

Multi-core RISC SoC Design & Implementation

Demonstration Viva

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201280376
ELEC5881M - Main Project

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Quick Links

Main Project

B. Lancaster

Introduction

Top Level
Design

Results

Conclusion

Appendix

- 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/>

Main Project

B. Lancaster

Introduction

Top Level
Design

Results

Conclusion

Appendix

- 1

Introduction
- 2

Top Level Design
- 3

Results
- 4

Conclusion

Main Project

B. Lancaster

Introduction

Why a project on CPUs?

Why Multi-core?

Why RISC?

Top Level Design

Results

Conclusion

Appendix

1

Introduction

Why a project on CPUs?

Why Multi-core?

Why RISC?

2

Top Level Design

3

Results

4

Conclusion

Why a project on CPUs?

Main Project

B. Lancaster

Introduction

Why a project on
CPUs?

Why Multi-core?

Why RISC?

Top Level
Design

Results

Conclusion

Appendix

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

Why Multi-core?

Main Project

B. Lancaster

Introduction

Why a project on
CPUs?

Why Multi-core?

Why RISC?

Top Level
Design

Results

Conclusion

Appendix

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

Why RISC?

Main Project

B. Lancaster

Introduction

Why a project on CPUs?

Why Multi-core?

Why RISC?

Top Level Design

Results

Conclusion

Appendix

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

1 Introduction

2 Top Level Design

Overview

Memory Map

Interconnect

ISA

Interrupts

Thread Synchronisation

Design Challenges

3 Results

4 Conclusion

Main Project

B. Lancaster

Introduction

Top Level
Design

Overview

Memory Map

Interconnect

ISA

Interrupts

Thread

Synchronisation

Design Challenges

Results

Conclusion

Appendix

Overview

Main Project

B. Lancaster

Introduction

Top Level
Design

Overview

Memory Map

Interconnect

ISA

Interrupts

Thread
Synchronisation

Design Challenges

Results

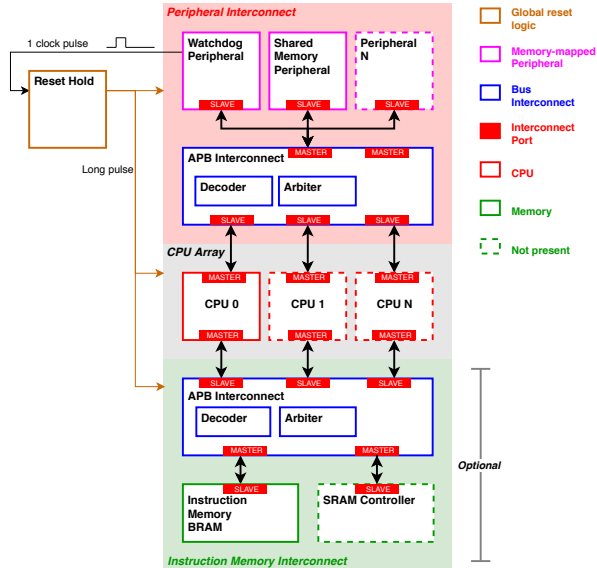
Conclusion

Appendix

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 Block Diagram



Main Project

B. Lancaster

Introduction

Top Level Design

Overview

Memory Map

Interconnect

ISA

Interrupts

Thread

Synchronisation

Design Challenges

Results

Conclusion

Appendix

Top Level Hierarchy

Main Project

B. Lancaster

Introduction

Top Level
Design

Overview

Memory Map

Interconnect

ISA

Interrupts

Thread

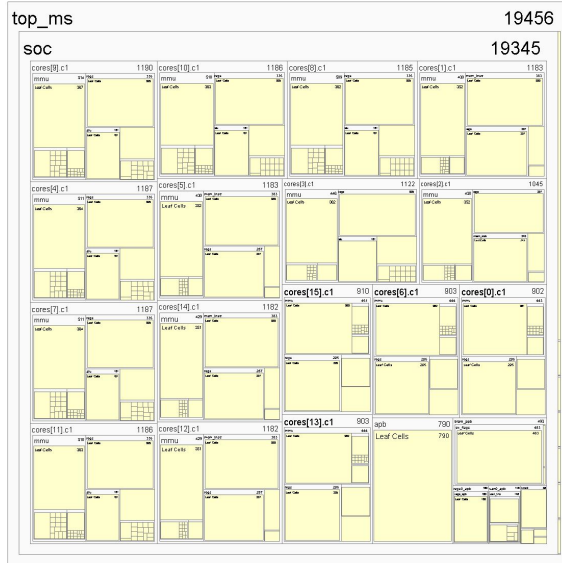
Synchronisation

Design Challenges

Results

Conclusion

Appendix



Memory Map

Main Project

B. Lancaster

Introduction

Top Level Design

Overview

Memory Map

Interconnect

ISA

Interrupts

Thread

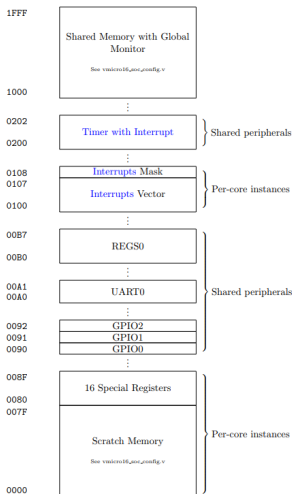
Synchronisation

Design Challenges

Results

Conclusion

Appendix



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

Interconnect

Main Project

B. Lancaster

Introduction

Top Level Design

Overview

Memory Map

Interconnect

ISA

Interrupts

Thread

Synchronisation

Design Challenges

Results

Conclusion

Appendix

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

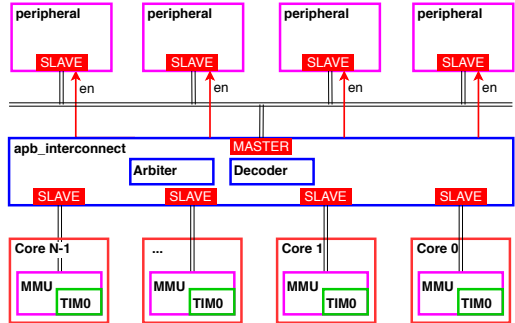


Figure: Vmicro16 interconnect

Interconnect Schematic

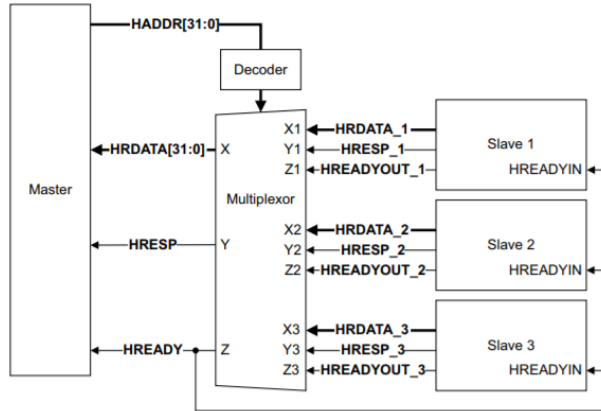


Figure: Source: ARM AHB-Lite Protocol Specification Figure 4-2.

Main Project

B. Lancaster

Introduction

Top Level
Design

Overview
Memory Map
Interconnect
ISA
Interrupts
Thread
Synchronisation
Design Challenges

Results

Conclusion

Appendix

Instruction Set Architecture

Main Project

B. Lancaster

Introduction

Top Level Design

Overview

Memory Map

Interconnect

ISA

Interrupts

Thread

Synchronisation

Design Challenges

Results

Conclusion

Appendix

- 16-bits
- 35 instructions
- HALT (low power)
- INTR
- HW multiply

	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=0
BR_GE	01000	Rd		0000 0100 S=0
BR_L	01000	Rd		0000 0101 S != 0
BR_LE	01000	Rd		0000 0110 Z=1 or (S != 0)
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

Timer Interrupt Example

Main Project

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Introduction

Top Level
Design

Overview

Memory Map

Interconnect

ISA

Interrupts

Thread

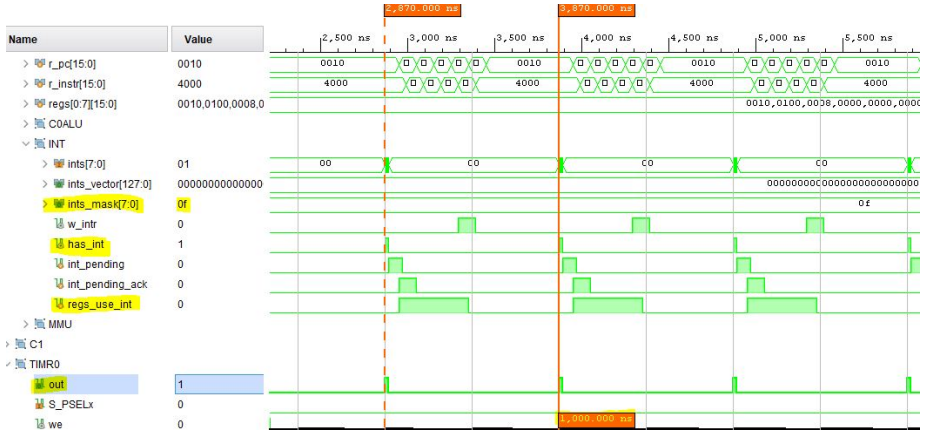
Synchronisation

Design Challenges

Results

Conclusion

Appendix



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

Thread Synchronisation

Main Project

B. Lancaster

Introduction

Top Level
Design

Overview
Memory Map
Interconnect
ISA
Interrupts
Thread
Synchronisation
Design Challenges

Results

Conclusion

Appendix

- Semaphores, mutexes, memory barriers
- Prevent race conditions
- LW[EX] and SW[EX]

```
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
```

Thread Synchronisation - Flow Chart

Main Project

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Introduction

Top Level
Design

Overview

Memory Map

Interconnect

ISA

Interrupts

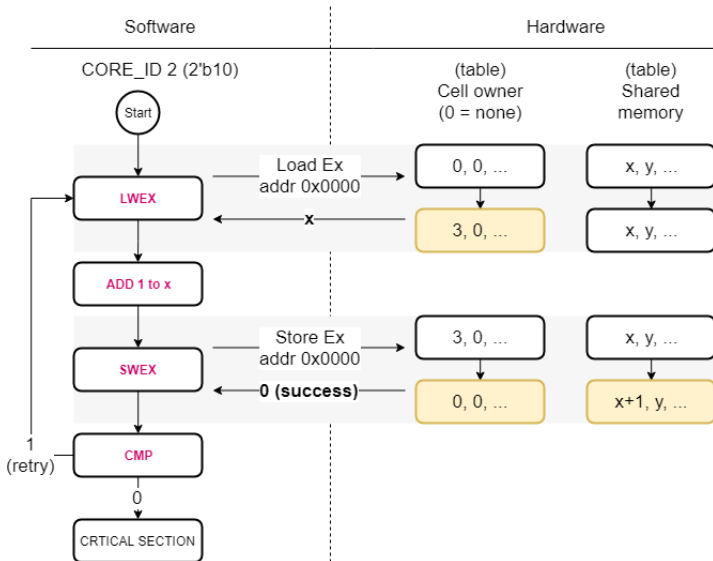
Thread
Synchronisation

Design Challenges

Results

Conclusion

Appendix



Thread Synchronisation - HW

Main Project

B. Lancaster

Introduction

Top Level
Design

Overview

Memory Map

Interconnect

ISA

Interrupts

Thread
Synchronisation

Design Challenges

Results

Conclusion

Appendix

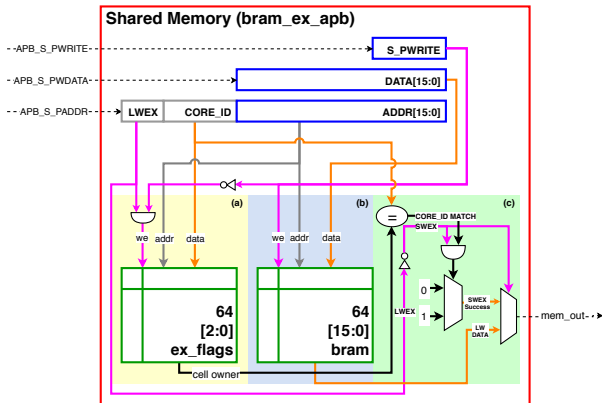


Figure: HW impl

Demo: 8 core number summation (sum.s)

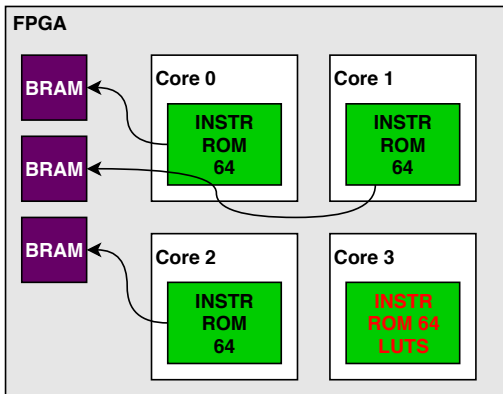
Design Challenges

Main Project

B. Lancaster

Memory Limitations

Each core has it's own instruction memory



Introduction

Top Level
Design

Overview

Memory Map

Interconnect

ISA

Interrupts

Thread

Synchronisation

Design Challenges

Results

Conclusion

Appendix

Design Challenges

[Main Project](#)

B. Lancaster

Memory Limitations - Solution Global instruction ROM

[Introduction](#)

[Top Level
Design](#)

[Overview](#)

[Memory Map](#)

[Interconnect](#)

[ISA](#)

[Interrupts](#)

[Thread](#)

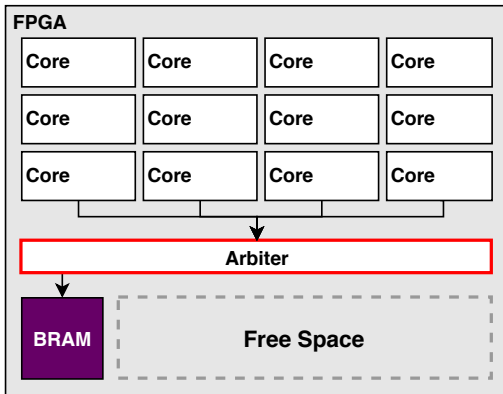
[Synchronisation](#)

[Design Challenges](#)

[Results](#)

[Conclusion](#)

[Appendix](#)



Main Project

B. Lancaster

Introduction

Top Level
Design

Results

Summation
Summation - Shared
Instruction ROM

Conclusion

Appendix

1 Introduction

2 Top Level Design

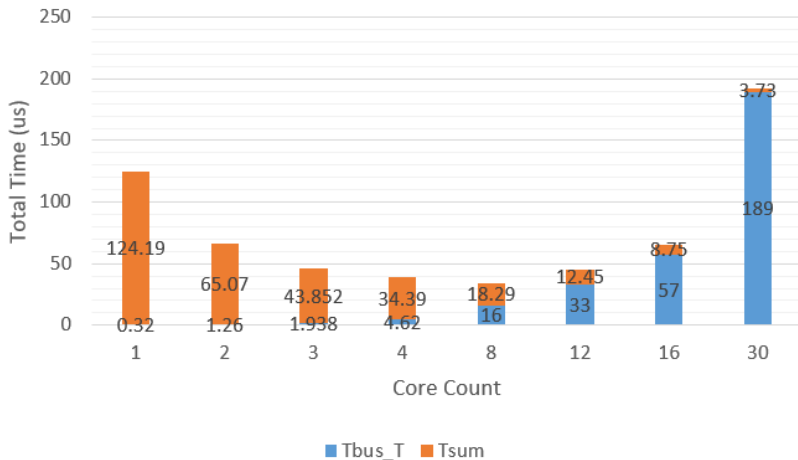
3 Results
Summation
Summation - Shared Instruction ROM

4 Conclusion

Summation - Multi-core vs Single-Core

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

Algorithm Time vs Core Count (N = 240)



Tbus_T Tsum

Main Project

B. Lancaster

Introduction

Top Level
Design

Results

Summation
Summation - Shared
Instruction ROM

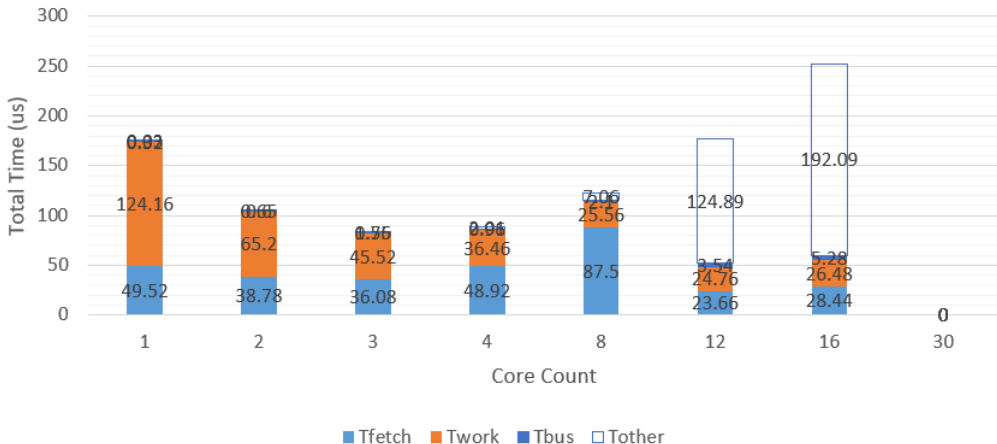
Conclusion

Appendix

Shared Instruction ROM

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

Shared ROM - Algorithm Time vs Core Count (N = 240)



Main Project

B. Lancaster

Introduction

Top Level
Design

Results

Conclusion

Accomplishments
Future Improvements
Q&A

Appendix

1 Introduction

2 Top Level Design

3 Results

4 Conclusion
Accomplishments
Future Improvements
Q&A

Accomplishments

Main Project

B. Lancaster

Introduction

Top Level
Design

Results

Conclusion

Accomplishments

Future Improvements

Q&A

Appendix

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

Future Improvements

Main Project

B. Lancaster

Introduction

Top Level
Design

Results

Conclusion

Accomplishments

Future Improvements

Q&A

Appendix

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

Q&A

Main Project

B. Lancaster

Introduction

Top Level Design

Results

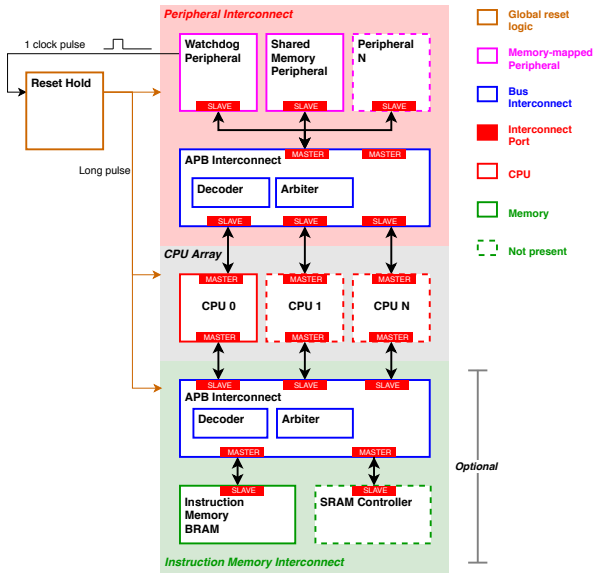
Conclusion

Accomplishments

Future Improvements

Q&A

Appendix



Q&A

Main Project

B. Lancaster

Introduction

Top Level
Design

Results

Conclusion

Accomplishments
Future Improvements
Q&A

Appendix

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

Main Project

B. Lancaster

Introduction

Top Level
Design

Results

Conclusion

Appendix

Appendix

Context Identification

Main Project

B. Lancaster

Introduction

Top Level
Design

Results

Conclusion

Appendix

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
								CORE_ID								0080 R
								NUM_CORES								0081 R
SHARED_MEMORY cells (default 4096)																0082 R
								NUM_PERIPHERALS								0083 R
User defined																0084 RW
⋮																
User defined																008F RW

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
```

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20	19	18	17	16	15											0
LE	SE	CORE_ID			Address											PADDR[20:0]
					Write data											PWDATA[15:0]
					Read Data											PRDATA[15:0]
															WE	PWRITE[0:0]
															EN	PENABLE[0:0]

Introduction

Top Level Design

Results

Conclusion

Appendix

83	62	41	20	0
Core N-1	\dots	Core 1	Core 0	

PADDR*NUMCORES-1:0 interconnect input.

BRAM Utilisation per Entity

Main Project

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Introduction

Top Level
Design

Results

Conclusion

Appendix

Design Runs		Utilization	x	
Block RAM Tile				
Name			Used	
▼	N	top_ms	10	
▼	I	soc (vmicro16_soc)	10	
>	I	bram_apb (vmicro16_bram_ex_apb)	2	
>	I	cores[0].c1 (vmicro16_core)	1	
>	I	cores[1].c1 (vmicro16_core__parameterized0)	1	
>	I	cores[2].c1 (vmicro16_core__parameterized1)	1	
>	I	cores[3].c1 (vmicro16_core__parameterized2)	1	
>	I	cores[4].c1 (vmicro16_core__parameterized3)	1	
>	I	cores[5].c1 (vmicro16_core__parameterized4)	1	
>	I	cores[6].c1 (vmicro16_core__parameterized5)	1	
>	I	cores[7].c1 (vmicro16_core__parameterized6)	1	

Halt State Low Power

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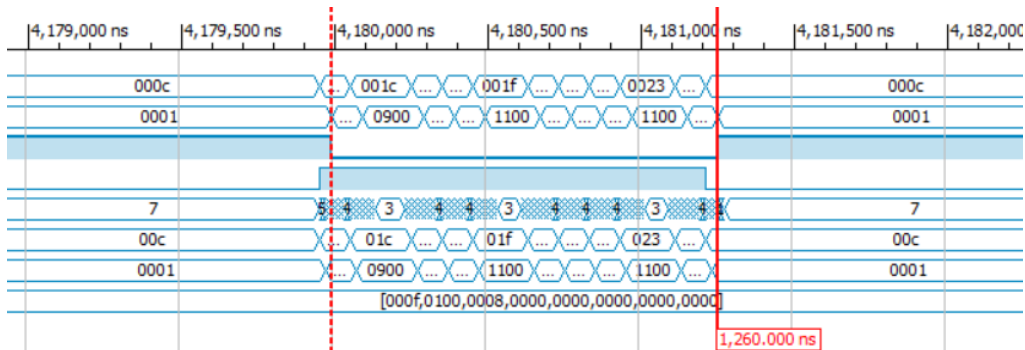
Introduction

Top Level
Design

Results

Conclusion

Appendix



Partial Address Decoding

Main Project

B. Lancaster

Introduction

Top Level
Design

Results

Conclusion

Appendix

