Elementos de Lógica Digital II

COMP09 µProcessor

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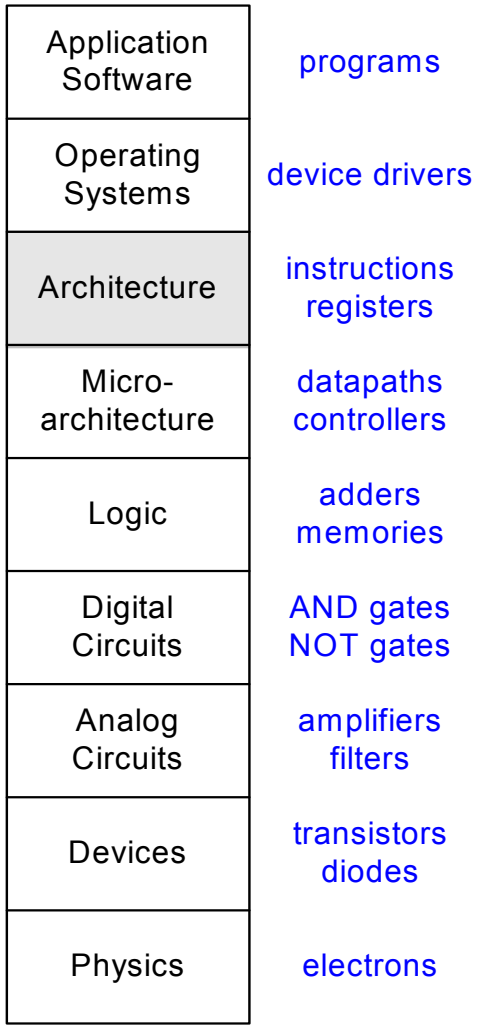
Introduction

- **Architecture:** the programmer's view of the computer
  - Defined by instructions (operations) and operand locations
- **Microarchitecture:** how to implement an architecture in hardware



Assembly Language

- To command a computer, you must understand its language.
  - **Instructions:** words in a computer's language
  - **Instruction set:** the vocabulary of a computer's language

- Instructions indicate the operation to perform and the operands to use.
  - **Assembly language:** human-readable format of instructions
  - **Machine language:** computer-readable format
    - Computers only understand 1's and 0's
    - Binary representation of instructions

Stored Program

- Sequence of instructions: only difference between two applications (for example, a text editor and a video game)
- To run a new program:
  - No rewiring required
  - Simply store new program in memory
- The processor hardware executes the program:
  - *fetches* (reads) the instructions from memory in sequence
  - performs the specified operation
- The program counter (PC) keeps track of the current instruction

What needs to be stored in memory?

- Instructions (also called *text*)
- Data
  - Global/static: allocated before program begins
  - Dynamic: allocated within program
- How big is memory?
  - At most 2^{32} = 4 gigabytes (4 GB)
  - From address 0x00000000 to 0xFFFFFFFF

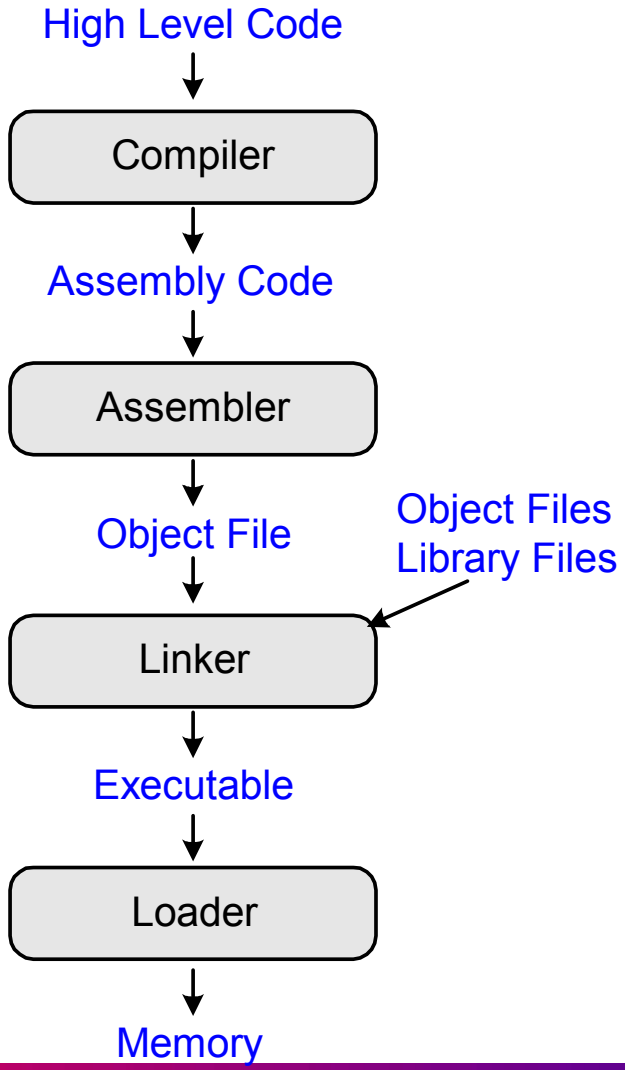
Ada Lovelace, 1815 - 1852

- Wrote the first computer program
- Her program calculated the Bernoulli numbers on Charles Babbage's Analytical Engine
- She was the only legitimate child of the poet Lord Byron

Programming

- High-level languages:
  - e.g., C, Java, Python
  - Written at more abstract level
- Common high-level software constructs:
  - if/else statements
  - for loops
  - while loops
  - array accesses
  - procedure calls
- Other useful instructions:
  - Arithmetic/logical instructions
  - Branching

How do we compile & run an application?



Grace Hopper, 1906 - 1992

- Graduated from Yale University with PhD in mathematics
- Developed first compiler
- Helped develop the COBOL programming language
- Highly awarded naval officer
- Received World War II Victory Metal and National Defense Service Medal, among others

RISC x CISC architecture

- RISC (Reduced Instruction Set Computer)
  - A small number of simple instructions
  - Hardware to decode and execute the instruction can be simple, small, and fast.
  - More complex instructions (that are less common) can be performed using multiple simple instructions.
- Other architectures, such as Intel's IA-32 found in many PC's, are ***complex instruction set computers* (CISC)**. They include complex instructions that are rarely used, such as the "string move" instruction that copies a string (a series of characters) from one part of memory to another.

The COMP09 µProcessor

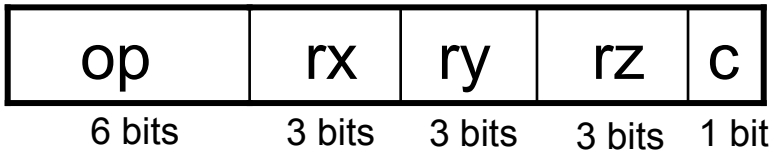
- COMP09 architecture:
  - Developed by Eduardo do Valle Simões and Vanderlei Bonato at ICMC/USP.
  - RISC architecture type
- 16-bit instructions
- Four instruction formats:
  - R-type: register operands
  - JB-type: jump and branch instruction type
  - C-type: system control
  - S-type: stack operations

The uCOMP09 register set

Name	Qtt	Purpose
R_n	0-7	General purpose
FR	1	Bits of flag
SP	1	Stack pointer
PC	1	Program counter
IR (interno)	1	Instruction register
MAR (interno)	1	Memory address buffer
MBR (interno)	1	Data memory buffer

Instruction format

- Register operands (R-type)
  - op = opcode
  - rx, ry, rz: registers
  - c: bit of carry



Data manipulation instructions

Direct address mode		
STORE END RX	MEM(END) <- RX	110001 | RX | xxx | xxx | x END
LOAD RX END	RX <- MEM(END)	110000 | RX | xxx | xxx | x END
Indirect address mode		
STOREIMED RX NR	MEM(RX) <- #NR	111001 | RX | xxx | xxx | x NR
LOADIMED RX NR	RX <- #NR	111000 | RX | xxx | xxx | x NR
Indexed address mode		
STOREINDEX RY RX	MEM(RY) <- RX	111101 | RX | RY | xxx | x
LOADINDEX RX RY	RX <- MEM(RY)	111100 | RX | RY | xxx | x
MOV RX RY	RX <- RY	110011 | RX | RY | xxx | x

Arithmetic instructions

ADD RX RY RZ	RZ<-RX+RY	100000 | RX | RY | RZ | 0
ADDC RX RY RZ	RZ<-RX+RY+C	100000 | RX | RY | RZ | 1
SUB RX RY RZ	RZ<-RX-RY	100001 | RX | RY | RZ | 0
SUBC RX RY RZ	RZ<-RX-RY+C	100001 | RX | RY | RZ | 1
MULT RX RY RZ	RZ<-RX*RY	100010 | RX | RY | RZ | 0
MULTC RX RY RZ	RZ<-RX*RY+C	100010 | RX | RY | RZ | 1
DIV RX RY RZ	RZ<-RX/RY	100011 | RX | RY | RZ | 0
DIVC RX RY RZ	RZ<-RX/RY+C	100011 | RX | RY | RZ | 1
INC RX	RX++	100100 | RX | xxx | xxx | 0
DEC RX	RX--	100100 | RX | xxx | xxx | 1

Logic instructions

LAND RX RY RZ	RZ<-RX AND RY	010010 | RX | RY | RZ | x
LOR RX RY RZ	RZ<-RX OR RY	010011 | RX | RY | RZ | x
LXOR RX RY RZ	RZ<-RX XOR RY	010100 | RX | RY | RZ | x
LNOT RX	RX<-NOT(RX)	010101 | RX | RY | xxx | x
ROT L RX	ROTATE TO LEFT	010000 | RX | xxx | x1x | 0
ROT R RX	ROTATE TO RIGHT	010000 | RX | xxx | x1x | 1
SHIFT L0 RX	SHIFT TO LEFT (FILL 0)	010000 | RX | xxx | x00 | 0
SHIFT L1 RX	SHIFT TO LEFT (FILL 1)	010000 | RX | xxx | x01 | 0
SHIFT R0 RX	SHIFT TO RIGHT (FILL 0)	010000 | RX | xxx | x00 | 1
SHIFT R1 RX	SHIFT TO RIGHT (FILL 1)	010000 | RX | xxx | x01 | 1
CMP RX RY	FR<-COND	010110 | RX | RY | xxx | x

Input and Output (I/O) instructions

Input

INCHAR RX	RX<-”00000000”&key	110101 | RX | xxx | xxx | x

Output

OUTCHAR RX RY	VIDEO(RY)<-CHAR(RX)	110001 | RX | RY | xxx | x

Instruction format

- Jump and Branch (JB-type)

Branch instructions

- Branchs only if the condition is true

BRA +/-INC	PC<-PC +/- INC	000001 | 0000 | +/- | INC
BEQ +/-INC	PC<-PC +/- INC	000001 | 0011 | +/- | INC
BNE +/-INC	PC<-PC +/- INC	000001 | 0101 | +/- | INC
BZ +/-INC	PC<-PC +/- INC	000001 | 1010 | +/- | INC
BNZ +/-INC	PC<-PC +/- INC	000001 | 1011 | +/- | INC
BC +/-INC	PC<-PC +/- INC	000001 | 0111 | +/- | INC
BNC +/-INC	PC<-PC +/- INC	000001 | 1000 | +/- | INC
BGR +/-INC	PC<-PC +/- INC	000001 | 0010 | +/- | INC
BLE +/-INC	PC<-PC +/- INC	000001 | 0001 | +/- | INC
BEG +/-INC	PC<-PC +/- INC	000001 | 0100 | +/- | INC
BEL +/-INC	PC<-PC +/- INC	000001 | 0101 | +/- | INC
BOV +/-INC	PC<-PC +/- INC	000001 | 1001 | +/- | INC
BNOV +/-INC	PC<-PC +/- INC	000001 | 1100 | +/- | INC

Jump instructions (all with END)

- Jumps to END only if the condition is true

JMP END	PC<-END	000010 | 0000 | x | xxxxx END
JEQ END	PC<-END	000010 | 0000 | x | xxxxx
JNE END	PC<- END	000010 | 0101 | x | xxxxx
JZ END	PC<- END	000010 | 1010 | x | xxxxx
JNZ END	PC<- END	000010 | 1011 | x | xxxxx
JC END	PC<- END	000010 | 0111 | x | xxxxx
JNC END	PC<- END	000010 | 1000 | x | xxxxx
JGR END	PC<- END	000010 | 0010 | x | xxxxx
JLE END	PC<- END	000010 | 0001 | x | xxxxx
JEG END	PC<- END	000010 | 0100 | x | xxxxx
JEL END	PC<- END	000010 | 0101 | x | xxxxx
JOV END	PC<- END	000010 | 1001 | x | xxxxx
JNOV END	PC<- END	000010 | 1100 | x | xxxxx

Call instructions (all with END)

- Calls the procedure only of the condition is true

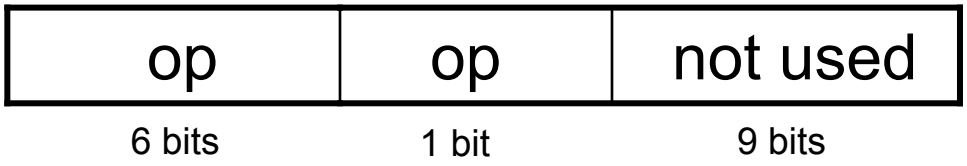
CALL END	MEM(SP)<-PC	000011 | 0000 | x | xxxxx
	PC<-END	END
	SP--	
CEQ END	idem	000010 | 0000 | x | xxxxx
CNE END	idem	000010 | 0101 | x | xxxxx
CZ END	idem	000010 | 1010 | x | xxxxx
CNZ END	idem	000010 | 1011 | x | xxxxx
CC END	idem	000010 | 0111 | x | xxxxx
CNC END	idem	000010 | 1000 | x | xxxxx
CGR END	idem	000010 | 0010 | x | xxxxx
CLE END	idem	000010 | 0001 | x | xxxxx
CEG END	idem	000010 | 0100 | x | xxxxx
CEL END	idem	000010 | 0101 | x | xxxxx
COV END	idem	000010 | 1001 | x | xxxxx
CNOV END	idem	000010 | 1100 | x | xxxxx

Return instruction

RTS	SP++ PC<=MEM(SP)	000100 | xxxx | x | xxxxx

Instruction format

- System control (C-type)

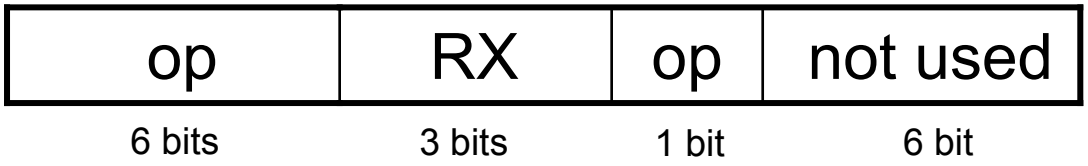


Control instructions

CLEARC	C<-0	001000 | 0 | xxxxxxxxx
SETC	C<-1	001000 | 1 | xxxxxxxxx
HALT	STOP EXECUTION	001111 | x | xxxxxxxxx
NOP	NO OPERATION	000000 | x | xxxxxxxxx

Instruction format

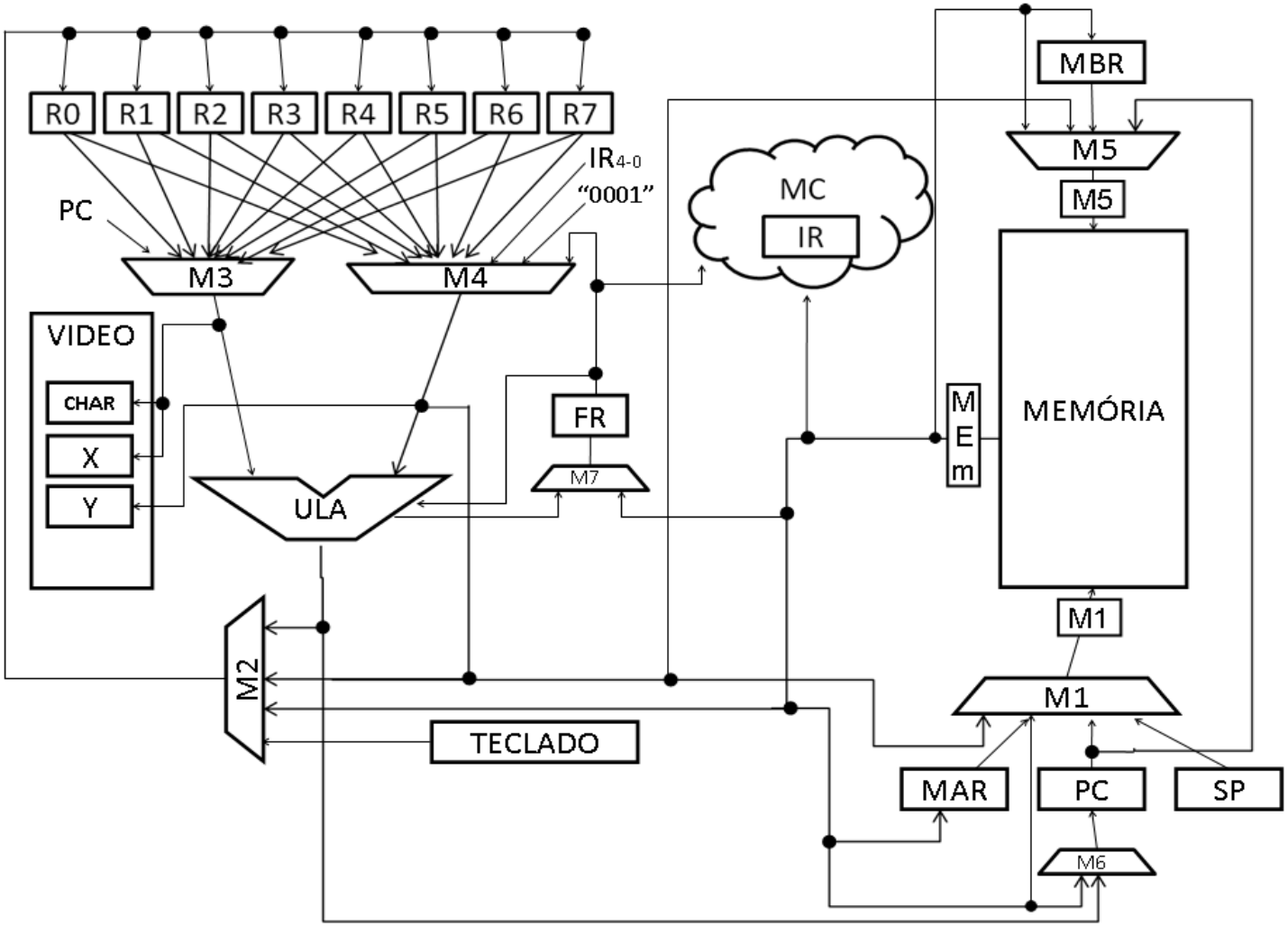
- Stack operations (S-type)



Stack instructions

PUSH RX	MEM(SP) <- RX SP--	000101 | RX | 0 | xxxxxx
PUSH FR	MEM(SP) <- FR SP--	000101 | xxx | 1 | xxxxxx
POP RX	RX <- MEM(SP) SP++	000110 | RX | 0 | xxxxxx
POP FR	FR <- MEM(SP) SP++	000110 | xxx | 1 | xxxxxx

The COMP09 processor microarchitecture



Exercises

- Convert the following COMP09 assembly code into machine language. Write the instructions in hexadecimal

```
INCHAR 0
INCHAR 1
OUTCHAR 0 1
```