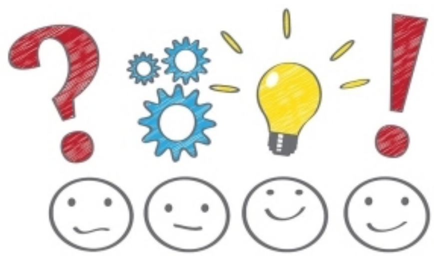
Admin

First lab and assign

We're off and running!

Check in



Today: From Assembly to C (and back again)

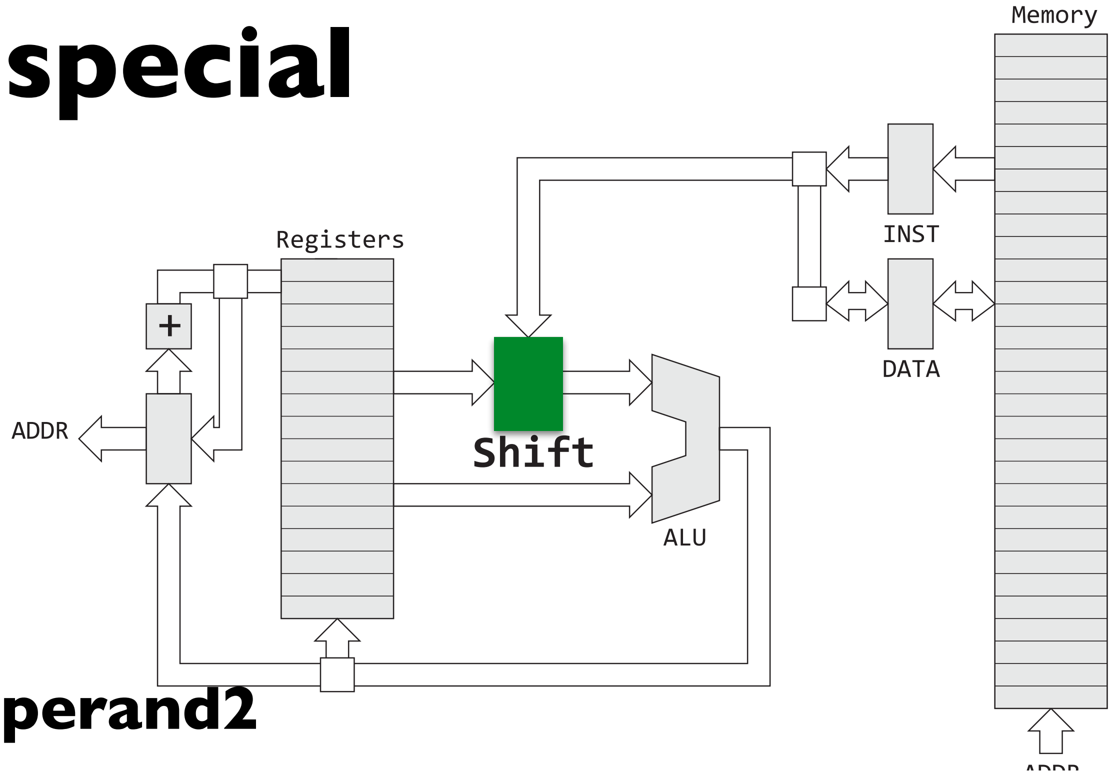
ARM condition codes, branch instructions

C language as "high-level" assembly

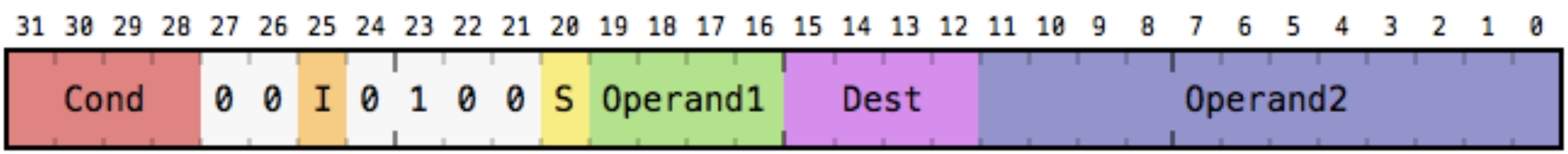
What does a compiler do?

Makefiles

Operand 2 is special

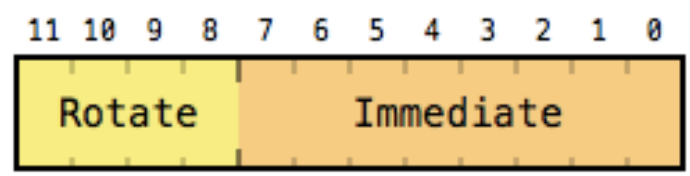


Dest = Operand1 op Operand2

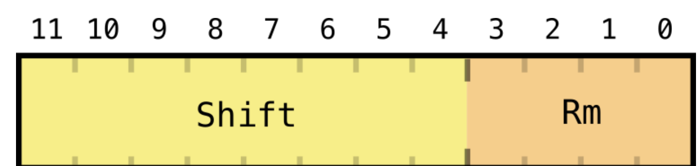


add r0, r1, #0x1f000
sub r0, r1, #6
rsb r0, r1, #6
add r0, r1, r2, lsl #3
mov r1, r2, ror #7

I=1

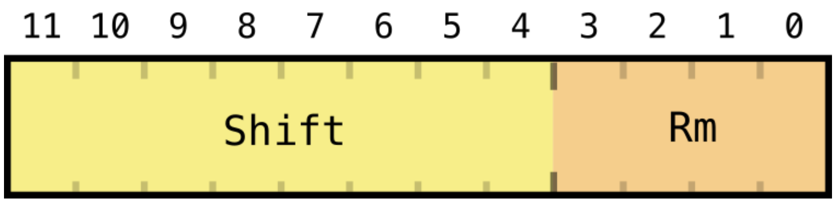


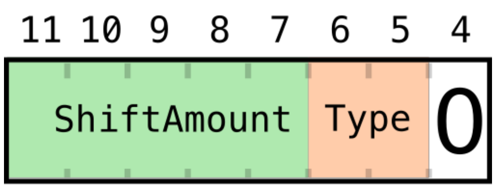
I=0



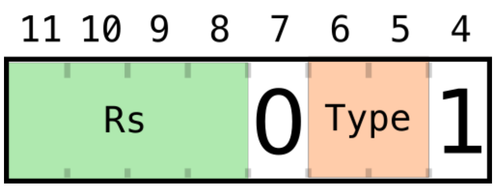
lsl, lsr, asr, ror

Shift Operand Details





Shift Rm by ShiftAmount



Shift Rm by Rs

00: lsl (logical shift left)
01: lsr (logical shift right)
10: asr (arithmetic shift right)
11: ror (rotate right)

Control flow

Instructions stored in memory contiguously

Register **pc** (**r15**) tracks address in memory where instructions are being read

Default is "straight-line" code: next instruction to execute is at next word address (**pc = pc + 4**)

branch instructions change what instruction is fetched, decoded, and executed next has effect of **pc = target**

b target

Above branch is unconditional (always taken)

Branches can also nne predicated on state of "condition codes"

Condition Codes

Z	result was 0
N	result was < 0
C	operation generated carry
V	operation had arithmetic overflow

(More on carry and overflow in later lecture…)

Which instructions set/clear codes?

cmp (like **sub**, but discards result)

tst (like **and**, but discards result)

Any data processing instruction suffixed with **s:**

adds movs orrs lsrs ...

s bit
(if on, instr will set condition codes)

Cond	0	0	I	0	1	0	0	S	Operand1	Dest	Operand2

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

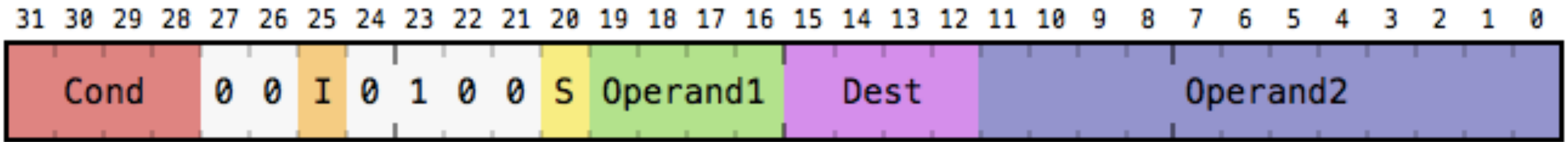
Branch instructions

b   target
bne target
bmi target
bge target
...

branch reads condition codes, as set by a previous instruction

If specific condition satisfied, branch is taken, **pc = target**
otherwise falls through, **pc = pc + 4**

Condition execution



The ability to conditionally execute is built into all ARM instructions! (not just **branch**…)

addeq r0, r0, #3
submi r1, r2, r3

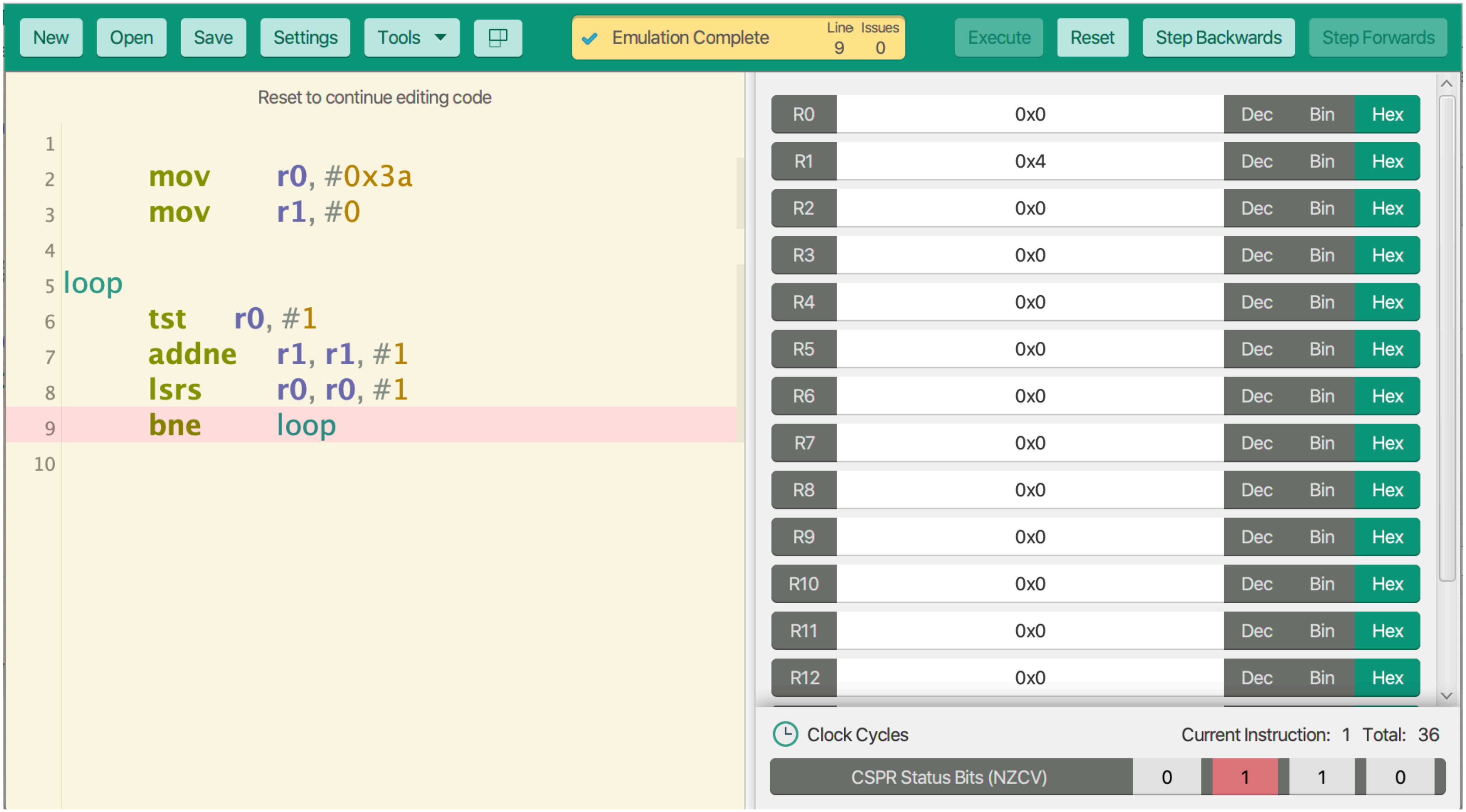
*Q: Given our earlier foray into machine-encoded instructions, what do you suspect is the condition represented by **0xe**?*

Challenge for you all:

Write an assembly program to count the "on" bits in a given numeric value

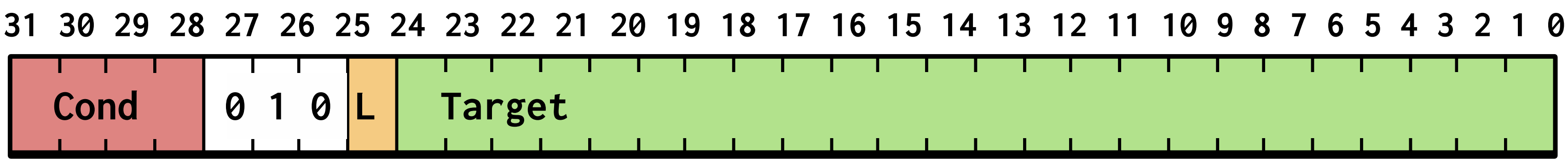
```
mov r0, #val
mov r1, #0

// r0 holds input value
// use r1 to store count of on bits in value
```

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 CC 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?

Why assembly?

What you see is what you get

No surprises

Precise control, timing

Unfettered access to hardware

Why C?

More concise

Easier to read

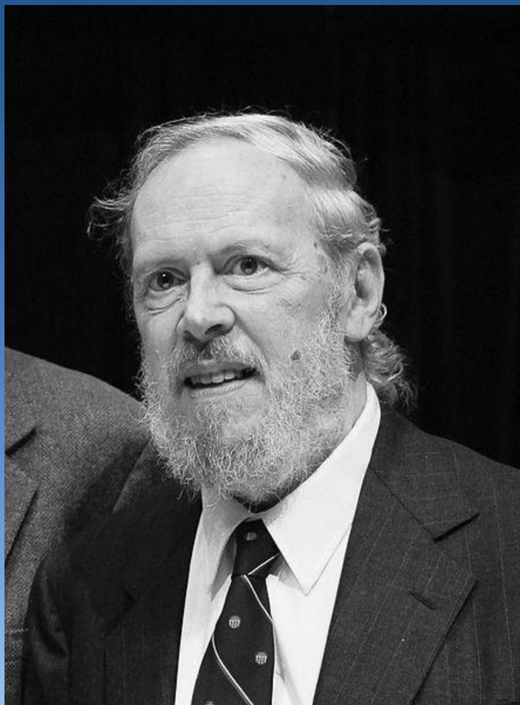
Can name variables and structures

Type-checking

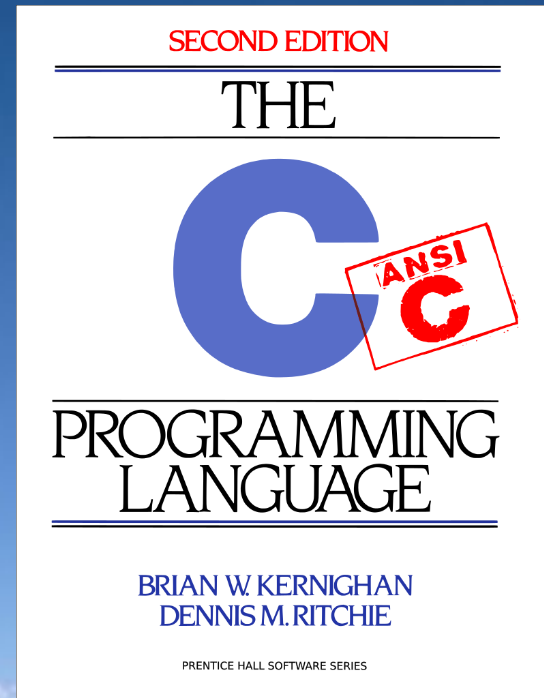
More portable (ARMv6, ARMv7, ARMv8...)

Functions!!

Real question is not whether to use assembly, but ***when****...*



Dennis Ritchie



C is the language of choice for systems programmers

Ken Thompson built UNIX using C

This is not coincidence!

C features closely model the ISA: data types, arithmetic/logical operators, control flow, access to memory, ... all provided in form of portable abstractions

"BCPL, B, and C family of languages 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*

The C Programming Language

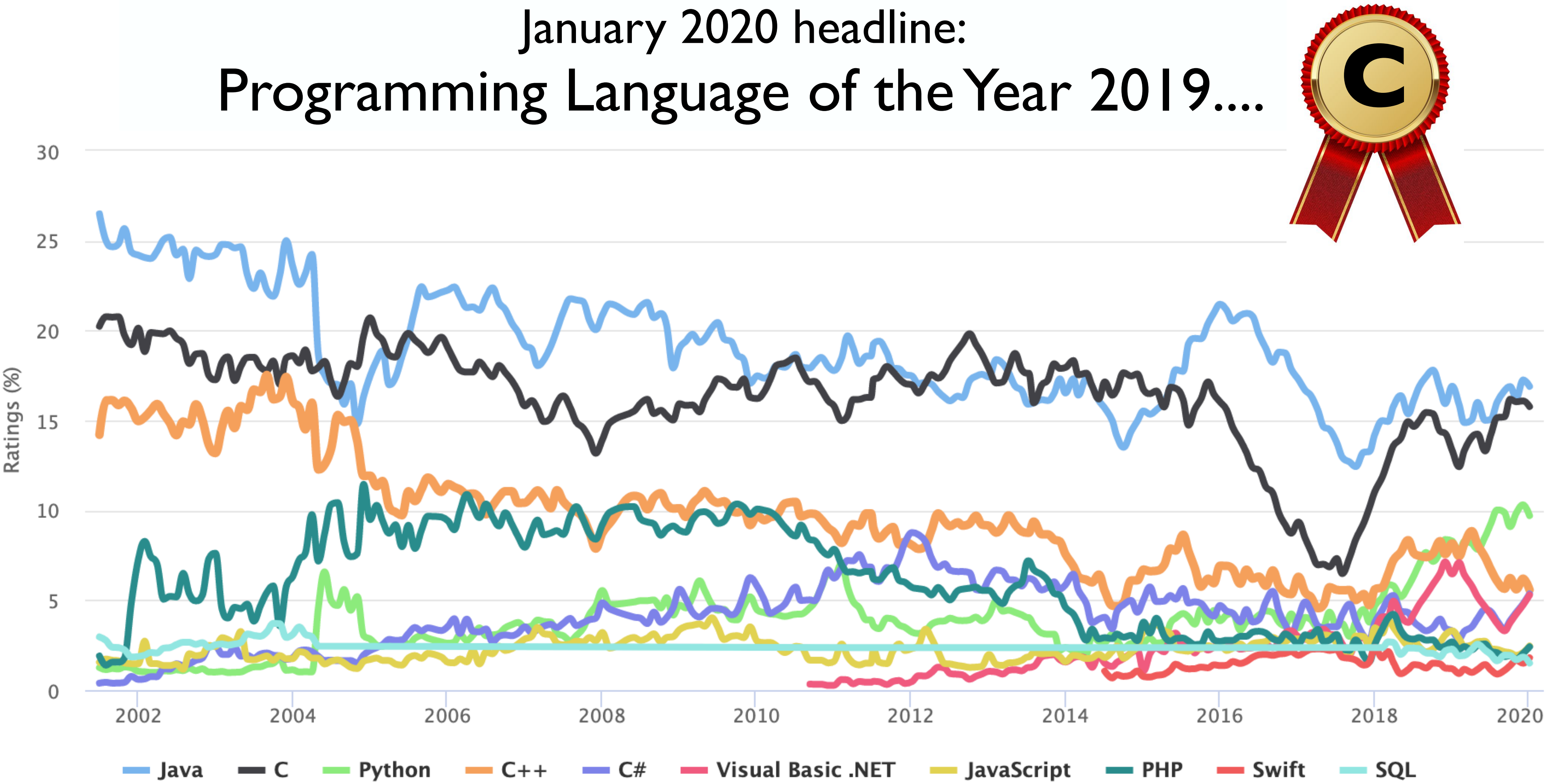
"C is quirky, flawed, and an enormous success"
— *Dennis Ritchie*

"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*

January 2020 headline:

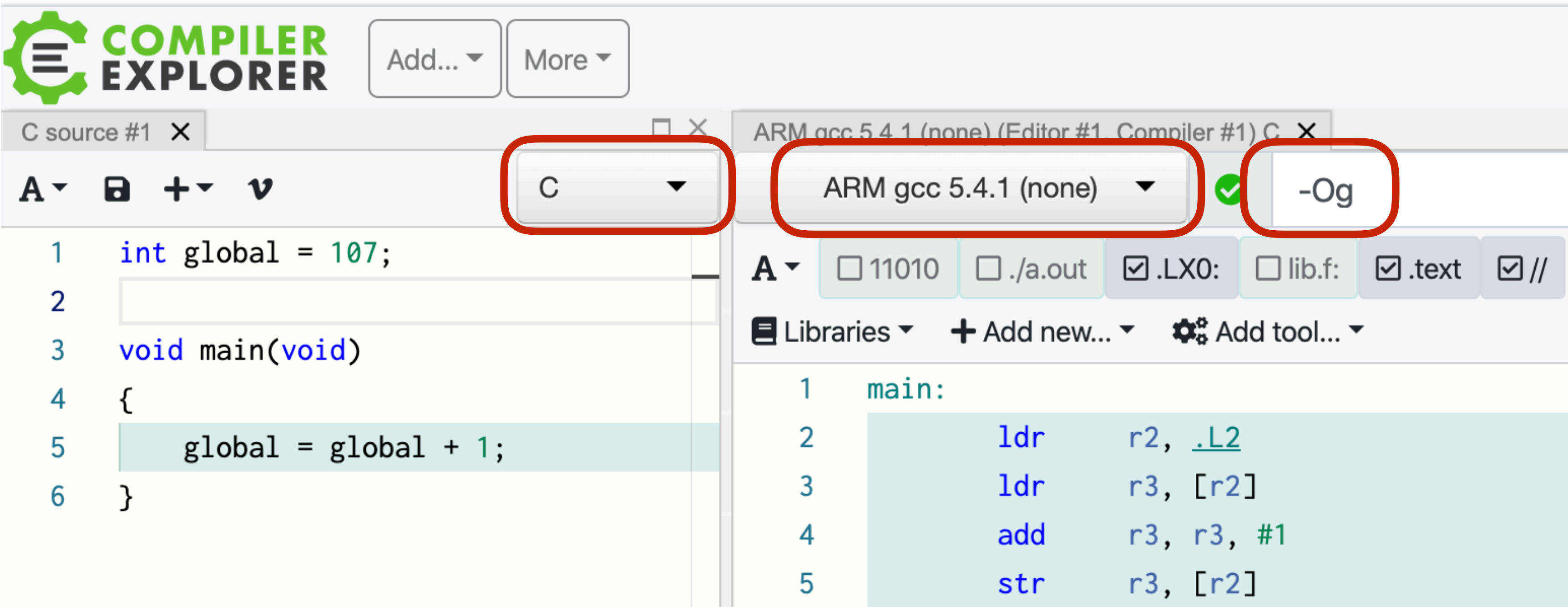
Programming Language of the Year 2019....



Programming language popularity over time

Compiler Explorer

is a neat interactive tool to see translation from C to assembly.
Let's try it now!



https://godbolt.org

Configure settings to follow along:
C
ARM gcc 5.4.1(none)
-Og

Why C?

Higher-level abstractions, structured programming

- Named variables, constants
- Arithmetic/logical operators
- Control flow

Portable

- Not tied to particular ISA or architecture

Low-level enough to get to machine when needed

- Bitwise operations
- Direct access to memory
- Embedded assembly, too!

Know your tools!

Assembler   as

Transform assembly code (text)
    into object code (binary machine instructions)

Mechanical rewrite, few surprises

Compiler   gcc

Transform C code (text)
    into object code
        (likely staged C ➜ asm ➜ object)

Complex translation, high artistry

Make

Build/compile your code using **make**

A **Makefile** describes how to build a piece of software

Rules, dependencies, and recipes

```
mine.bin: mine.s
	arm-none-eabi-as mine.s -o mine.o
	arm-none-eabi-objcopy mine.o -O binary mine.bin

install: mine.bin
	rpi-install.py mine.bin

clean:
	rm *.o *.bin
```

Make

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install: blink.bin
    rpi-install.py blink.bin

clean:
    rm *.o *.bin
```

Rule

Dependency

Recipe

Target

Make

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```

Here's the rule to make build.bin

It depends on build.s; if that changes, run this recipe again

Here are the steps (recipe) to produce build.bin

Make

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Writing out and recipes explicitly like this is onerous, so make has all kinds of ways to match patterns, define variables, etc.