THE MIT MULTI-ALU PROCESSOR

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August 25, 1997
The Vanishing Processor

64 bit processor w/ pipelined FPU (R4600) = 400Mλ²

- \( \lambda = 1/2 \) feature size, process independent
- 4% of today’s die
- 0.13% of today’s system (256MB)
What to Do?

- Increase processing per unit memory
  - 16% of 256MB system
  - 96 times peak performance
  - 1.5 times silicon area cost
Outline

1. Motivation
2. M-Machine Architecture
   - Instruction Level Parallelism
   - Communication
3. MAP Chip Implementation
4. Summary
The Multi-ALU Node

Highly integrated node (6 chips) containing:

- 8 MBytes of external memory
- MAP Processor
  - 44KB cache (D+I)
  - 4 register files
  - 6 Integer units, 1 FPU
  - NI + Router
Multiple ALUs

Problem: Current multi-ALU control is inadequate

- Superscalar
  - Issue logic and register file at scaling limits
  - Empty issue slots
- VLIW
  - Variable latency
  - Empty issue slots
- Multiprocessor
  - Long interaction latency
Processor Coupling

- Compile-time scheduling (across clusters)
  - Instruction Level Parallelism
  - Independent cluster execution
  - Register-register communication
  - Tolerates slip between clusters
- Runtime multithreading (each cluster)
  - Hides variable latencies
  - Exploits slip between clusters
Addressing and Communication

- Guarded Pointers
  - Capability based addressing
  - No table lookup
  - Independent addressing and protection

- Send Instruction
  - Register-register transmit

- Fast message handling
  - Dedicated thread
Node Compilation

• Multiflow Compiler port
  – C Compiler
  – Optimized single cluster code
  – Statically scheduled code across clusters

• Runtime System
  – C Library
  – Lightweight threads (local and remote)

• SCP Group – Caltech/Syracuse
  – Steve Taylor, Daniel Maskit, Bryan Chow
MAP Chip Implementation

• The Goals
  – Validate mechanisms
  – 4 clusters/1600 MFlops
  – 13 million transistors, 100 MHz

• The Resources
  – 0.7μm (0.5μm effective), 5-metal process; 18mm x 18mm die
  – MIT personnel: average 8 students and staff
    * Architecture, logic/circuit design
  – Cadence Spectrum Design
    * Chip assembly, layout
    * Design flow
    * Clock distribution design and analysis
• 160KB SRAM
• 3D Router
• 8 IPs, 4 FPIUS
44KB SDRAM
2D Router
6 IUs, 1 FPU
Final Floorplan: 4/15/97
MAP Team Accomplishments

- 5 Million transistor, 64-bit custom microprocessor
- Fully characterized standard cell library
- Composable datapath cell library
- 5 SRAM arrays
- Radix 8 multiplier array w/ domino logic
- IEEE format FPU
  - 4 cycle pipelined MULA
  - 20 cycle DIV/SQRT
- 7 ported register file
- 64 bit custom adder
- Low voltage simultaneous bidirectional pads
Lessons from the Implementation

1. Custom Cell Placement vs. Full Custom datapaths
   - Cost: 40% increased area
   - Benefit: Creation and modification flexibility

2. Architecture greatly affects estimation accuracy
   - 55% utilization in arithmetic control
   - 40% utilization in pipeline control

3. Cadence Spectrum Design was critical
   - Reality check for density
   - Tool flow and physical design
   - Expertise with the fabrication process
Summary

- M-Machine makes better use of silicon area
  - Instruction Level Parallelism: Processor Coupling
  - Coarser grained parallelism
    * Protection: Guarded Pointers
    * Communication: Send instruction
- Clean Sheet Design: Be careful what you wish for!
  - Difficult to predict area, critical path, effort...
- Why build it?
  - Because it is *not* there
- http://www.ai.mit.edu/projects/cva