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Applying Dataflow and Transactions to Lee Routing

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Aims

- Looking at general purpose programming on commodity systems
- Evaluate an implementation of dataflow combined with transactions
- Lee's algorithm for circuit routing as a test application
- Impact on programmability
- Speedup

Multicore as commodity, need to parallelise irregular algorithms such as Lee

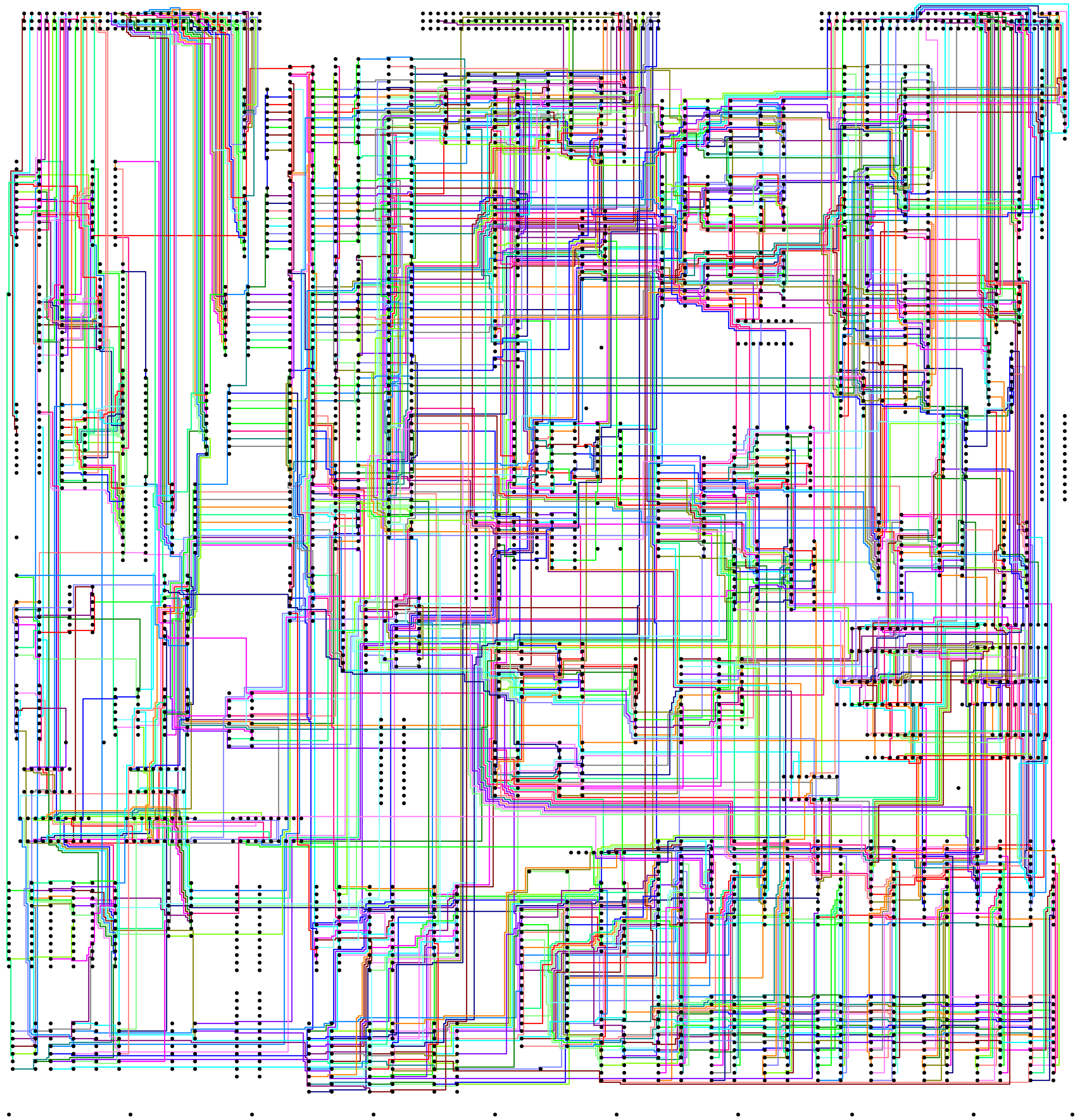
Dataflow

Creation of parallelism

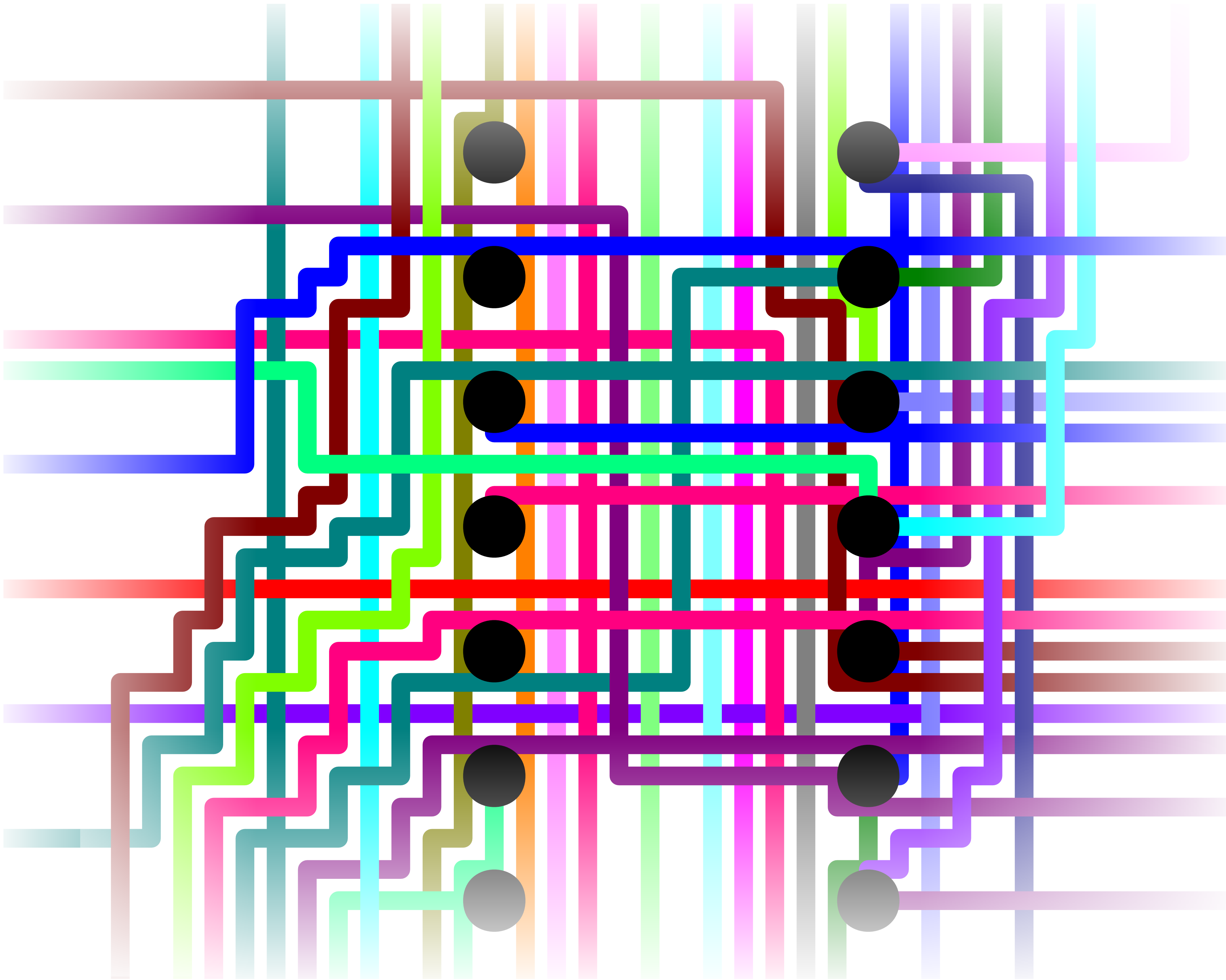
Transactions

Access to shared state

Simple implementations that achieve speedup



Example application – circuit routing



Example application – circuit routing

5	4	3	4	5	6				
4	3	2	3	4	5	6			
3	2	1	2	3	4	5	6		
2	1	S	1	2	3	4	5	6	
3	2	1	2	3	4	5	6		
4	3	2	3	4	5	6			
5	4	3	4	5	6	E			
6	5	4	5	6					
	6	5	6						
		6							

5	4	3	4	5	6				
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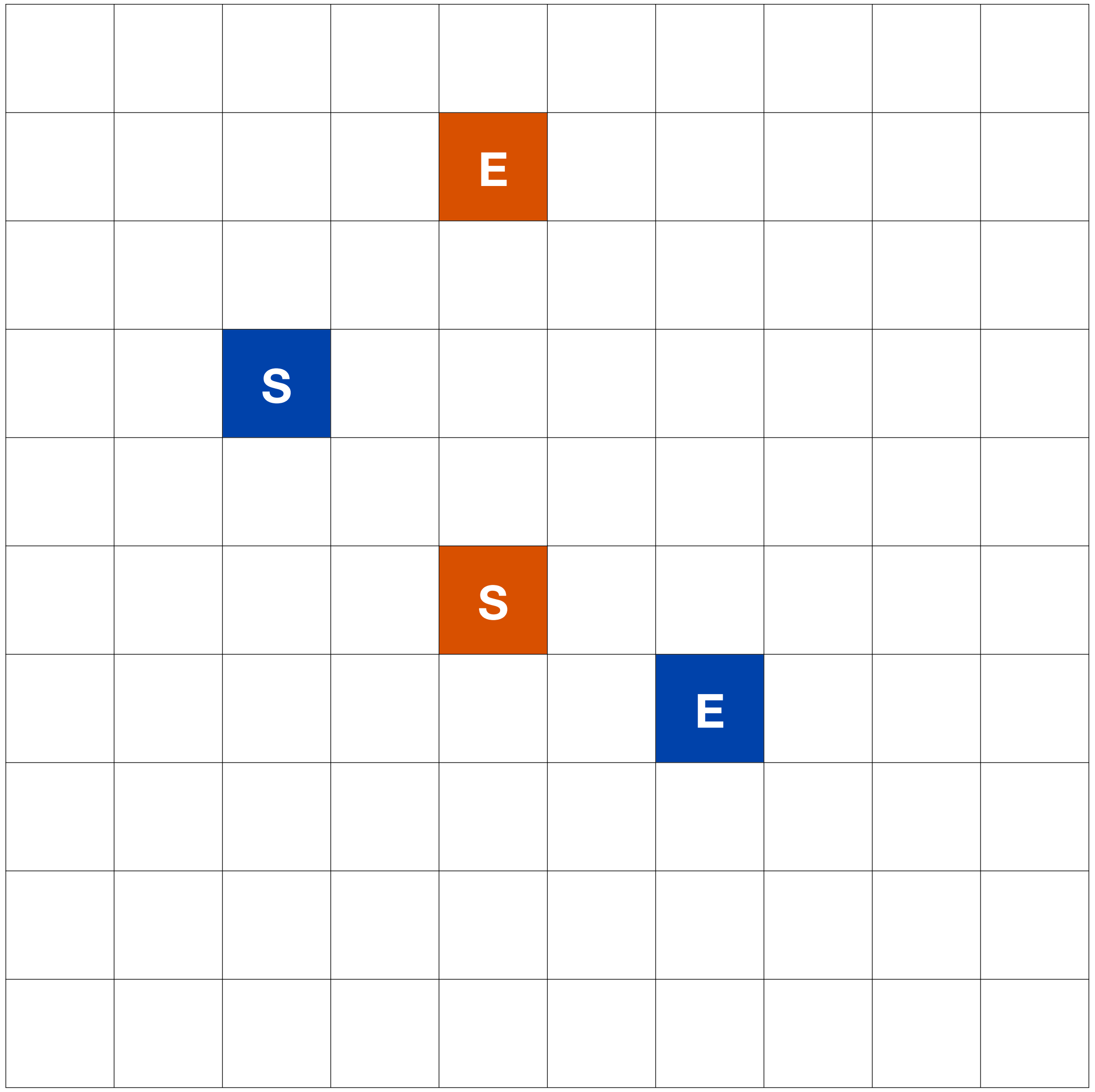
4	3	2	3	4	5	6			
5	4	3	4	5	6	E			
6	5	4	5	6					
	6	5	6						
		6							

Lee's algorithm – sequential

9	8	9							
8	7	8	9	E					
7	6	7	8	9					
6	5						9		
5	4	3	2	1	2		8	9	
4	3	2	1	S	1		7	8	9
5	4	3	2	1	2		6	7	8
6	5	4	3	2	3	4	5	6	7
7	6	5	4	3	4	5	6	7	8
8	7	6	5	4	5	6	7	8	9

9	8	9							
8	7	8	9	E					
7	6	7	8	9					
6	5						9		
5	4	3	2	1	2		8	9	
4	3	2	1	S	1		7	8	9
5	4	3	2	1	2		6	7	8
6	5	4	3	2	3	4	5	6	7
7	6	5	4	3	4	5	6	7	8
8	7	6	5	4	5	6	7	8	9

Lee’s algorithm – sequential



Lee’s algorithm – sequential

Lee’s algorithm – parallel

- Lots of routes
- Find enough independent routes
- Where on the board will a route go?
- Very difficult to lock before starting

Dataflow

- Functional
- Functions scheduled when input ready
- Pass input from function to function
- All ready functions can be run in parallel
- Supports traditional parallelism - divide and conquer

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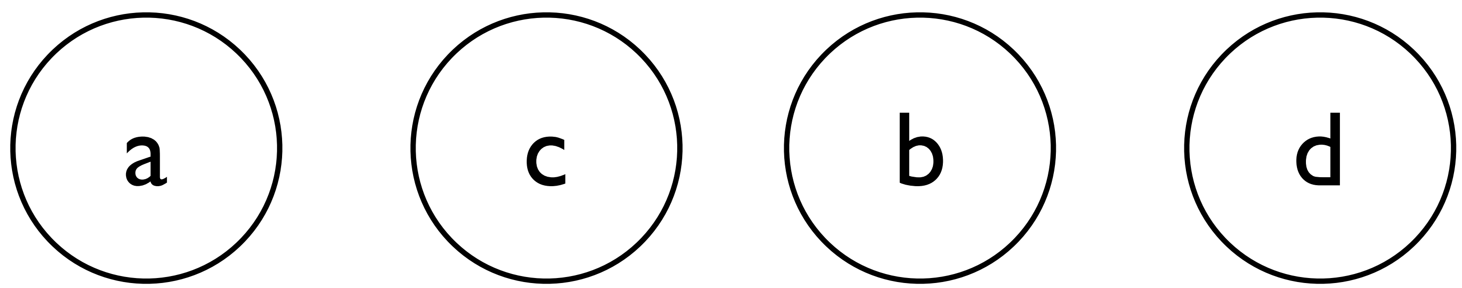
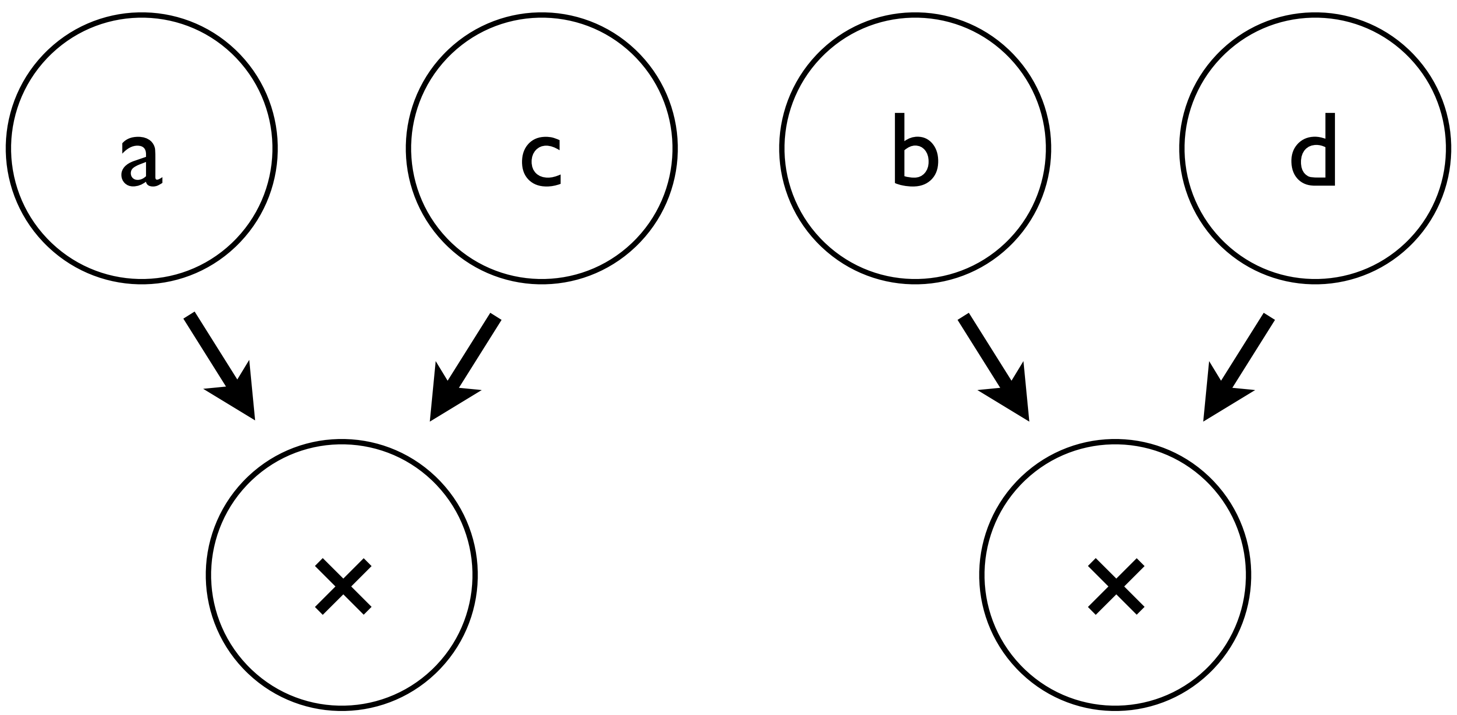
Dataflow

$$innerProduct\ (a, b)\ (c, d) = (a \times c) + (b \times d)$$



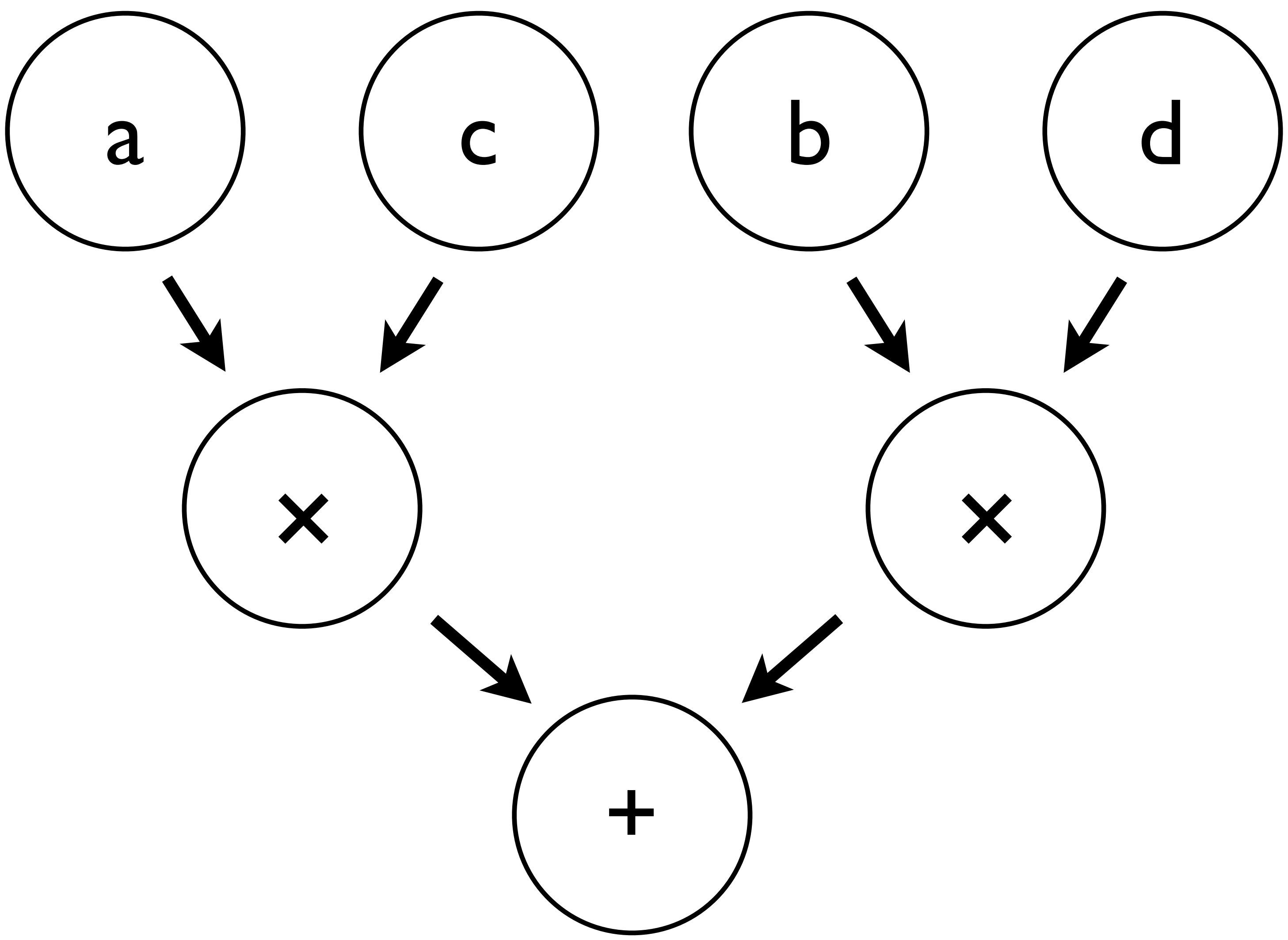
Dataflow

$$innerProduct\ (a, b)\ (c, d) = (a \times c) + (b \times d)$$



Dataflow

$$\mathit{innerProduct}\ (a, b)\ (c, d) = (a \times c) + (b \times d)$$



Transactional memory

- Semantic annotation of code that is to be executed atomically
- Often optimistic – roll back and retry
- Often implemented using locks, atomic instructions
- Suits irregular algorithms as dependencies can be handled only when they occur

Tools

- Scala
- Transactional memory: MUTS
- Dataflow: DFLib
- Teraflux project – http://www.teraflux.eu

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Implementation of Lee

- Sequential
- Coarse locked
- Transactional: MUTS
- Dataflow + transactional: MUTS + DFLib

lock
copy board state
unlock

. . . produce a solution . . .

lock

is the solution still valid:
    save it to the board
else:
    retry it later

unlock

Accessing shared state – coarse lock

atomically:
    copy board state

. . . produce a solution . . .

atomically:
    is the solution still valid:
        save it to the board
    else:
        retry it later

Accessing shared state – transactions

for each core:
    fork a new thread:
        loop while work:
            lock worklist
            take a route
            unlock

...solve the route...

            lock solutions
            add to the list of solutions
            unlock

Scheduling – threads

solutions_thread = **create collector thread** (n)

for each route:

route_thread = **create thread** (solveRoute)

route_thread.arg1 ← board

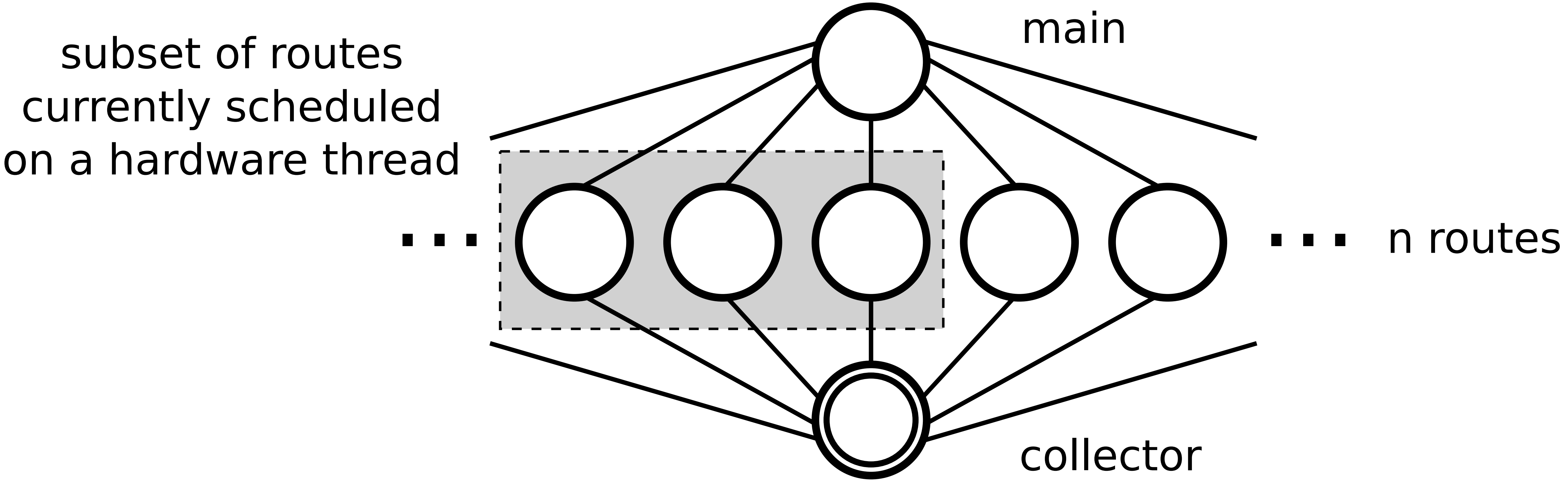
route_thread.arg2 ← route

route_thread.arg3 ← boardState

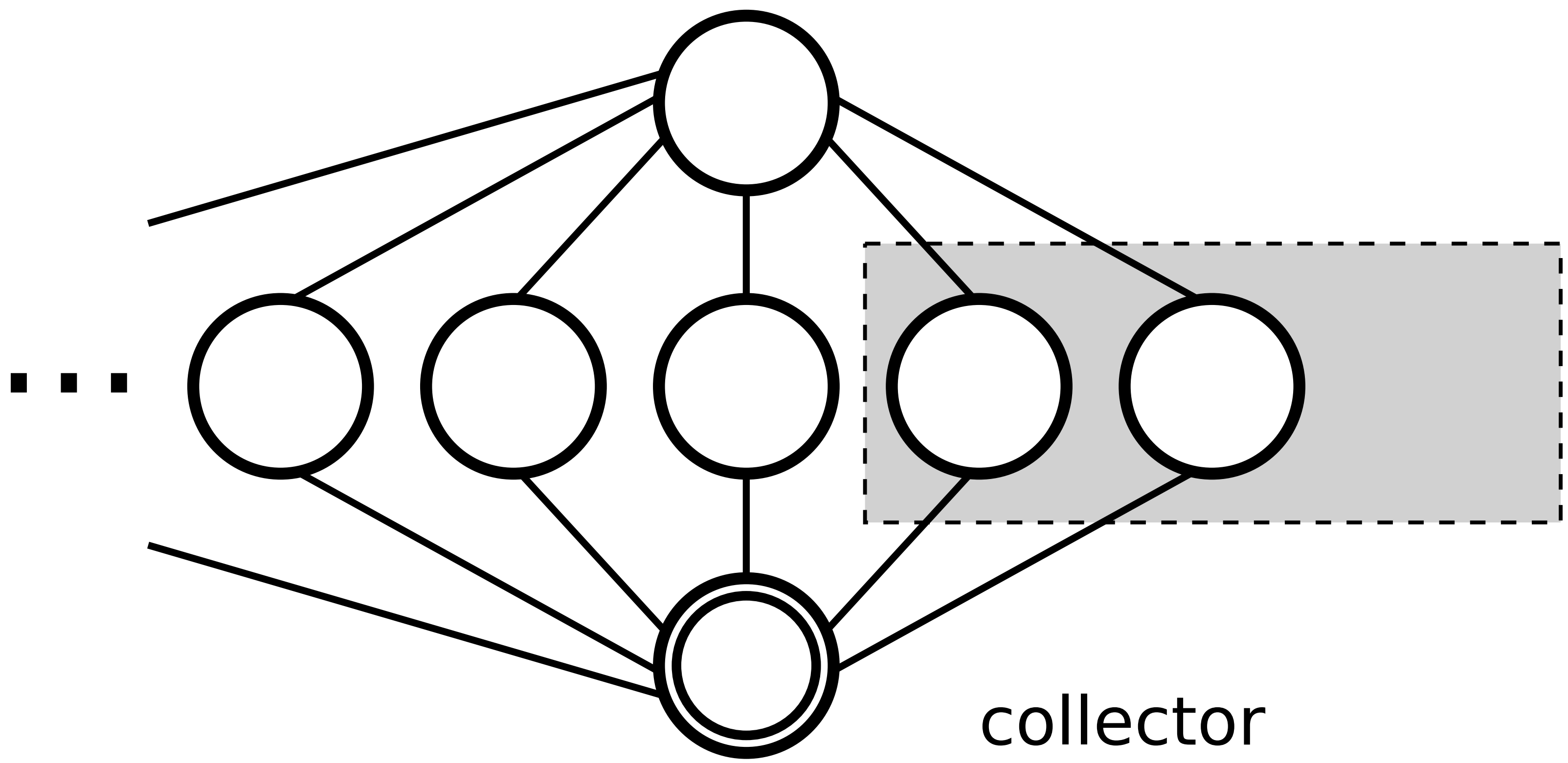
route_thread.output → solutions_thread

solutions_thread.output → …

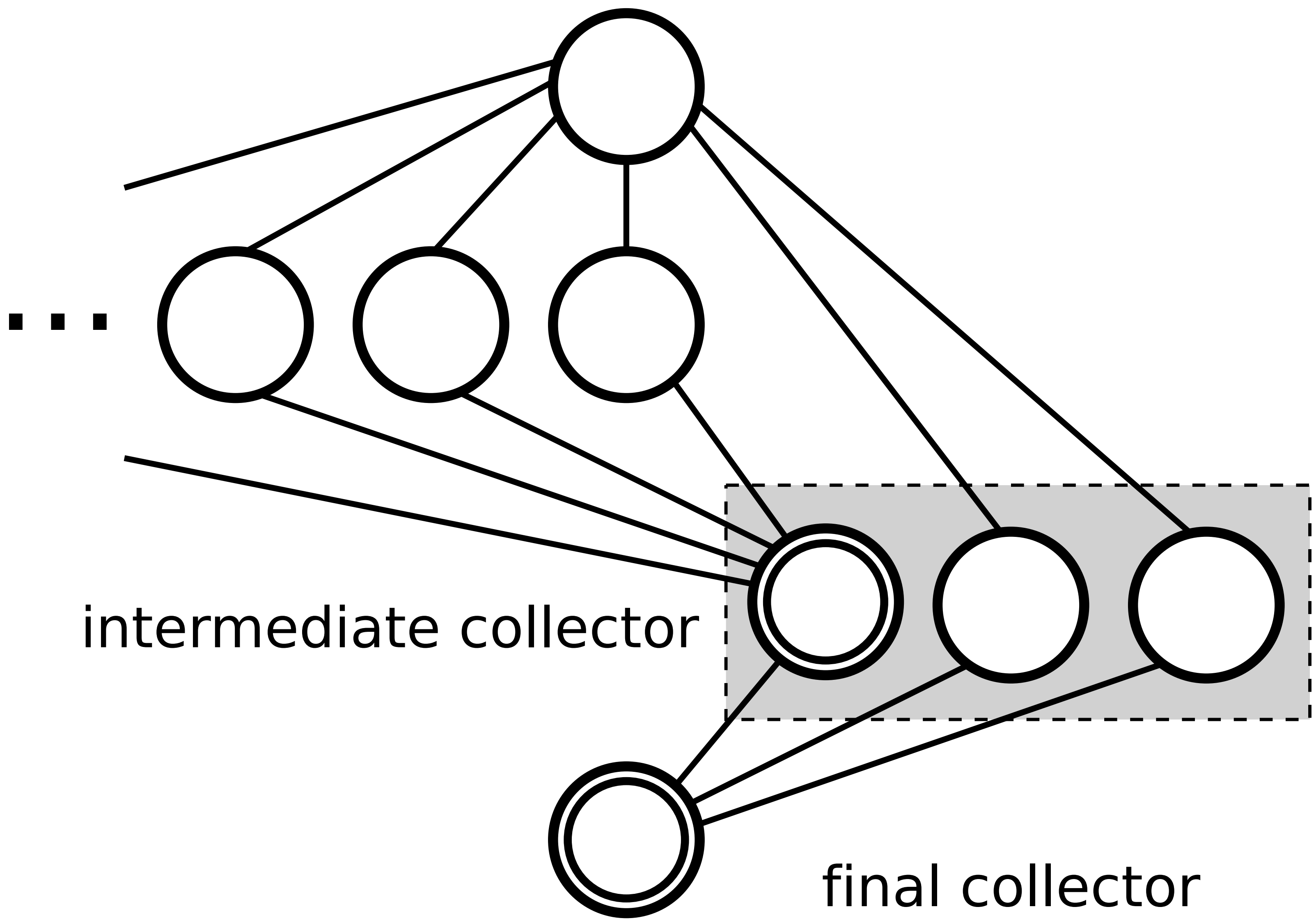
Scheduling – dataflow


subset of routes
currently scheduled
on a hardware thread
main
n routes
collector

Dataflow



Dataflow



Dataflow

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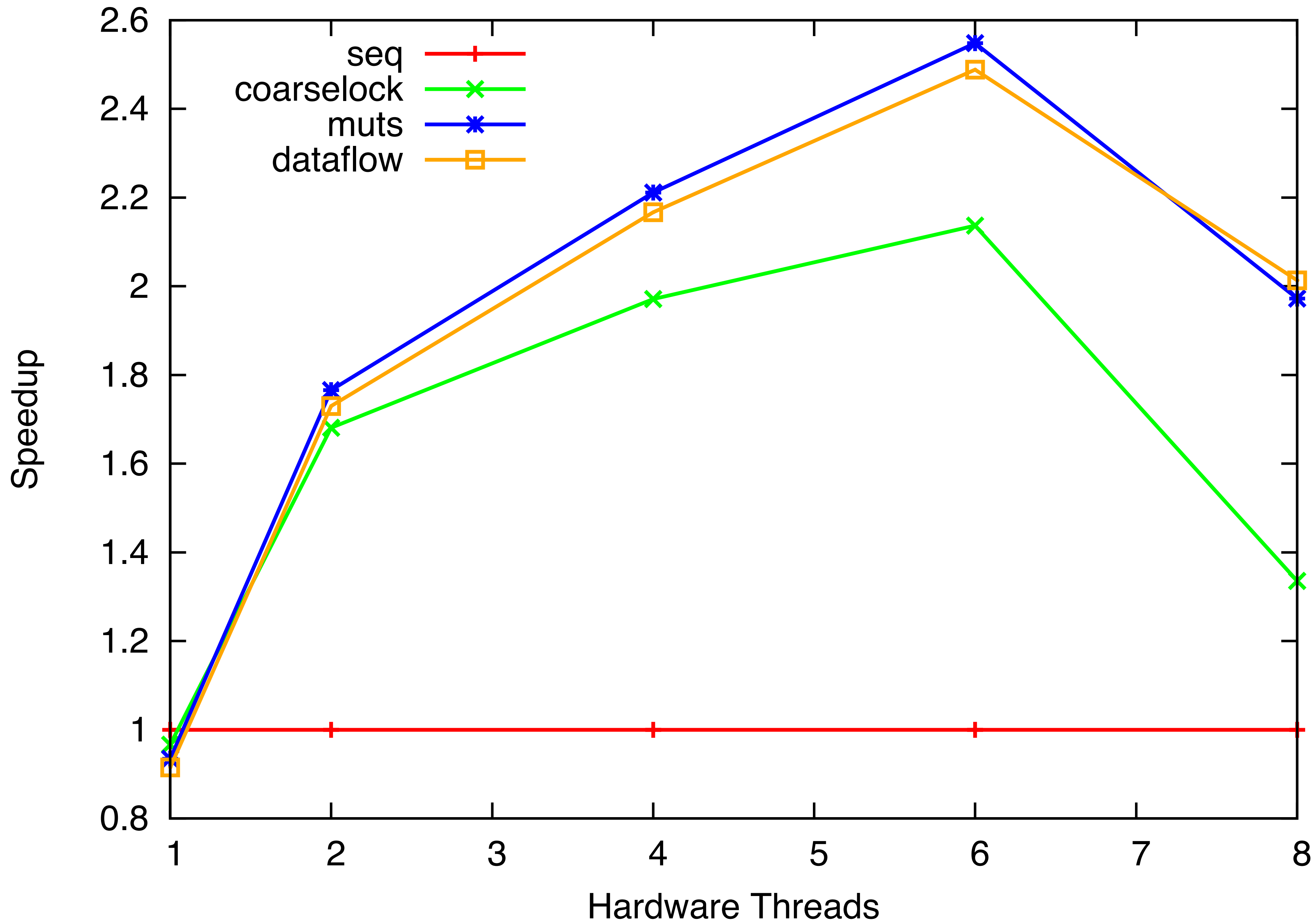
Implementation	Lines of code	Parallel operations
Sequential	251	0
Coarse lock	330 (+79)	11
Transactional	328 (+77)	6
Dataflow + transactional	300 (+49)	5

Code metrics

Experimental Design

We have simpler programs – do we still get a decent speedup?

- Commodity hardware
- Intel Core i7 920, 4 cores each with 2-way SMT
- SuSE 11.2, Linux 2.6
- Java 1.6, Scala 2.9, MUTS 1.1
- Wall clock run time, excluding setup and IO
- 10 repetitions with mean and SD recorded



Speedup relative to sequential

Conclusions

- Dataflow can be combined with transactions
- Lee shows certain properties that are currently difficult to parallelise
- Together dataflow and transactions are easier to program than on their own
- Together they produce performance similar to transactions on their own, and faster than coarse locks

http://apt.cs.man.ac.uk/projects/TERAFLUX/MUTS/
(or just search for "scala muts")

Questions

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TERAFLUX

EPSRC
Engineering and Physical Sciences Research Council

```
val boardStateForFreeze = boardStateVar.take()        // Lock
val privateBoardState = boardStateForFreeze.freeze
boardStateVar.put(boardStateForFreeze)                // Unlock

                                    ...

val boardStateForLay = boardStateVar.take()           // Lock

val verified = verifyRoute(route, solution, boardStateForLay)

if (verified)
    layRoute(route, solution, boardStateForLay)
else
    scheduleForRetry(route)

boardStateVar.put(boardStateForLay)                   // Unlock
```

Coarse lock

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```
val privateBoardState = atomic { boardState.freeze }

                        ...

atomic {
    if (verifyRoute(route, solution, boardState))
        layRoute(route, solution, boardState)
    else
        scheduleForRetry(route)
}
```

Transactional

```scala
val threads = for (n <- 0 until threadsCount) yield
    new Thread(new Runnable() {
        def run() = {
            while (...) {
                var routes = routesVar.take()    // Lock
                                            ...
                routesVar.put(routes)            // Unlock

                if (route == null) {
                                            ...
                } else {
                    val solution = solveRoute(board, route, boardStateVar)

                    var solutions = solutionsVar.take()    // Lock
                    solutions ::= solution
                    solutionsVar.put(solutions)            // Unlock
                }
            }
        }
    })
```

Threads with a work list

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```
val solutionCollector =
    DFManager.createCollectorThread[Solution](routes.length)

for (route <- routes) {
    val routeSolver = DFManager.createThread(solveRoute _)
    routeSolver.arg1 = board
    routeSolver.arg2 = route
    routeSolver.arg3 = boardState
    routeSolver.arg4 = solutionCollector.token1
}

solutionCollector.addListener(solutionsOut)
```

Dataflow