

Lab1: RISC-V Assembly Language Programming

CS10014 Computer Organization

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Acknowledgements and Disclaimer

- Slides were developed in the reference with
 - RISC-V Programming
 - https://riscv-programming.org/book/riscv-book.html
 - CENG3420, CUHK
 - https://www.cse.cuhk.edu.hk/~byu/CENG3420/2022Spring/slides/l ab1-1.pdf



Outline

- RISC-V Assembly Programming
 - Labels
 - Symbols
 - Directives
- RARS RISC-V Assembly Simulator



Generating native programs

- A native program is a program
 - Encoded using instructions that can be directly executed by the computer hardware

C Code

```
int main ()
{
    int r = func (10);
    return r+1;
```

RISC-V assembly code

```
.text
.aliqn 2
main:
  addi sp, sp, -16
  li a0, 10
      ra, 12(sp)
  SW
  jal func
  lw ra, 12(sp)
  addi a0, a0, 1
  addi sp, sp, 16
  ret
```



Generating native programs

• A compiler

- translate a program from one language to another
- riscv64-unknown-elf-gcc -mabi=ilp32 -march=rv32i -S main.c -o main.s
- The RV32I assembly program will be stored on the main.s file

• An Assembler

- A assembler is a tool that translates a program in assembly language into a program in machine language
- The GNU assembler tool (as) is an assembler
- The assembler produces object files (.o) that are encoded in binary and contains code in machine language
- riscv64-unknown-elf-as -mabi=ilp32 -march=rv32i main.s -o main.o



Generating native programs

- A linker
 - A tool that 'links' together one or more object files
 - Produces an executable file

riscv64-unknown-elf-ld -m elf32lriscv main.o mylib.o -o main.x

main.x is an executable file





Labels

- A label in assembly language
 - As a marker that represent program location
 - 'x:' label identifies a program location that contains a variable, which is allocated and initialized by the directive .word 10

RISC-V assembly code

x:
 .word 10
sum10:
 lw a0, x
 addia0, a0, 10
 ret

• 'sum10:' label identifies the program location that contains the first instruction of the sum10 routine



Program Symbol

- Program symbols
 - "names" that are associated with numerical values
 - The "symbol table" is a data structure that maps each program system to its value
 - "nm" tool helps us to inspect the symbol table of a program

```
$ riscv64-unknown-elf-nm sum10.0
00000004 t .L0
00000004 t sum10
00000000 t x
```



Program Symbol

- Using the ".set" directive
 - Explicitly define symbols
 - The follow example that uses **.set** directive to define a symbol named answer and assign value 42 to it
 - Two symbols: answer, get_answer

```
.set answer, 42
get_answer
li a0, answer
ret
```



Global vs local Symbols

- Local symbols
 - Only visible on the same file
 - By default, the assembler registers labels as local symbols
- The .global directive
 - Instructs the assembler to register a label as a global symbol

```
.global exit
exit:
li a0, 0
li a7, 93
ecall
```



Program Entry Point

- The entry point is defined by an address
 - The address of the first instruction that must be executed
 - The linker sets the entry point field on the executable file and looks for a symbol named start
 - The linker sets the entry point to a default value (the address of the first instruction of the program) if the linker cannot find "start" symbol

```
.global start
start:
li a0, 10
li a1, 20
jal exit
```



Program Section

- The assembly program is usually organized in 'sections'
 - A section may contain data or instructions
 - The contents of each section are mapped to a set of consecutive main memory addresses
 - .text
 - Store the program instructions
 - .data
 - Store initialized global variables
 - .bss
 - Store uninitialized global variables
 - .rodata
 - Store constants



Executable File (ELF)

- When linking multiple object files
 - The linker groups information from sections with the same name and places them together into a single section on the exec. File
 - .text are mapped to addresses 8000 to 8007
 - .data are mapped to addresses 800d to 8011





Assembly Language

- Assembly program contains
 - Comment
 - Labels
 - Usually defined by a name ended with the suffix ":"
 - Assembly instructions
 - Converted by the assembler into machine instructions
 - E.g. addi a0, a1, 1
 - Assembly directives
 - Commands used to coordinate the assembling process
 - E.g. .word 10
 - Instruct the assembler to assemble a 32-bit value (10) into the program



Program Structure I

- Plain text file with data declarations
- Data declaration section is followed by program code section

Data Declarations

- Identified with assembler directive .data
- Declares variable names used in program
- Storage allocated in main memory (e.g., RAM)
- <name>: .<datatype> <value>



Program Structure II

Code

- placed in section of text identified with assembler directive .text
- contains program code (instructions)
- starting point for code e.g. execution given label **start:**

Comments

Anything following # on a line



Program Structure III

The structure of an assembly program looks like this:

Program outline

- # Comment giving name of program and description
- # Template.asm
- # Bare-bones outline of RISC-V assembly language program

```
.globl _start
```

- .data # variable declarations follow this line
 # ...
- .text # instructions follow this line

```
_start: # indicates start of code
# ...
```

End of program, leave a blank line afterwards is preferred



An Example RISC-V Assembly Program

```
.global start
 2
 3
    .data
    welcome msg: .asciz "Welcome!"
 4
 5
 6
    .text
     start:
 7
                       \# STDOUT = 1
 8
 9
                       addi a0, x0, 1
10
                       # Load the address of 'welcome msg'
11
                       la al, welcome msg
                       # Length of the string
12
                       addi a2, x0, 8
13
                       # Linux write system call
14
15
                       addi a7, x0, 64
                       # Call linux service to output the string
16
17
```



- RARS
 - The RISC-V Assembler, Runtime, and Simulator for RISC-V assembly language programs
 - **RARS** supports RISC-V IMFDN ISA base (riscv32 & riscv64)
 - **RARS** supports debugging using breakpoints like ebreak
 - **RARS** supports side by side comparison from pseudoinstruction to machine with intermediate steps
 - You need to Java environment to run RARS
 - https://www.java.com/download/ie_manual.jsp
 - Download RARA
 - <u>https://github.com/TheThirdOne/rars/releases/tag/v1.6</u>



- How to run RARS?
 - Execute the command to start RARS: java -jar <rars jar path>
 - In Windows OS
 - Ensure you have installed Java Environment
 - Right click rars1_6.jar
 - Open with -> Java (TM) SE Platform



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89		17	2	0+00000000100281
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	test (10	5	0=0000000000000000000000000000000000000
91		e1	6	0+0000000000000000000000000000000000000
92	.globl_start	12	7	0w0000000000000000000000000000000000000
93	_start: nop	80	8	0±0000000000000000000000000000000000000
		*1	9	020000000000000000000000000000000000000
94		al.	11	0+0000000000000000000000000000000000000
95	F	42	12	0+0000000000000000000000000000000000000
96	# Arithmetic tests	63	13	0w0000000000000000000000000000000000000
		**	- 14	0=0000000000000000000000000000000000000
97		65	15	0+0000000000000000000000000000000000000
98		e6	16	0v000000000000
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National Yang Ming Chiao Tung University Computer Architecture & System Lab

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100	STILW X14, XI, U		s4	20	0x0000000000000000000000000000000000000
101	li x7, 0xffffffff80000000		15	21	0w0000000000000000000000000000000000000
102	1i gp, 2		s6	22	0±0000000000000000000000000000000000000
102	bme x14 x7 fail		1	24	0w0000000000000000000000000000000000000
103			49	25	0=0000000000000000000000000000000000000
104			s10	26	0+0000000000000000000000000000000000000
105	test_3: li x1, 0xffffffff80000000		s11	27	0#0000000000000000000000000000000000000
106	srliw x14, x1, 1		1.5	29	0+0000000000000000000000000000000000000
107	1i x7. 0x000000040000000		15	30	0w0000000000000000000000000000000000000
107	11 - 2		46	31	0=0000000000000000000000000000000000000
108	11 gp, 3		pe		0±000000000400000
109	bne x14, x7, fail				
110					
111	test 4: li xl. 0xfffffff8000000				
4					
Line: 100	olumn: 18 🖉 Show Line Numbers		Registe	ers panel	
Message	S Run I/O				
	Assemble: assembling F:\Research\misc\TA\CENG3420\tools\test.asm				
	Farning in F:\Research\misc\IA\CEB03420\tools\test am line 312 column 2: RANS does not recognize the .g	abal directive. Ignered. Brogram information papal			
	Farning in F: \Research\misc\TA\CEB03420\tools\test anm line 318 column 2: RARS does not recognize the .g	abal directive. Igared Program mormation panel			
Clear	Assemble: operation completed successfully.				



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and the state of t									Registers Floating P	oint Control and Status	
Segment						Text	segment panel	o* 0*	Name	Number	Value
Address Co	de Datir				Gource		and an		142.0	0	0x0000000
PUDITES 01	Dape.	107			ovurce				78	1	010000000
0400400000 0400		NJ start nop						6	17	1	0e000000
0-00400008 0-00	NORMA ALE & ST OF C		GITTITITIO						0		A.400000
0+0040000+ 0+00	the start of the s	100 milia att. at	0						10		0-00000
0-00400010 0-80	0001571-i x7.0-fff80000	101 11 22 0-55556	4480000000						1	2	0-00000
0+00400014 0+00	0.78.794 +44.8 x7. x7.0								-2		0-000000
0+00400012 0+00	2000193 addi x3.x0.2	102 li m 2							40		0-00000
0x0040001c 0x34	171e63 has x14, x7, 0x00000358	103 has s14 s7, fr	ail						41	9	0+00000
0+00400020 0+80	0000067 lui x1.0xfff80000	105 test 3; 1i zl.	0xffffffff80000000						-0	10	0x000000
0+00400024 0+00	0000096 addie x1, x1. 0								al	11	0x000000
0x00400028 0x00	010d71b arlis x14, x1, 1	106 urlis x14. x1.	1						2	12	0x000000
0x0040002c 0x40	0000357 lui x7. 0x00040000	107: 1s x7. 0x000000	30040000000						13	13	0x00000
0x00400030 0x00	038394 addie x7, x7, 0	A CONTRACTOR OF A CONTRACTOR O							a4	14	0x00000
0x00400034 0x00	0300293 addi x3. x0. 3	108: 1i gp. 3							eő	15	0w00000
0x00400038 0x32	2771+63 bas x14. x7, 0x0000033e	109: bne 114. 17. fe	il constant						a6	16	0x00000
0x00400034 0x80	00000b7 lus s1.0sfff80000	111: test_4: li st.	0xffffffffff0000000						a7	17	0x00000
A. A									12	18	0±00000
								- Aller - Alle	e)	19	0x00000
Seament						Data	segment nanel	a 17	14	20	0±00000
						Data	segment paner		15	21	0±00000
Address	Value (+0)	Value (+4)	Value (+8)	Value (+c)	Value (+10)	Value (+14)	Value (+18)	Value (+1c)	66 Be	22	0x00000
0x10010000	0=00000000	0±00000000	0w00000000	0x000000000	0x00000000	0x00000000	0w00000000	●x000000000 ▲	87	23	0+000000
0x10010020	0w00000000	0x00000000	0x00000000	0x000000000	0+00000000	0x00000000	0+00000000	0+00000000	88	24	0+000000
0x10010040	0v0000000	0x00000000	0±00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	19	25	0±00000
0x10010060	0x0000000	0x0000000	0w00000000	0x00000000	0x00000000	0±00000000	0x00000000	0x00000000	\$10	20	0+000000
0x10010080	0+00000000	0x0000000	0w00000000	0x00000000	0v0000000	0x00000000	0±00000000	0+00000000	411	27	0+000000
0x100100a0	0w00000000	0x0000000	0w00000000	0x0000000	0x00000000	0x00000000	0x00000000	0x00000000	13	28	0x00000
0x100100a0	0x0000000	0x0000000	0±00000000	0±00000000	0x00000000	0x00000000	0#00000000	6±00000000	t4	29	0±000000
0x100100+0	0w0000000	0x0000000	0w0000000	0x00000000	0x00000000	0x00000000	0±0000000	0000000000	15	30	0x00000
0x10010100	0#00000000	Dx0000000	0w00000000	D±00000000	0x00000000	0x00000000	0x00000000	0000000000	16	31	0±00000
0x10010120	0w00000000	0±00000000	0x00000000	0x00000000	0w00000000	0x00000000	0x00000000	0x0000000	pe :-		0±00000
0x10010140	0+0000000	0x0000000	0±00000000	0x000000x0	0x00000000	0x00000000	0±0000000	0000000000			
0x10010160	0w0000000	0x00000000	0w00000000	0x00000000	0w0000000	0x00000000	0x0000000	0x00000000			
Ca10010180	020000000	0x0000000	0x00000000	000000000	0±00000000	000000000	0±0000000	0100000000			
0x100101 e0	000000000	Px00000000	0±00000000	5×00000000	0400000000	0000000040	0x00000000	• 000000000	Da	aistars panal	
		44	0x10010000 (data)	C Maxadacimal Addres	nen 📿 Hexadacimal Value	CLASCE			Ke	gisters parer	
			(and a log	the second second second							
s Run IO	hling F:\Research\misc\TA\CEBO	0420\teels\test.mom						1			
S Run HO											
S Run 10	and the second state of the second				and the second	State and a state of the state	and the second se				
S Run 10	www.chlmise\TA\CEBG3420\v1.	Start am line 312 colum	n 2: BAS down not recom	ive the clobal diversi	ve Imired Th	and the second se					
S Run HO Assemble assem Farming in F. U	Avenue ch/miss/IA/CEBG3420/tools	Atest and line 312 column	m 2. BABS down not recogn	ize the global directi	re Ignered Prog	ram information	on panel				
S Run HO Assemble: assem Farming in F. U Farming in F. U	lesenrch/miss/IA/CENG3420/tools lesenrch/miss/IA/CENG3420/tools	\text and line 312 colum \text and line 318 colum	m 2: NAS éces not recop m 2: NAS éces not recop	ire the global directi are the global directi	ve Igared Prog	ram information	on panel				



- RARS shortcut in windows OS
 - Create a new source file: Ctrl + N
 - Close the current source file: Ctrl + W
 - Assemble the source code: F3
 - Execute the current source code: F5
 - Step running: F7
 - Instructions & System call query: F1