TEACHING CPUS TO HIGH SCHOOL STUDENTS

LESSONS, TAKEAWAYS AND HURDLES

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EVERYTHING OPEN 2025

HOW DID I GET HERE

- Linux kernel developer at IBM
- One of the former coordinators of the Canberra Computer Science Enrichment Program
- Former tutor at ANU

CANBERRA COMPUTER SCIENCE ENRICHMENT

- Run by the CoLab
- Aims to encourage high school students to pursue computer science
- Topics varied based on presenters
- Students nominated by their teachers

WHY TEACH THIS?

- I was already teaching it
- I wanted to give students an understanding of how electrical devices can compute

- Go from digital logic to a working implementation of a processor
- As little hidden as possible

STARTING WITH THE ARCHITECTURE

- Turing complete
- Simple enough to implement in four sessions
- Need to be able to write simple but non-trivial programs
- Easy to hand assemble

STARTING WITH THE ARCHITECTURE

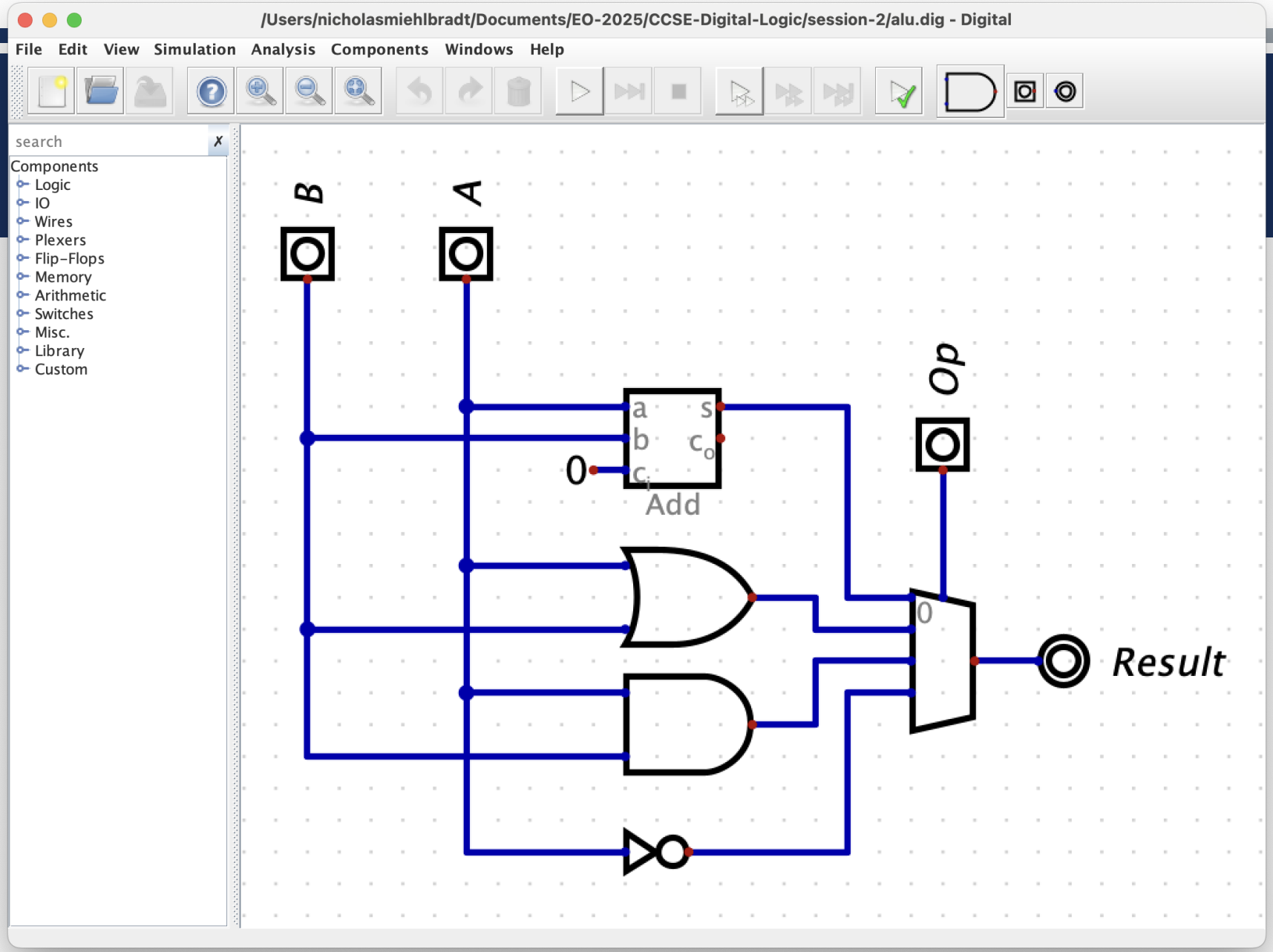
- Existing ISA ✖
- Existing teaching ISA ✖
- Create my own ✔

STARTING WITH THE ARCHITECTURE

- Regular format RISC style
  - Align things to 4 bits → Easy to hand assemble
  - add r3, r1, r2 → 1000 0011 0001 0010 → 0x8312
- Omit key features
  - Call instructions, multiple jump instructions, reading program counter
  - Limitations spark discussion

THE TOOL - DIGITAL

- Digital logic simulator
- Developed by Helmut Neemann
- Open source (of course)


/Users/nicholasmiehlbradt/Documents/EO-2025/CCSE-Digital-Logic/session-2/alu.dig - Digital
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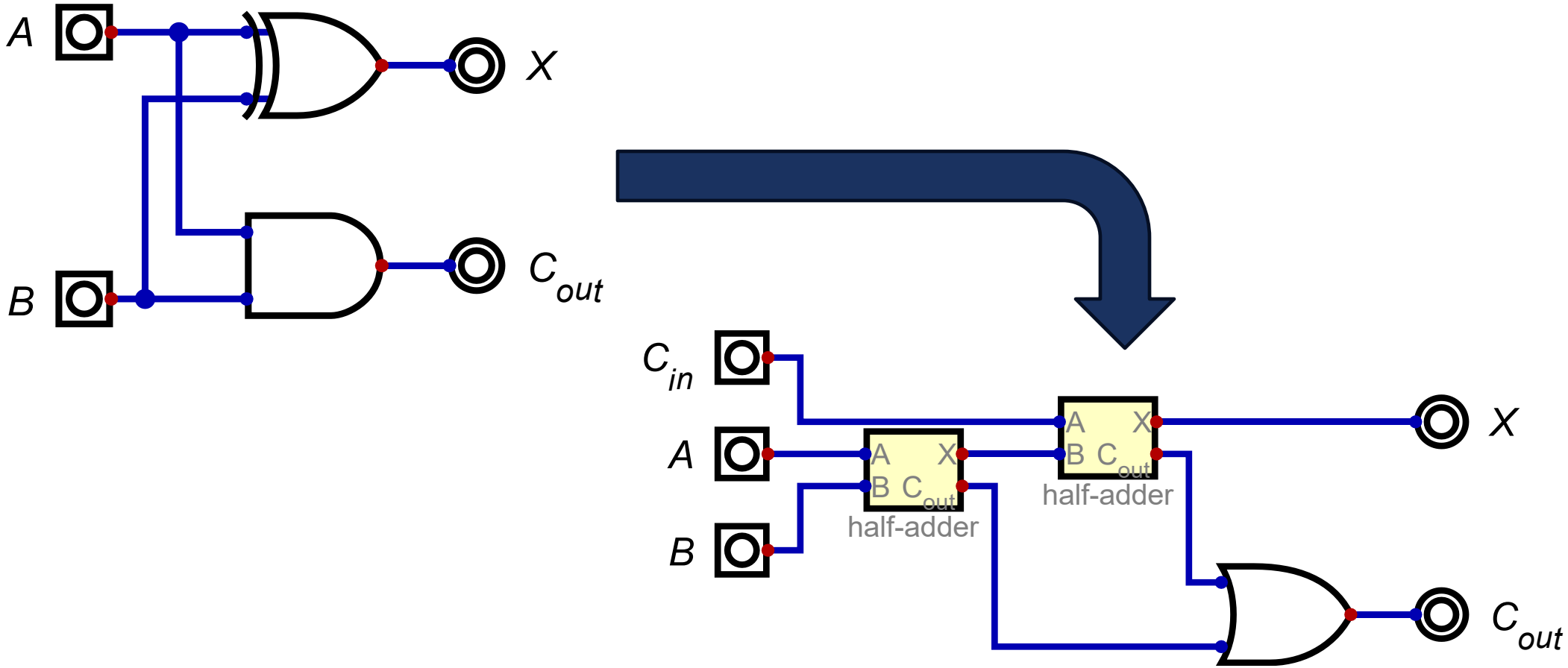
Result

THE TOOL - DIGITAL

- Great playground for introductory digital circuit design
- Good library of built-in components
- Ability to create your own custom sub-circuits

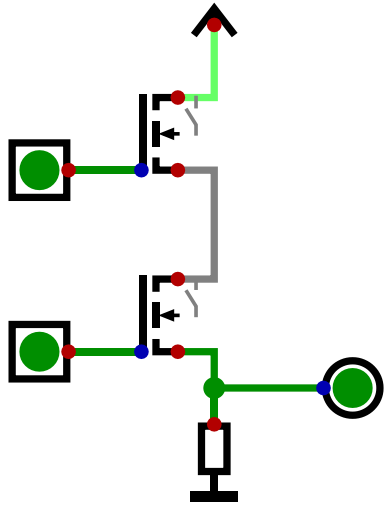
THE TOOL - DIGITAL



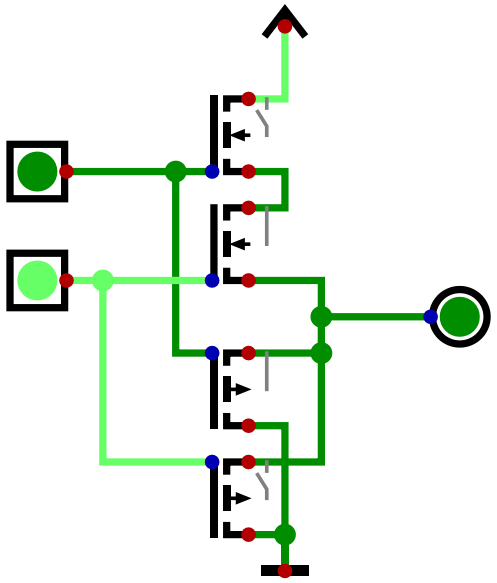
THE TOOL - DIGITAL

AND gates

Resistor-Transistor-Logic



Transistor-Transistor-Logic

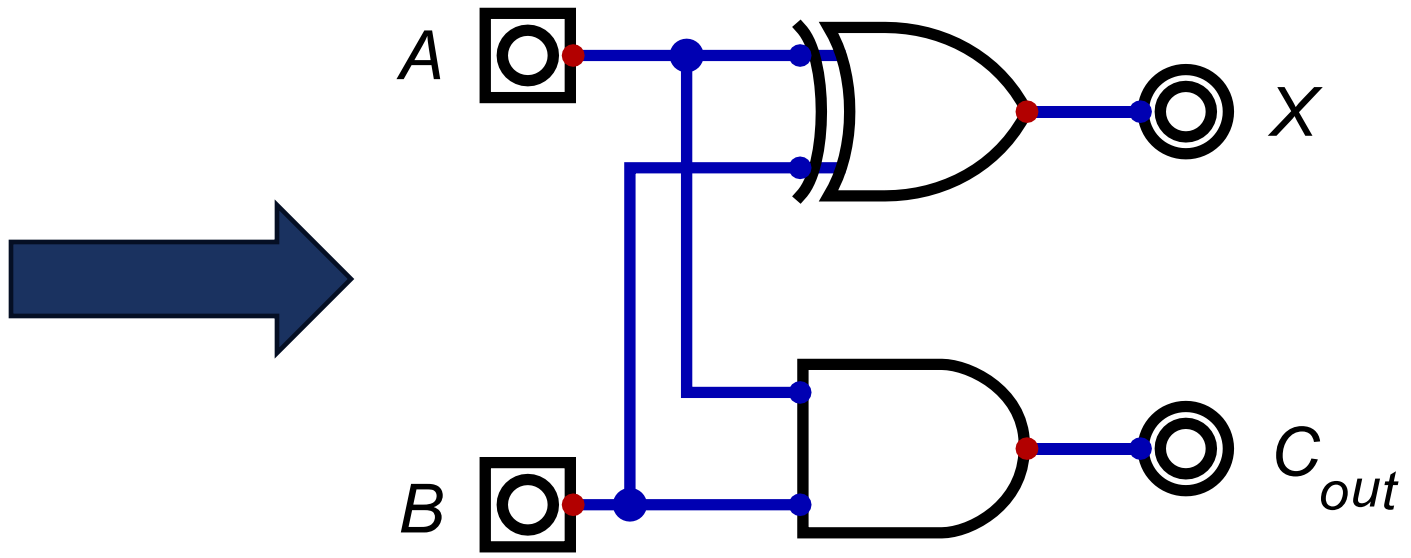


SESSION OUTLINE

- Started with basic combinatorial logic
  - Going from truth tables to a circuit
  - No rigorous approach
- Use encapsulation to identify and reuse generic components

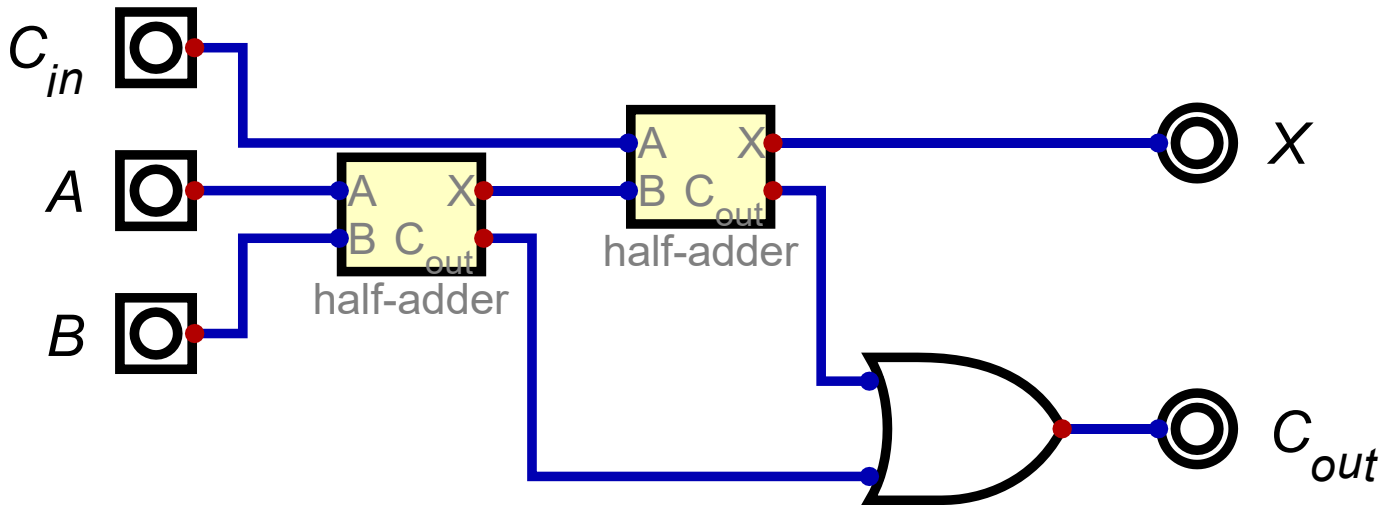
SESSION OUTLINE

A	B	S	C_{out}
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1



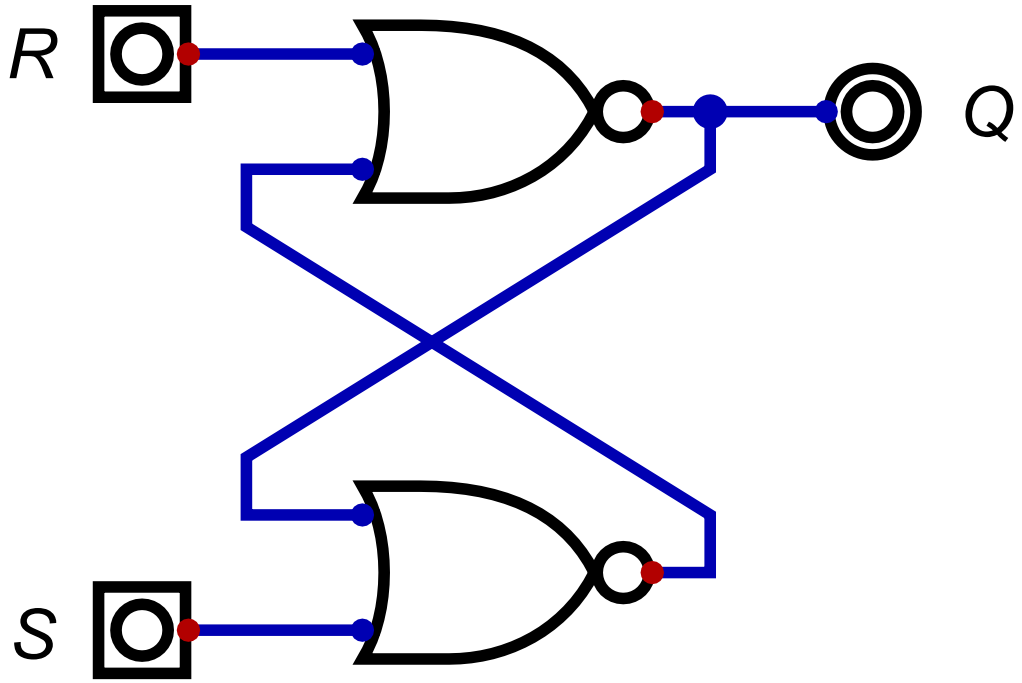
SESSION OUTLINE

A	B	C_{in}	S	C_{out}
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1



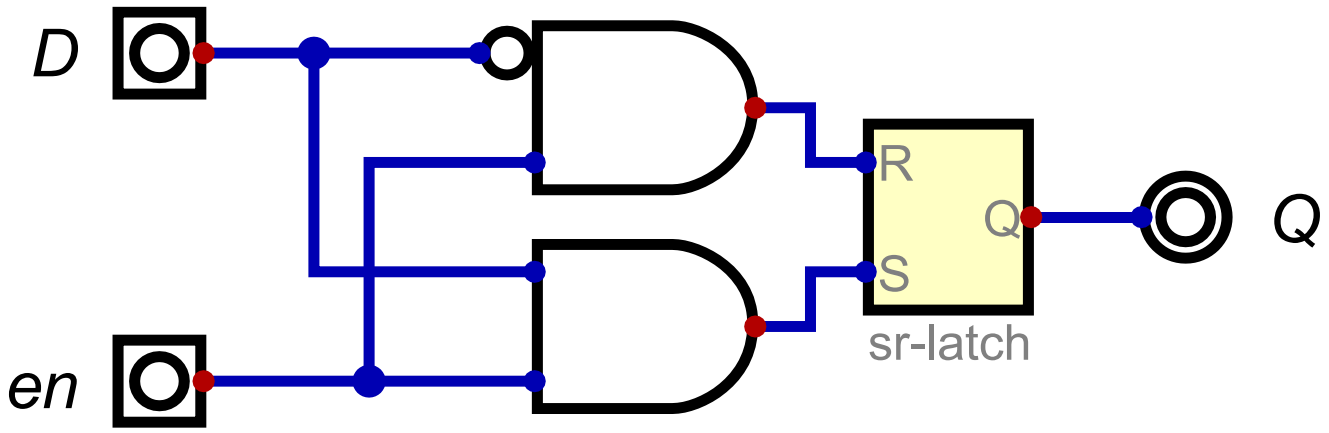
SESSION OUTLINE

- Sequential logic
  - Presented SR latch



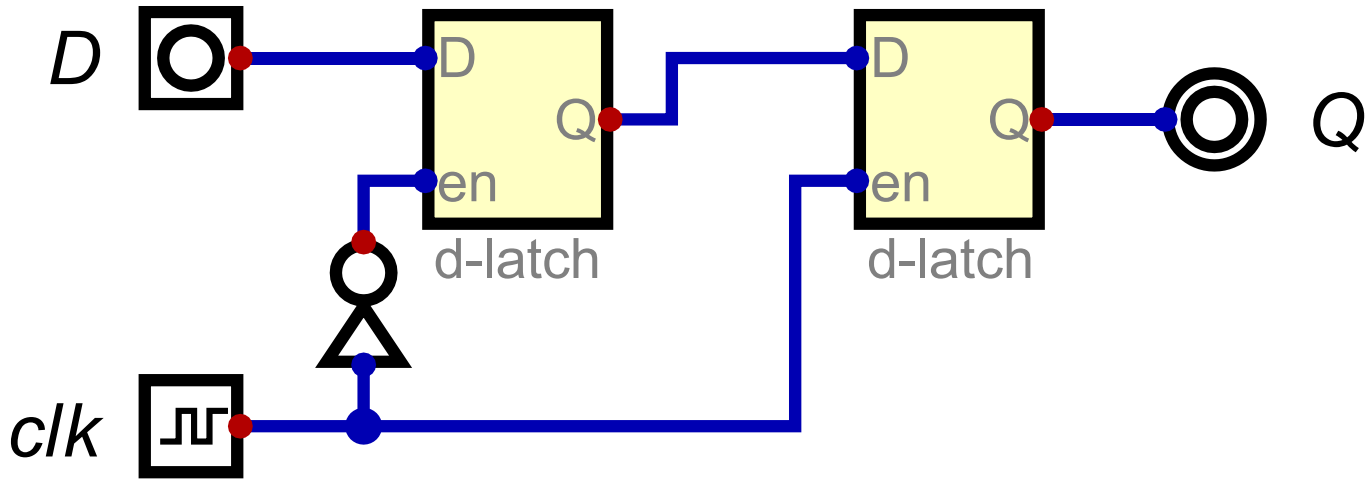
SESSION OUTLINE

- Sequential logic
  - Presented SR latch
  - Used combinatorial logic to upgrade to D latch



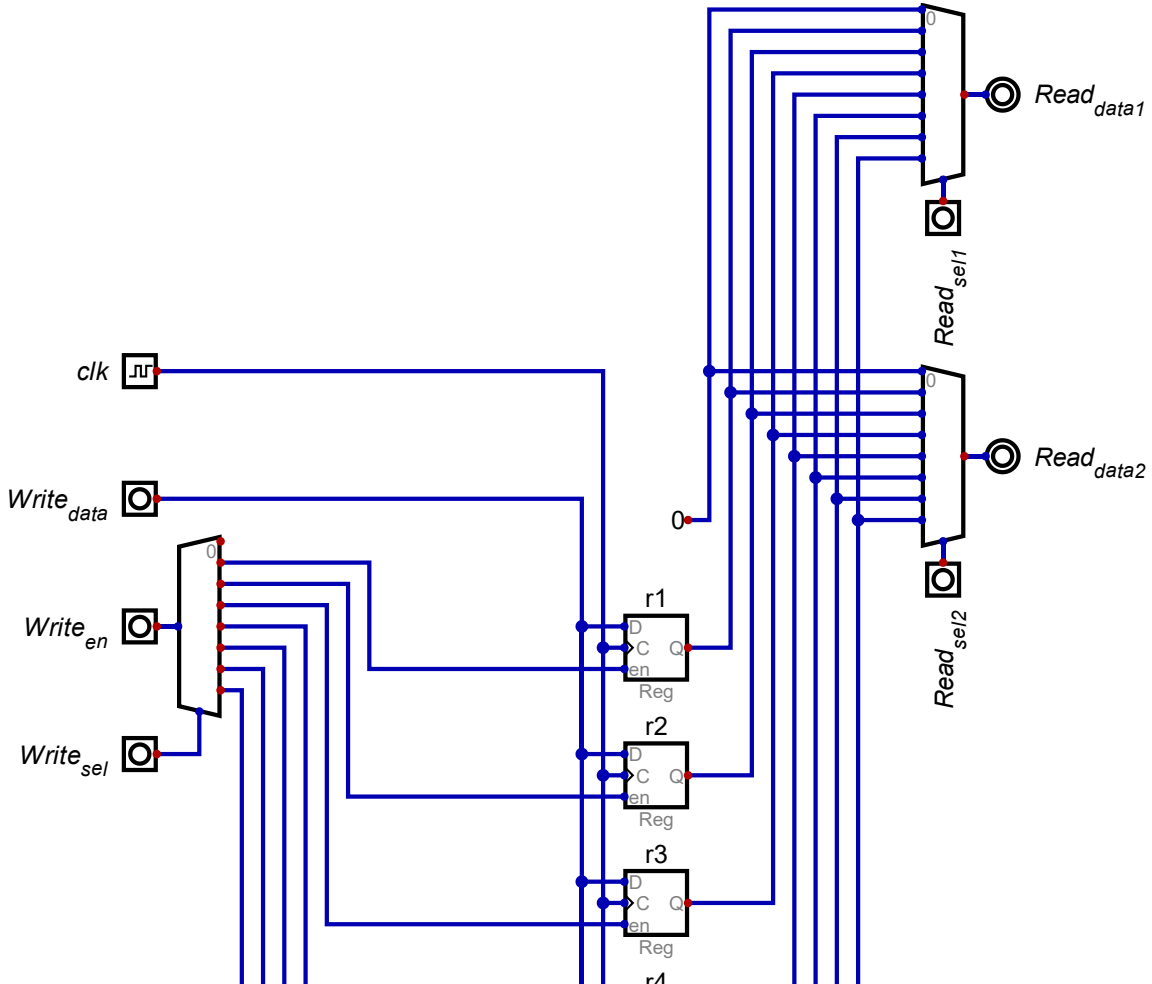
SESSION OUTLINE

- Sequential logic
  - Presented SR latch
  - Used combinatorial logic to upgrade to D latch
  - Continued to D flip flop



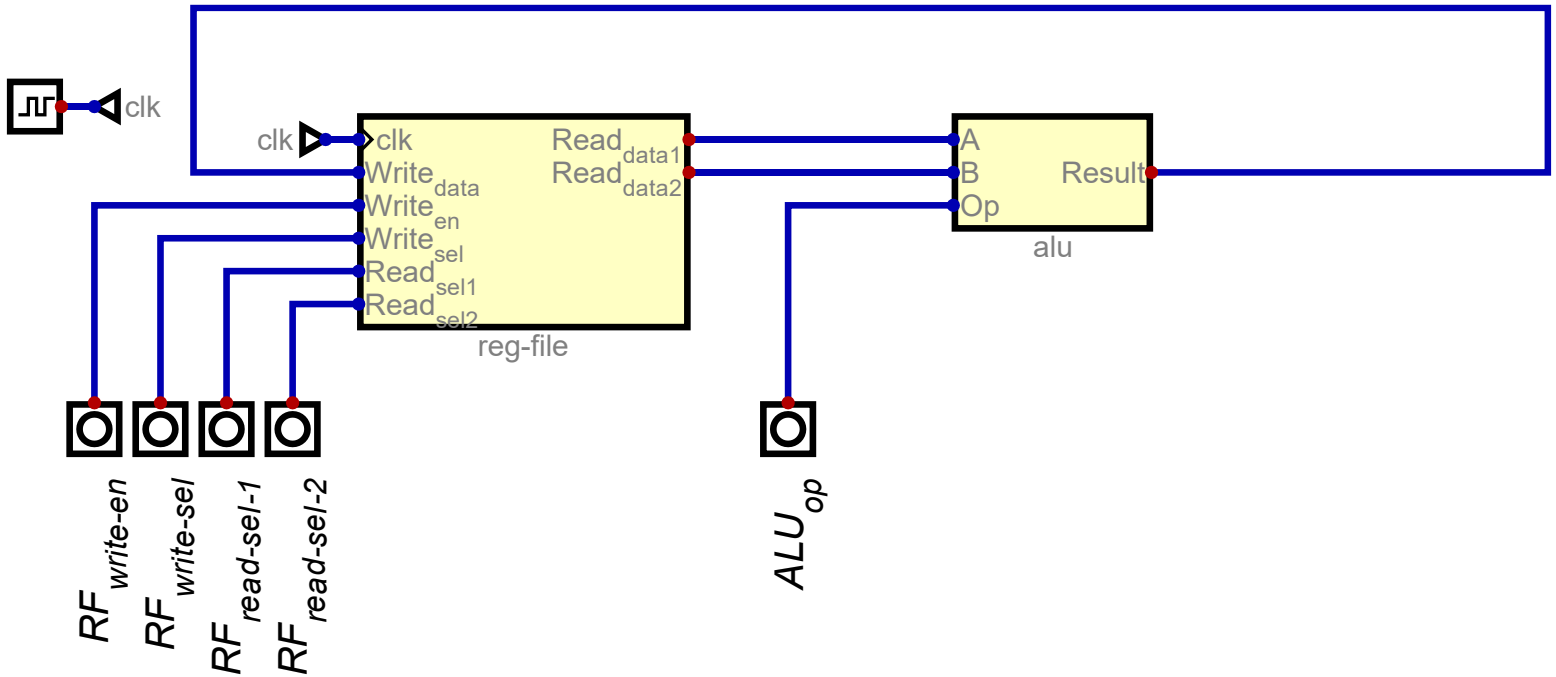
SESSION OUTLINE

- Combined it all to make a register file



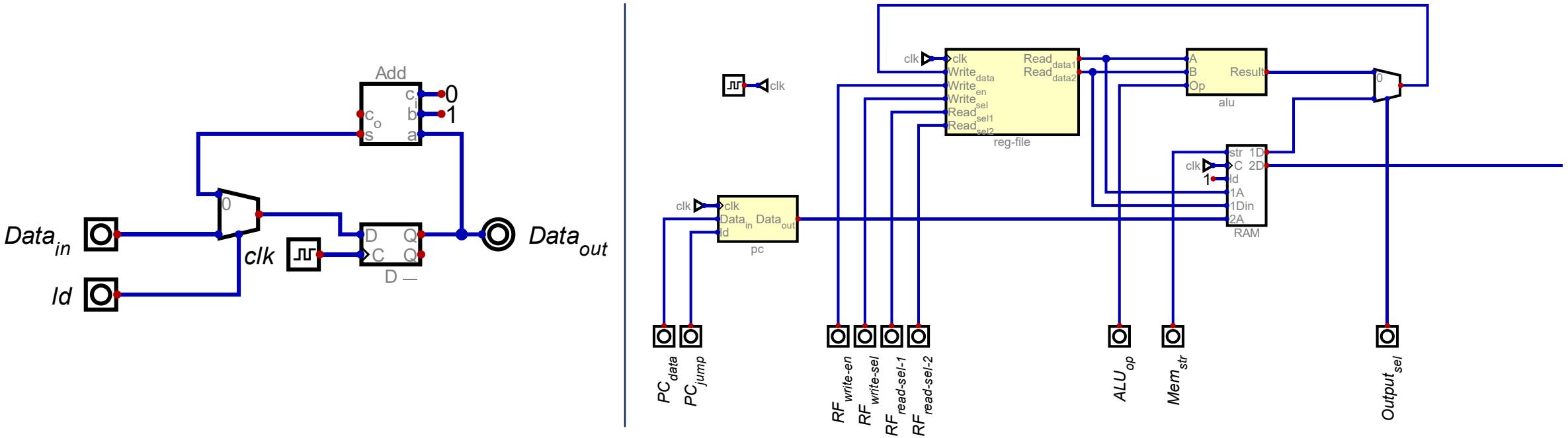
SESSION OUTLINE

- Hooked together the register file and ALU to create a ‘manual’ CPU



SESSION OUTLINE

- Introduced memory as a means of storing a list of instructions
- Program counter gets the next instruction

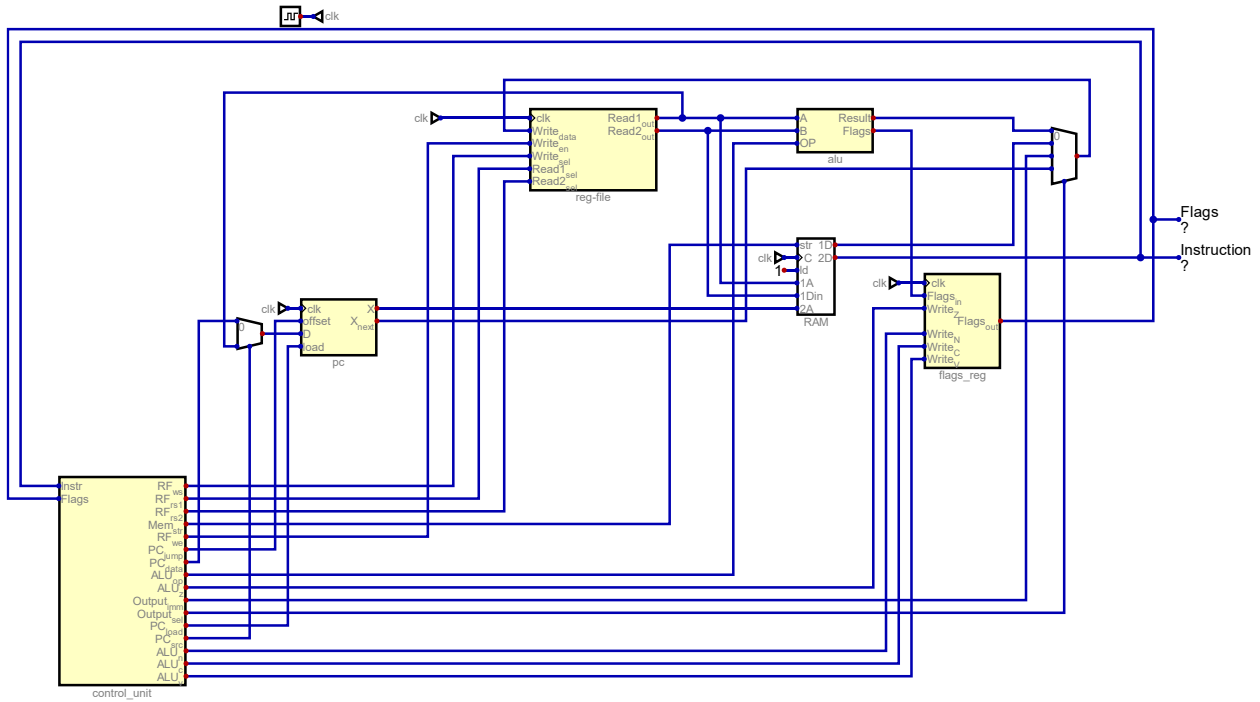


SESSION OUTLINE

- Control Unit → Just combinatorial logic
- Adding in all the other bits
  - Zero flag
  - put instruction
  - Offset program counter
    - Sign Extended Immediate
    - 1000 0001 → 1111 1111 1000 0001

SESSION OUTLINE

- All done! We made a CPU
- Got students to write and hand assemble some programs



ISA REVISITED

- Students quickly became frustrated writing programs – this was good!
  - How can we write functions?
  - How can we do things like greater/less than tests?
  - How do we subtract?
- Struggles prompted interesting discussion

WHAT DIDN'T GO WELL

- Felt too lecture-y at times?
- Session pacing – didn't account for perceived complexity
- Some black boxes – sequential logic, register file, sign extension

THINGS TO IMPROVE

- Spread over more sessions
- Some exercises needed to be more guided, some need more room for exploration
- Give students more time with Digital
- Reorder some topics - bring control unit before memory

WRAP UP

- Sessions were generally well received – several students cited it as their favorite of the year!
- Gave a good launching point for discussions students wanted to have
- Helped me to improve my teaching skills

THANK YOU

LINKS

- Slides: github.com/NMiehlbradt/talks
- Session Materials
- Digital