COL216
Computer Architecture

Introduction

6th Jan, 2022

What this course is about?

PROGRAMS

- Expressions
- Types
- Conditions
- Loops
- Functions
- Classes
- Threads

Computer Architecture

CIRCUITS

- Transistors (v, i)
- Gates (1, 0)
- Flip-flops
- Registeers
- Memories
- ALUs
- FSMs

Many programming languages

C

C++

Java

Python

Matlab

Computer Architecture

CIRCUITS

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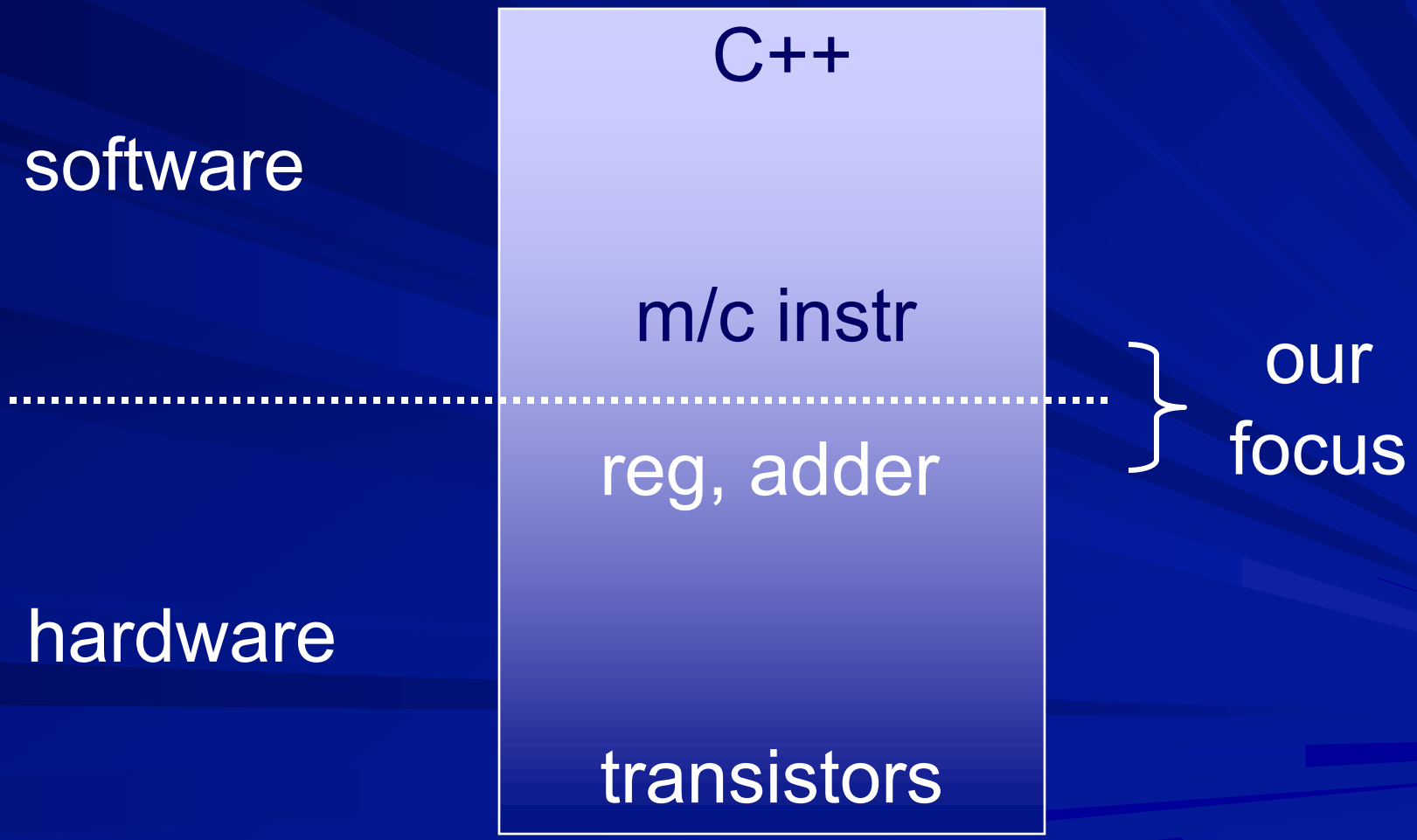
- Flip-flops
- Registers
- Memories
- ALUs
- FSMs

Hardware/software interface



Software Abstraction

```
swap (int v[ ], int k);
{ int temp;
        temp   = v[k]
        v[k]     = v[k+1];
        v[k+1] = temp;
}
```

C

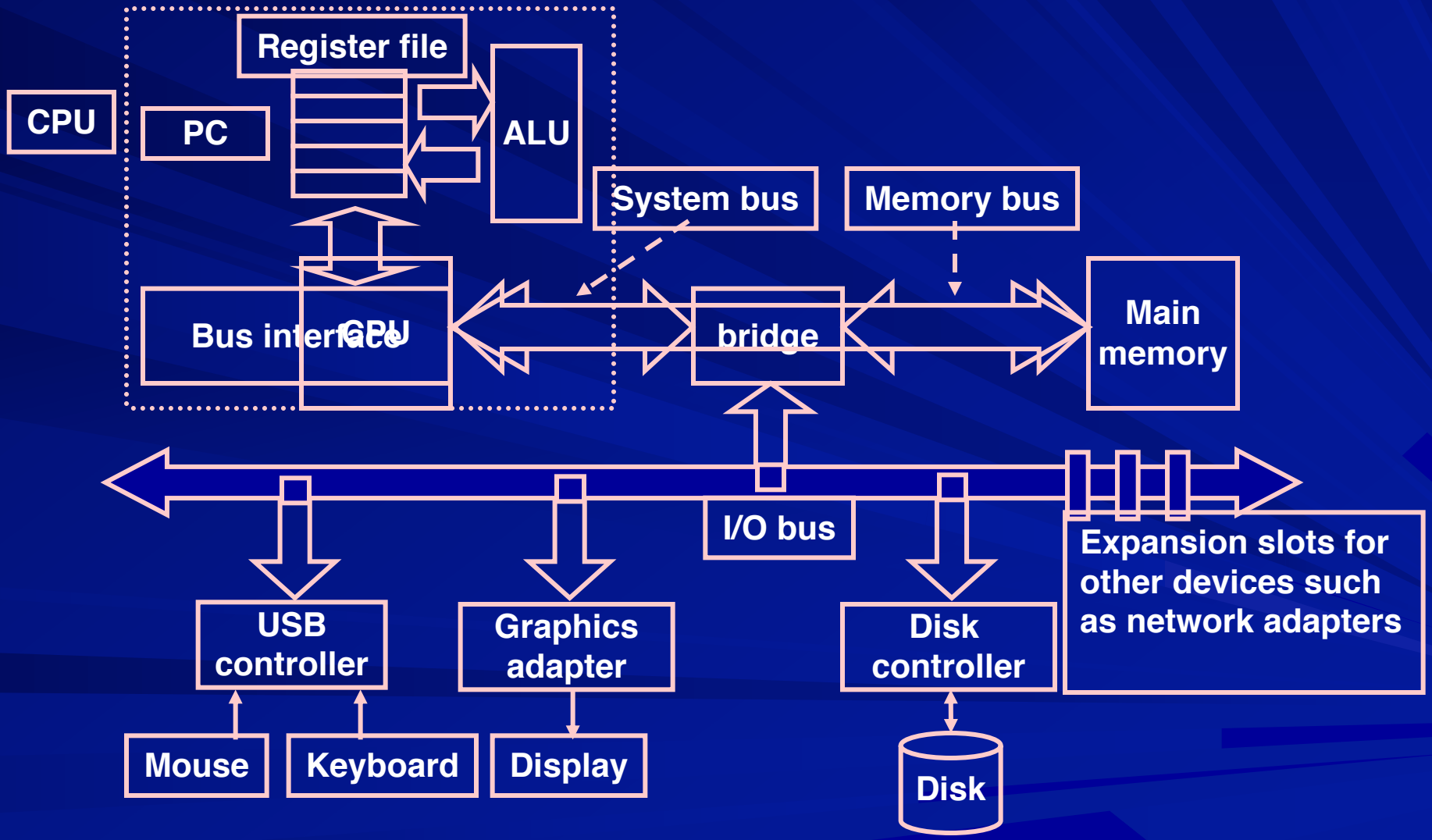
```
swap:
        mul  r3, r5, r4
        add  r2, r3, r2
        ldr    r6, [r2, #0]
        ldr    r7, [r2, #4]
        str    r7, [r2, #0]
        str    r6, [r2, #4]
        mov pc, lr
```

assembly

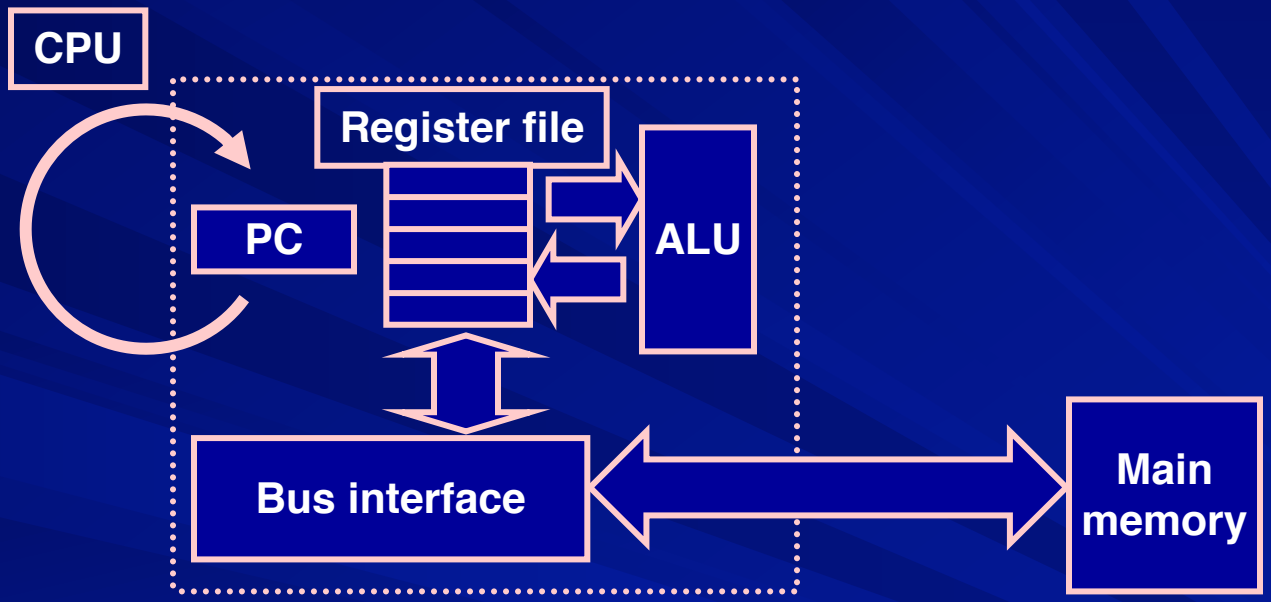
machine code

```
00001000:    E0030495
00001004:    E0832002
00001008:    E5926000
0000100C:    E5927004
00001010:    E5827000
00001014:    E5826004
00001018:    E1A0F00E
```

Hardware abstraction



Instruction execution



- Instructions for arithmetic
- Instructions to move data
- Instructions for decision making

How instructions are encoded?

Can you use a ‘bare’ computer?

- What can a ‘bare computer’ or just the hardware do?
- A ‘bare’ computer is like an unfurnished building
- A computer usually comes with ‘hardware’ and ‘system software’

Role of System Software

- Compiler
  - different compilers for different programming languages
- Libraries
- Linker
- Loader
- Operating system

Why define machine instructions?

- Design hardware that understands high level language program
- Synthesize the program of interest into hardware

Machines (and languages)

- Different types of computers
  - Desktops, laptops, servers
  - Tablets, smart phones
  - Data centres, super computers
- Multiple manufacturers

AMD	H-P	Intel
IBM	Motorola	NVIDIA
NXP	Qualcomm	Samsung . . .

What we will study

ARM (Advanced RISC Machine)

- Most popular 32 bit ISA (Instruction set architecture)
- Used extensively in embedded systems and mobile / hand held computing devices
- Easy to understand

Arithmetic instructions

- There are 2 operands and 1 result
- The order is fixed (result destination first)

Example:

C code: a = b + c

ARM code: add a, b, c

actually: add r1, r2, r3

registers associated with variables by compiler

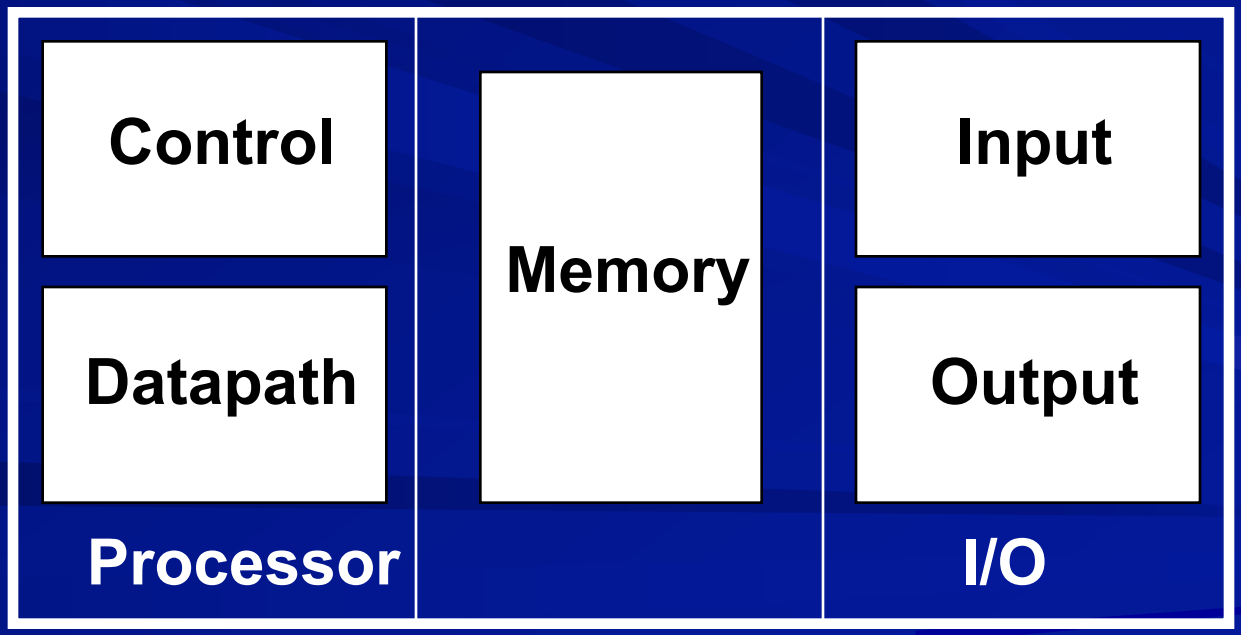
ARM arithmetic

- Simplicity favors efficient implementation
- Operands must be registers, only 16 registers provided (smaller is faster)
- Expressions need to be broken

C code	ARM code
a = b + c + d;	add r7, r2, r3
	add r1, r7, r4
e = f – (a + b);	add r7, r1, r2
	sub r5, r6, r7

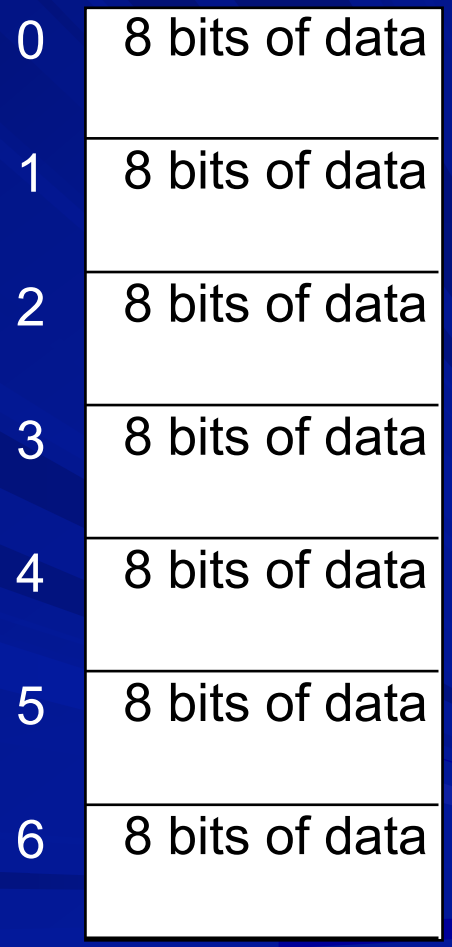
Registers vs. Memory

- Scalars mapped to registers
- Structures, arrays etc in memory



Memory Organization

- Viewed as a large, single-dimension array, with an address.
- A memory address is an index into the array
- "Byte addressing" means that the index points to a byte of memory.



Words and Bytes

- 2^{32} bytes : byte addresses from 0 to 2^{32}-1
- 2^{30} words : byte addresses 0, 4, 8, ... 2^{32}-4

Big endian byte order

0	1	2	3
4	5	6	7

Little endian byte order

3	2	1	0
7	6	5	4

Non-aligned word

3	2	1	0
7	6	5	4

Instructions to access memory

Load / store instructions

C : v = A[8];

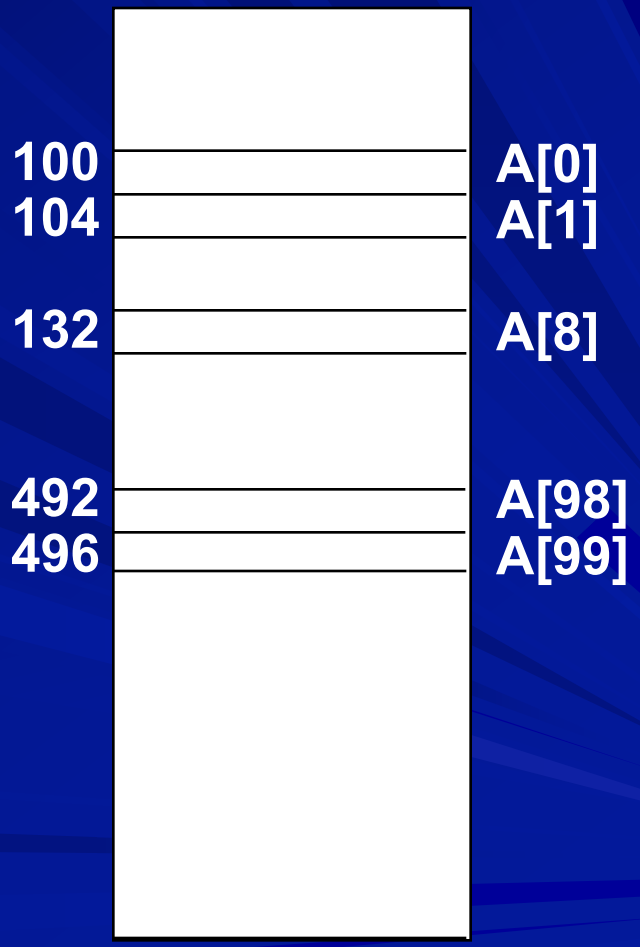
ARM :

ldr r1, [r2, #32] {r2 has 100}

or

ldr r1, [r2, #100] {r2 has 32}

{not possible if address of A[0] is large}



Load / Store example

C code: `A[8] = A[8] + h;`

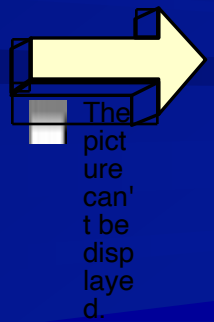
ARM code:

```
ldr   r1, [r2, #32]
add   r1, r1, r3
str   r1, [r2, #32]
```

A simple example

```
swap (int v[ ], int k);
{ int temp;
    temp   = v[k]
    v[k]     = v[k+1];
    v[k+1] = temp;
}
```

What does this code do?




```
swap:
@  r2 has addr of v[0]
@  r5 has k, r4 has #4

    mul  r3, r5, r4
    add  r2, r3, r2
    ldr   r6, [r2, #0]
    ldr   r7, [r2, #4]
    str   r7, [r2, #0]
    str   r6, [r2, #4]

    return
```

Accessing bytes and half words

- ldr, str load/store word
- ldrb, strb load/store byte
- ldrh, strh load/store half word

Control

- Decision making instructions - alter the control flow
- Compare instruction : cmp
- Conditional branch instructions : beq, bne
- Example:

```
if (i == j)                cmp r1, r2
    h = i + j;             bne  L
k = k – i;                 add  r3, r1, r2
                       L:  sub  r4, r4, r1
```

Control

- Unconditional branch instructions:

  b label

- Example:

```
if (i == j)                          cmp r1, r2
    h = i + j;                       bne Lab1
else                                 add r3, r1, r2
    h = i - j;                       b Lab2
k = k - i;              Lab1:        sub r3, r1, r2
                        Lab2:        sub r4, r4, r1
```

Other conditional branch instructions

- blt: branch if less-than
- ble: branch if less-than-or-equal
- bgt: branch if greater-than
- bge: branch if greater-than-or-equal

Writing a simple loop for Σ_i A[i]

```
    s = 0;
    i = 0;
L:  s = s+A[i];
    i++;
    if (i<n) goto L;
```

Writing a simple loop for $\Sigma_i A[i]$

s = 0;	mov r1, #0
i = 0;	mov r2, #0

L: s = s+A[i];	L: mul r3, r2, r7 @ r7 = 4
	add r3, r3, r4 @ r4=&A[0]
	ldr r5, [r3, #0]
	add r1, r1, r5

i++;	add r2, r2, #1
if (i<n) goto L;	cmp r2, r6 @ r6 = n blt L

Improving code: pointer vs. index

```
    s = 0;                  mov  r1, #0
    i = 0;                  mov  r2, #0
    p = &A[0];              mov  r3, r4
L:  s = s + *p;         L:  ldr  r5, [r3, #0]
                            add  r1, r1, r5
    p++;                    add  r3, r3, #4
    i++;                    add  r2, r2, #1
    if (i<n) goto L;        cmp  r2, r6        @ r6 = n
                            blt  L
```

Improving code further

```
s = 0;                    s = 0;
i = 0;
p = &A[0];                p = &A[0];
                          q = p+100;
L: s = s + *p;            L: s = s + *p;
p++;                      p++;
i++;
if (i<n) goto L;          if (p<q) goto L;
```

Improving code further

```
    s = 0;
    p = &A[0];
    q = p+100;
L:  s = s + *p;

    p++;
    if (p<q) goto L;
```

```
    mov  r1, #0
    mov  r3, r4
    add  r6, r3, #400
L:  ldr  r5, [r3, #0]
    add  r1, r1, r5
    add  r3, r3, #4
    cmp  r3, r6        @ r6 = q
    blt  L
```

Complete Assembly Program

```
        .equ SWI_Exit. 0x11
        .text
        mov  r1, #0
        ldr    r3, =AA
        add   r6, r3, #400
L:      ldr    r5, [r3, #0]
        add   r1, r1, r5
        add   r3, r3, #4
        cmp  r3, r6          @ r6 = q
        blt    L
        swi   SWI_Exit
        .data
AA:     .space 400
        .end
```

How to execute this program?

ARMSim#

- Simulator for ARM7TDMI architecture
- Developed by University of Victoria, Canada
- Includes an assembler
- Allows step-by-step execution and break-points
- Displays contents of registers and memory
- Supports input-output
- A plug-in simulates a particular ARM board

Before we close,

Book

Primary reference:

- John L. Hennesy & David A. Patterson, "Computer Organization & Design : The Hardware / Software Interface", Morgan Kaufmann Publishers.

Chapters to be covered

1. Computer Abstractions and Technology
2. Instructions: Language of Computer
3. Arithmetic for Computers
4. The Processor
5. Large and Fast: Exploiting Memory Hierarchy
6. Storage and Other I/O Topics
7. Multicores, Multiprocessors and Clusters

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Evaluation plan

- Tests + quizzes 70
- Laboratory work 30

Passing requirement:

tests + quizzes ≥ 30% AND lab ≥ 40%

Attendance Policy

- 100%, subject to timely and satisfactory explanation/evidence for any absence
- Required for seeking alternative arrangements for missed tests/quizzes/lab sessions, E grade, I grade or for any other special requests

Thank you