USP - ICMC - SSC

SSC 0511 - Sist. Informação - 2o. Semestre 2014

Disciplina de Organização de Computadores Digitais

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Página Pessoal: http://www.icmc.usp.br/~fosorio/

Material on-line: Wiki ICMC:

http://wiki.icmc.usp.br/index.php/SSC-511-2014(fosorio)

IRM
Lab. de Robótica Móvel
CROB
Centro de Robótica da USP

Aula 05t

Apresentação da Aula

Conteúdos Abordados:

1. **Microprocessador 6502**

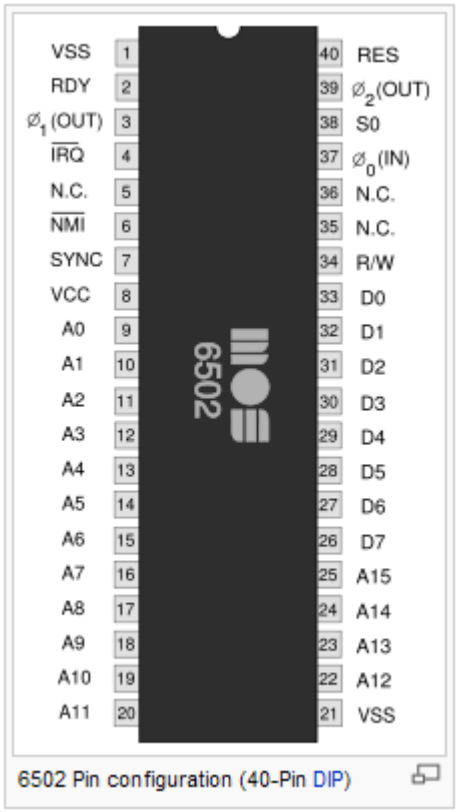
   - Microprocessador Comercial MOSTEK 6502
   - Usado no Apple II, Atari (400, 800, 2600), Commodore (VIC-20)
   - Emulador do Apple II

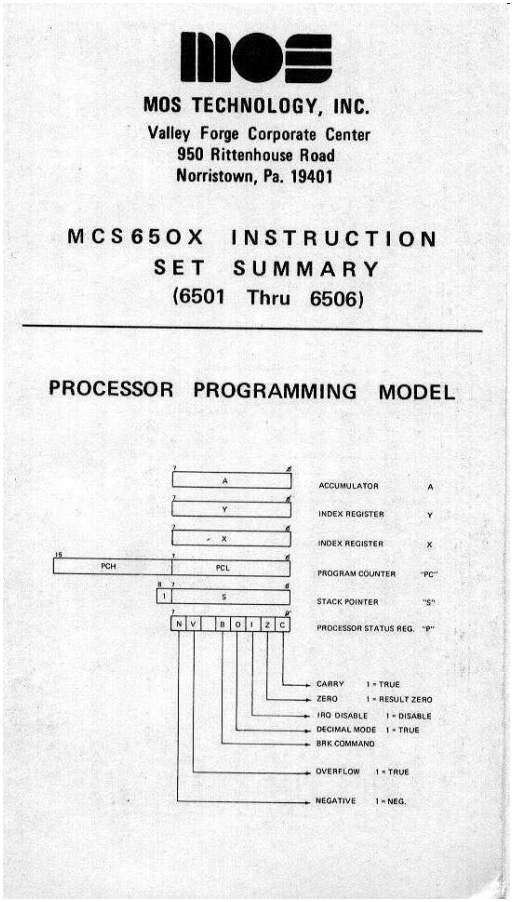
   - Arquitetura da CPU: Registradores, ULA, Barramento
   - CPU: Principais Características
   - Modos de Endereçamento
   - Principais Instruções
   - Simulador do 6502

Arquitetura de Microprocessador Comercial

MosTech 6502 - Adotado no Apple II

Microprocessador de 8 bits dados e 16 bits de endereço





* http://en.wikipedia.org/wiki/MOS_Technology_6502

Arquitetura de Microprocessador Comercial

MosTech 6502 - Adotado no Apple II

Microprocessador de 8 bits dados e 16 bits de endereço

Registers

The 6502 only has 6 registers. Five are 8 bits wide, one is 16 bits wide.

A		Accumulator
X		Index Register X
Y		Index Register Y
PCH	PCL	Program Counter
S		Stack Pointer
P		Processor Status (Flags)

Processor Status Register

N	V	-	B	D	I	Z	C

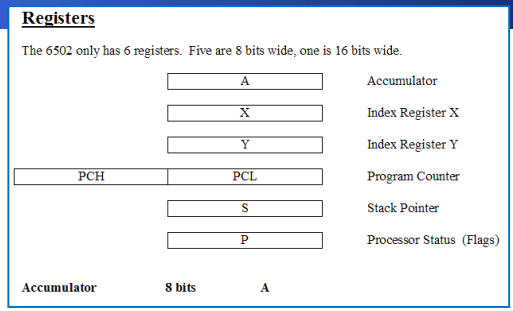
N - Negative Flag
V - Overflow Flag
B - Break Command
D - Decimal Mode
I - Int. Disable
Z - Zero Flag
C - Carry Flag

Accumulator **8 bits** **A**

* Simulador: 6502 Simulator / Site: http://home.pacbell.net/michal_k/ / By Michal Kowalski

Arquitetura de Microprocessador Comercial

MosTech 6502 - Adotado no Apple II



Accumulator **8 bits** **A**

Used for all arithmetic and logical operations (apart from increments and decrements). Data must be loaded into the Acc before it can be manipulated.

Index Register X **8 bits** **X**

Usually used to hold counters or offsets for accessing memory. Contents can be compared with memory locations and incremented and decremented.

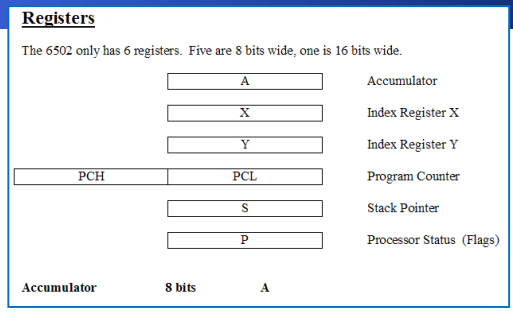
Unlike other registers (including the Y register), can be used to get a copy of the stack pointer or change its value.

Index Register Y **8 bits** **Y**

Usually used to hold counters or offsets for accessing memory. Contents can be compared with memory locations and incremented or decremented.

Arquitetura de Microprocessador Comercial

MosTech 6502 - Adotado no Apple II



Program Counter **16 bits** **PC**

Contains the address of the next instruction to be executed. Automatically incremented by the hardware, but can be altered by a jump, branch or subroutine call / return.

Stack Pointer **8 bits** **S**

The 6502 uses a 256 byte stack located on page 1 ($0100 to $01FF). The stack pointer is an 8 bit register that holds the least significant byte of the next free location on the stack. This means that the stack cannot be moved. The stack starts at $01FF and grows downward. When a byte is pushed onto the stack, the stack pointer is decremented. When something is popped off the stack, it is incremented.

The hardware does not detect stack overflow. The programmer must ensure that the program does not make excessive demands on the stack space.

Arquitetura de Microprocessador Comercial

MosTech 6502 - Adotado no Apple II

Microprocessador de 8 bits dados e 16 bits de endereço

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Accumulator **8 bits** **A**

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Arquitetura de Microprocessador Comercial

MosTech 6502 - Adotado no Apple II

N - Negative Flag
V - Overflow Flag
B - Break Command
D - Decimal Mode
I - Int. Disable
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C - Carry Flag

Processor Status Register

N	V	-	B	D	I	Z	C

Also known as the flags register. Used to indicate the results of an operation. Each bit in the register signifies a different condition. Some of the instructions allow you to test the values of various bits, set them, clear them, and push the entire set onto the stack (or pop them off).

Carry Flag C

The carry flag is set if the last operation caused an overflow from the most significant bit (bit 7) of the result or an underflow from the least significant bit (bit 0).

This condition is set during arithmetic instructions, comparison instructions and during logical shifts. It can be explicitly set using the 'Set Carry Flag' (SEC) instruction and cleared with 'Clear Carry Flag' (CLC).

Zero Flag Z

The zero flag is set if the result of the last operation was zero.

Arquitetura de Microprocessador Comercial

MosTech 6502 - Adotado no Apple II

Processor Status Register

N	V	-	B	D	I	Z	C

```
N - Negative Flag
V - Overflow Flag
B - Break Command
D - Decimal Mode
I - Int. Disable
Z - Zero Flag
C - Carry Flag
```

Interrupt Disable **I**

The interrupt disable flag is set if the program has executed a 'Set Interrupt Disable' (SEI) instruction. While this flag is set the processor will not respond to interrupts from external devices until it is cleared by a 'Clear Interrupt Disable' (CLI) instruction.

Decimal Mode **D**

While the decimal mode flag is set the processor will obey the rules of Binary Coded Decimal (BCD) arithmetic during addition and subtraction. The flag can be explicitly set using 'Set Decimal Flag' (SED) and cleared with 'Clear Decimal Flag' (CLD).

Break Command **B**

The break command bit is set when a BRK instruction has been executed and an interrupt has been generated to process it.

Arquitetura de Microprocessador Comercial

MosTech 6502 - Adotado no Apple II

Processor Status Register

N	V	-	B	D	I	Z	C

```
N - Negative Flag
V - Overflow Flag
B - Break Command
D - Decimal Mode
I - Int. Disable
Z - Zero Flag
C - Carry Flag
```

Overflow Flag V

The overflow flag is set during arithmetic operations if the result has yielded an invalid 2's complement result (e.g. adding two positive numbers and ending up with a negative result: 64 + 64 => -128).

If the most significant bit of the two numbers being added is the same, and if it is different to the msb of the result, then the overflow flag will be set.

Negative Flag N

The negative flag is set if the result of the last operation had the most significant bit (bit 7) set to a one.

Microprocessador 6502

Programação 6502 – Addressing Modes

A MOS 6502 processor in a DIP-40 plastic package.

Basic Specifications

Clock speed 1, 2 and even 3 Mhz models were available.

Wordlength 8 bits

Input / Output Memory mapped.

There are no I/O registers in the processor, so a set of memory addresses will be allocated to the I/O devices. The motherboard hardware will ensure that if a value is written to memory address $E000 (for example), it will be sent straight to a specific output device.

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Microprocessador 6502

Programação 6502 – Addressing Modes

A MOS 6502 processor in a DIP-40 plastic package.

Addresses

Address bus 16 bits

Addresses in the range	0000000000000000	to	1111111111111111	binary
or	$0000	to	$FFFF	hex

can be accessed by the processor.

Adressable Memory is therefore 64 Kb

Little endian Addresses stored least significant byte first.

A 16 bit address needs to be stored in two consecutive bytes. A little endian processor will store the address $458D as $8D followed by the byte $45.

Microprocessador 6502

Programação 6502 – Addressing Modes

Paged Memory

Memory is viewed as a set of 256 byte pages.

The first page ($0000 to $00FF) is called the '**Zero page**', and can be accessed by using a special addressing mode which enables you to use shorter and therefore faster executing instructions.

This makes it useful for storing tables of values or addresses that are going to be accessed frequently by your program.

The second page ($0100 to $01FF) is used to hold the **system stack**. This is used to keep track of values, especially during subroutine calls. It cannot be moved.

Other reserved locations:

$FFFA	Address of NMI handler
$FFFB	ditto
$FFFC	Address of power on reset location
$FFFD	ditto
$FFFE	BRK / interrupt request handler
$FFFF	ditto

Microprocessador 6502

Programação 6502 – Addressing Modes

Principais Modos de endereçamento

Absolute (Direct) addressing

The operand is the address in memory where the data item can be found.

LDA	$6F55		This instruction will access memory location $6F55, and copy the contents into the accumulator register.

Immediate addressing

The operand is the data item.

LDA	#41		This instruction will load the number 41 ($29) into the accumulator register.

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Microprocessador 6502

Programação 6502

Principais Modos de endereçamento

Indexed addressing

The operand is added to the contents of the index register, and this gives the location in memory of the data.

LDA	$4F10,X		$34		This instruction will access the memory location $4F44, and copy the contents into the accumulator.
			Index Register X		

Indirect addressing

The operand is the address of a memory location which contains the address of the data item.

LDA	($2B57)		2B57	3C
			2B58	6A
			6A3C	44

This instruction will load the data item 44 into the accumulator register.

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Microprocessador 6502

Programação 6502

Principais Modos de endereçamento

Relative addressing

This is used in conjunction with branches. The operand is a 2's comp number (-128 - +127) which is added to the address of the instruction following the branch instruction to give the address of the instruction to be jumped to.

4545	BEQ	$13	This BEQ command will cause control to be passed to the instruction in location $4547 + $13 = $455A, provided that the zero flag is set.
4547	LDA	$9333	

Resumo: (ver documentação associada ao Simulador do 6502)

Absolute aaaa
Zero Page aa
Immediate #aa
Implicit
Accumulator A
Absolute Indexed, X aaaa, X
Absolute Indexed, Y aaaa, Y

Zero Page Indexed, X aa, X
Zero Page Indexed, Y aa, Y
Indirect Absolute (aaaa)
Indexed Indirect (aa, X)
Indirect Indexed (aa), Y
Relative aa

* Simulador: 6502 Simulator / Site: http://home.pacbell.net/michal_k/ / By Michal Kowalski

Microprocessador 6502

Programação 6502 – Instruction Set

Principais Instruções

Load and Store Group

●	LDA	Load Accumulator	N,Z
	LDX	Load X Register	N,Z
	LDY	Load Y Register	N,Z
●	STA	Store Accumulator	
	STX	Store X Register	
	STY	Store Y Register	

Arithmetic Group

●	ADC	Add with Carry	N,V,Z,C
●	SBC	Subtract with Carry	N,V,Z,C

Increment and Decrement Group

●	INC	Increment a memory location	N,Z
	INX	Increment the X register	N,Z
	INY	Increment the Y register	N,Z
●	DEC	Decrement a memory location	N,Z
	DEX	Decrement the X register	N,Z
	DEY	Decrement the Y register	N,Z

Register Transfer Group

TAX	Transfer accumulator to X	N,Z
TAY	Transfer accumulator to Y	N,Z
TXA	Transfer X to accumulator	N,Z
TYA	Transfer Y to accumulator	N,Z

Logical Group

AND	Logical AND	N,Z
EOR	Exclusive OR	N,Z
ORA	Logical Inclusive OR	N,Z

Compare and Bit Test Group

●	CMP	Compare accumulator	N,Z,C
	CPX	Compare X register	N,Z,C
	CPY	Compare Y register	N,Z,C
	BIT	Bit Test	N,V,Z

Shift and Rotate Group

ASL	Arithmetic Shift Left	N,Z,C
LSR	Logical Shift Right	N,Z,C
ROL	Rotate Left	N,Z,C
ROR	Rotate Right	N,Z,C

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Microprocessador 6502

Programação 6502

Instruction Set

Principais Instruções

Subroutine and Interrupt Group

● JSR	Jump to a subroutine	
● RTS	Return from subroutine	
BRK	Force an interrupt	B
RTI	Return from Interrupt	All
NOP	No Operation	

Jump and Branch Group

● JMP	Jump to another location	
BCC	Branch if carry flag clear	
BCS	Branch if carry flag set	
● BEQ	Branch if zero flag set	
BMI	Branch if negative flag set	
● BNE	Branch if zero flag clear	
BPL	Branch if negative flag clear	
BVC	Branch if overflow flag clear	
BVS	Branch if overflow flag set	

Stack Group

TSX	Transfer stack pointer to X	N,Z
TXS	Transfer X to stack pointer	
● PHA	Push accumulator on stack	
PHP	Push processor status on stack	
● PLA	Pull accumulator from stack	N,Z
PLP	Pull processor status from stack	All

Status Flag Change Group

CLC	Clear carry flag	C
CLD	Clear decimal mode flag	D
CLI	Clear interrupt disable flag	I
CLV	Clear overflow flag	V
SEC	Set carry flag	C
SED	Set decimal mode flag	D
SEI	Set interrupt disable flag	I

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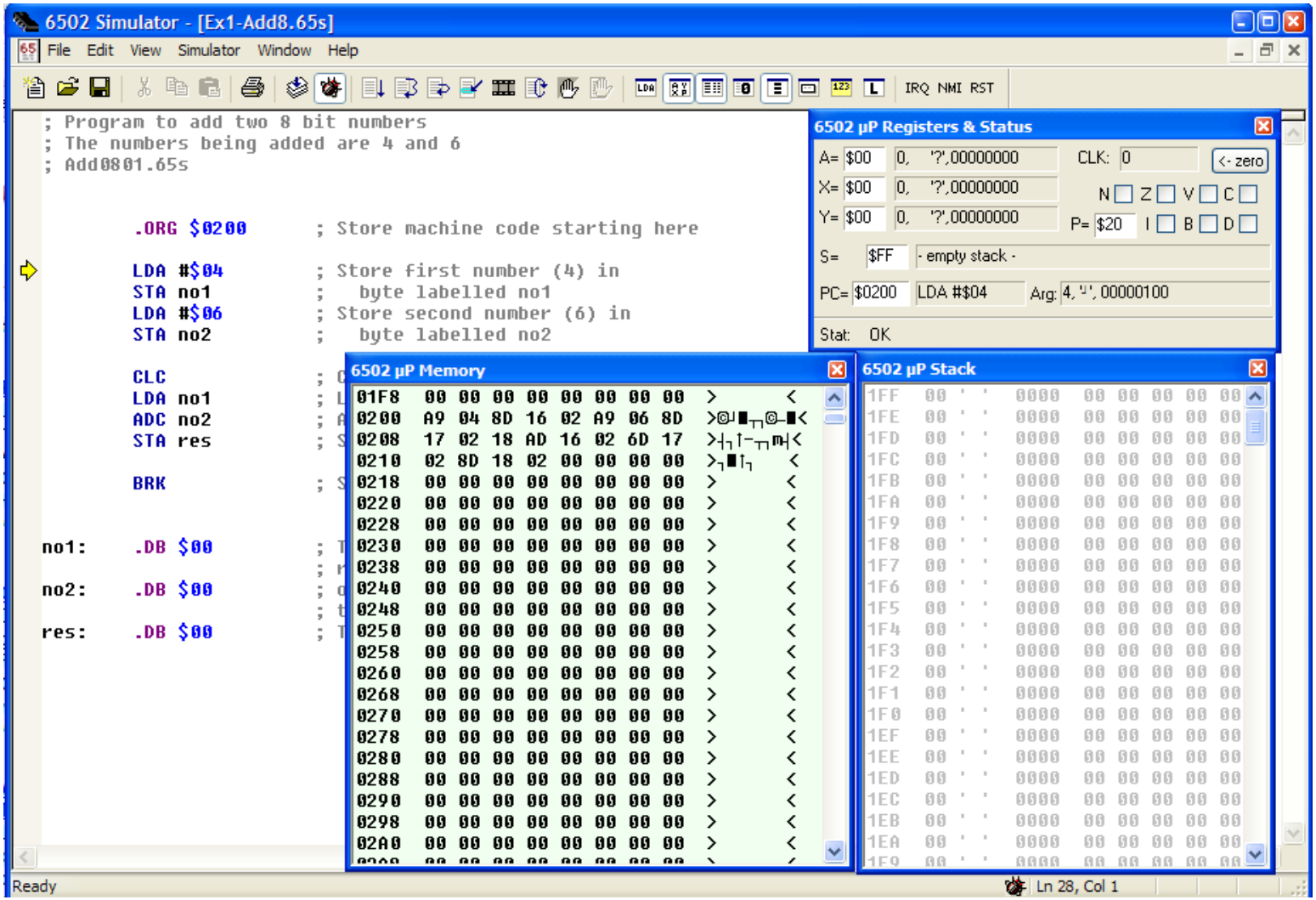
Microprocessador 6502

MosTech 6502 - Adotado no Apple II



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Microprocessador 6502

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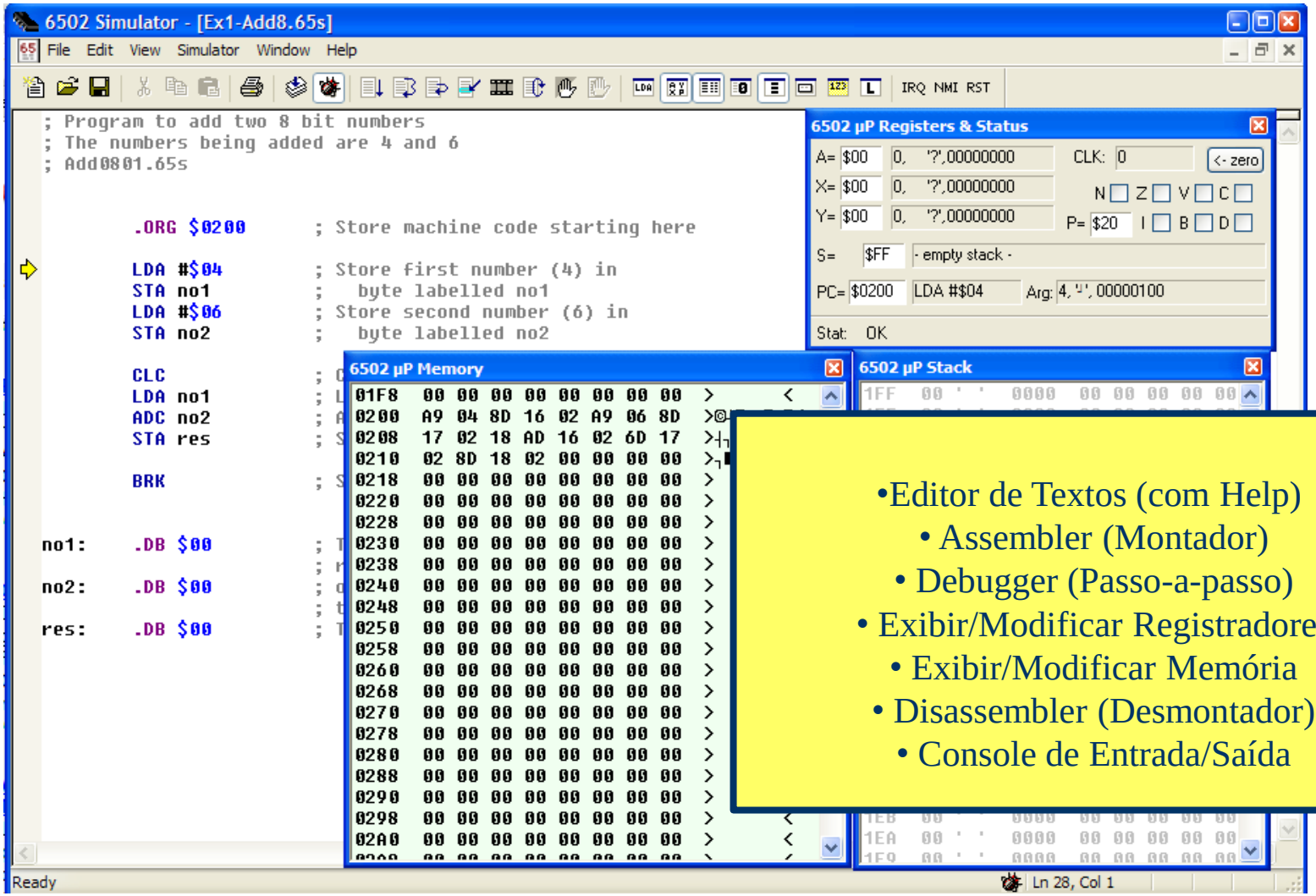

- Editor de Textos (com Help)
- Assembler (Montador)
- Debugger (Passo-a-passo)
- Exibir/Modificar Registradores
- Exibir/Modificar Memória
- Disassembler (Desmontador)
- Console de Entrada/Saída

* Simulador: 6502 Simulator / Site: http://home.pacbell.net/michal_k/ / By Michal Kowalski

Microprocessador 6502

MosTech 6502 - Adotado no Apple II

Programação do 6502 – Exercícios

1) Somar 2 valores de 8 bits

```
;
; Programa para somar dois valores de 8 bits
;
            .ORG    $1000
inicio:     LDA     #$05
            ADC     #$34
            STA     Result
            BRK

Result:     .DB     $00
```


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Microprocessador 6502

MosTech 6502 - Adotado no Apple II

Programação do 6502 – Exercícios

1) Somar 2 valores de 16 bits

```
                .ORG $1000
        Resultado = $4000
inicio: CLC
        LDA     V1L
        ADC     V2L
        STA     ResL
        LDA     V1H
        ADC     V2H
        STA     ResH
        BRK
```

```
        .ORG    $2000
V1L:    .DB     $FF
V1H:    .DB     $01
V2L:    .DB     $01
V2H:    .DB     $01
ResL:   .DB     $00
ResH:   .DB     $00
```

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Microprocessador 6502

MosTech 6502 - Adotado no Apple II

Programação do 6502 – Exercícios

1) Somar 2 valores de 8 bits
2) Somar 2 valores de 16 bits (considerando o “vai um”)
3) Somar vários valores de 8 bits (A + B + C + D + E)
4) Subtrair valores de 8 bits (A – B)
5) Contador: Laço de contagem até 10
6) Somar os dados de um vetor
7) Somar valores com mais de 8 bits (!)
8) Multiplicar 2 valores
9) Pesquisar um dado em uma tabela

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Microprocessador 6502

MosTech 6502 - Adotado no Apple II

Programação do 6502 – Exercícios

1) Escrever a mensagem “HELLO WORLD” na Console
2) Ler uma tecla do teclado e exibir na Console
3) Ler um texto do teclado e exibir na Console
4) Fazer um programa com uma sub-rotina
   - Ler mensagem de Texto
   - Escrever mensagem de Texto
5) Fazer um programa com um laço que leia uma tecla:
   - Se for ‘E’: ler um número e empilhar na pilha
   - Se for ‘D’: Desempilhar o valor da pilha e exibir na tela
   - Se for ‘X’: Termina a execução do programa

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Microprocessador 6502

MosTech 6502 - Adotado no Apple II

Programação do 6502 – Exercícios

Consulte os exemplos de programas em:

http://osorio.wait4.org/SSC0610/6502/Exemplos/

http://osorio.wait4.org/SSC0610/6502/Programs/

Consulte a documentação sobre o simulador em:

http://osorio.wait4.org/SSC0610/6502/Docs/ **ou**

http://osorio.wait4.org/SSC0610/6502/6502_Docs.zip

Consulte a documentação sobre as instruções do processador 6502 e como programá-lo em:

http://osorio.wait4.org/SSC0610/6502/DataSheet/

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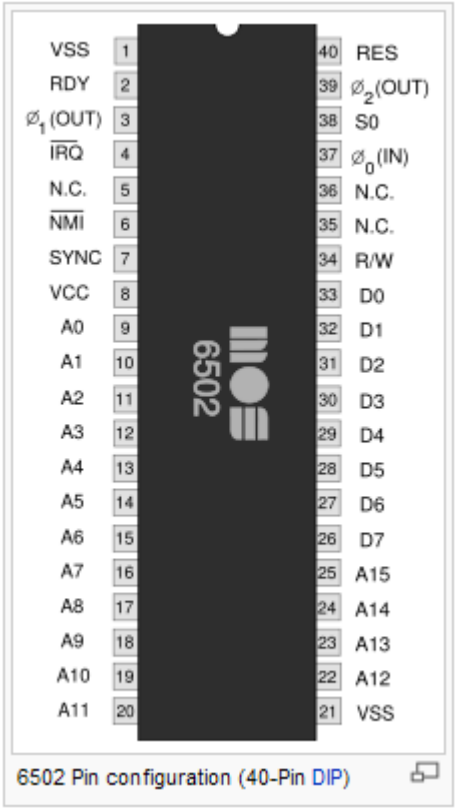
Input/Output (I/O) – Entrada/Saída (E/S):

- Método usado para acessar os dispositivos de I/O no 6502

  - I/O mapeado em memória
    Acesso a memória de I/O
    Instruções tipo LDA, STA

    Instruction Set:
    Sem Instruções Específicas para I/O

    Exemplo: 6502
    > Não possui instruções especiais de I/O
    > Não possui hardware específico para I/O



6502 Pin configuration (40-Pin DIP)

Entrada e Saída

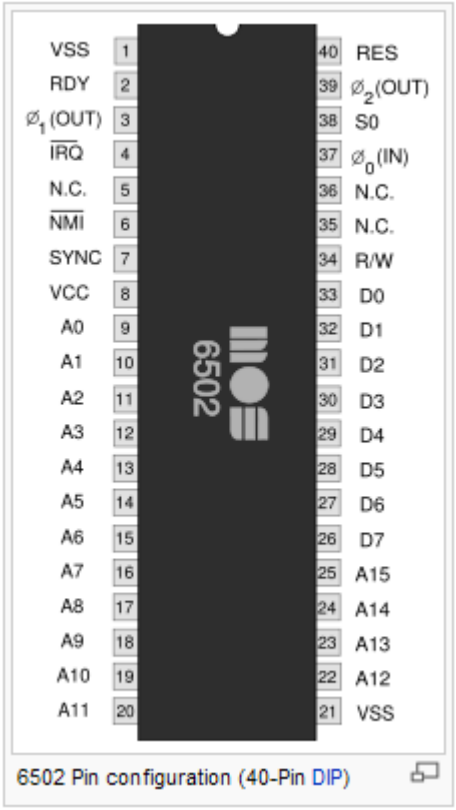
Input/Output (I/O) – Entrada/Saída (E/S):

- Método usado para acessar os dispositivos de I/O no 6502

- I/O mapeado em memória
  Acesso a memória de I/O
  Instruções tipo LDA, STA

  Exemplos:
  APPLE – Acesso ao “Speaker”
  End. $C030

  Simulador 6502
  Acesso ao Vídeo: $E000,$E002,$E003
  Acesso ao Teclado: $E004



6502 Pin configuration (40-Pin DIP)

Entrada e Saída

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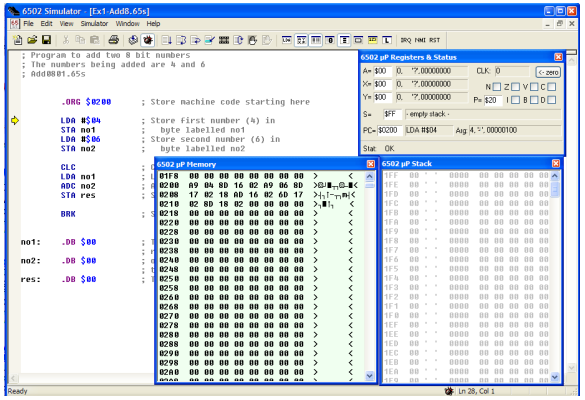


  - I/O mapeado em memória
    Acesso a memória de I/O
    Instruções tipo LDA, STA

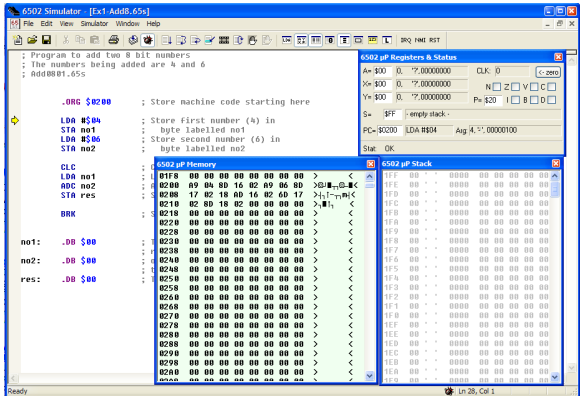
$E000 Clear terminal window
$E001 Ascii code will be sent to terminal screen and displayed as a character
$E002 Ascii code will be sent to screen and displayed as above, but CR/LF will be ignored
$E003 Ascii code will be sent to screen and displayed as a hexadecimal number

$E005 Controls horizontal location of cursor
$E006 Controls vertical location of cursor.

Entrada e Saída

Input/Output (I/O) – Entrada/Saída (E/S):

- Método usado para acessar os dispositivos de I/O no 6502



$E000 Clear terminal window
$E001 Ascii code will be sent to terminal screen and displayed as a character
$E005 Controls horizontal location of cursor
$E006 Controls vertical location of cursor.

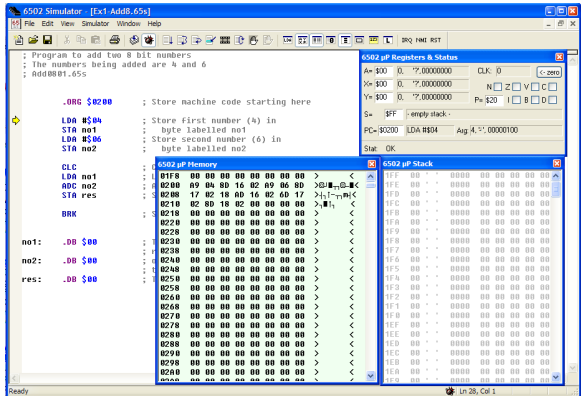
```
io_putc    = $E001
io_posx    = $E005
io_posy    = $E006

           .ORG $300
inicio:    LDA #$0A
           STA io_posx                ; This will send cursor to column 10
           LDA #$05
           STA io_posy                ; This will send cursor to row 5
           LDA #'A'
           STA io_putc
           STA io_putc
           STA io_putc
           BRK
```

Entrada e Saída

Input/Output (I/O) – Entrada/Saída (E/S):

- Método usado para acessar os dispositivos de I/O no 6502



- I/O mapeado em memória
  Acesso a memória de I/O
  Instruções tipo LDA, STA

$E004 If a character has been typed
into the terminal screen,
it will be copied to this location

Teclado...
ASCII, echo, Press-Release,
Leitura múltipla, Scan-Codes,

```
inicio:   LDA #$00
          STA $E000   ; Limpa Tela
Loop:     LDA $E004
          CMP #00     ; Espera tecla
          BEQ Loop
          STA $E002   ; Exibe Echo
Pula:     CMP #$0D    ; Enter: FIM
          BNE Loop
          BRK

; Leitura de teclado por "Pooling"
```

INFORMAÇÕES SOBRE A DISCIPLINA

USP - Universidade de São Paulo - São Carlos, SP
ICMC - Instituto de Ciências Matemáticas e de Computação
SSC - Departamento de Sistemas de Computação

Prof. Fernando Santos OSÓRIO
Web institucional: http://www.icmc.usp.br/ssc/
Página pessoal: http://www.icmc.usp.br/~fosorio/
E-mail: fosorio [at] icmc. usp. br ou fosorio [at] gmail. com

Disciplina de Organização de Computadores Digitais / BSI
Web disciplina: Wiki ICMC - Http://wiki.icmc.usp.br
> Programa, Material de Aulas, Critérios de Avaliação,
> Lista de Exercícios, Trabalhos Práticos, Datas das Provas