Multi-core RISC Processor Design & Implementation

Demonstration Viva

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ELEC5881M - Main Project

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Quick Links

- GitHub repository: `https://github.com/bendl/vmicro16`
- Full Report: `https://github.com/bendl/vmicro16/blob/master/docs/reports/build/ELEC5881M_Ben_Lancaster_201280376_Final.pdf`

Why Multi-core?

Block Title

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Why RISC?

Overview

What this project produces:

- **System-on-Chip with multi-processor functionality**
  Tested on FPGA hardware with 1-96 CPU cores.

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- **Software/Assembly compiler**
  PRCO304 programming language/Intel assembly syntax.

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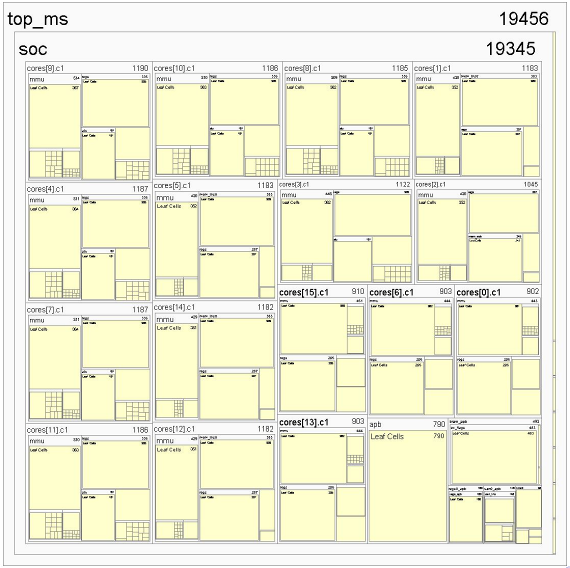
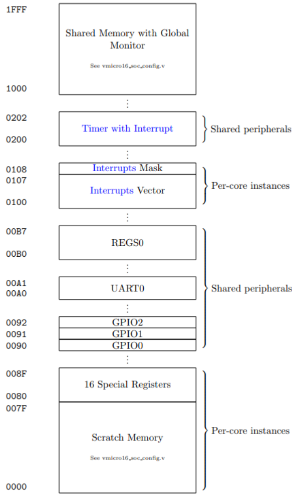
- **Custom 16-bit RISC CPU**
  With interrupts and its own Instruction Set Architecture (ISA).
- **Software/Assembly compiler**
  PRCO304 programming language/Intel assembly syntax.
- **Aimed at Design Engineers, not end users**
  Project is provided as source code/design files for Design Engineers to customise and implement in hardware themselves.

Top Level Hierarchy



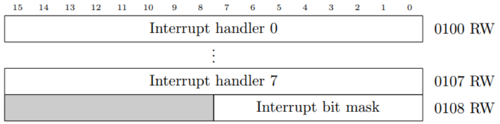
Memory Map

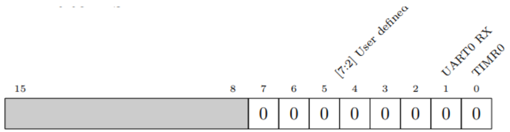


- **Shared Memory with Global Monitor**
- Timer with Interrupt
- Per-core Interrupt Vector and Mask
- Shared Register Set
- UART Transceiver
- Multiple GPIO ports
- Per-core scratch memory
- **Per-core Special Registers**
- Customisable by designers

Interconnect

Interrupts





```
entry:
    // Set interrupt vector at 0x100
    // Move address of isr0 function to vector[0]
    movi    r0, isr0
    // create 0x100 value by left shifting 1 8 bits
    movi    r1, #0x1
    movi    r2, #0x8
    lshft   r1, r2
    // write isr0 address to vector[0]
    sw      r0, r1

    // enable all interrupts by writing 0x0f to 0x108
    movi    r0, #0x0f
    sw      r0, r1 + #0x8
    halt                      // enter low power idle state

isr0:                         // arbitrary name
    movi    r0, #0xff         // do something
    intr                      // return from interrupt
```

Demo: 2 Core LED toggle (GPIO0) with TIMR0 1s interrupt (interrupts_2.s)

Timer Interrupt Example

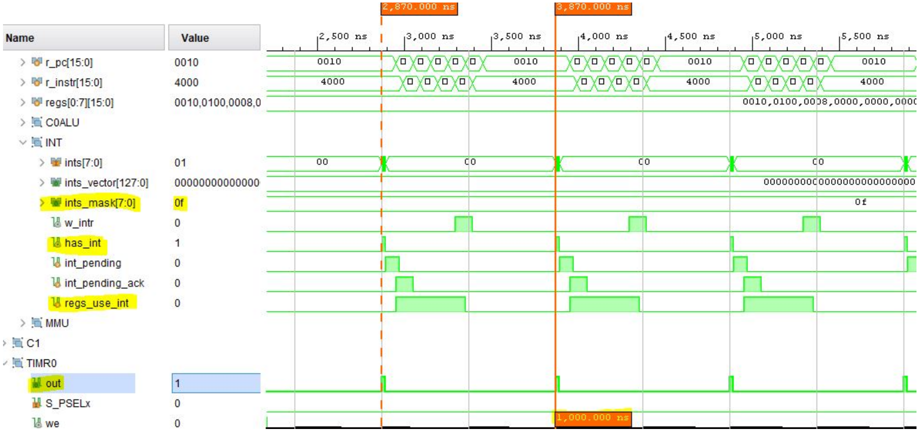


Figure: TIMR0 1us interrupt with context switching

Timer Peripheral Registers

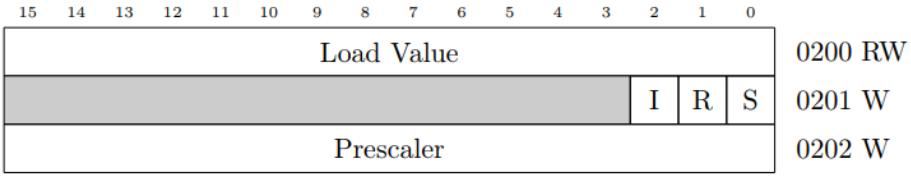


Figure: $t = 20ns * load * prescaler$

Resolution (32-bit timer): 20ns to 85s.
Examples:

- For 1us: Load = 0x32, Prescaler = 0 (20ns * 0x32 = 1000ns)
- For 1s: Load = 0x1000, Prescaler = 0x3000 (demo) (20ns * 0x1000 * 0x3000 = approx. 1s)

HW/SW Requirements

Hardware:

- **Bus Arbitration**
  (scheduling: priority, rotating, etc.)

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Software:

- **Semaphores/Mutexes**
  (exclusive memory access)
- **Thread synchronisation**
  (memory barriers)
- **Context identification**
  What core am I?
  How many cores?
  How much memory?

Context Identification

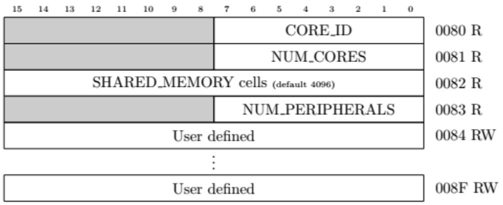

Figure: Special Registers 0x0080 to 0x008F

```
entry:
    // get core idx 0x80 in r7
    movi    r7, #0x80
    lw      r7, r7

    // Branch away if not core 0
    cmp     r7, r0
    movi    r0, exit
    br      r0, BR_NE

    // Core 0 only instructions
    nop     r0, r0
    nop     r0, r0
    nop     r0, r0

exit:
    halt    r0, r0
```

Atomic Instructions

- Enables semaphores, mutexes, memory barriers
- Prevent race conditions between threads/cores
- LW[EX] and SW[EX]

Example:

```
try_inc:
    lwex    r0, r1
    // increment by 1
    addi    r0, #0x01
    // attempt store
    swex    r0, r1
    // check success (== 0)
    cmp     r0, r3
    // branch if failed
    movi    r4, try_inc
    br      r4, BR_NE
```

Exclusive Access

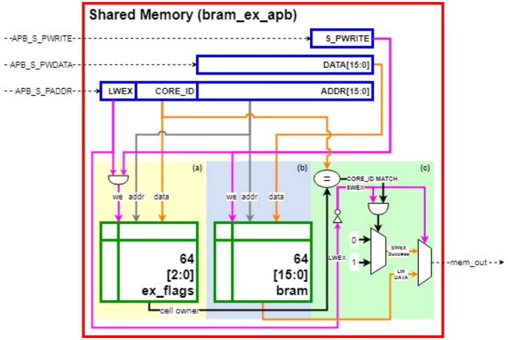

Figure: ”Global Monitor” = track exclusive access to memory locations

Demo: 8 core number summation (sum.s)

Multi-core vs Single-Core for Summation

- Each core has low work load
    - Sum subset of numbers in for loop
- Ideal scenario for parallelism
    - Highly parallelisable
    - Few inter-thread dependencies

Insert graph showing core count vs total time

Results 1

Accomplishments

- **Near complete System-on-Chip design with various peripherals**
  Timers, GPIO, UART, Registers, Memory
- **Common multi-thread/core synchronisation primitives**
  Semaphores, Mutexes, Memory Barriers, Atomic Instructions
- **AMBA APB bus interface with Global Monitor**
  Timers, GPIO, UART, Registers, Memory
- **Working shared bus arbitration**
  Schedules access to shared resources
- **Working FPGA implementation for a 96 core design**
  Nearly fills Cyclone V FPGA on the DE1-SoC
- **Interrupts with hardware context-switching**
  Low latency to react to interrupt
- **Acknowledges design limitations and attempts to overcome**
  LUT resources, block memories, power and temperature requirements

Future Improvements

- **Working Global Reset**
  Global resets are expensive (LUT resources)
  Resetting block memories is not trivial
- **On-chip Programming**
  Use the UART0 receiver to program each cores flash memory
- **Per-core gating/enabling**
  Improve power efficiency for ASIC implementation by disabling cores at run-time via software.
- **Improve memory bottleneck**
  Each core requires it's own memory - reduce by multiplexing access to a single large memory.

Q&A