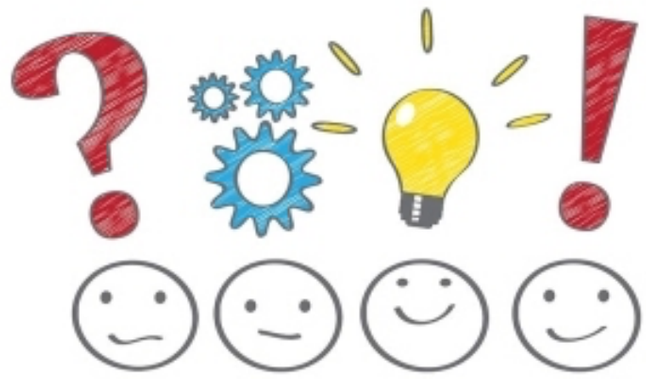
Admin

Lab I => Assign I

You will be working fully in assembly!

We're off and running!



Check in

Today: From Assembly to C
(and back again)

Branch instructions, PC-relative

C language as "high-level" assembly

What does a compiler do?

Makefiles

Control flow, pc register

Instructions stored in contiguous memory

pc tracks address in memory where instructions are being read

pc register separate from **x0-x31**, not accessible to most instructions, use special instructions to access/change **pc**

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

jump instruction assigns **pc** to different address

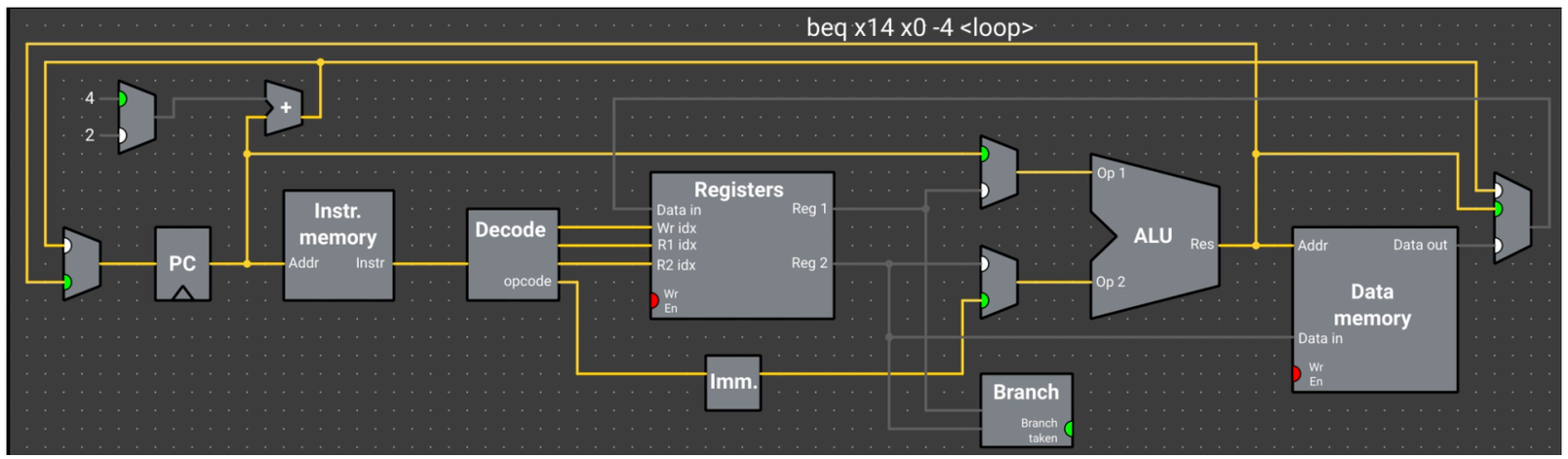
```
j target
```

Jump is unconditional (always taken)
Branch is conditionally taken based on test

Branch instructions

Mnemonic	Action
`BEQ rs1,rs2,imm12`	`Branch equal (rs1 = rs2)`
`BNE rs1,rs2,imm12`	`Branch not equal (rs1 ≠ rs2)`
`BGE rs1,rs2,imm12`	`Branch greater than or equal (rs1 ≥ rs2)`
`BLT rs1,rs2,imm12`	`Branch less than (rs1 < rs2)`

Q: How to... branch greater? Branch less-equal? Branch zero? Branch negative?



If condition satisfied, branch is taken (`pc = pc + imm12`)
otherwise falls through (`pc = pc + 4`)

Challenge for you

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

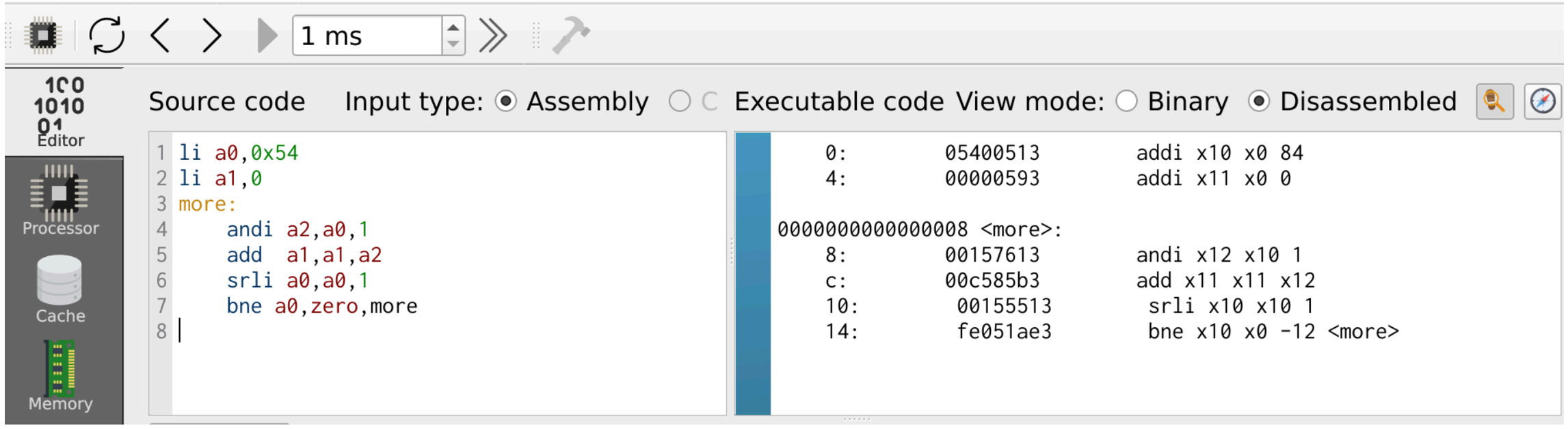
```
li a0, val
li a1, 0

// a0 holds input value
   // use a1 to store count of on bits in value
```

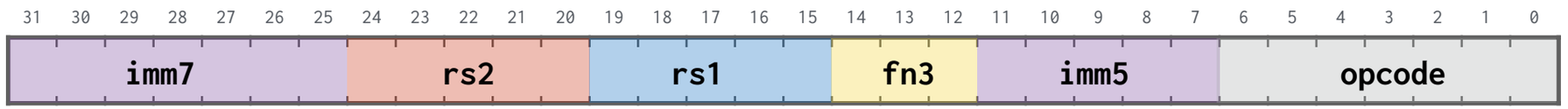
Hints:

- The rest of the program is only four lines of code (and a label). You do not need to use a terminating loop, e.g., **loop: j loop** (though that's fine)
- Focus on the "Logical Operations" from the RISC-V Instruction-Set handout

One Solution



Branch instruction encoding




```
if rs1 cmp_op rs2 pc = pc + imm12
```

- branch target computed as PC-relative offset
- purple bits encode offset (immediate)
- "position-independent" code

12-bit immediate expressed as count of 2-byte steps

Q: How far can this reach?

ISA design is an art form!

As much about what is **omitted** as what is **included**

All registers general-purpose registers, no act on memory ("load-store")

Simplicity (avoid redundancies, single addressing mode)

Isolate architecture from implementation (no delay slots branch/load, no condition codes)

Regularity: all instructions 4-bytes (2 for compressed)

Handling/placement of bits in encoding for ease of decode/data path

Modular, extensible (tiny base ISA, orthogonal additions)

Data-informed design (learn from past)

Why assembly?

What you see is what you get

No surprises

Precise control, timing

Unfettered access to hardware

***But**... tedious, hard to read, hardware-specific*

Why C?

More concise

Easier to read

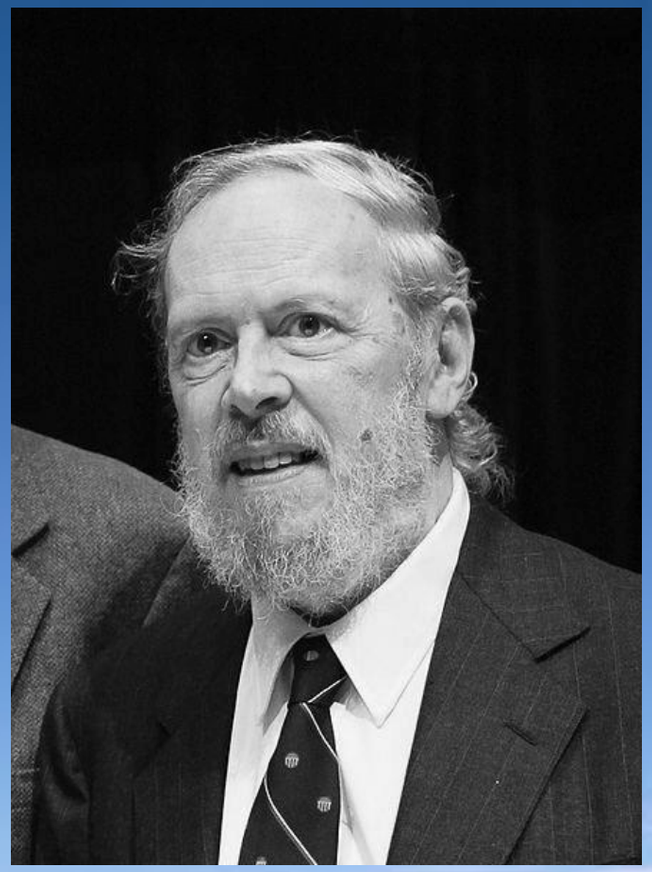
Can name variables and structures

Type-checking

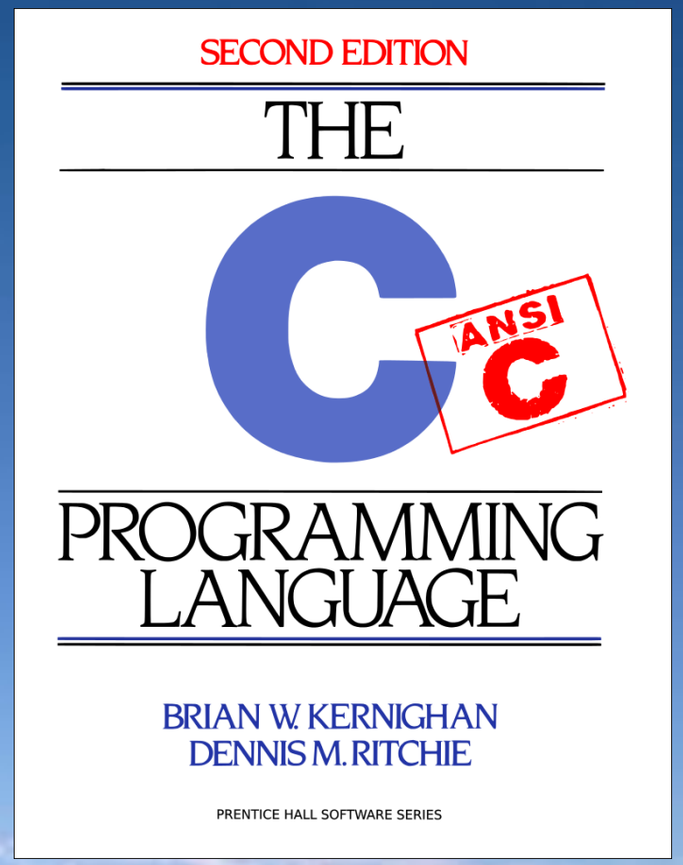
More portable, architecture-neutral

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*

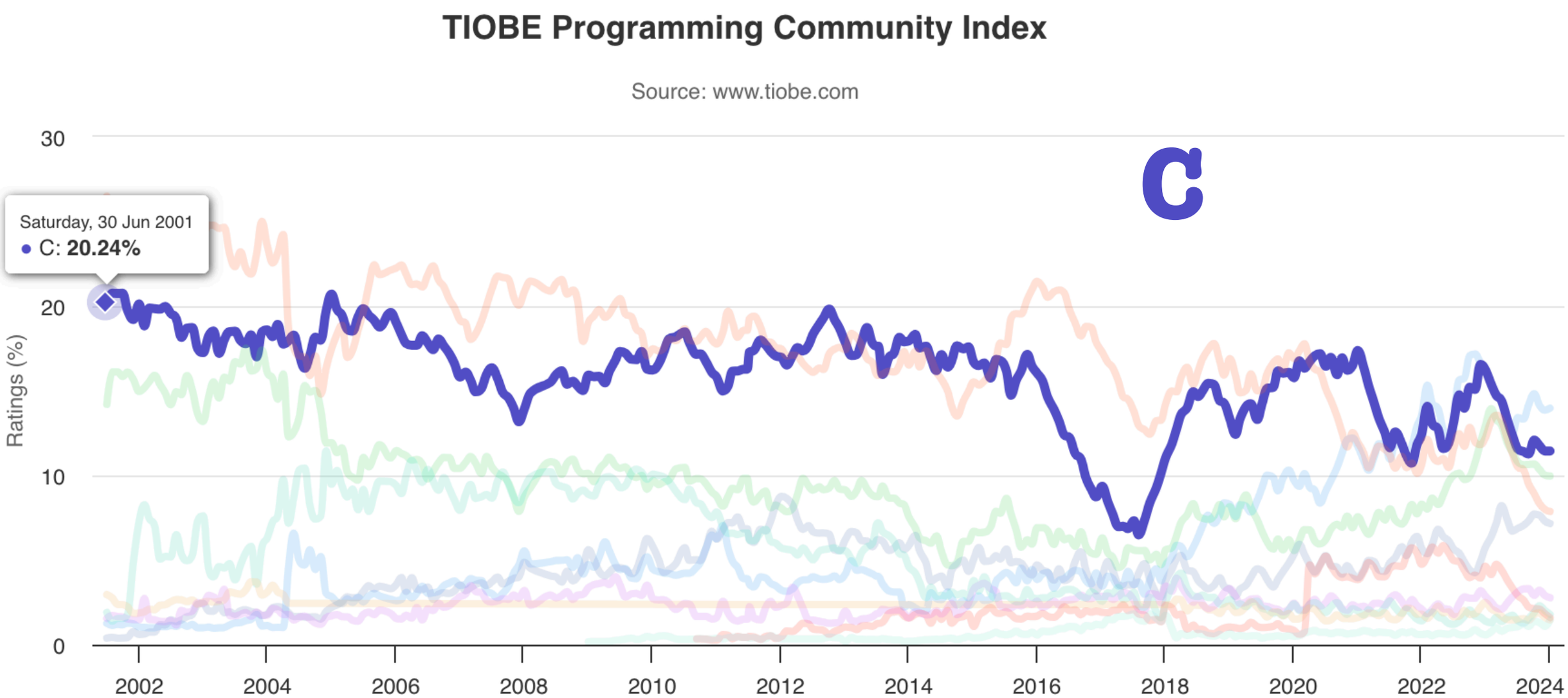
The C Programming Language

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

"C gives the programmer what the programmer wants; few restrictions, few complaints"
— *Herbert Schildt*

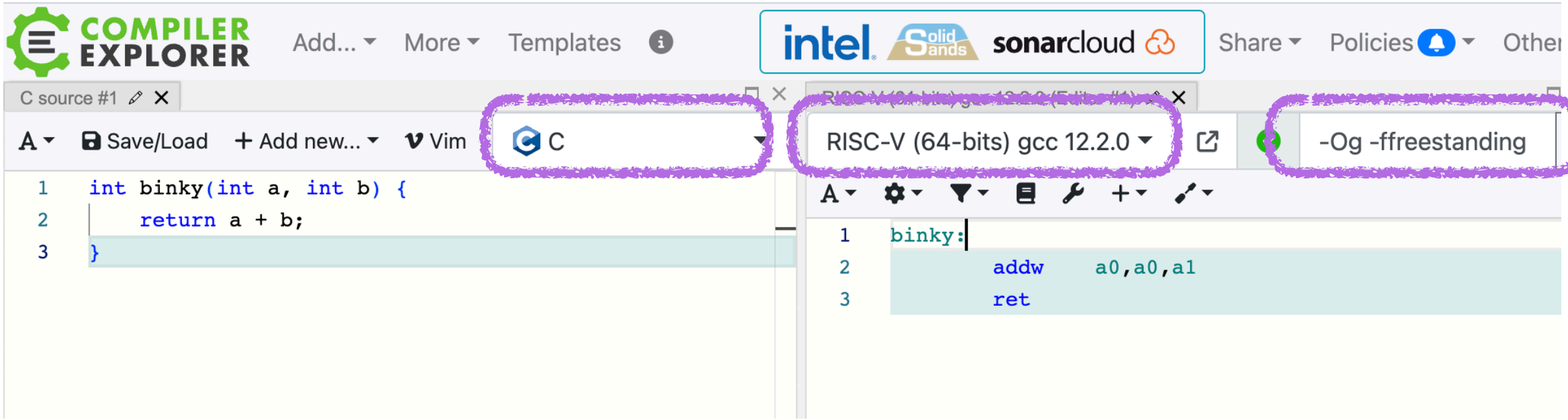
"C: A language that combines all the elegance and power of assembly language with all the readability and maintainability of assembly language"
— *Unknown*

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`
`RISC-V (64 bits) gcc 12`
`-Og -ffreestanding`

Major props to the C compiler

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!

Compile-time vs. runtime

Compile-time: compiler running on your laptop

- read C source text, parse/check semantically valid
- analyze code to understand structure/intent
- generate assembly instructions, assembler to binary

Runtime: program binary running on Pi

- load machine instructions to memory
- fetch/decode/execute

Optimizer does work at CT to streamline count of instructions to be executed at RT

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

One-step build process using **make**

Makefile is text file that describes build steps as "recipes"

Dependencies determine which steps needed to re-build

Rule

```
blink.bin: blink.s
```

Recipe

```
	riscv64-unknown-elf-as blink.s -o blink.o
	riscv64-unknown-elf-objcopy blink.o -O binary blink.bin
```

Target `run:` Dependency `blink.bin`

```
run: blink.bin
	mango-run blink.bin
```

Writing out explicit recipes becomes onerous, so **make** has all kinds of ways to match patterns, define variables, etc.

Make pattern rules

```
NAME = myprogram

ARCH = -march=rv64imac -mabi=lp64
CFLAGS = $(ARCH) -g -Og -Wall -ffreestanding
LDFLAGS =  $(ARCH) -nostdlib

all : $(NAME).bin

%.bin: %.elf
	riscv64-unknown-elf-objcopy $< -O binary $@

%.elf: %.o
	riscv64-unknown-elf-gcc $(LDFLAGS) $< -o $@

%.o: %.c
	riscv64-unknown-elf-gcc $(CFLAGS) -c $< -o $@
```

Bare-metal vs. Hosted

The default build process for C assumes a *hosted* environment.

What does a hosted system have that we don't?

- standard libraries
- standard start-up sequence
- OS services

To build bare-metal, our Makefile disables these defaults
We supply our own replacements where needed

Build settings for bare-metal

Compile freestanding

```
CFLAGS = -ffreestanding
```

Link excludes standard library and start files

```
LDFLAGS = -nostdlib
```

Link with gcc if need software floating point

```
LDLIBS = -lgcc
```

Write our own code for all libs and start files

This puts us in an exclusive club…