Embedded Systems with ARM Cortex-M Microcontrollers
in Assembly Language and C

Chapter 3
ARM Instruction Set Architecture

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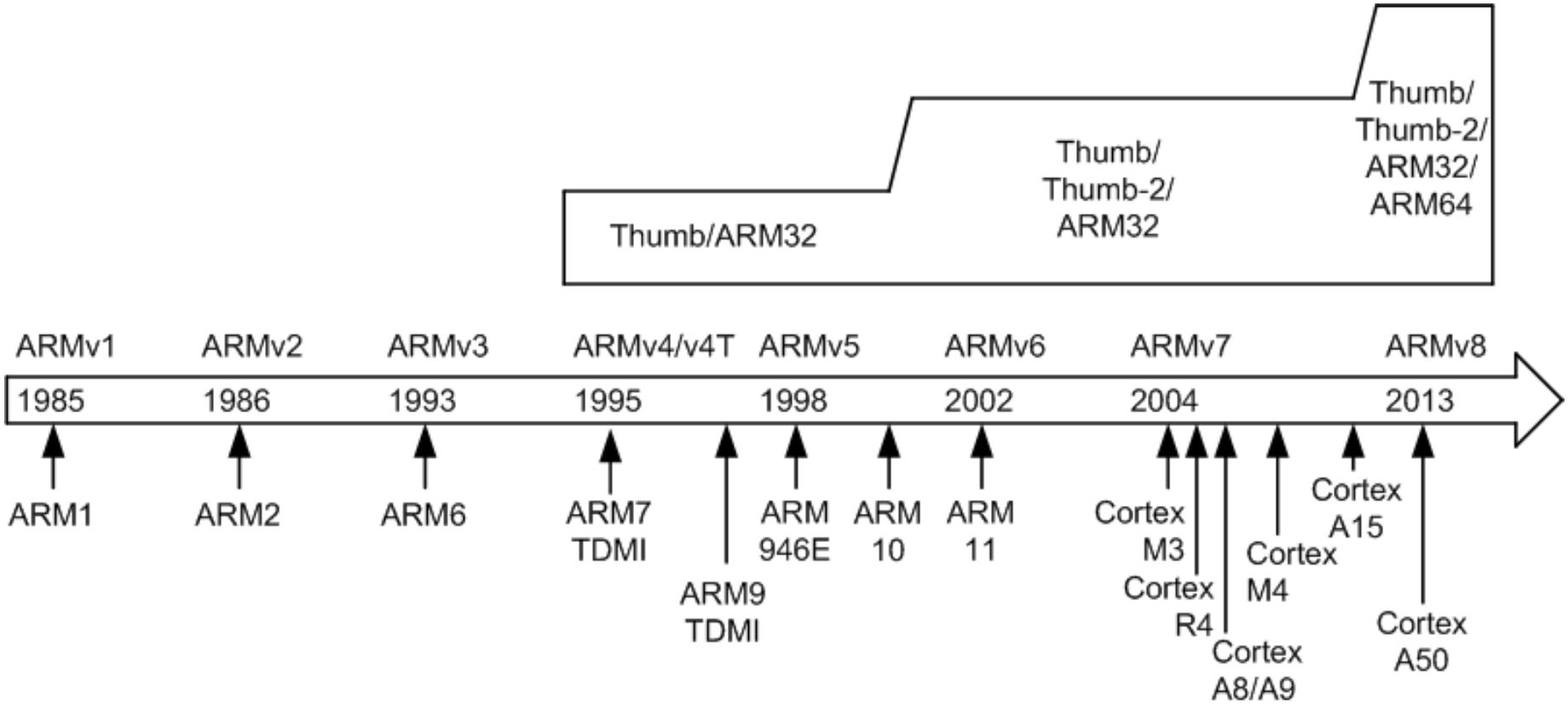
History


Thumb/ARM32
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M3
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A15
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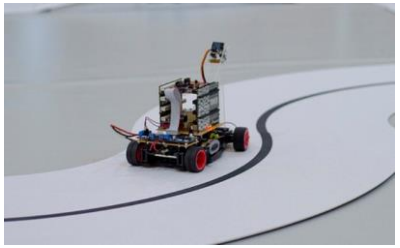
ARM Cortex Processors

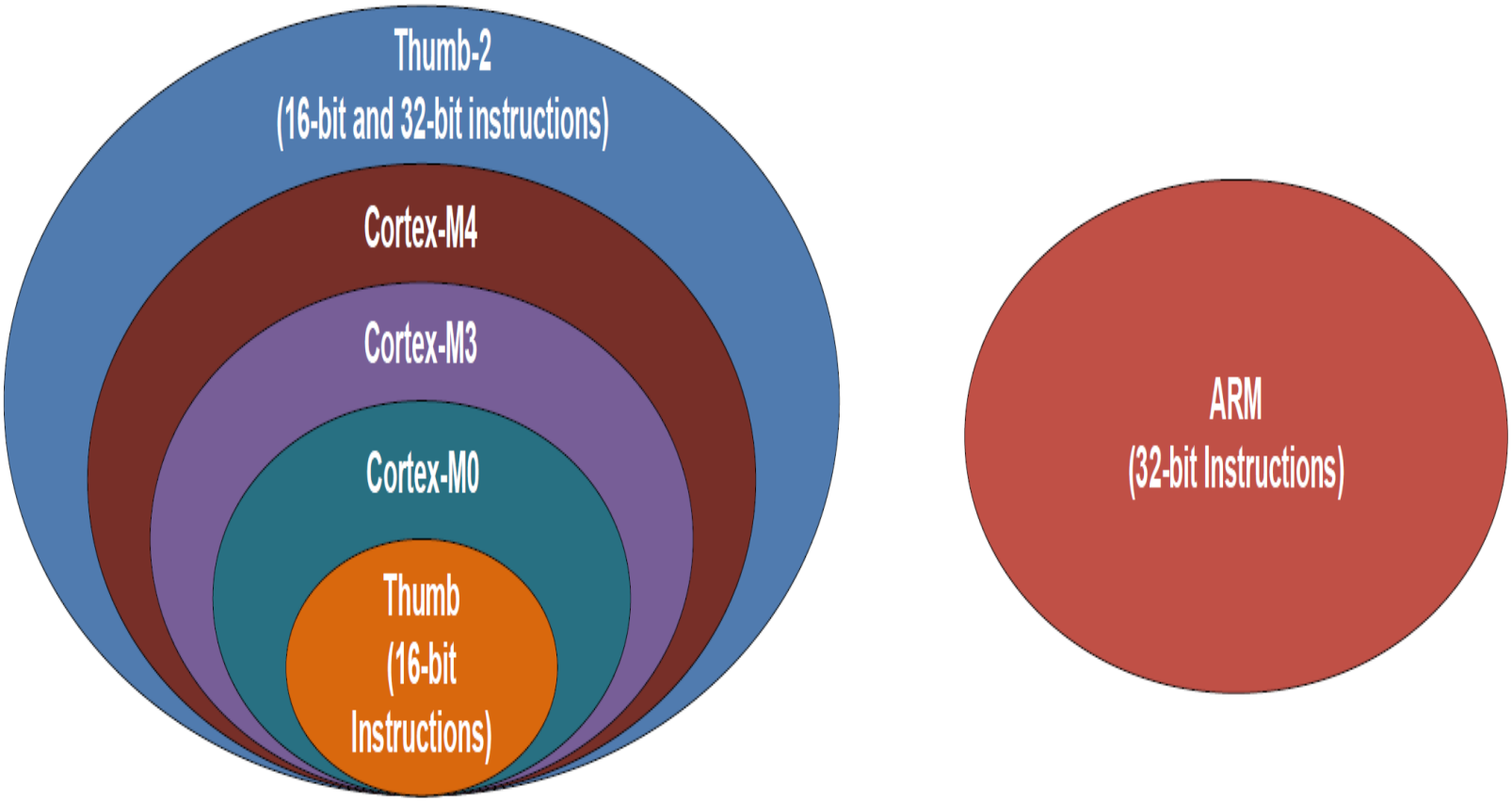
- ARM Cortex-A family:
  - **A**pplications processors
  - Support OS and high-performance applications
  - Such as Smartphones, Smart TV

- ARM Cortex-R family:
  - **R**eal-time processors with high performance and high reliability
  - Support real-time processing and mission-critical control

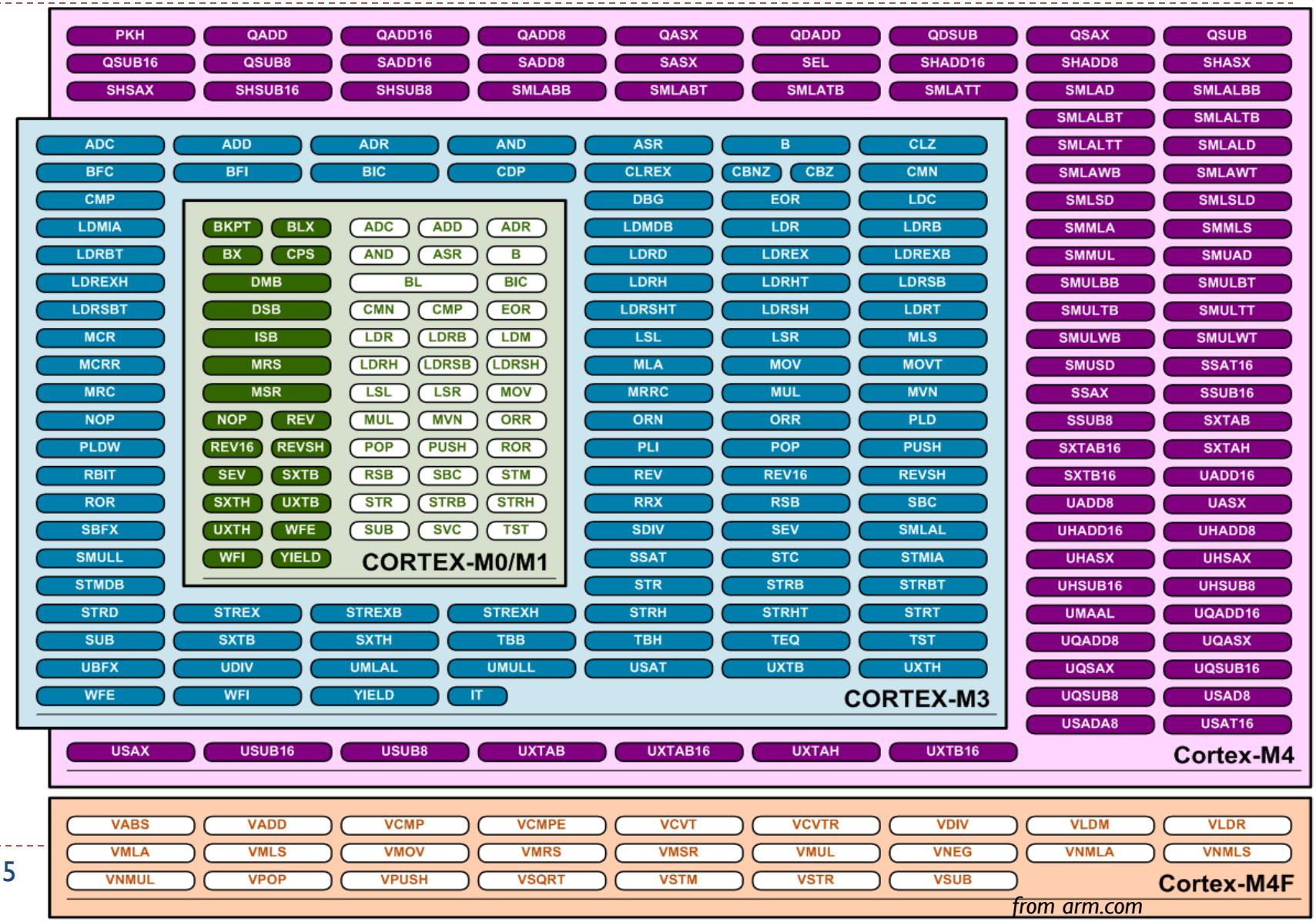
- ARM Cortex-M family:
  - **M**icrocontroller
  - Cost-sensitive, support SoC



Instruction Sets

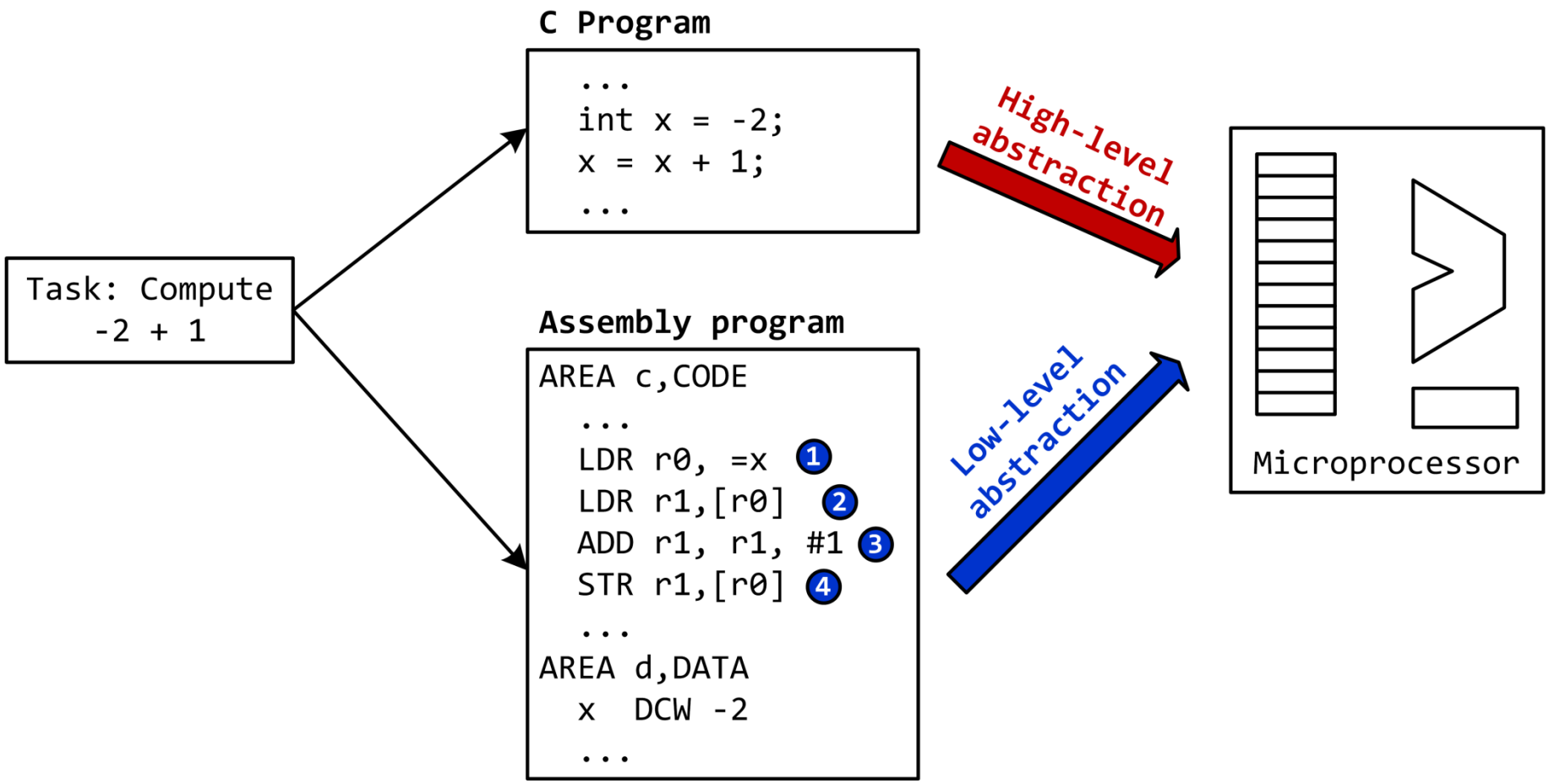


Instruction Sets

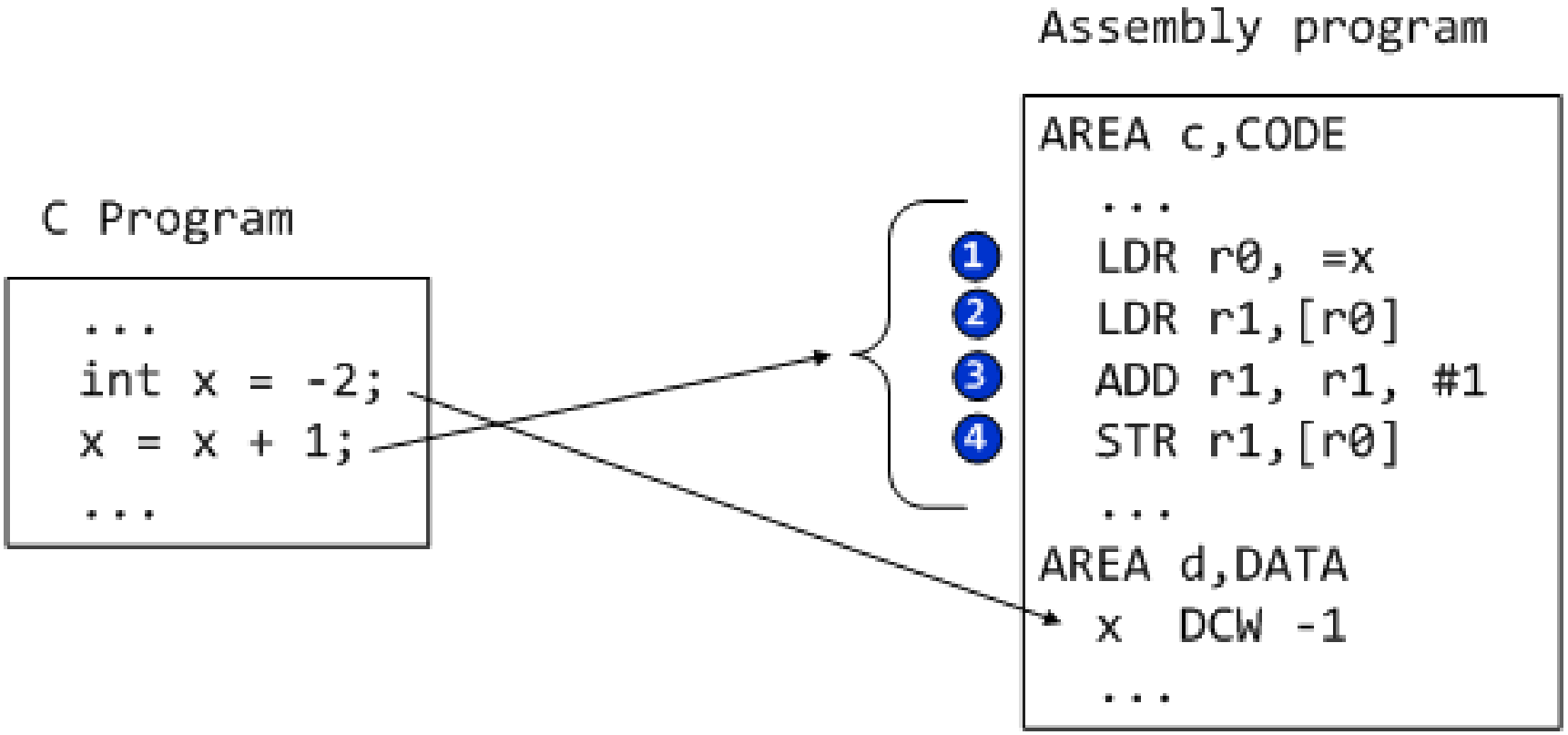


from arm.com

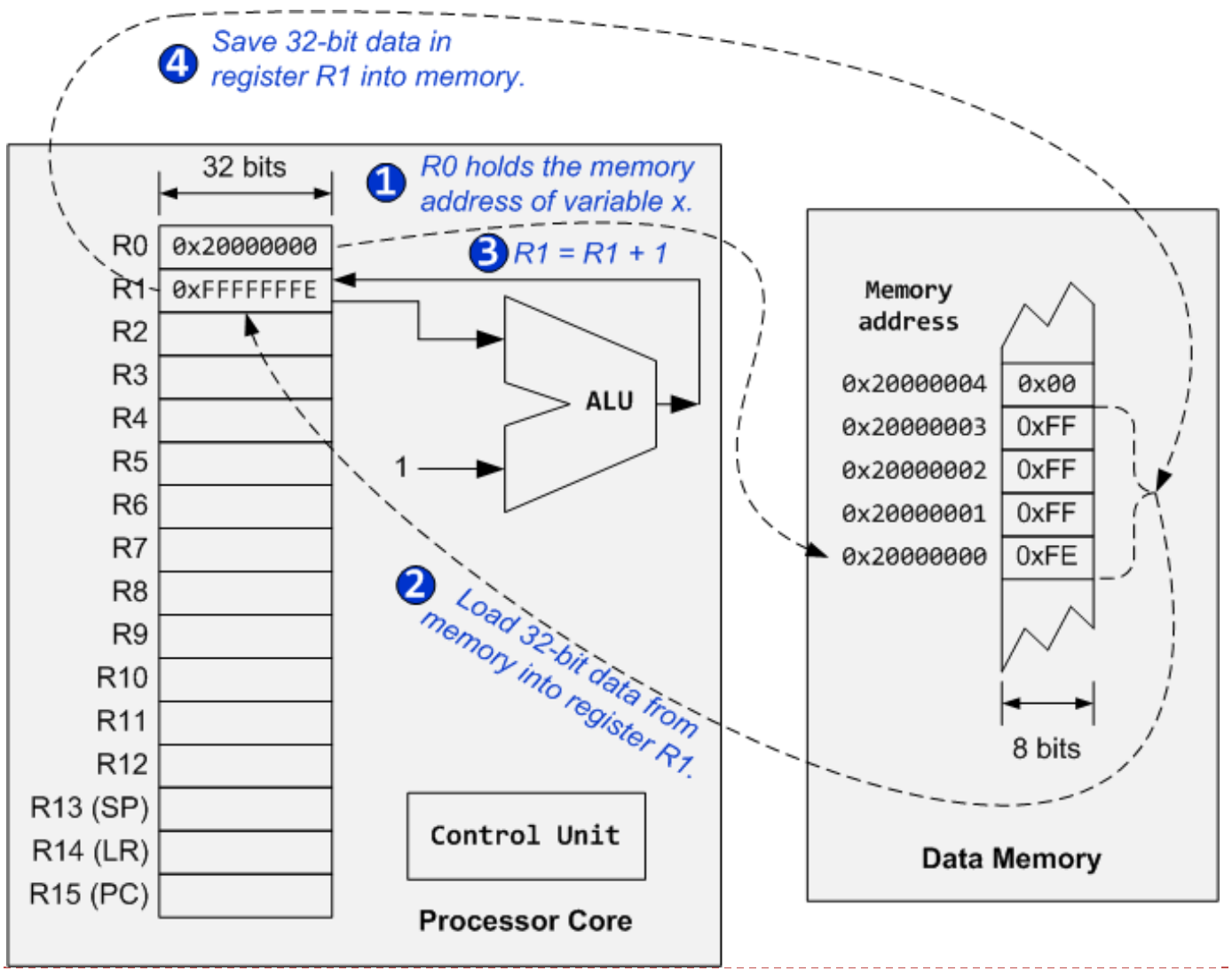
From C to Assembly



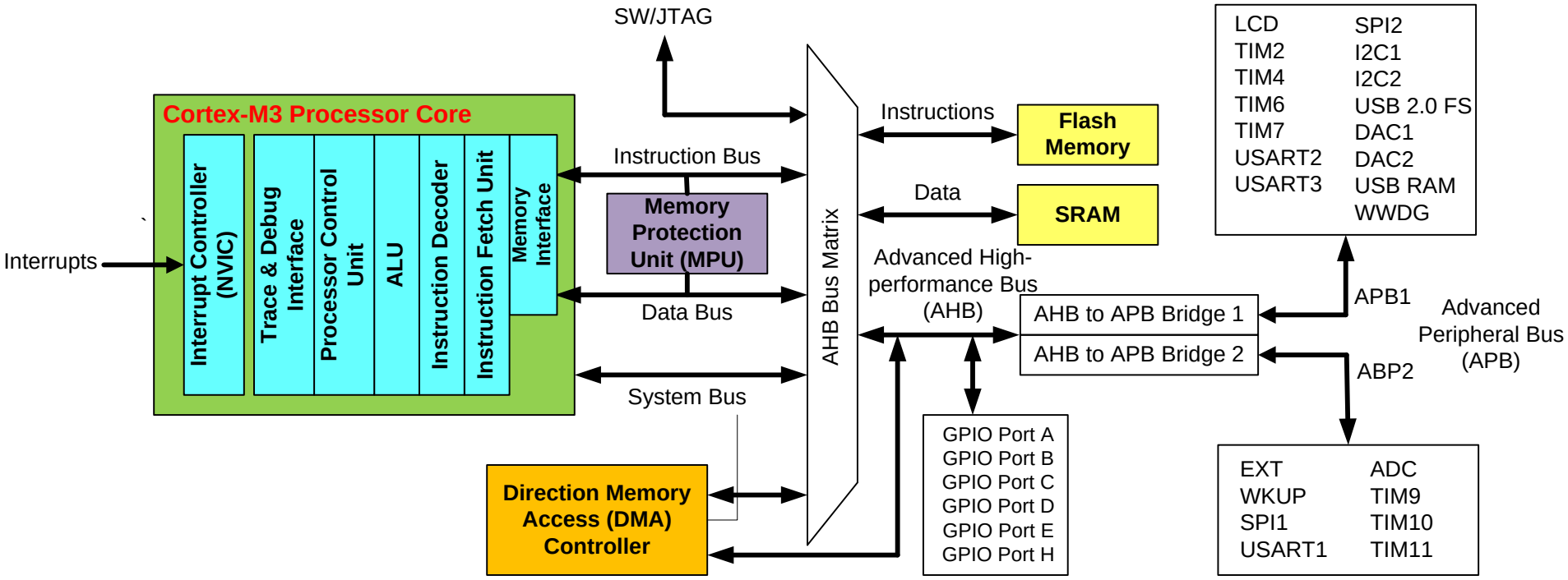
Load-Modify-Store



Load-Modify-Store

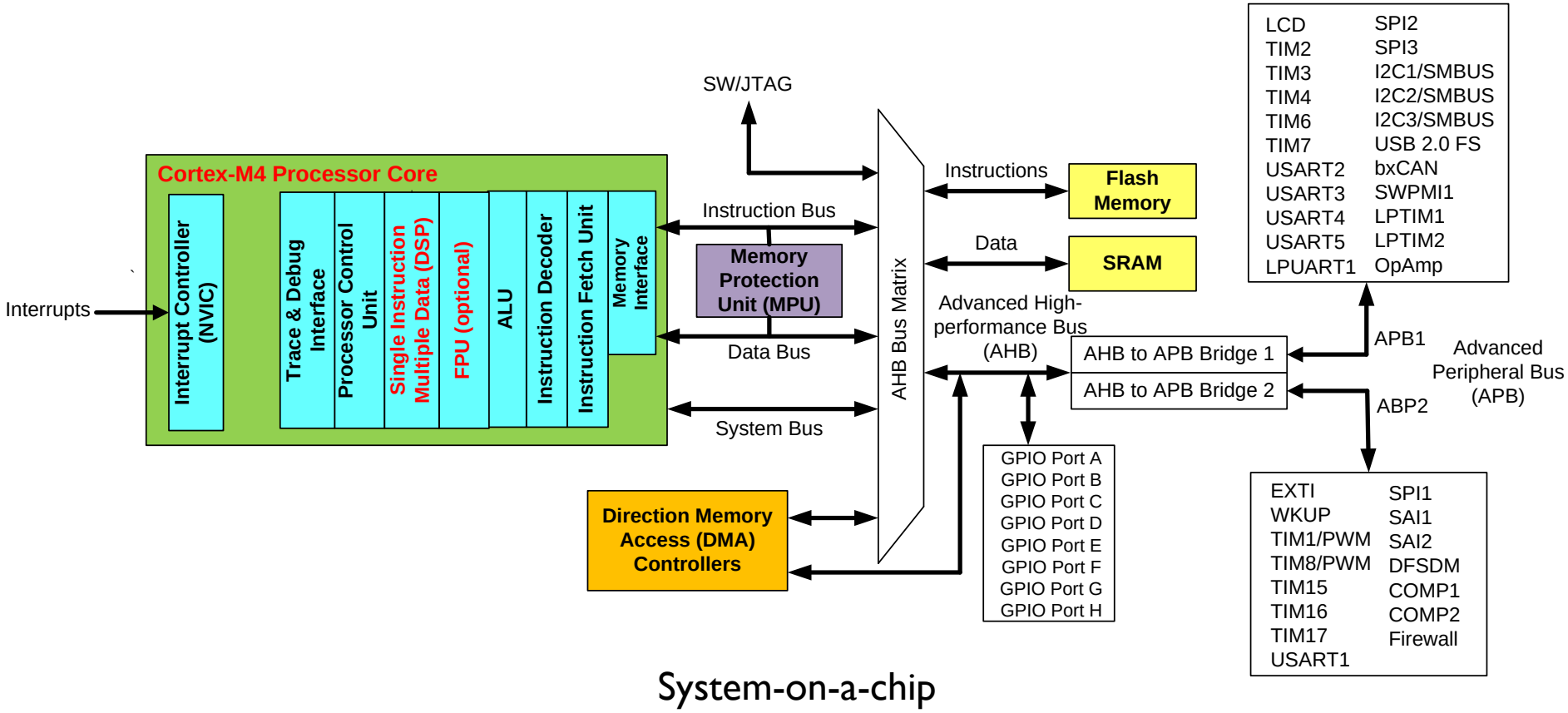


ARM Cortex-M3 Organization (STM32L1)



System-on-a-chip

ARM Cortex-M4 Organization (STM32L4)



System-on-a-chip

Assembly Instructions Supported

- Arithmetic and logic
  - Add, Subtract, Multiply, Divide, Shift, Rotate
- Data movement
  - Load, Store, Move
- Compare and branch
  - Compare, Test, If-then, Branch, compare and branch on zero
- Miscellaneous
  - Breakpoints, wait for events, interrupt enable/disable, data memory barrier, data synchronization barrier

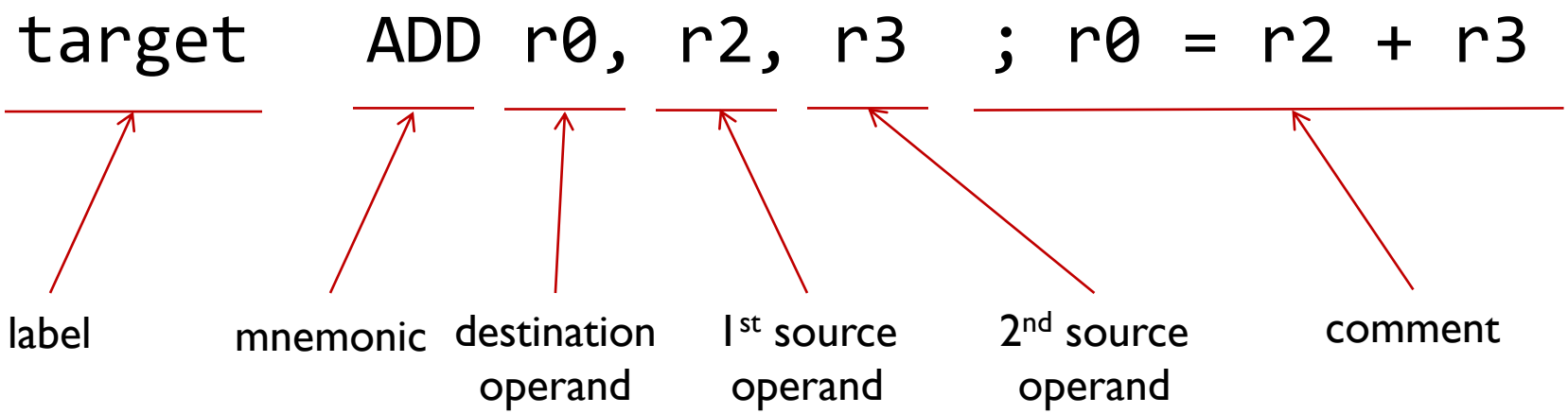
ARM Instruction Format

```
label          mnemonic operand1, operand2, operand3    ; comments
```

- Label is a reference to the memory address of this instruction.
- Mnemonic represents the operation to be performed.
- The number of operands varies, depending on each specific instruction. Some instructions have no operands at all.
  - Typically, operand1 is the destination register, and operand2 and operand3 are source operands.
  - operand2 is usually a register.
  - operand3 may be a register, an immediate number, a register shifted to a constant amount of bits, or a register plus an offset (used for memory access).
- Everything after the semicolon ";" is a comment, which is an annotation explicitly declaring programmers' intentions or assumptions.

ARM Instruction Format

```
label   mnemonic operand1, operand2, operand3    ; comments
```



ARM Instruction Format

```
label          mnemonic operand1, operand2, operand3    ; comments
```

Examples: Variants of the ADD instruction

```
ADD r1, r2, r3      ; r1 = r2 + r3
ADD r1, r3          ; r1 = r1 + r3
ADD r1, r2, #4      ; r1 = r2 + 4
ADD r1, #15         ; r1 = r1 + 15
```

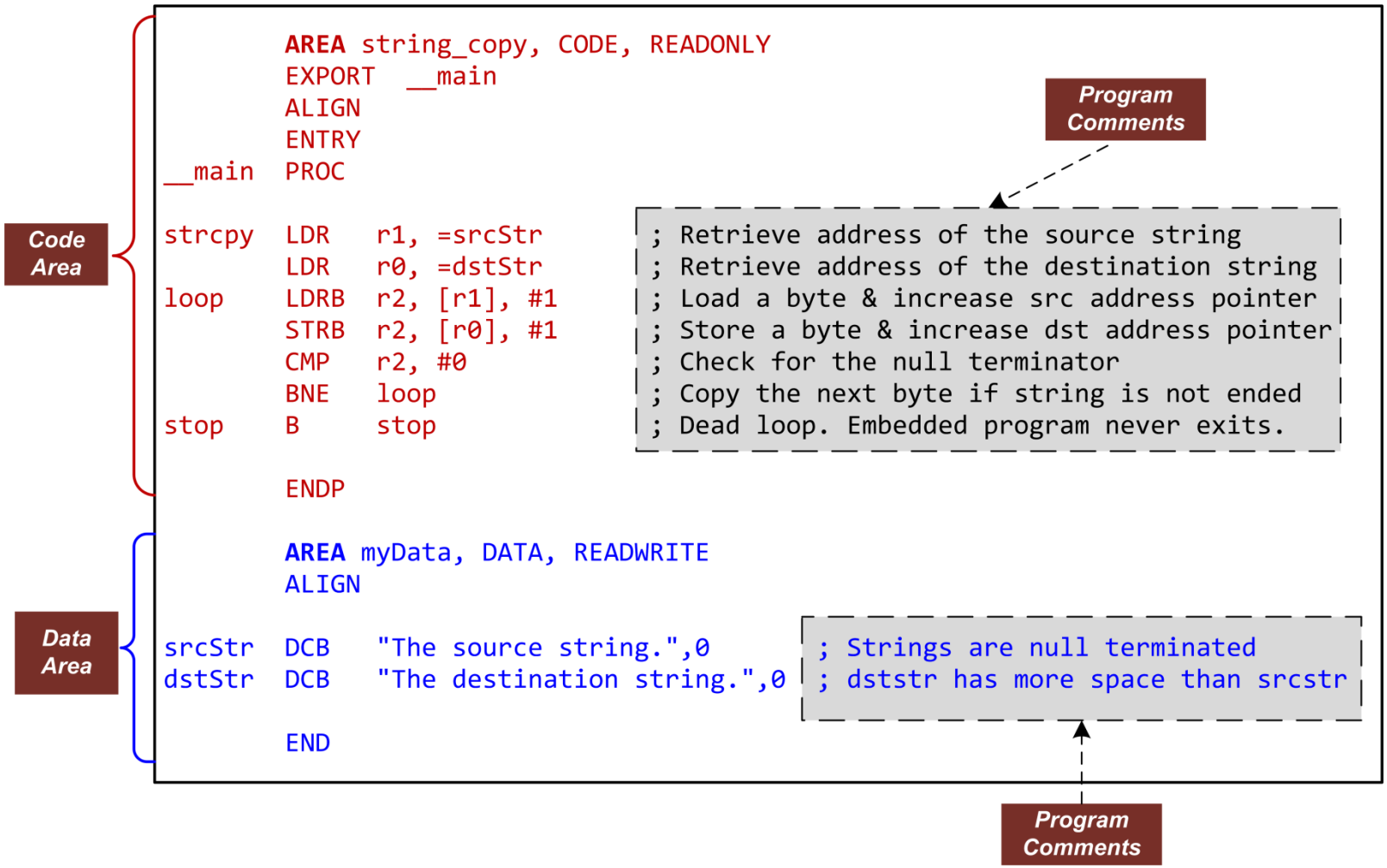
First Assembly

Code Area

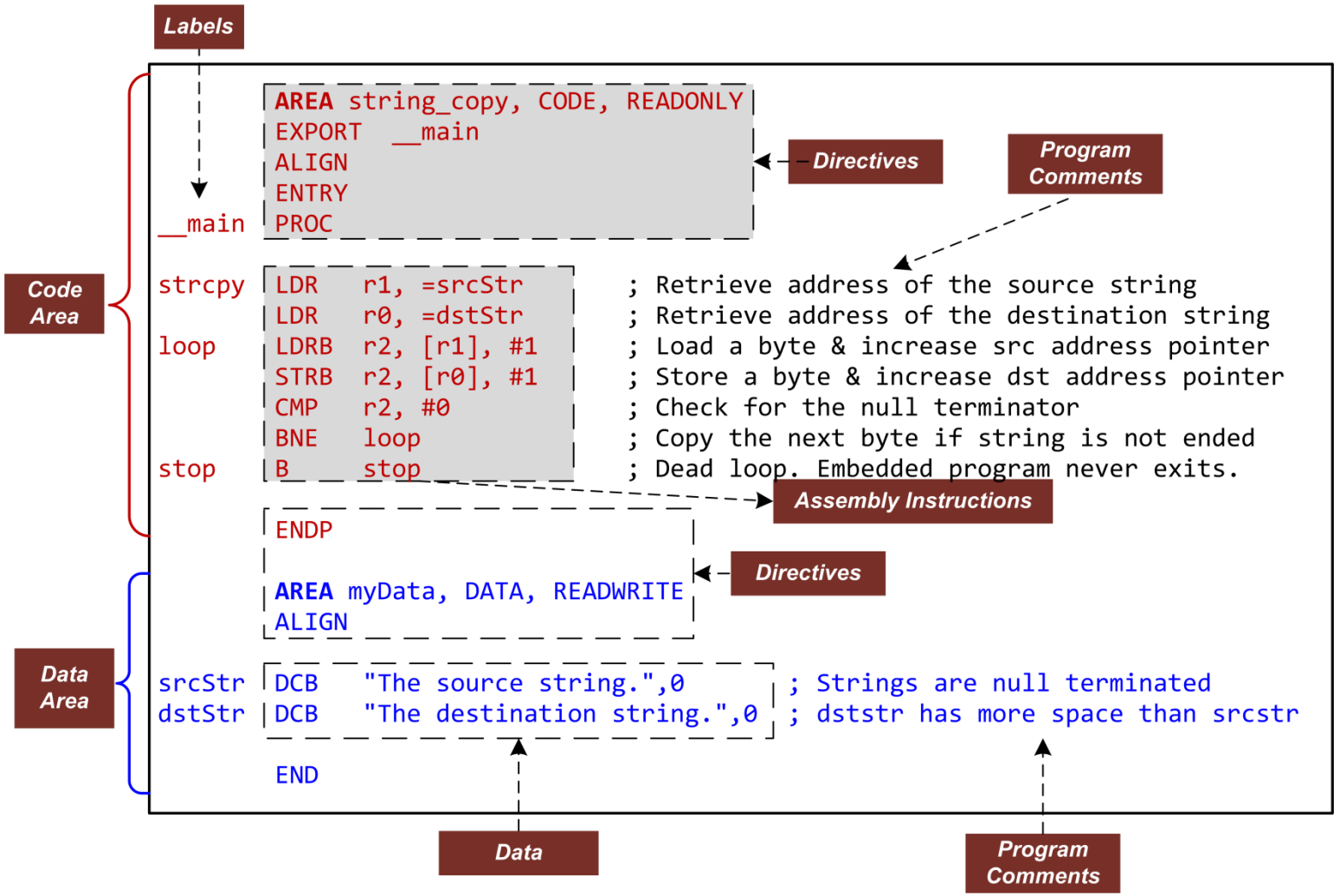
Data Area

```
        AREA string_copy, CODE, READONLY
        EXPORT  __main
        ALIGN
        ENTRY
__main  PROC

strcpy  LDR   r1, =srcStr       ; Retrieve address of the source string
        LDR   r0, =dstStr       ; Retrieve address of the destination string
loop    LDRB  r2, [r1], #1      ; Load a byte & increase src address pointer
        STRB  r2, [r0], #1      ; Store a byte & increase dst address pointer
        CMP   r2, #0            ; Check for the null terminator
        BNE   loop              ; Copy the next byte if string is not ended
stop    B     stop              ; Dead loop. Embedded program never exits.

        ENDP

        AREA myData, DATA, READWRITE
        ALIGN

srcStr  DCB   "The source string.",0       ; Strings are null terminated
dstStr  DCB   "The destination string.",0  ; dststr has more space than srcstr

        END
```

First Assembly



First Assembly



Assembly Directives

- Directives are **NOT** instruction. Instead, they are used to provide key information for assembly.

AREA	Make a new block of data or code
ENTRY	Declare an entry point where the program execution starts
ALIGN	Align data or code to a particular memory boundary
DCB	Allocate one or more bytes (8 bits) of data
DCW	Allocate one or more half-words (16 bits) of data
DCD	Allocate one or more words (32 bits) of data
SPACE	Allocate a zeroed block of memory with a particular size
FILL	Allocate a block of memory and fill with a given value.
EQU	Give a symbol name to a numeric constant
RN	Give a symbol name to a register
EXPORT	Declare a symbol and make it referable by other source files
IMPORT	Provide a symbol defined outside the current source file
INCLUDE/GET	Include a separate source file within the current source file
PROC	Declare the start of a procedure
ENDP	Designate the end of a procedure
END	Designate the end of a source file

Directive: AREA

```
          AREA myData, DATA, READWRITE ; Define a data section
Array     DCD 1, 2, 3, 4, 5            ; Define an array with five integers

          AREA myCode, CODE, READONLY  ; Define a code section
          EXPORT  __main               ; Make __main visible to the linker
          ENTRY                        ; Mark the entrance to the entire program
__main    PROC                         ; PROC marks the begin of a subroutine
          ...                          ; Assembly program starts here.
          ENDP                         ; Mark the end of a subroutine
          END                          ; Mark the end of a program
```

- The AREA directive indicates to the assembler the start of a new data or code section.
- Areas are the basic independent and indivisible unit processed by the **linker**.
- Each area is identified by a name and areas within the same source file **cannot share the same name.**
- An assembly program must have **at least one code area**.
- By default, a code area can only be read (READONLY) and a data area may be read from and written to (READWRITE).

Directive: ENTRY

```
          AREA myData, DATA, READWRITE ; Define a data section
Array     DCD 1, 2, 3, 4, 5            ; Define an array with five integers

          AREA myCode, CODE, READONLY  ; Define a code section
          EXPORT  __main               ; Make __main visible to the linker
          ENTRY                        ; Mark the entrance to the entire program
__main    PROC                         ; PROC marks the begin of a subroutine
          ...                          ; Assembly program starts here.
          ENDP                         ; Mark the end of a subroutine
          END                          ; Mark the end of a program
```

- The ENTRY directive marks **the first instruction to be executed** within an application program.
- There must be **exactly one** ENTRY directive in an application, no matter how many source files the application has.

Directive: END

```
          AREA myData, DATA, READWRITE ; Define a data section
Array     DCD 1, 2, 3, 4, 5            ; Define an array with five integers

          AREA myCode, CODE, READONLY  ; Define a code section
          EXPORT  __main               ; Make __main visible to the linker
          ENTRY                        ; Mark the entrance to the entire program
__main    PROC                         ; PROC marks the begin of a subroutine
          ...                          ; Assembly program starts here.
          ENDP                         ; Mark the end of a subroutine
          END                          ; Mark the end of a program
```

- The END directive indicates the end of a source file.
- Each assembly program must end with this directive.

Directive: PROC and ENDP

```
          AREA myData, DATA, READWRITE ; Define a data section
Array     DCD 1, 2, 3, 4, 5            ; Define an array with five integers

          AREA myCode, CODE, READONLY  ; Define a code section
          EXPORT  __main               ; Make __main visible to the linker
          ENTRY                        ; Mark the entrance to the entire program
__main    PROC                         ; PROC marks the begin of a subroutine
          ...                          ; Assembly program starts here.
          ENDP                         ; Mark the end of a subroutine
          END                          ; Mark the end of a program
```

- PROC and ENDP are to mark the start and end of a function (also called subroutine or procedure).
- A single source file can contain multiple subroutines, with each of them defined by a pair of PROC and ENDP.
- PROC and ENDP cannot be nested. We cannot define a function within another function.

Directive: EXPORT and IMPORT

```
          AREA myData, DATA, READWRITE ; Define a data section
Array     DCD 1, 2, 3, 4, 5            ; Define an array with five integers

          AREA myCode, CODE, READONLY  ; Define a code section
          EXPORT  __main               ; Make __main visible to the linker
          ENTRY                        ; Mark the entrance to the entire program
__main    PROC                         ; PROC marks the begin of a subroutine
          ...                          ; Assembly program starts here.
          ENDP                         ; Mark the end of a subroutine
          END                          ; Mark the end of a program
```

- The EXPORT declares a symbol and makes this **symbol visible** to the linker.
- The IMPORT gives the assembler a symbol that is **not defined locally** in the current assembly file. The symbol must be defined in another file.
- The IMPORT is similar to the "extern" keyword in C.

Directive: Data Allocation

Directive	Description	Memory Space
DCB	Define Constant Byte	Reserve 8-bit values
DCW	Define Constant Half-word	Reserve 16-bit values
DCD	Define Constant Word	Reserve 32-bit values
DCQ	Define Constant	Reserve 64-bit values
DCFS	Define single-precision floating-point numbers	Reserve 32-bit values
DCFD	Define double-precision floating-point numbers	Reserve 64-bit values
SPACE	Defined Zeroed Bytes	Reserve a number of zeroed bytes
FILL	Defined Initialized Bytes	Reserve and fill each byte with a value

Directive: Data Allocation

```
 AREA   myData, DATA, READWRITE
hello   DCB    "Hello World!",0  ; Allocate a string that is null-terminated

dollar  DCB    2,10,0,200        ; Allocate integers ranging from -128 to 255

scores  DCD    2,3.5,-0.8,4.0    ; Allocate 4 words containing decimal values

miles   DCW    100,200,50,0      ; Allocate integers between –32768 and 65535

Pi      DCFS   3.14              ; Allocate a single-precision floating number

Pi      DCFD   3.14              ; Allocate a double-precision floating number

p       SPACE  255               ; Allocate 255 bytes of zeroed memory space

f       FILL   20,0xFF,1         ; Allocate 20 bytes and set each byte to 0xFF

binary  DCB    2_01010101        ; Allocate a byte in binary

octal   DCB    8_73              ; Allocate a byte in octal

char    DCB    ‘A’               ; Allocate a byte initialized to ASCII of ‘A’
```

Directive: EQU and RN

```
; Interrupt Number Definition (IRQn)
BusFault_IRQn    EQU  -11        ; Cortex-M3 Bus Fault Interrupt
SVCall_IRQn      EQU   -5        ; Cortex-M3 SV Call Interrupt
PendSV_IRQn      EQU   -2        ; Cortex-M3 Pend SV Interrupt
SysTick_IRQn     EQU   -1        ; Cortex-M3 System Tick Interrupt

Dividend         RN    6         ; Defines dividend for register 6
Divisor          RN    5         ; Defines divisor for register 5
```

- The EQU directive associates a symbolic name to a numeric constant. Similar to the use of #define in a C program, the EQU can be used to define a constant in an assembly code.
- The RN directive gives a symbolic name to a specific register.

Directive: ALIGN

```
    AREA example, CODE, ALIGN = 3   ; Memory address begins at a multiple of 8
    ADD r0, r1, r2                  ; Instructions start at a multiple of 8

    AREA myData, DATA, ALIGN = 2    ; Address starts at a multiple of four
a   DCB 0xFF                        ; The first byte of a 4-byte word
    ALIGN 4, 3                      ; Align to the last byte (3) of a word (4)
b   DCB 0x33                        ; Set the fourth byte of a 4-byte word
c   DCB 0x44                        ; Add a byte to make next data misaligned
    ALIGN                           ; Force the next data to be aligned
d   DCD 12345                       ; Skip three bytes and store the word
```

Directive: INCLUDE or GET

```
        INCLUDE constants.s        ; Load Constant Definitions
        AREA main, CODE, READONLY
        EXPORT  __main
        ENTRY
__main  PROC
        ...
        ENDP
        END
```

- The INCLUDE or GET directive is to include an assembly source file within another source file.
- It is useful to include constant symbols defined by using EQU and stored in a separate source file.