Parallel programming with Session Java

Nicholas Ng (`nickng@doc.ic.ac.uk`)

Imperial College London

Motivation

- Parallel designs are difficult, error prone (eg. MPI)
- Session types *ensure* communication safety in concurrent systems
- So use session types to design *safe* parallel algorithms for high performance clusters

Contributions

- An implementation of parallel n-body simulation
  1. Programmed in **Session Java (SJ)**, a full implementation of **session types**
  2. Uses **FPGA** on the AXEL heterogeneous cluster
- A formal description of **multicast outwhile, inwhile** SJ primitives in session types
- Showed type soundness, progress property in SJ parallel programs connected in a ring topology
- Proved SJ n-body implementation deadlock free

Session types

- Typing system for [HVK98] π-calculus
- π-calculus models structured interactions between processes
- Main idea: communication primitives should have a **dual**

Example

(Conventional type system) `int i = 9`

- `i` is type `int`
- 9 is type `int`

Process A: $c_{ab}!\langle 9 \rangle; P$ (send 9 to B via channel c_{ab})
Process B: $c_{ab}?(x).Q$ (receive x from A via channel c_{ab})

- A is type Send `int` (or $c_{ab}: ![int]$)
- B is type Receive `int` (or $c_{ab}: ?[int]$)

Session programming with SJ

Session Java (SJ) [HYH08]

- A full implementation of **binary** session types in Java
- Provides a socket programming interface with eg. `accept()`, `request()`, `send()`, `receive()`

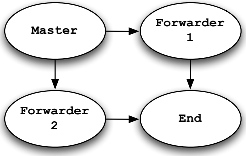
Workflow of a SJ program:

1. Declare session type/`protocol` of program in SJ
2. SJ compiler checks local session type conformance
3. Runtime duality check with communicating program

SJ features for parallel programming

- Iteration chaining
- Multi-channel `inwhile` and `outwhile` in place of reduce-scatter operations

Master: `<s1,s2>.outwhile(i<42){...}`
Forwarder1: `s3.outwhile(s1.inwhile){...}`
Forwarder2: `s4.outwhile(s2.inwhile){...}`
End: `<s3,s4>.inwhile(){...}`



Simple example: N-body simulation

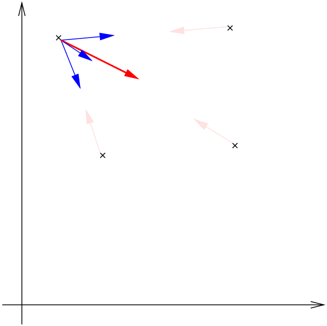


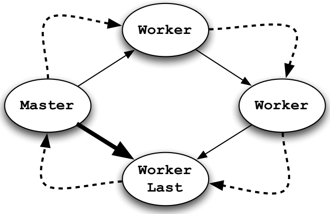
Figure: Result force is vector sum of all forces

- n particles following Newton's laws of motion
- Calculate the result force acting on each particle
- Displace the particle based on net force acting on it

Simple example: N-body simulation

- Implemented in a *ring* topology
- 3 kinds of processes - Master, Worker (multiple), LastWorker

1. Each allocated a partition of particles
2. Calculate resultant forces on received set of particles
3. Forward to next node
4. Repeat until end of one time step



Another example: Jacobi method

- Iteration-based method for solving the Discrete Poisson Equation
- Used in physics and natural sciences
- Given initial prediction, iterate until converged or upper limit of iterations

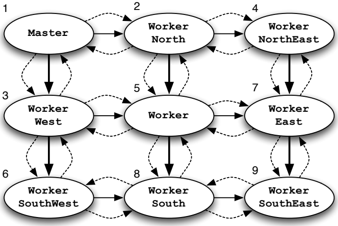
-	edge	edge	-
edge	value	value	edge
edge	value	value	edge
-	edge	edge	-

Figure: A sub-matrix of calculation

Another example: Jacobi method

- Implemented in a *mesh* topology (2D decomposition)
- 9 kinds of processes - one for each edge case and a Worker in the center

1. Each allocated a sub-matrix of values
2. Calculate average of neighbouring values for all element
3. exchange edges to adjacent sub-grid
4. Repeat until converged



AXEL: a heterogeneous cluster

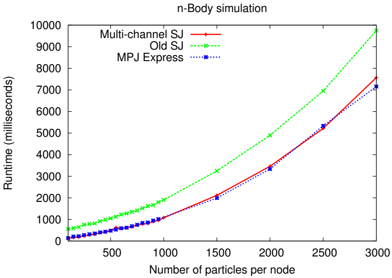
Axel [TL10] is a heterogeneous cluster that contains different *Processing Elements* (PE) on each node:

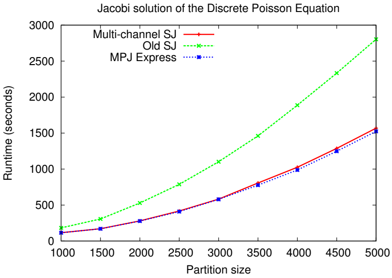
- **CPU** Off-the-shelf *multicore* x86 architecture CPU
- **GPU** *Graphics Processing Unit*, nVidia Tesla, dedicated General Purpose GPU
- **FPGA** *Field Programmable Gate Arrays*, reconfigurable hardware

- AXEL is a 16-node NNUS cluster
- Each node can be used as individual PC
- Connected by high speed Ethernet

Performance benchmark results

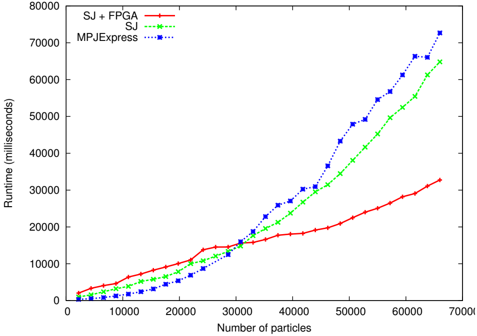
- Against MPJ Express [SCB09], implementation of MPI in Java
- Performance competitive (Left: N-body simulation, Right: Jacobi method)





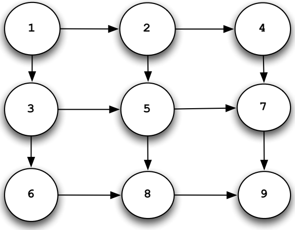
Performance benchmark results (with FPGA)

- Better performance with more particles
- Best performance: SJ+FPGA **2x** faster than SJ implementation



Well-formed topology

- Multichannel `inwhile` and `outwhile` not safe on its own
- Well-formed topology: Topology constructed as DAG with 1 root node and 1 *sink* node
- Individual pairs of sessions are dual
- Iteration controlled by a single condition in the Master node
- Deadlock freedom for group of processes in well-formed topology



Future (and ongoing) work

C based language implementing session types

- Higher performance with FPGA or other acceleration hardware
- Can integrate with AXEL or similar HPC applications toolchain

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