Multi-core RISC SoC 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`
- This presentation: `https://github.com/bendl/vmicro16/blob/master/docs/reports/build/ELEC5881M_Ben_Lancaster_201280376_viva.pdf`
- About me: https://bendl.me/

Why a project on CPUs?

- **CPUs will be used for the rest of humanity**
- **Understand design constraints and considerations**
- **Prepare myself for future employment/work**

Why Multi-core?

- **Rate of single-core speed improvements slowing**
- **Future of computing = parallel**

Why RISC?

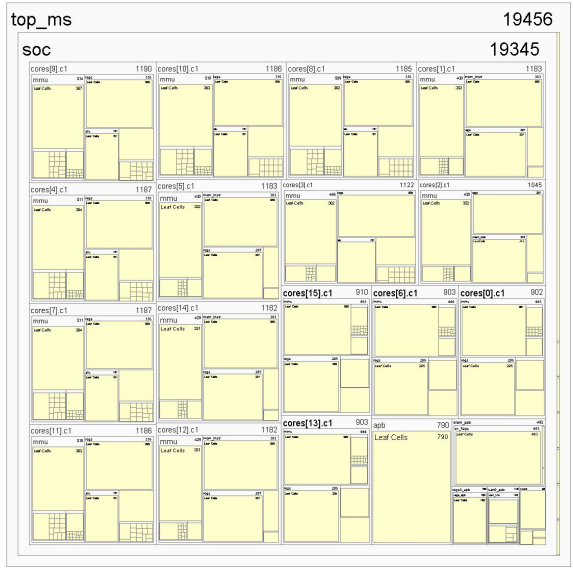
- Simpler design & impl
- Smaller = fit more cores on a chip
- Previous experience + future work
- I'm a RISC purist

Overview

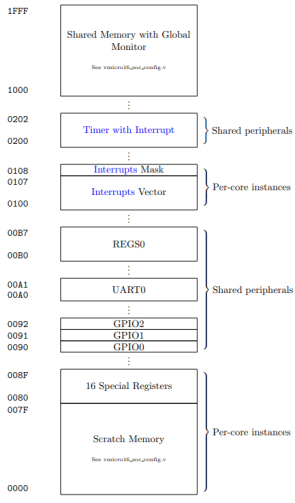
What this project produces:

- System-on-Chip with multi-processor functionality
- Custom 16-bit RISC CPU
- Software/Assembly compiler
- Aimed at Design Engineers, not end users

Top Level Hierarchy



Memory Map



- **Shared Memory***
- Timer + interrupts
- UART send/receive
- GPIO
- Scratch memory
- Extra registers
- + more

Interconnect

- AMBA APB Bus
- Tristate & Non-tristate (mux) impl
- Originally Wishbone, now APB
- AHB too complex (limited time)
- Various schedulers

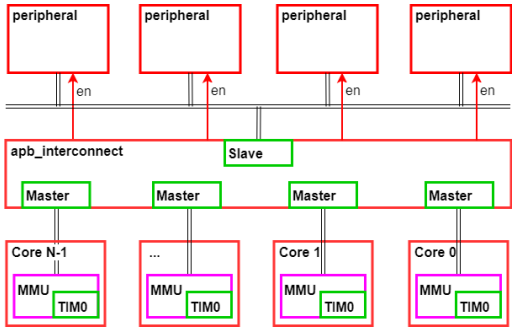


Figure: Vmicro16 interconnect

Interconnect Schematic

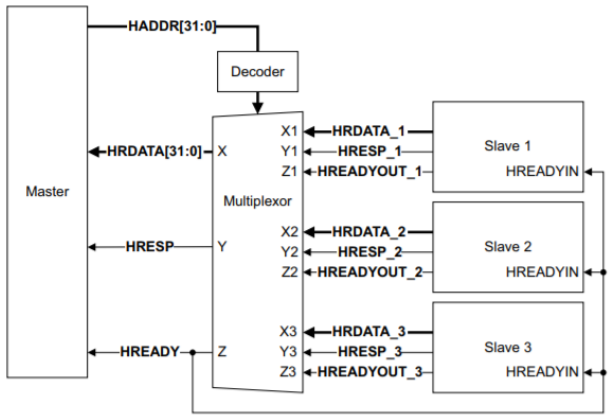


Figure: Source: ARM AHB-Lite Protocol Specification Figure 4-2.

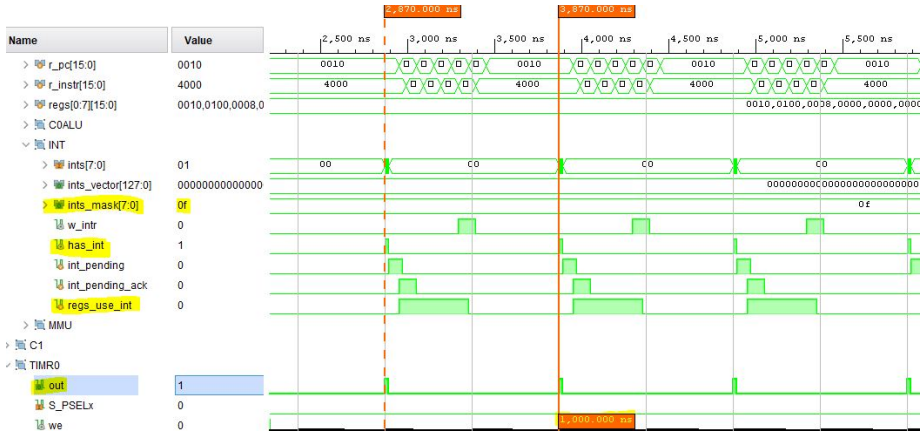
Instruction Set Architecture

- \+ 16-bits, 38 instructions
- \+ Simple load/store arch
- \+ (Un)signed instructions
- \+ Compact
- \+ Optional hardware multiply instruction
- – Only 8 registers
- – No good compiler support

	15-11	10-8	7-5	4-0	rd ra simm5
	15-11	10-8	7-0		rd imm8
	15-11	10-0			nop
	15	14:12	11:0		extended immediate
SPCL	**00000**	**11 bits**			**NOP**
SPCL	00000	11h'000			NOP
SPCL	00000	11h'001			HALT
SPCL	00000	11h'002			Return from interrupt
LW	00001	Rd	Ra	s5	Rd <= RAM[Ra+s5]
SW	00010	Rd	Ra	s5	RAM[Ra+s5] <= Rd
BIT	**00011**	**Rd**	**Ra**	**s5**	**bitwise operations**
BIT_OR	00011	Rd	Ra	00000	Rd <= Rd | Ra
BIT_XOR	00011	Rd	Ra	00001	Rd <= Rd ^ Ra
BIT_AND	00011	Rd	Ra	00010	Rd <= Rd & Ra
BIT_NOT	00011	Rd	Ra	00011	Rd <= ~Ra
BIT_LSHFT	00011	Rd	Ra	00100	Rd <= Rd << Ra
BIT_RSHFT	00011	Rd	Ra	00101	Rd <= Rd >> Ra
MOV	00100	Rd	Ra	X	Rd <= Ra
MOVI	00101	Rd	i8		Rd <= i8
ARITH_U	**00110**	**Rd**	**Ra**	**s5**	**unsigned arithmetic**
ARITH_UADD	00110	Rd	Ra	11111	Rd <= uRd + uRa
ARITH_USUB	00110	Rd	Ra	10000	Rd <= uRd - uRa
ARITH_UADDI	00110	Rd	Ra	0AAAA	Rd <= uRd + Ra + AAAA
ARITH_S	**00111**	**Rd**	**Ra**	**s5**	**signed arithmetic**
ARITH_SADD	00111	Rd	Ra	11111	Rd <= sRd + sRa
ARITH_SSUB	00111	Rd	Ra	10000	Rd <= sRd - sRa
ARITH_SSUBI	00111	Rd	Ra	0AAAA	Rd <= sRd - sRa + AAAA
BR	**01000**	**Rd**	**i8**		**conditional branch**
BR_U	01000	Rd	0000 0000		Any
BR_E	01000	Rd	0000 0001		Z=1
BR_NE	01000	Rd	0000 0010		Z=0
BR_G	01000	Rd	0000 0011		Z=0 and S=O
BR_GE	01000	Rd	0000 0100		S=O
BR_L	01000	Rd	0000 0101		S != O
BR_LE	01000	Rd	0000 0110		Z=1 or (S != O)
BR_S	01000	Rd	0000 0111		S=1
BR_NS	01000	Rd	0000 1000		S=0
CMP	01001	Rd	Ra	X	SZO <= CMP(Rd, Ra)
SETC	01010	Rd	Imm8		Rd <= (Imm8 _f_ SZO) ? 1 : 0
MULT	01011	Rd	Ra	X	Rd <= uRd * uRa
HALT	01100	X			
LWEX	01101	Rd	Ra	s5	Rd <= RAM[Ra+s5]
SWEX	01110	Rd	Ra	s5	RAM[Ra+s5] <= Rd Rd <= 0|1 if success

SW Example

Timer Interrupt Example



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

HW/SW Requirements

Hardware:

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

Software:

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Software:

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- **Thread synchronisation** (memory barriers)

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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

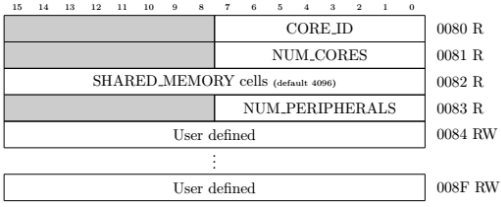


Figure: Special Registers 0x0080 to 0x008F

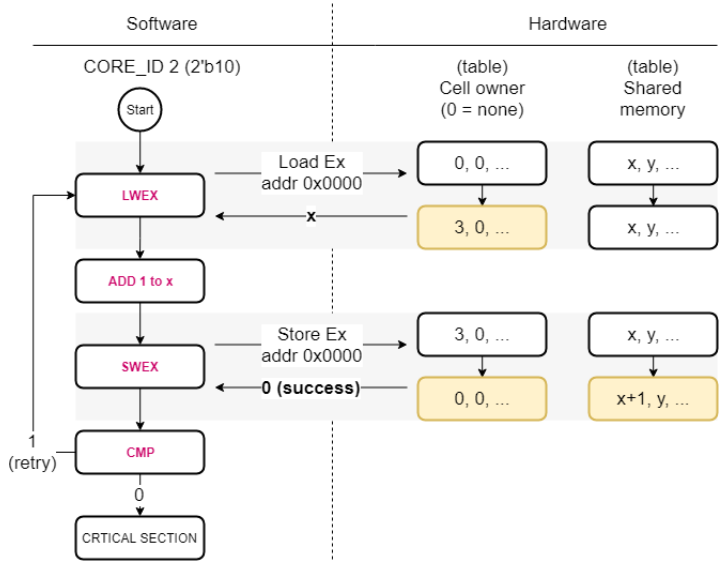
```
entry:
    // get core idx 0x80 in r7
    movi    r7, #0x80
    lw      r7, r7

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

    // Core 0 only instructions
    nop
    nop
    nop

exit:
    halt
```

Atomic Instructions

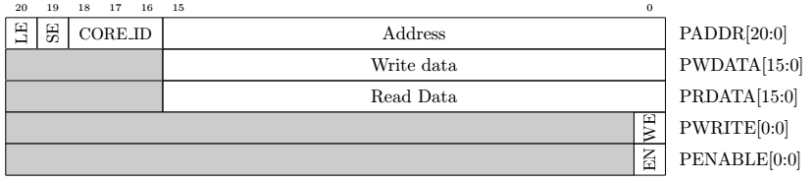
- Enables semaphores, mutexes, memory barriers
- Prevent race conditions between threads/cores
- LW[EX] and SW[EX]
- Implementation in next slide

```
try_inc:
    // load and lock
    // (if not already locked)
    lwex    r0, r1
    // do something
    // (i.e. add 1 (semaphore))
    addi    r0, #0x01
    // attempt store
    swex    r0, r1

    // check success (== 0)
    cmp     r0, r3

    // if not equal (NE), retry
    movi    r4, try_inc
    br      r4, BR_NE

critical:
    // r0 is latest value
```

Exclusive Access Flow Chart



HW - How do I know which core this lwex/swex is from?



The Core Idx is sent with each MMU request to the shared bus.

PADDR*NUMCORES-1:0 interconnect input.

Exclusive Access


```
mutex_claim:
    // load and lock
    // (if not already locked)
    lwex    r0, r1
    // do something
    // (i.e. add 1 (semaphore))
    addi    r0, #0x01
    // attempt store
    swex    r0, r1

    // check success (== 0)
    cmp     r0, r3

    // if not equal (NE), retry
    movi    r4, mutex_claim
    br      r4, BR_NE

critical:
    nop
```

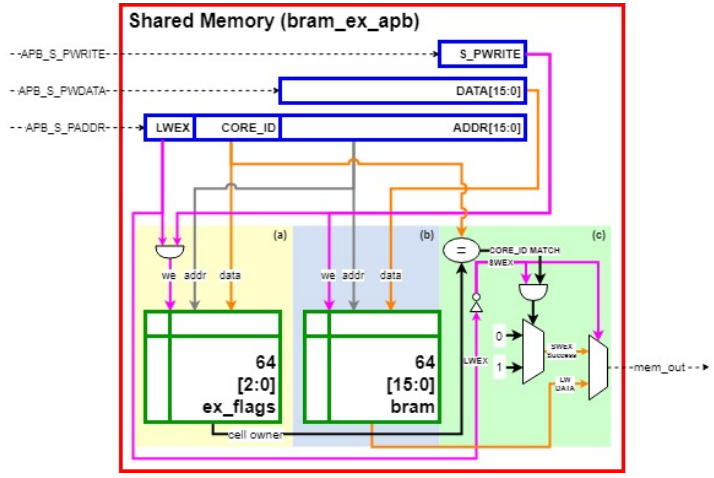


Figure: HW impl

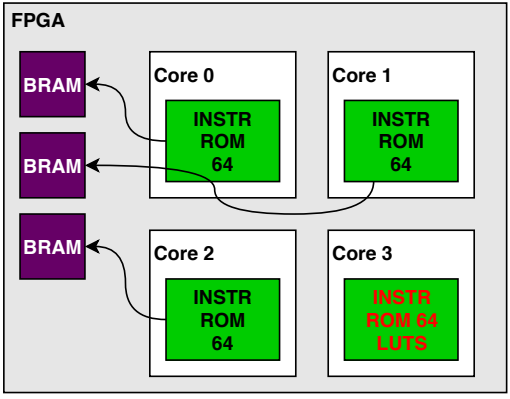
Demo: 8 core number summation (sum.s)

Design Challenges

Memory Limitations

Each core has it's own instruction memory

- \+ Fast fetching and branching
- – Requires a dedicated BRAM (FPGA) per core
- – Limited BRAM blocks available
- – **Reduces maximum core count**

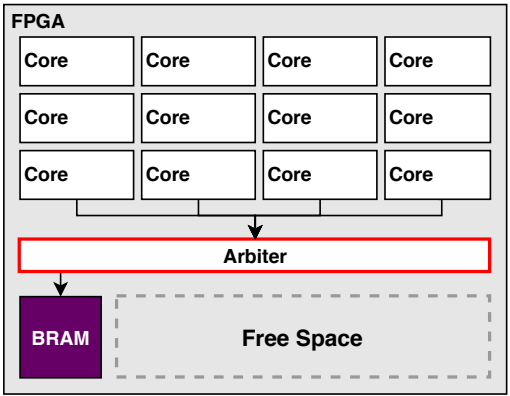


Design Challenges

Memory Limitations - Solution

Global instruction ROM

- \+ Single BRAM
- \+ Smaller core size
- − **Slow access times**
- \+ **Increases maximum core count**



1 Introduction

2 Top Level Design

3 Multi-core Functionality

4 Results

Summation

Summation - Shared Instruction ROM

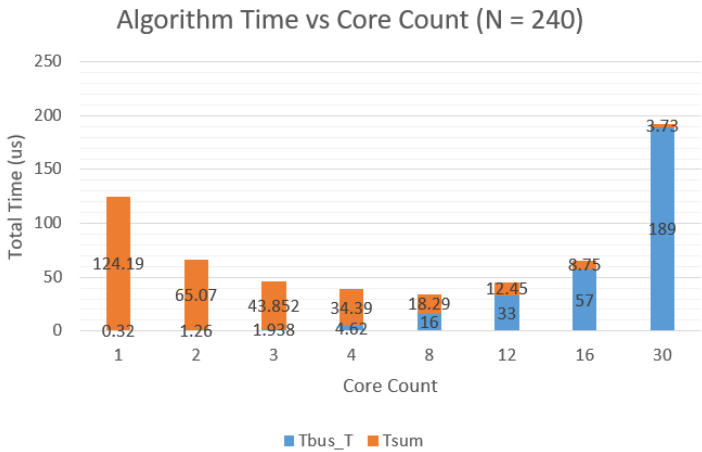
5 Conclusion

Summation - Multi-core vs Single-Core

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

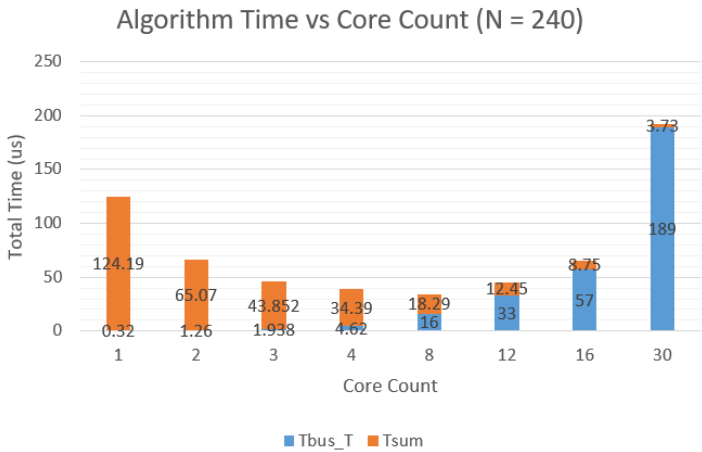
Summation - Multi-core vs Single-Core

240 samples (@30 cores = 8 samples per core)



Multi-core vs Single-Core for Summation

240 samples (@30 cores = 8 samples per core)



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Accomplishments

Future Improvements

Q&A

Accomplishments

- **System-on-Chip with peripherals**
  Timers, GPIO, UART, Registers, Memory
- **Common multi-thread/core synchronisation primitives**
  Semaphores, Mutexes, Memory Barriers, Atomic Instructions
- **AMBA APB bus interconnects**
- **Interrupts with hardware context-switching**
- **Understanding of limitations and solutions**

Future Improvements

- **Global Reset**
- **On-chip Programming**
- **Per-core gating/enabling**
- **Improve memory bottleneck**

Q&A

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- Presentation tools:
  - Latex Beamer
  - `\usecolortheme{orchid}`
  - `\useoutertheme[hideothersubsections]{sidebar}`