	2.31s	0.83s	finished
#6	#3	#3	#8 #9	#7 #8 #9	1.48s	1.48s	2.18s	0.70s	finished
#7	#6	#19 #16	#4		2.18s	7.24s	7.96s	0.74s	finished
#8	#6	#6	#17 #18	#16 #17 #18	2.18s	2.19s	2.71s	0.52s	finished
#9	#6	#6	#20 #21	#19 #20 #21	2.18s	2.19s	3.12s	0.93s	finished
#10	#5	#22 #13	#4		2.31s	10.54s	11.28s	0.74s	finished



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Available Today

http://apt.cs.man.ac.uk/projects/TERAFLUX/DFScala/

or Google for 'manchester dfscala'

- Currently used in research into combining dataflow with transactional memory
- Research into irregular parallelism

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DFScala in a Nutshell

- Focus on programmability
- Coarse-grained
- Nodes are written as Scala functions
- Edges are normal function arguments
- Graphs are statically checked for type-safety
- Real software, plus tooling, available today
- Empirical results show it is scalable and can be applied to make a high performance collections library