Goals for today

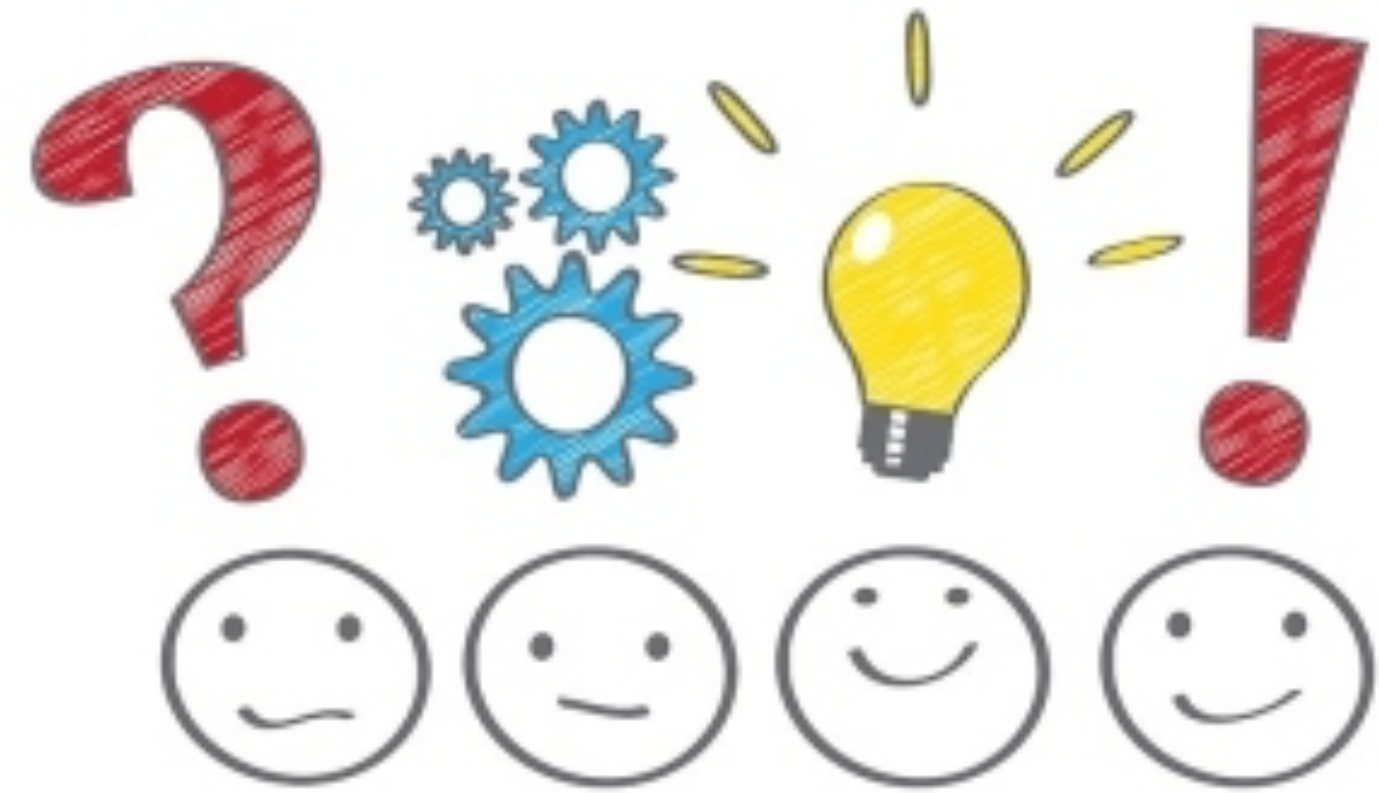
ARM condition codes, branch instructions

C language as “high-level” assembly

Relationship of C to asm

What does a compiler do?

Check in!



Control flow

Instructions stored in contiguous memory

Register pc (r15) uses to track where in memory to read instructions

"Straight-line" code: next instruction to execute is at next highest memory address

Redirect control flow by changing pc, typically via branch operation

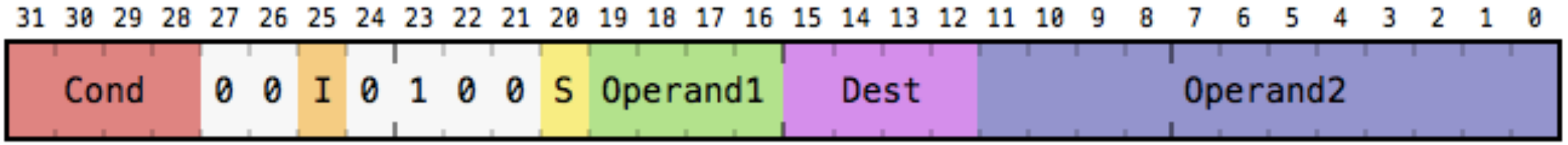
```
b target
```

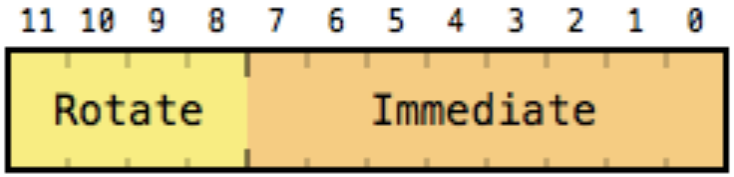
Branch can be conditional as well as unconditional (predicted execution)

Data processing operations

```
dst = operand1 op operand2
```

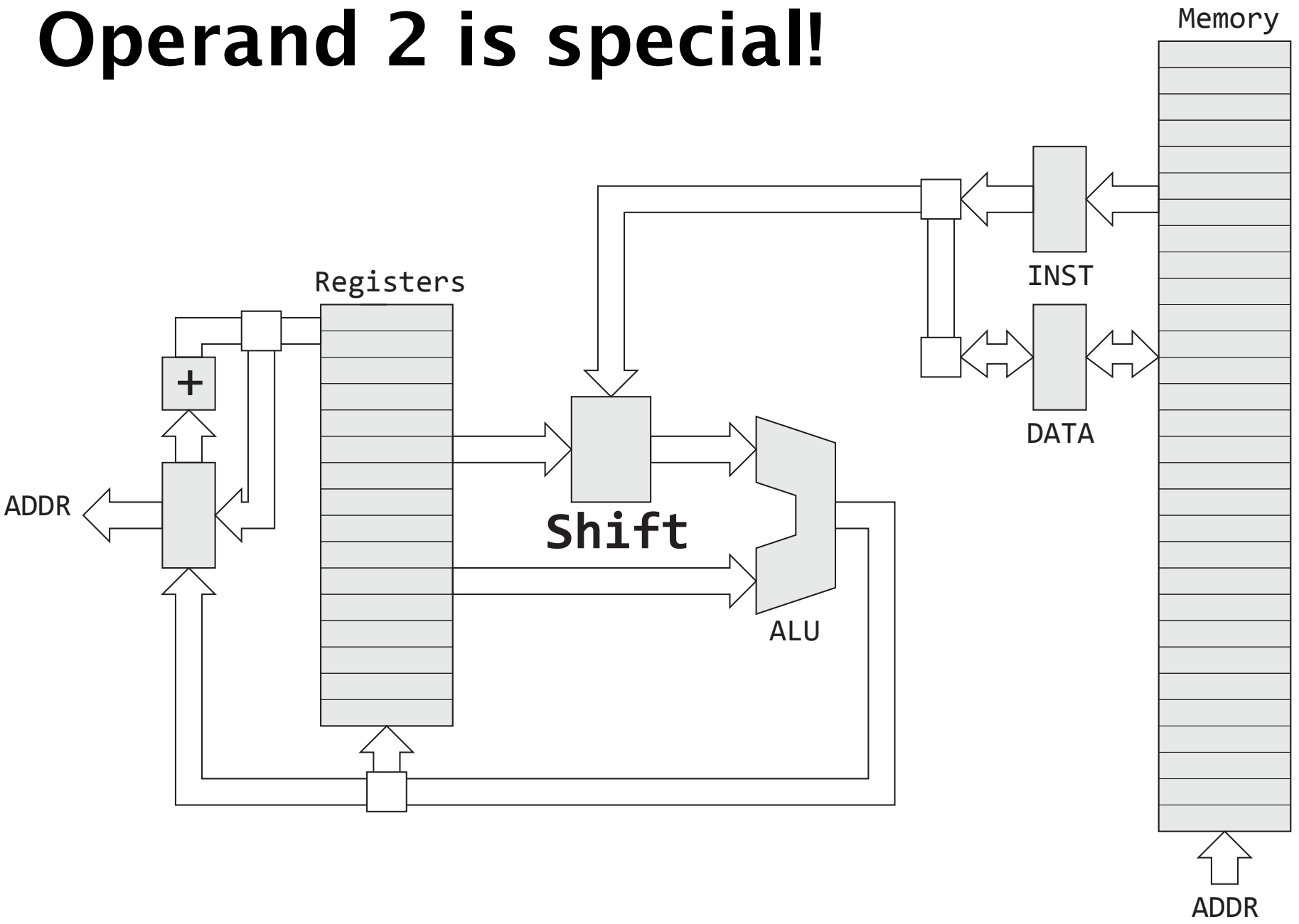
S bit on -> instruction will also set condition codes






```
add  r0, r1, r1
adds r0, r1, r1
add r0, r1, r1, lsl #1
```

Operand 2 is special!



Condition Codes

Z set if result is 0, clear otherwise

N set if result is < 0, clear otherwise

C set if result generated carry

V set if result had arithmetic overflow

(More on carry and overflow later…)

Code	Suffix	Description	Flags
0000	EQ	Equal / equals zero	Z
0001	NE	Not equal	!Z
0010	CS / HS	Carry set / unsigned higher or same	C
0011	CC / LO	Carry clear / unsigned lower	!C
0100	MI	Minus / negative	N
0101	PL	Plus / positive or zero	!N
0110	VS	Overflow	V
0111	VC	No overflow	!V
1000	HI	Unsigned higher	C and !Z
1001	LS	Unsigned lower or same	!C or Z
1010	GE	Signed greater than or equal	N == V
1011	LT	Signed less than	N != V
1100	GT	Signed greater than	!Z and (N == V)
1101	LE	Signed less than or equal	Z or (N != V)
1110	AL	Always (default)	any

Branch instructions

```
b target
bne target
bmi target
bge target
```

Reads condition codes set by a previous instruction

(may be **cmp** or **tst** or other "s" instruction)

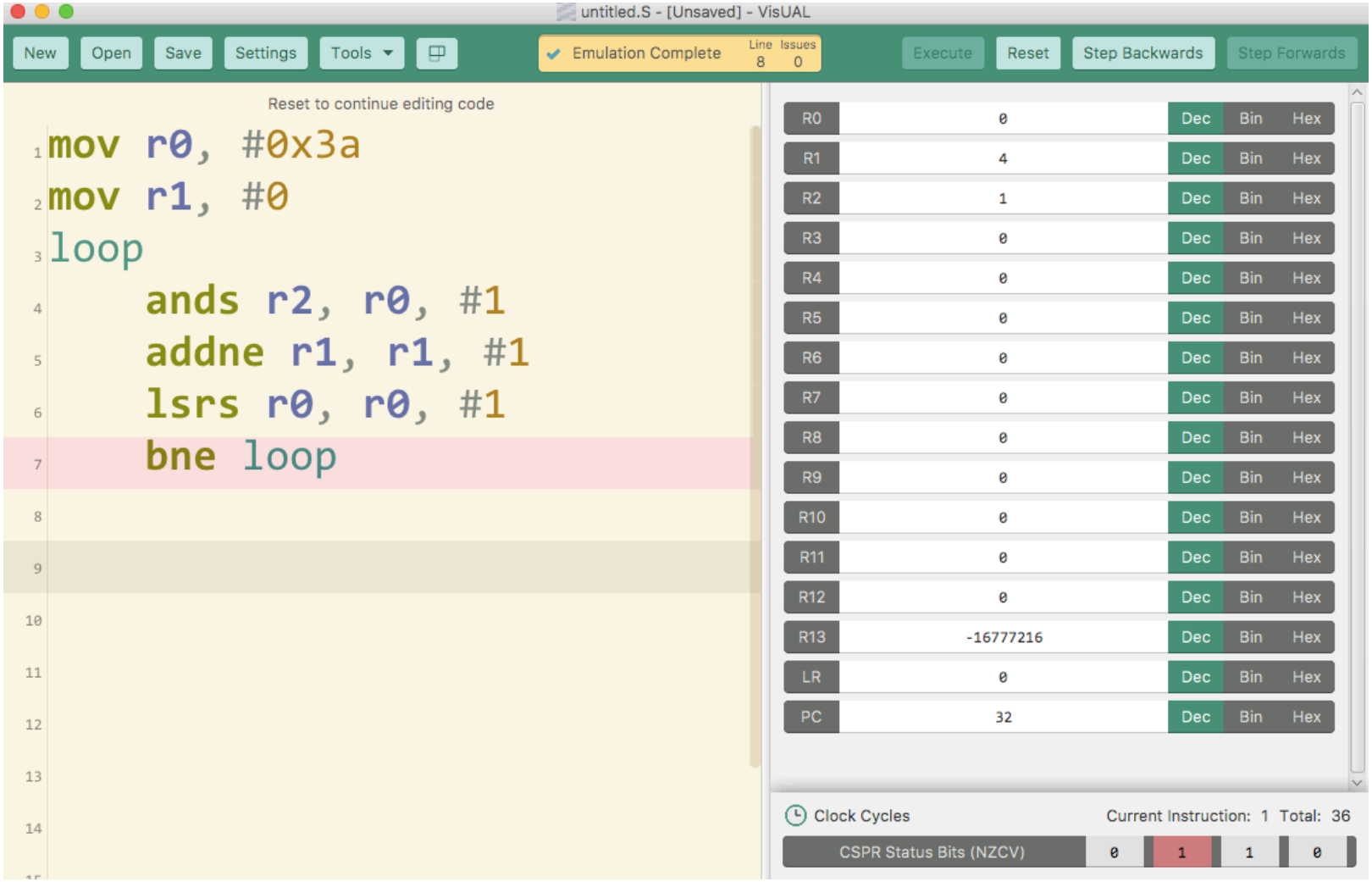
Branch taken if condition(s) satisfied

Challenge!

Write assembly program to count the number of "on" bits in a given number

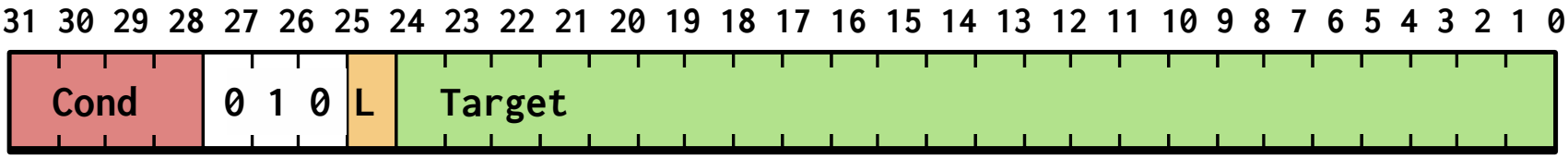
```
mov r0, #val
mov r1, #0

// count bits in val in r0
// put result in r1
```

VisUAL ARM Emulator



https://salmanarif.bitbucket.io/visual/

Branch instruction encoding



b (bal) branch always

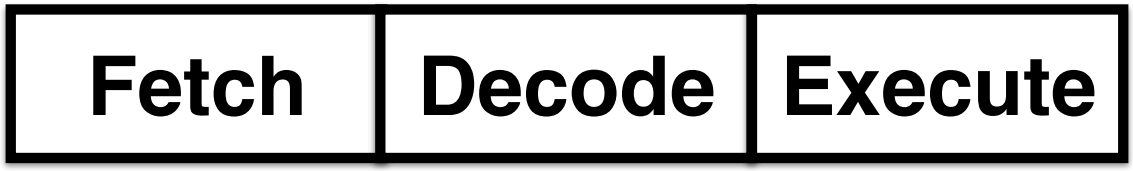
1110 1010 tttt tttt tttt tttt tttt tttt

beq branch if zero flag set

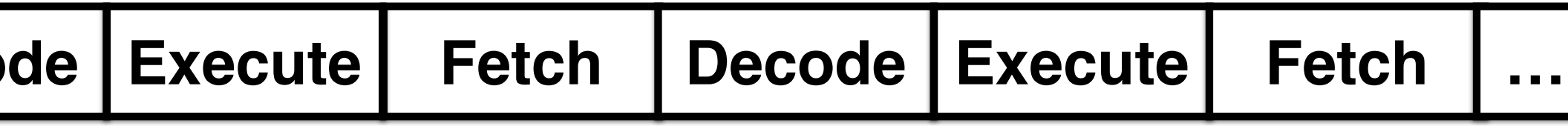
0000 1010 tttt tttt tttt tttt tttt tttt

branch target is PC-relative offset
green bits encode offset, counted in 4-byte words
Q: How far can this reach?

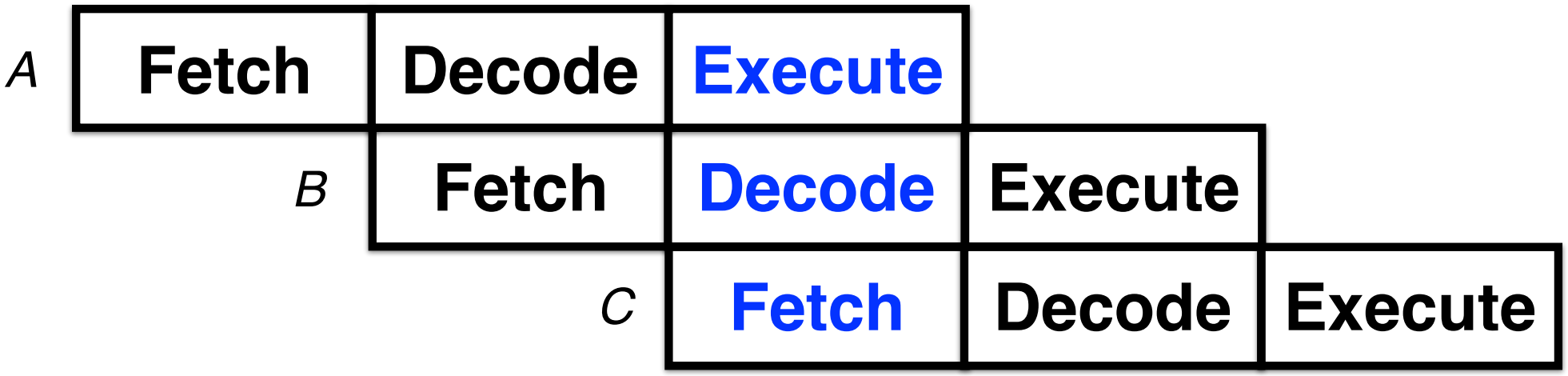
3 steps per instruction



3 instructions takes 9 steps in sequence



To speed things up, steps are overlapped ("pipelined")



During cycle that instruction *A* is executing, PC has advanced twice, holds address of instruction being fetched (*C*). This is 2 instructions past *A* (PC+8)

```
    18:   e3a0283f mov    r2, #0x3fc000
    1c:   e2522001 subs   r2, r2, #1
    20:   1afffffd bne    1c

// 1a          branch if not equal
// fffffd -3 (two's complement)
// offset is 8 + -3*4 = -4
```

PC-relative addressing used for data too! (ldr/str)

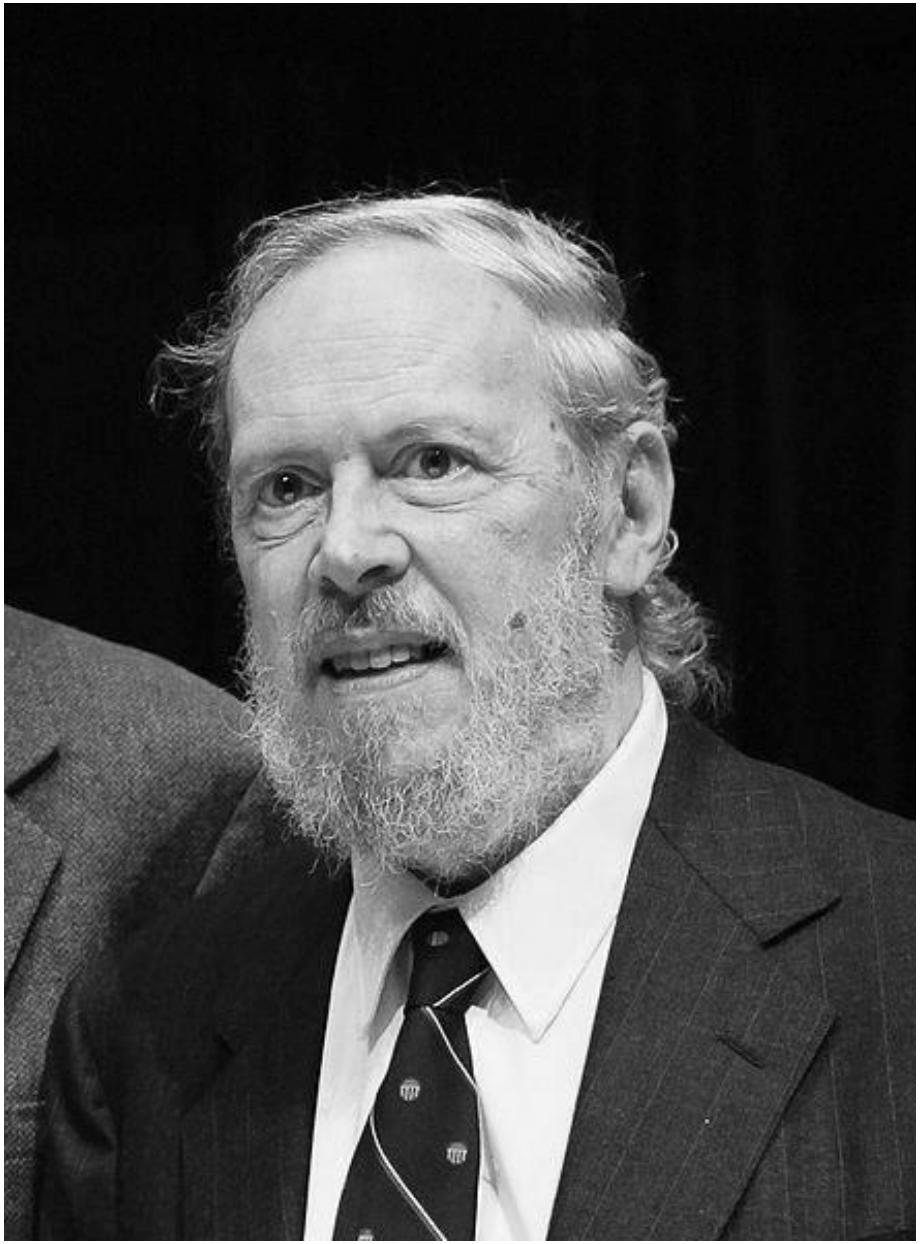
ISA design is an art form!

Some neat things about ARM design

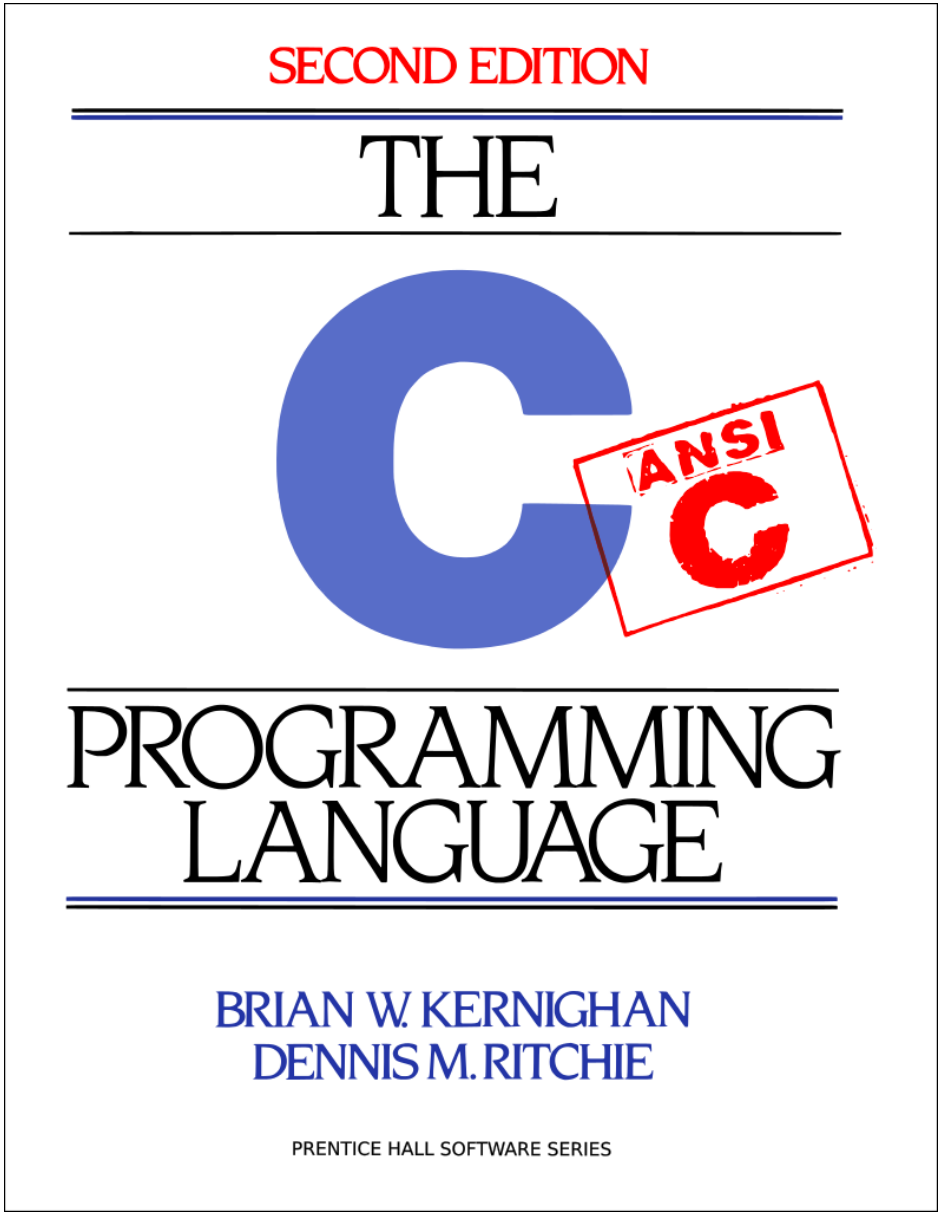
- Commonalities across operations
  - Register vs. immediate operands
  - Use of barrel shifter
  - All registers treated same (with a few caveats)
  - Predicated execution
  - Set condition code (or not)

Orthogonality leads to composability


100 FEET BELOW
SEA LEVEL



Dennis Ritchie



The C Programming Language

“C is quirky, flawed, and an enormous success”
— Dennis Ritchie

“C gives the programmer what the programmer wants; few restrictions, few complaints”
— Herbert Schildt

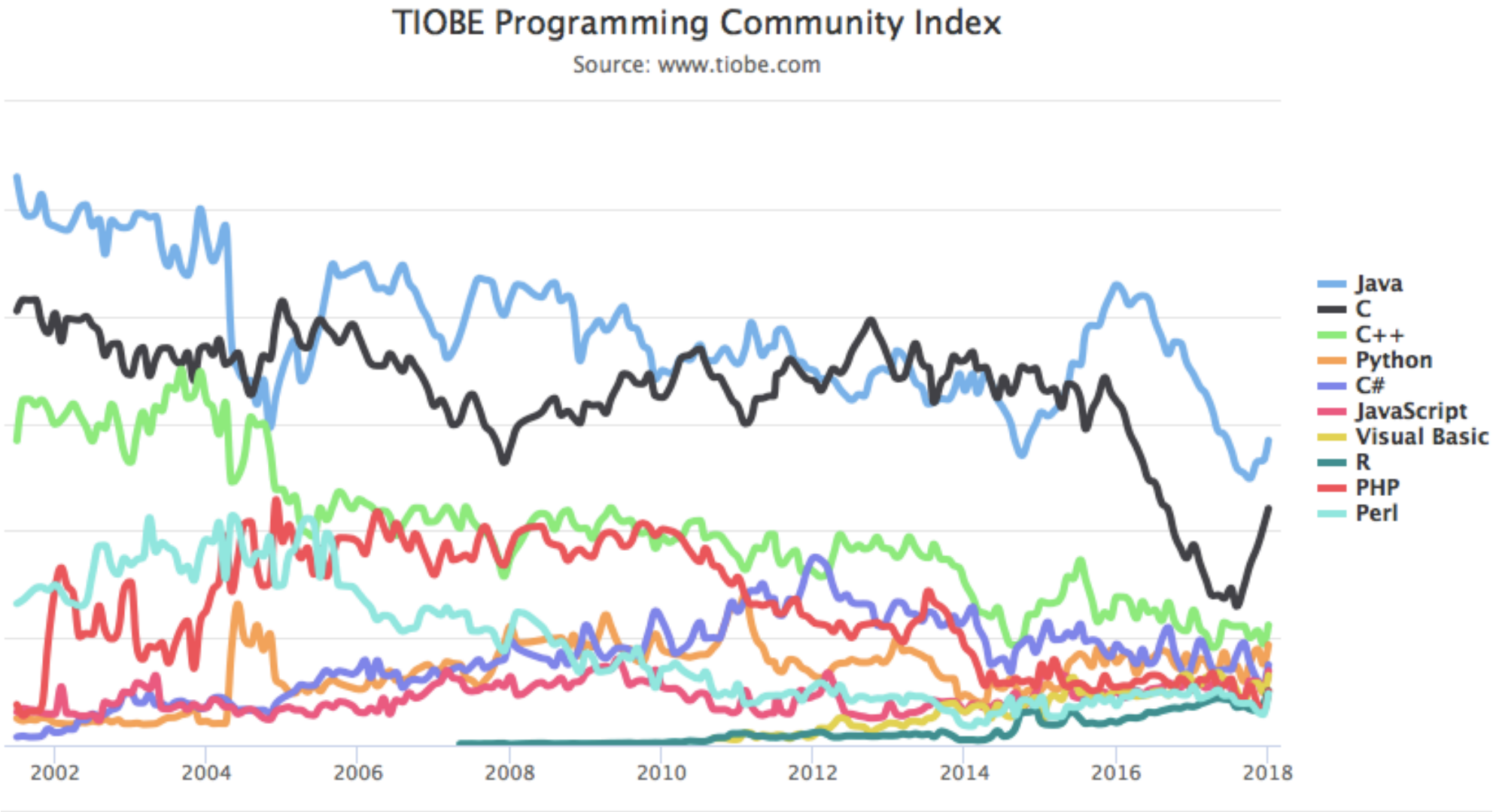
“C: A language that combines all the elegance and power of assembly language with all the readability and maintainability of assembly language”
— Unknown

Ken Thompson built UNIX using C

http://cm.bell-labs.com/cm/cs/who/dmr/picture.html

“BCPL, B, and C all fit firmly in the traditional procedural family (of languages) typified by Fortran and Algol 60. They are particularly oriented towards system programming, are small and compactly described, and are amenable to translation by simple compilers. They are “close to the machine” in that the abstractions they introduce are readily grounded in the concrete data types and operations supplied by conventional computers, and they rely on library routines for input-output and other interactions with an operating system.
…
At the same time, their abstractions lie at a sufficiently high level that, with care, portability between machines can be achieved.”

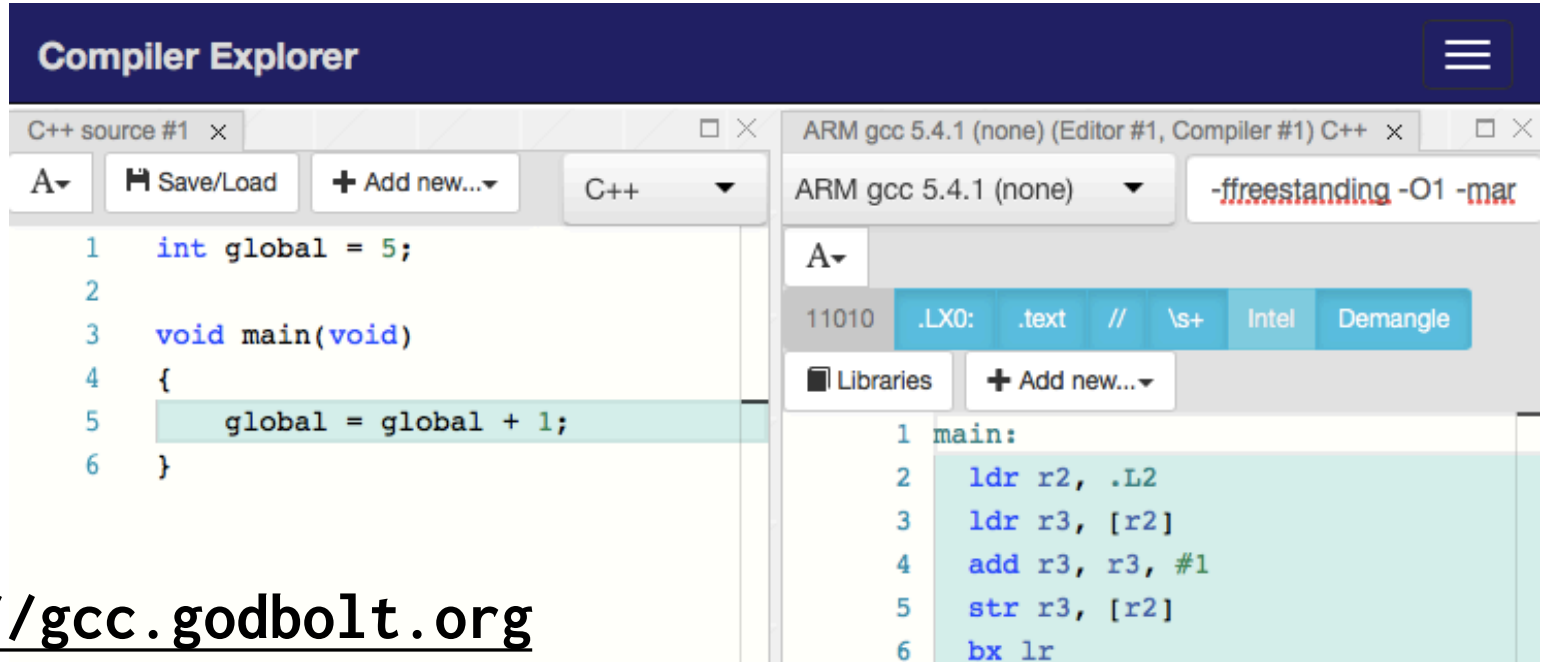
- Dennis Ritchie



Programming language popularity over time

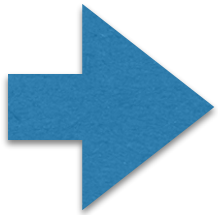
C language features closely model the ISA: data types, arithmetic/logical operators, control flow, access to memory, …

Compiler Explorer is a neat interactive tool to see translation



https://gcc.godbolt.org

```
.equ DELAY, 0x3F0000

ldr r0, FSEL2
mov r1, #1
str r1, [r0]
mov r1, #(1<<20)

loop:
 ldr r0, SET0
 str r1, [r0]
 mov r2, #DELAY
 wait1:
     subs r2, #1
     bne wait1
 ldr r0, CLR0
 str r1, [r0]
 mov r2, #DELAY
 wait2:
     subs r2, #1
     bne wait2
 b loop

FSEL2: .word 0x20200008
SET0:  .word 0x2020001C
CLR0:  .word 0x20200028
```



C?

let's do it!

Know your tools!

Assembler (as)

Transform assembly code (text)
into object code (binary machine instructions)
Mechanical translation, few surprises

Compiler (gcc)

Transform C code (text)
into object code
(likely staged C-> asm -> object)
Complex translation, high artistry

When coding directly in assembly, the instructions you see are the instructions you get, no surprises!

For C source, you may need to drop down to see what compiler has generated to be sure of what you're getting

What transformations are *legal* ?
What transformations are *desirable* ?