Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

02 – Arrays

CS1022 – Introduction to Computing II

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Arrays

Nothing very new here … we have already been using arrays!

Array – an ordered collection of elements stored sequentially in memory

e.g. integers, ASCII characters, lottery numbers

Homogeneous elements?

(at least with respect to size)

Dimension: number of elements in array

Address	Memory	Index
	. . .	
0xA000101C	??????	
0xA0001018	31	5
0xA0001014	28	4
0xA0001010	127	3
0xA000100C	9	2
0xA0001008	28	1
0xA0001004	3	0
0xA0001000	??????	
0xA0000FFC	??????	
	. . .	

← 32 bits = 1 word →

Accessing (loading/storing) Array Elements

Efficient access at a specific index is an important feature of arrays

Referred to as “random access”

Example: retrieve the 4th element (index=3) of an array of words

Step 1: translate array index into byte offset from start address of array in memory

<byte offset> = <index> × <elem size>

Step 2: add byte offset to array base address to access element

<address> = <array start address> + <byte offset>

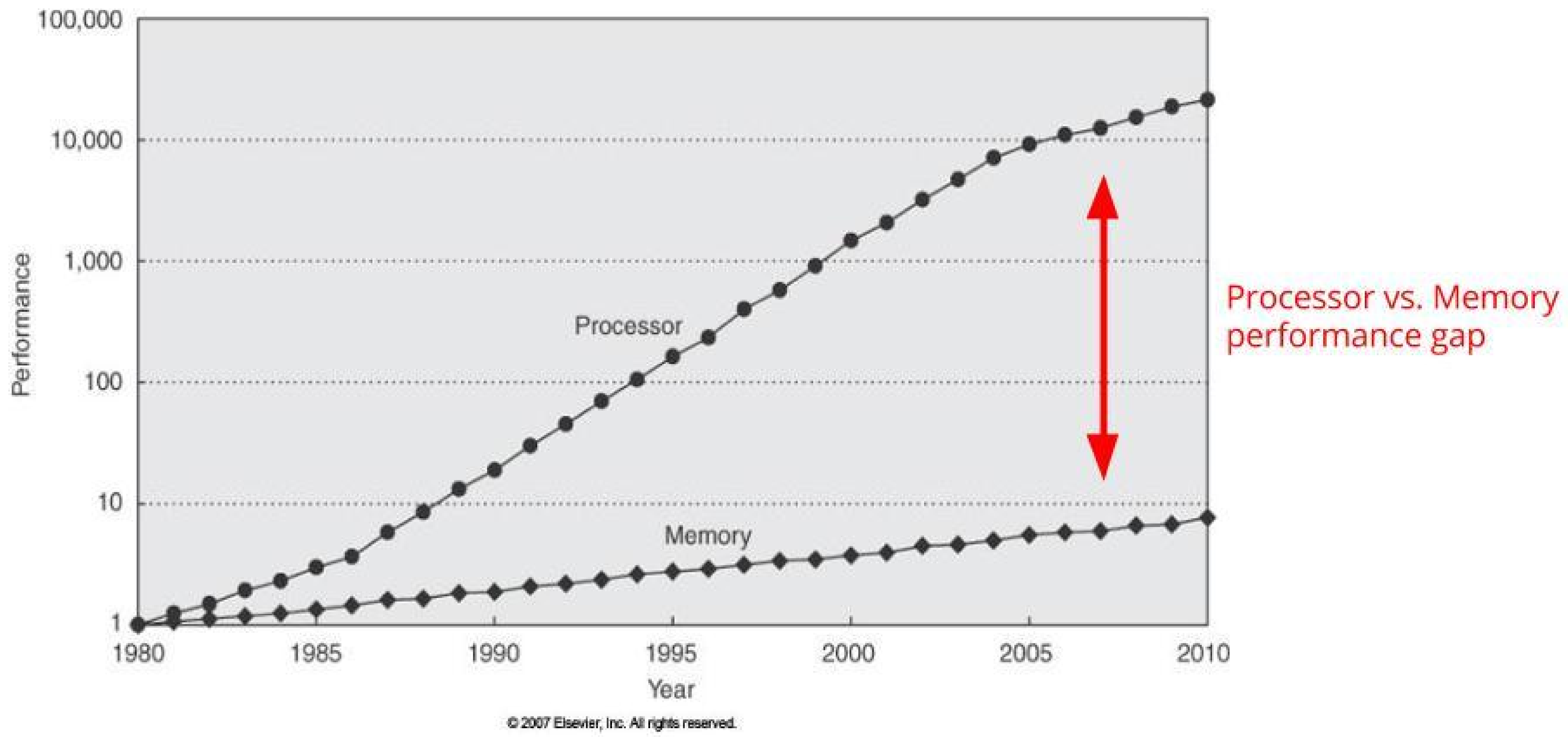
Efficient random access using Scaled Register Offset addressing mode:

```
LDR r4, =array              ; pArr = start address of array
LDR r5, =3                  ; index = 3 (4th element)
LDR r6, [r4, r5, LSL #2]    ; elem = Memory.Word[pAarr + (index * 4)]
```

Aside (Not Examinable) Relative Performance

Generally CPU speed increases much faster than memory access speed

Relatively speaking, memory is getting slower*



Memory speed lags behind CPU speed

Array Access Example - Sum

Déjà Vu!

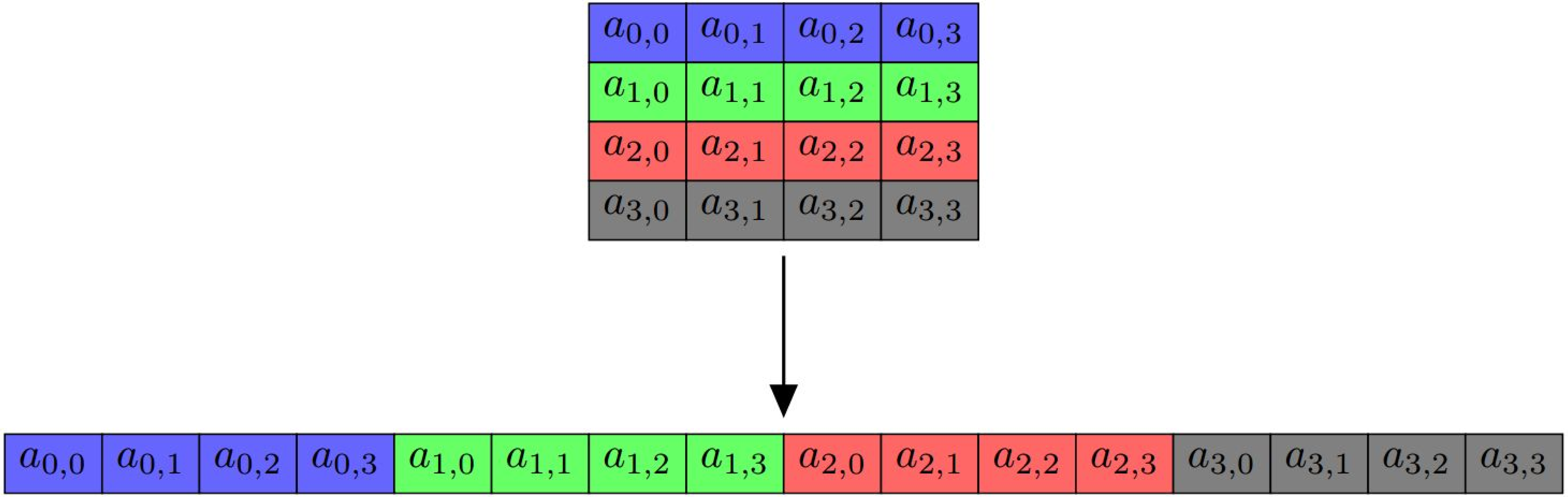
```
  LDR R1, =myArray ; start address of myArray
  LDR R0, =0  ; sum = 0
  LDR R4, =0  ; count = 0

whSum CMP R4, #10 ; while (count < 10)
  BHS eWhSum  ; {
  LDR R6, [R1, R4, LSL #2] ;  num = myArray[count]
  ADD R0, R0, R6 ;  sum = sum + num
  ADD R4, R4, #1 ;  count = count + 1
  B whSum ; }
eWhSum      ;
```

The pseudo-code comments have changed but the program is identical (See **Addressing Modes**)

Arrays can have more than one dimension

e.g. a two-dimensional array – analogous to a table containing elements arranged in rows and columns

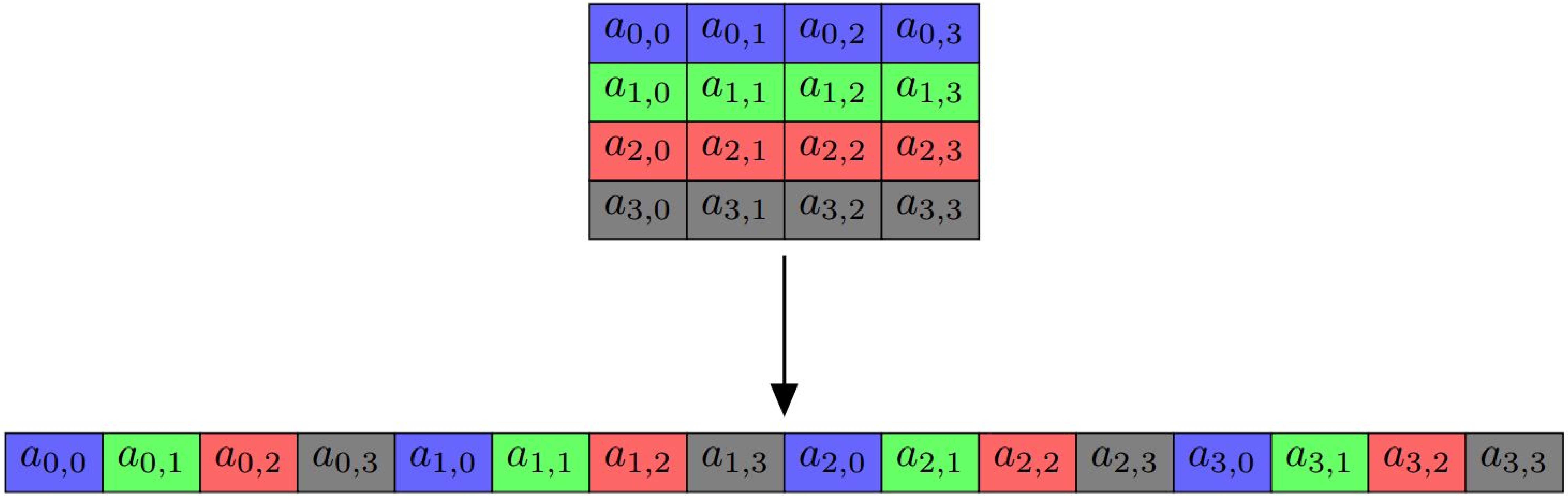
Stored in memory by mapping the 2D array into 1D memory, e.g.



2D Arrays

Row-major order: 2D array is stored in memory by storing each row contiguously in memory

Column-major order: 2D array is stored in memory by storing each column contiguously in memory (in image)



2D Array Example

2D array declared in memory

```
    AREA TestData, DATA, READWRITE

col_size  EQU  6       ; just for convenience, not required
row_size  EQU  8       ; just for convenience, not required

array   DCD  6, 3, 8, 2, 5, 2, 9, 1   ; row 0
    DCD  3, 7, 2, 8, 5, 7, 2, 7   ; row 1
    DCD  2, 4, 7, 4, 2, 6, 7, 4   ; row 2
    DCD  1, 9, 3, 2, 9, 5, 6, 8   ; row 3
    DCD  7, 5, 3, 7, 5, 8, 2, 1   ; row 4
    DCD  6, 4, 8, 9, 0, 3, 2, 5   ; row 5
```

… or equivalently …

```
    AREA TestData, DATA, READWRITE

col_size  EQU  6       ; just for convenience, not required
row_size  EQU  8       ; just for convenience, not required

array   DCD  6, 3, 8, 2, 5, 2, 9, 1, 3, 7, 2, 8, 5, 7, 2, 7, 2, 4, 7, 4, 2
    DCD  6, 7, 4, 1, 9, 3, 2, 9, 5, 6, 8, 7, 5, 3, 7, 5, 8, 2, 1, 6, 4
    DCD  8, 9, 0, 3, 2, 5
```

Accessing 2D Array Elements

Example: retrieve the element at the 4th row and 3rd column of a 2D array of words with 6 rows and 8 columns – array[3][2]

Step 1: translate 2D array index into 1D array index

<index> = (<row> × <row size>) + <col>

Step 2: translate 1D array index into byte offset from start address of array in memory

<byte offset> = <index> × <elem size>

Step 3: add byte offset to array base address to access element

<address> = <array base address> + <byte offset>

2D Array Access Example

Example: retrieve the element at the 4th row and 3rd column of a 2D array of words with 6 rows and 8 columns – array[3][2]

```
LDR r4, =array ; pArr = address of array start
LDR r5, =col_size; load col_size
LDR r6, =row_size; load row_size

; looking for array[3][2] (4th row, 3rd column)

LDR r1, =3  ; row = 3
LDR r2, =2  ; col = 4

; <byte offset> = ((row * <row_size>) + col) * <elem size>

MUL r7, r1, r6  ; index = row * row_size
ADD r7, r7, r2  ; index = index + col
LDR r0, [r4, r7, LSL #2] ; elem = Memory.Word[ pArr + (index*4) ]
```

Multi-dimension arrays

e.g. a 3D array of size sz×sy×sx

In general, the index of element a[z][y][x] is:

$$index = ((z \times sy \times sx) + (y \times sx) + x)$$

e.g. a 4D array of size sz×sy×sx×sw

In general, the index of element a[z][y][x][w] is:

$$index = ((z \times sy \times sx \times sw) + (y \times sx \times sw) + (x \times sw) + w)$$

Warning: an array of bytes with odd dimensions may cause the data following the array to be odd aligned, requiring padding of one byte (similarly for half-words)

Array Padding

Occasionally you will see the following warning when working with memory (particularly later on in the course)

“warning: A1581W: Added n bytes of padding at address 0xnnnn”

The following demonstrates it

```
      Area    padding,    DATA,   READWRITE

chars   DCB    “abcde”
nums    DCD    -1, 122, 13
```

Array Padding

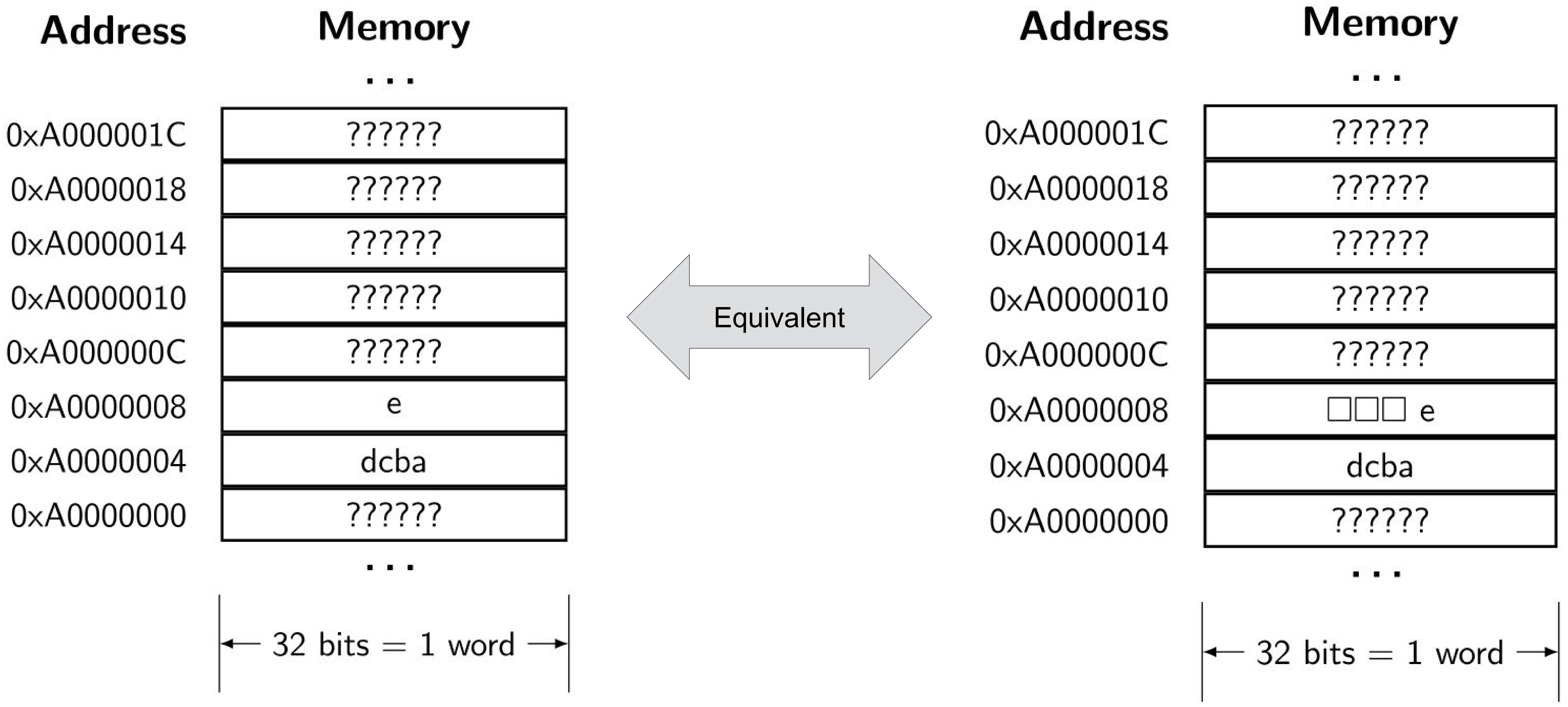
Loading just “chars” into memory for now

```
      Area    padding,    DATA,   READWRITE

chars   DCB   “abcde”
;comment for now;nums    DCD   -1, 122, 13
```

Address	Memory
	...
0xA000001C	??????
0xA0000018	??????
0xA0000014	??????
0xA0000010	??????
0xA000000C	??????
0xA0000008	e
0xA0000004	dcba
0xA0000000	??????
	...

← 32 bits = 1 word →

Array Padding



Array Padding

Now store the numbers (not what actually happens

```
      Area     padding,    DATA,   READWRITE

chars   DCB    “abcde”
nums    DCD    -1;comment for now;, 122, 13
```

Address	Memory
	...
0xA000001C	??????
0xA0000018	??????
0xA0000014	??????
0xA0000010	??????
0xA000000C	□□□ 0xFF
0xA0000008	0xFFFFFF e
0xA0000004	dcba
0xA0000000	??????
	...

← 32 bits = 1 word →

Array Padding

Now store the numbers (not what actually happens

```
      Area    padding,    DATA,   READWRITE

chars   DCB   “abcde”
nums    DCD   -1, 122, 13
```