

Engineering Cryptographic Software

An introduction to the Cortex-M4

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Our platform: Arm

- ▶ Company designs CPUs, does not build them
- ▶ Market leader for mobile devices, embedded systems

- ▶ ARMv7E-M architecture
- ▶ Cortex-M4 implements this architecture
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- ▶ Released in 2010, widely deployed
- ▶ STM32F407VGT6
 - ▶ Cortex-M4 + peripherals
- ▶ 1024 KB flash
- ▶ 192 KB SRAM
- ▶ 168 MHz CPU

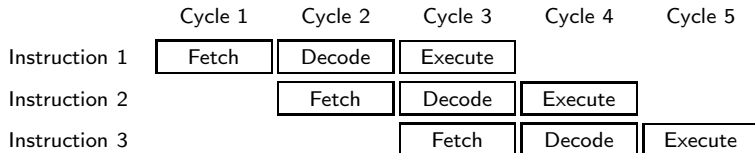


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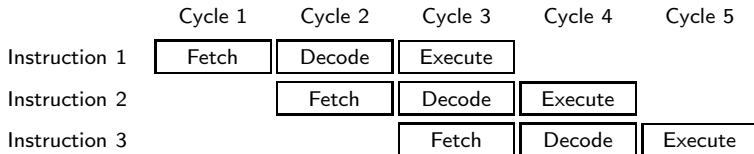
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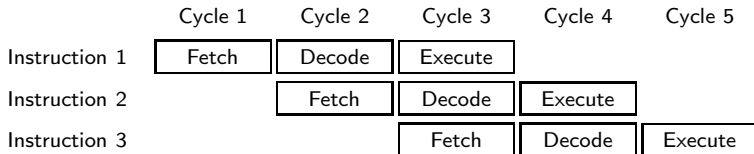
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- ▶ Branching breaks this
 - ▶ But remedied by branch prediction + speculative execution
- ▶ Execute happens in one cycle: dependencies do not cause stalls

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- ▶ STM32F407 has cache to flash memory
- ▶ Lookups from constant tables go through cache → **timing leakage!**
- ▶ Binaries also run on Cortex-M7, which has cached access to RAM

- ▶ Write “constant-time” code!
 - ▶ No branching on secret data
 - ▶ No memory access at secret locations

Registers

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- ▶ Some special registers
 - ▶ r13: sp (stack pointer)
 - ▶ r14: lr (link register)
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- ▶ Some special registers
 - ▶ r13: sp (stack pointer)
 - ▶ r14: lr (link register)
 - ▶ r15: pc (program counter)
- ▶ r0–r12 are general purpose and can be freely used
- ▶ r14 can be used inside a function if spilled and restored before return
- ▶ r13 and r15 should be used only for their purpose

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- ▶ Shifts/rotates: `ror`, `lsl`, `lsr`, `asr`
- ▶ All have variants with registers as operands and with a constant ('immediate')

Combined barrel shifter

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- ▶ Two instructions for the price of one, only costs 1 cycle
- ▶ Optimized code uses this all the time
- ▶ Possible with most arithmetic instructions

Barrel shifter example

Possible:

```
mov r0, #42
mov r1, #37
ror r1, r1, #1
orr r2, r0, r1
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More efficient:

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- ▶ Barrel shifter does not update Rm, i.e. r1 and r2!

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mov r0, #42
b somelabel
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somelabel:
...
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 - ▶ `bls label` (`r0 <= r1`, unsigned)
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 - ▶ `bge label` (`r0 >= r1`, signed)
 - ▶ And many more

Conditional branches (example)

► In C:

```
uint32_t a, b = 100;

for (a = 0; a <= 50; a++) {
    b += a;
}
```

► In asm:

```
mov r0, #0    // a
mov r1, #100  // b

loop:
add r1, r0    // b += a

add r0, #1    // a++
cmp r0, #50   // compare a and 50
bls loop     // loop if <=
```

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- ▶ Can load from the stack without moving sp (in a few slides)
- ▶ Not popping all pushed values will crash the program

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- ▶ 'word' = 32 bit, 'halfword' = 16 bit, 'doubleword' = 64 bit, 'byte' = 8 bit, 'nibble' = 4 bit
- ▶ Can directly insert words and bytes as 'data'

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.data
somedata:
    .word 0x01234567, 0xfedcba98
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- ▶ For global constants in ROM/flash, use `.section .rodata`

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- ▶ `ldm/stm r0, {r1,r2,r5}` loads/stores multiple from consecutive memory locations
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- ▶ `push {r0,r1} == stmdb sp!, {r0,r1}`
 - ▶ *'store multiple decrement before'*

Subroutines

```
somelabel:  
    add r0, r1  
    add r0, r1, ror #2  
    add r0, r1, ror #4  
    bx lr
```

```
main:  
    bl somelabel  
    mov r4, r0  
    mov r0, r2  
    mov r1, r3  
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- ▶ Some performance overhead due to branching

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- ▶ For *private* subroutines: can ignore this ABI

Architecture Reference Manual

- ▶ Large PDF that includes all of this, and more
- ▶ Available online: <https://developer.arm.com/documentation/ddi0403/eb/>
- ▶ See Chapter A7 for instruction listings and descriptions

Architecture Reference Manual

A6.7.3 ADD (immediate)

This instruction adds an immediate value to a register value, and writes the result to the destination register. It can optionally update the condition flags based on the result.

Encoding T1 All versions of the Thumb ISA.

ADDS <Rd>, <Rn>, #<imm3>

Outside IT block.

ADD<C> <Rd>, <Rn>, #<imm3>

Inside IT block.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	1	1	1	0	imm3			Rn			Rd		

d = UInt(Rd); n = UInt(Rn); setflags = !InITBlock(); imm32 = ZeroExtend(imm3, 32);

Encoding T2 All versions of the Thumb ISA.

ADDS <Rdn>, #<imm8>

Outside IT block.

ADD<C> <Rdn>, #<imm8>

Inside IT block.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	1	1	0	Rdn			imm8							

d = UInt(Rdn); n = UInt(Rdn); setflags = !InITBlock(); imm32 = ZeroExtend(imm8, 32);

Encoding T3 ARMv7-M

ADD{S}<C> .W <Rd>, <Rn>, #<const>

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
[...]																[...]															

Architecture Reference Manual

Assembler syntax

ADD{S}<C><Q> {<Rd>}, <Rn>, #<const>

ADDW<C><Q> {<Rd>}, <Rn>, #<const>

where:

S	If present, specifies that the instruction updates the flags. Otl update the flags.
<C><Q>	See <i>Standard assembler syntax fields</i> on page A6-7.
<Rd>	Specifies the destination register. If <Rd> is omitted, this reg
<Rn>	Specifies the register that contains the first operand. If the S (<i>SP plus immediate</i>) on page A6-26. If the PC is specified fo
<const>	Specifies the immediate value to be added to the value obta allowed values is 0-7 for encoding T1, 0-255 for encoding T See <i>Modified immediate constants in Thumb instructions</i> o allowed values for encoding T3.

Time to get to work!

- ▶ If you haven't "walked through" the STM32F4 getting started, do so.
- ▶ If you never wrote assembly before, download this example in your assignment folder:
[https://github.com/denigreco/
crypto_engineering_asm_example.git](https://github.com/denigreco/crypto_engineering_asm_example.git)
- ▶ Otherwise, start working on ChaCha20
- ▶ These slides are also on the course website