

# **CS107e**

# **Computer Systems from the Ground Up**

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Maria Fernandez, Blake Jones,  
Liana Keesing, Anna Mistele

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<https://cs107e.github.io/>



**Chris**



**Maria**



**Blake**



**Liana**



**Anna**

# **Who is Chris Gregg?**

- Career:
  - Johns Hopkins University Bachelor's of Science in Electrical and Computer Engineering
  - Seven years active duty, U.S. Navy (14+ years reserves)
  - Harvard University, Master's of Education
  - Seven years teaching high school physics (Brookline, MA and Santa Cruz, CA)
  - University of Virginia, Ph.D. in Computer Engineering
  - Three years teaching computer science at Tufts University
  - Senior Lecturer at Stanford (arrived, Fall 2016)
- Personal website: <https://web.stanford.edu/~cgregg>



# **Learning Goal I**

Understand how computers  
represent data,  
execute programs,  
and control peripherals

# OK

```
int myvar;  
int calc() {...}
```

```
int a = 20;  
unsigned int b = 6;  
if (a < b) {...}
```

```
long counter;  
for (counter = 0;  
     counter < 10000000000;  
     counter++) {}
```

# Not OK

```
int calc() {  
    int myvar;  
    ...  
}
```

```
int a = -20;  
unsigned int b = 6;  
if (a < b) {...}
```

```
volatile long counter;  
for (counter = 0;  
     counter < 10000000000;  
     counter++) {}
```

# Why?

**OK**

```
int myvar;  
int calc() {...}
```

```
int a = 20;  
unsigned int b = 6;  
if (a < b) {...}
```

```
long counter;  
for (counter = 0;  
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```

**Not OK**

```
int calc() {  
    int myvar;  
    ...  
}
```

```
int a = -20;  
unsigned int b = 6;  
if (a < b) {...}
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volatile long counter;  
for (counter = 0;  
     counter < 10000000000;  
     counter++) {}
```

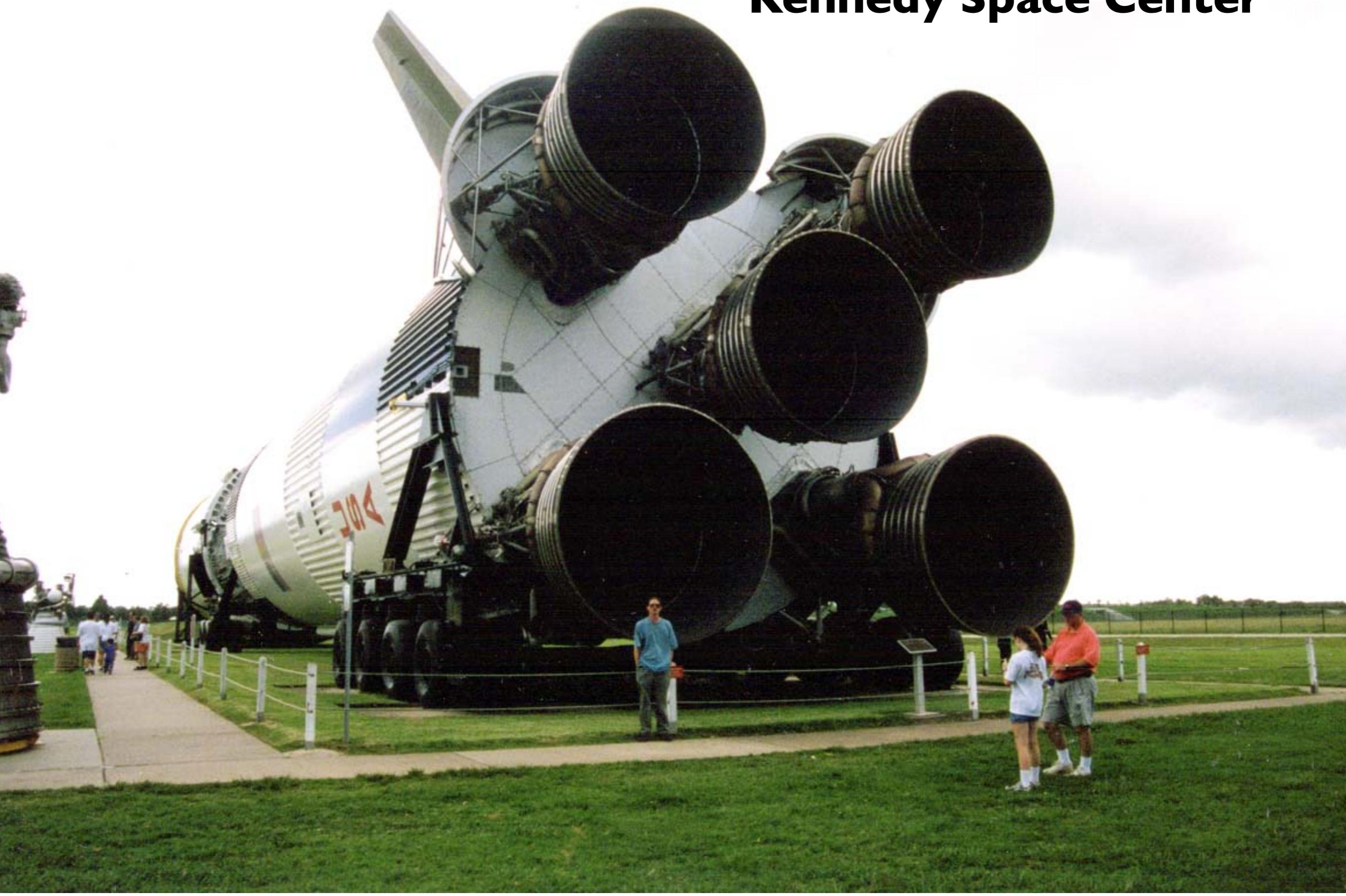
```
int main( ) {  
    ...  
}
```

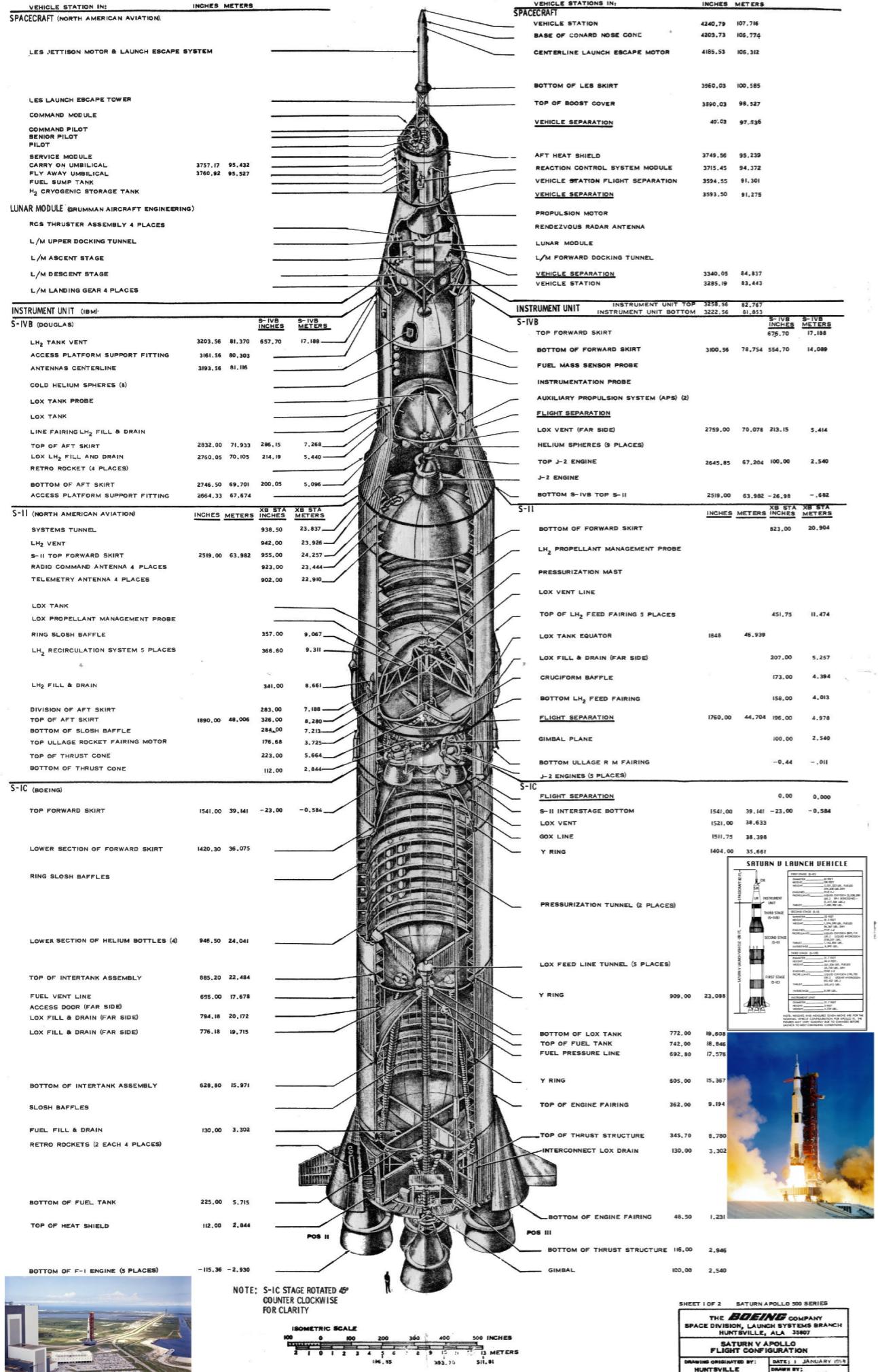
How does your program start  
at the first instruction of  
main()?  
Or does it really?

**First steps are often the hardest**

**That's why we're here!**

# **Saturn V Kennedy Space Center**





# Command Module 64,000 lbs

# Saturn V 6,200,000 lbs

# Payload 1.5% of total weight

# Falcon 9





**Engineer for Excellence!**

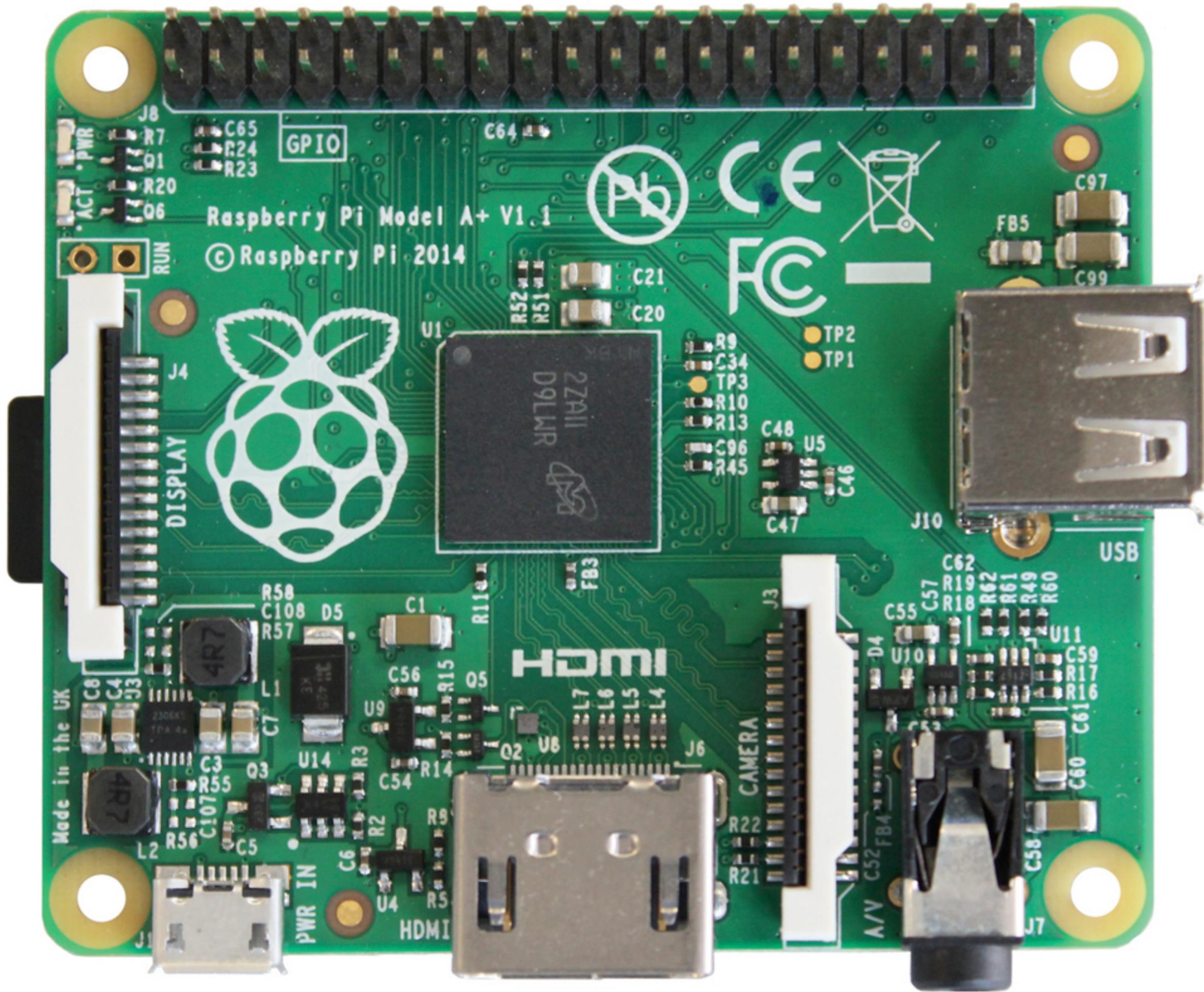
**Perseverance!**

# **Bare Metal on the Raspberry Pi**

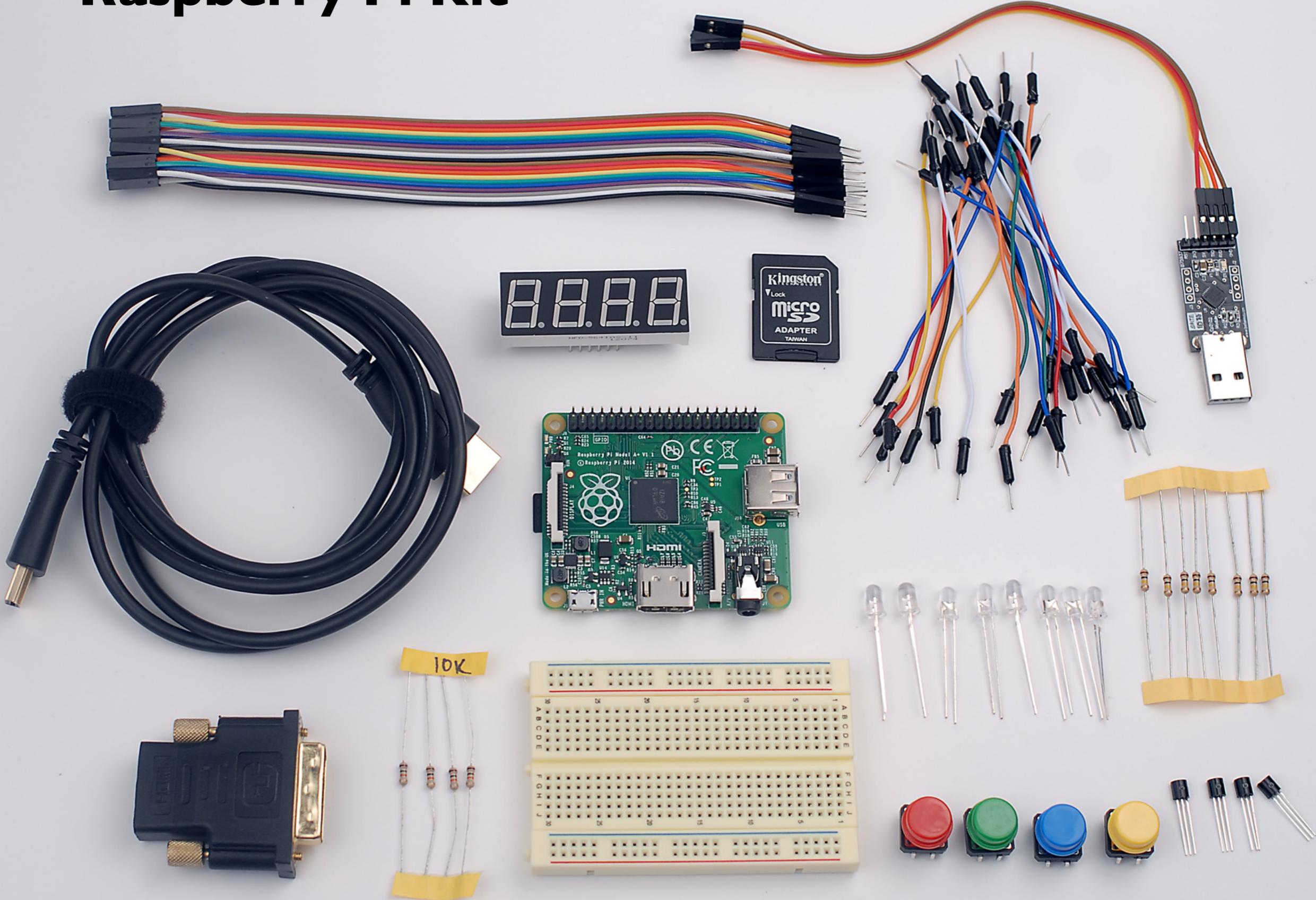
**Definition:** Bare metal programming involves no operating system (programmer constructs libraries)

Bare metal programs boot and startup on their own, and directly control peripherals

*You'll understand every line of code in the system.*



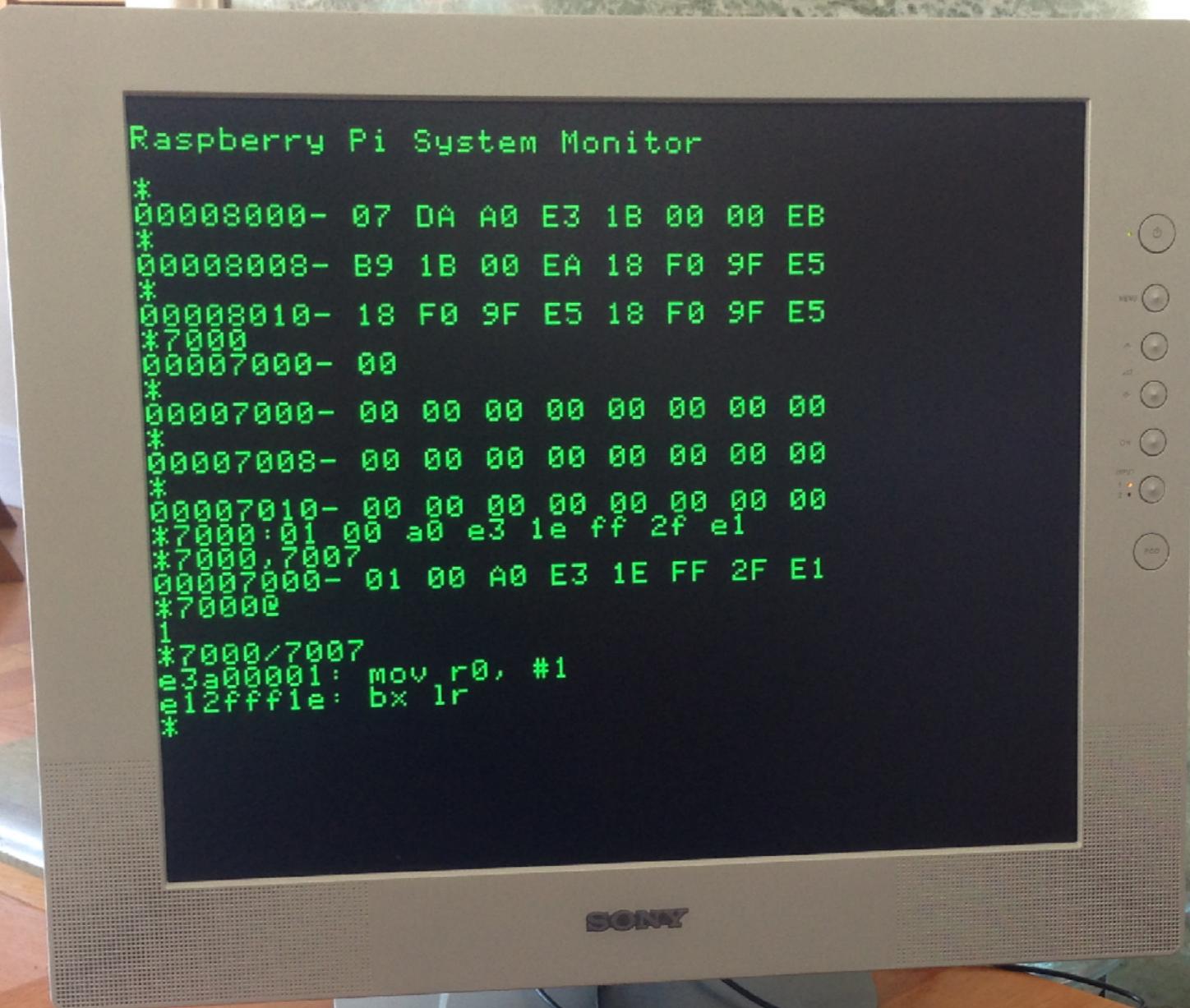
# Raspberry Pi Kit



# **Raspberry Pi Shell**

Raspberry Pi System Monitor

```
*00008000- 07 DA A0 E3 1B 00 00 EB
*00008008- B9 1B 00 EA 18 F0 9F E5
*00008010- 18 F0 9F E5 18 F0 9F E5
*7000
00007000- 00
*00007000- 00 00 00 00 00 00 00 00
*00007008- 00 00 00 00 00 00 00 00
*00007010- 00 00 00 00 00 00 00 00
*7000:01 00 a0 e3 1e ff 2f e1
*7000,7007
00007000- 01 00 A0 E3 1E FF 2F E1
*7000@
1
*7000/7007
e3a00001: mov r0, #1
e12fffffe: bx lr
*
```



**Almost every instruction  
will be code you've written!**

# **Learning Goal 2**

**Master your tools  
Learn their value**

# Software Tools

UNIX command line: bash, cd, ls, ...

Programming languages: C, ...

gcc

as

ld

binutils: nm, objcopy, objdump, ...

make

git and github.com

documentation: markdown

# Different Tools for Different Jobs



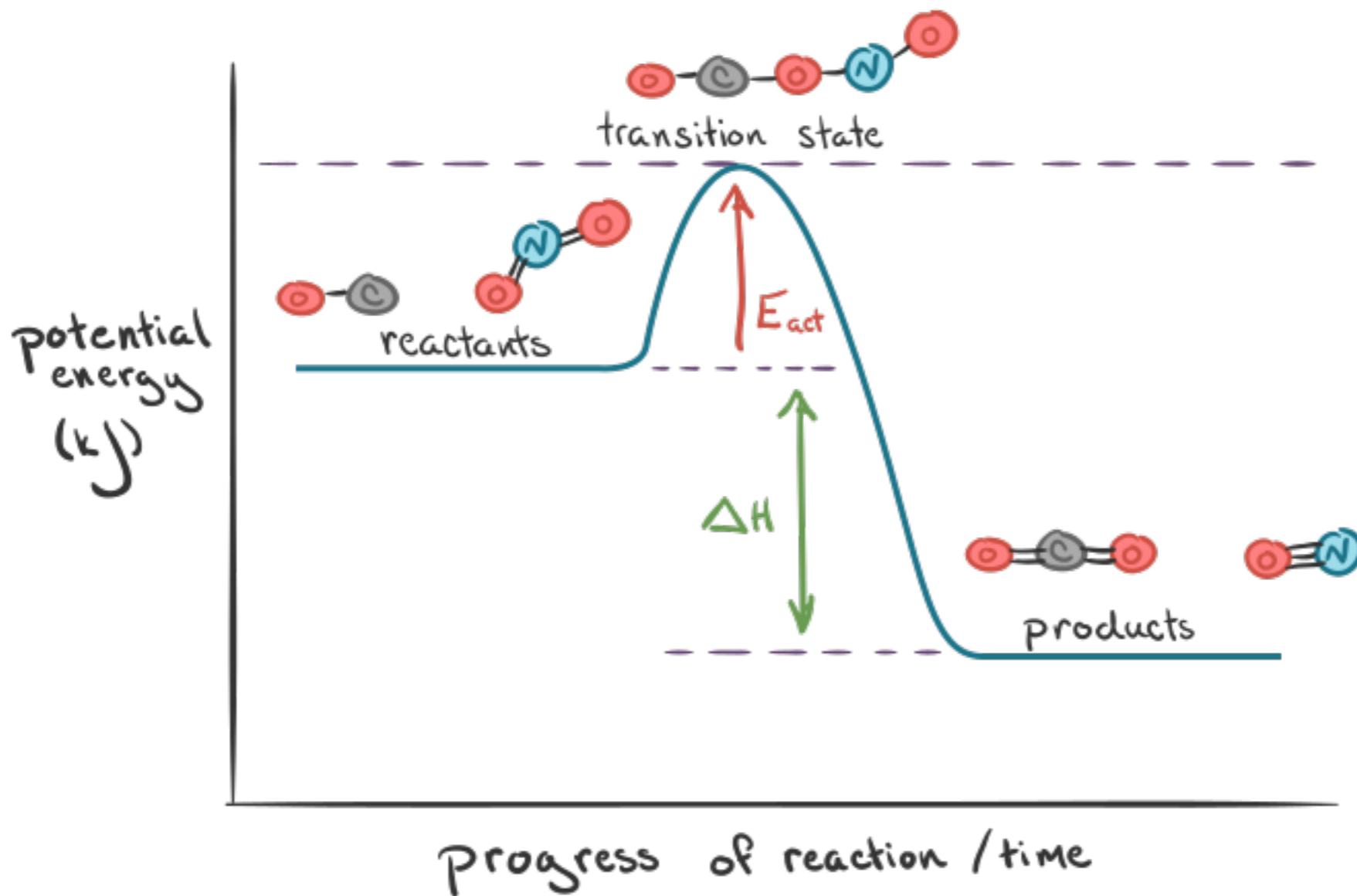
<http://dans-woodshop.blogspot.com/>

# Organized Development Environment



<http://amhistory.si.edu/juliachild/>

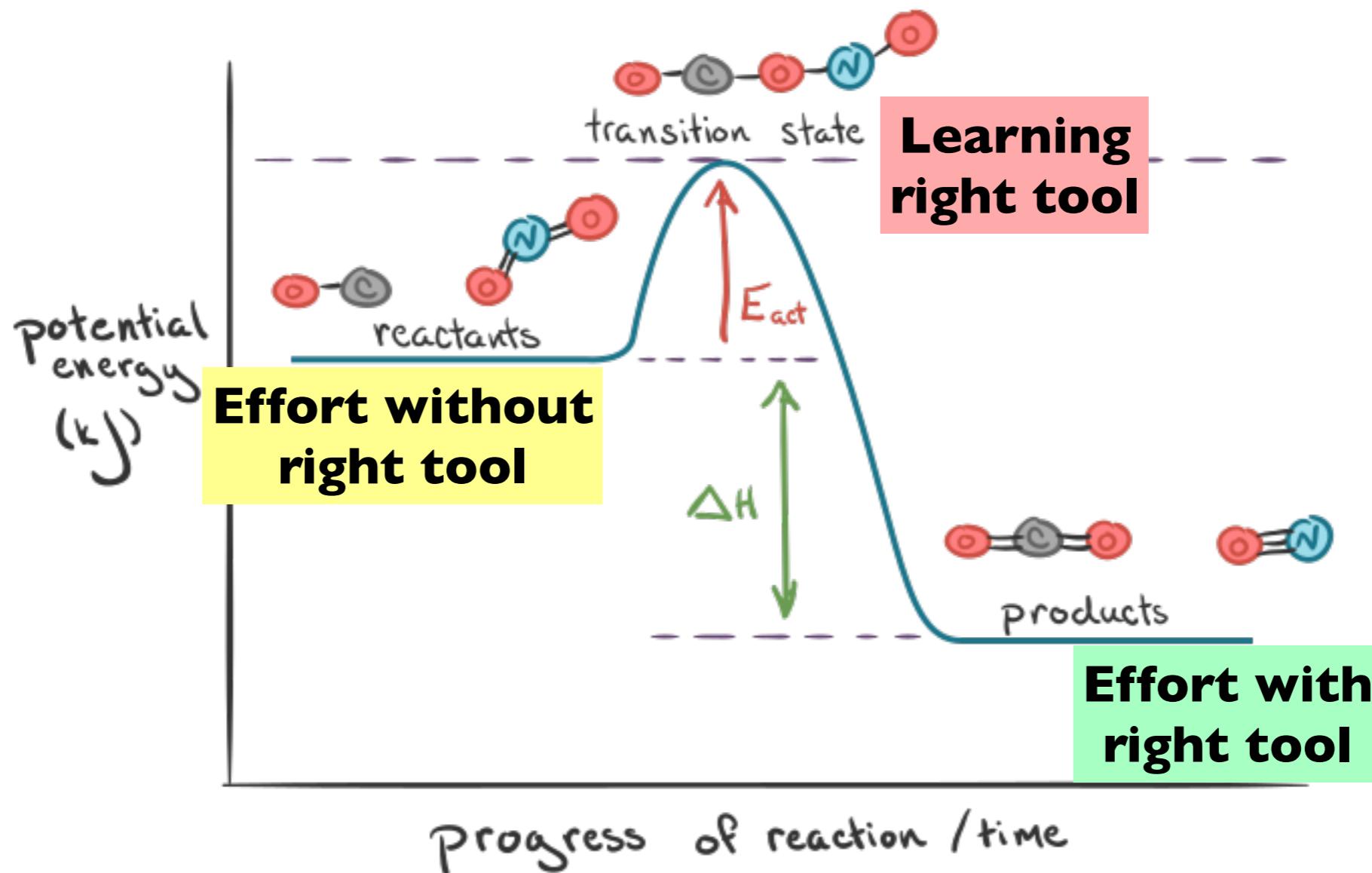
# Don't Avoid Activation Energy



**Figure from Khan Academy**

<https://www.khanacademy.org/test-prep/mcat/chemical-processes/thermochemistry/a/endothermic-vs-exothermic-reactions>

# Don't Avoid Activation Energy



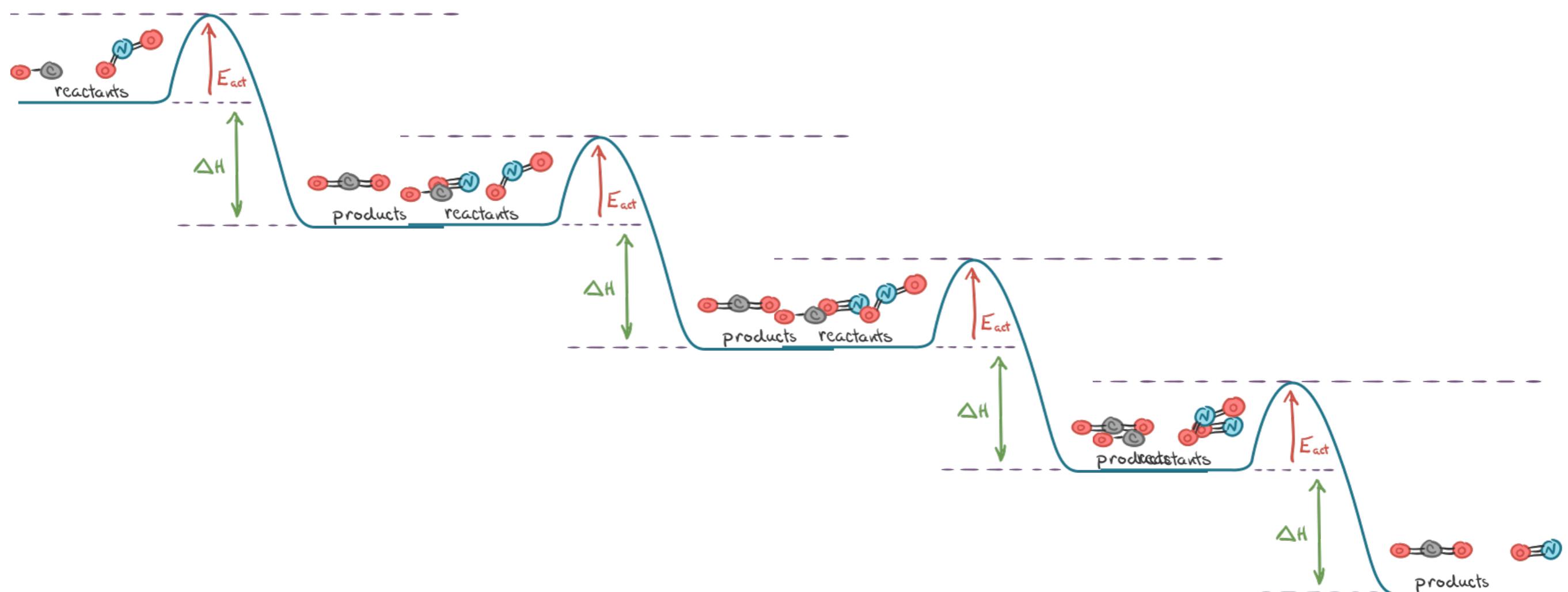
**Figure from Khan Academy**

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A close-up photograph showing a person's hands working on a piece of wood. The person is using a chisel to shave off thin layers of wood, creating a pile of shavings on the workbench. The workbench is made of light-colored wood and shows signs of use. In the background, there are some tools and a bottle of water. The overall scene suggests a workshop or a woodworking environment.

Practice, Practice, Practice



It never ends... 1000x improvements possible!

**Figure from Khan Academy**

<https://www.khanacademy.org/test-prep/mcat/chemical-processes/thermochemistry/a/endothermic-vs-exothermic-reactions>

# Debugging and Troubleshooting



# **Administration**

# **Weekly Cadence**

Each week has a focus topic

Pair of coordinated lectures on Fri and Mon

Mandatory lab on Wednesdays (either  
10:30am-12:30pm, or 1:30pm-3:30pm)

Assignment handed out Wed evening (after lab),  
YEAH hours on Thu, assignment due following Tue at  
6 pm.

# Laboratories

Attendance is **mandatory**

Do exercises and complete check-list

Leave lab ready for assignment: walks you through tricky bit (hardware/software interface) to get you started

Philosophy: lots-of-help, hands-on, collaborative

We will organize your lab into small (2-3 person) breakout groups so you can do the lab with mute off and chat/collaborate. Initially groups are randomly assigned, later in the quarter we will let you choose partners if you want to.

# Assignments

7 assignments

- Build on each other

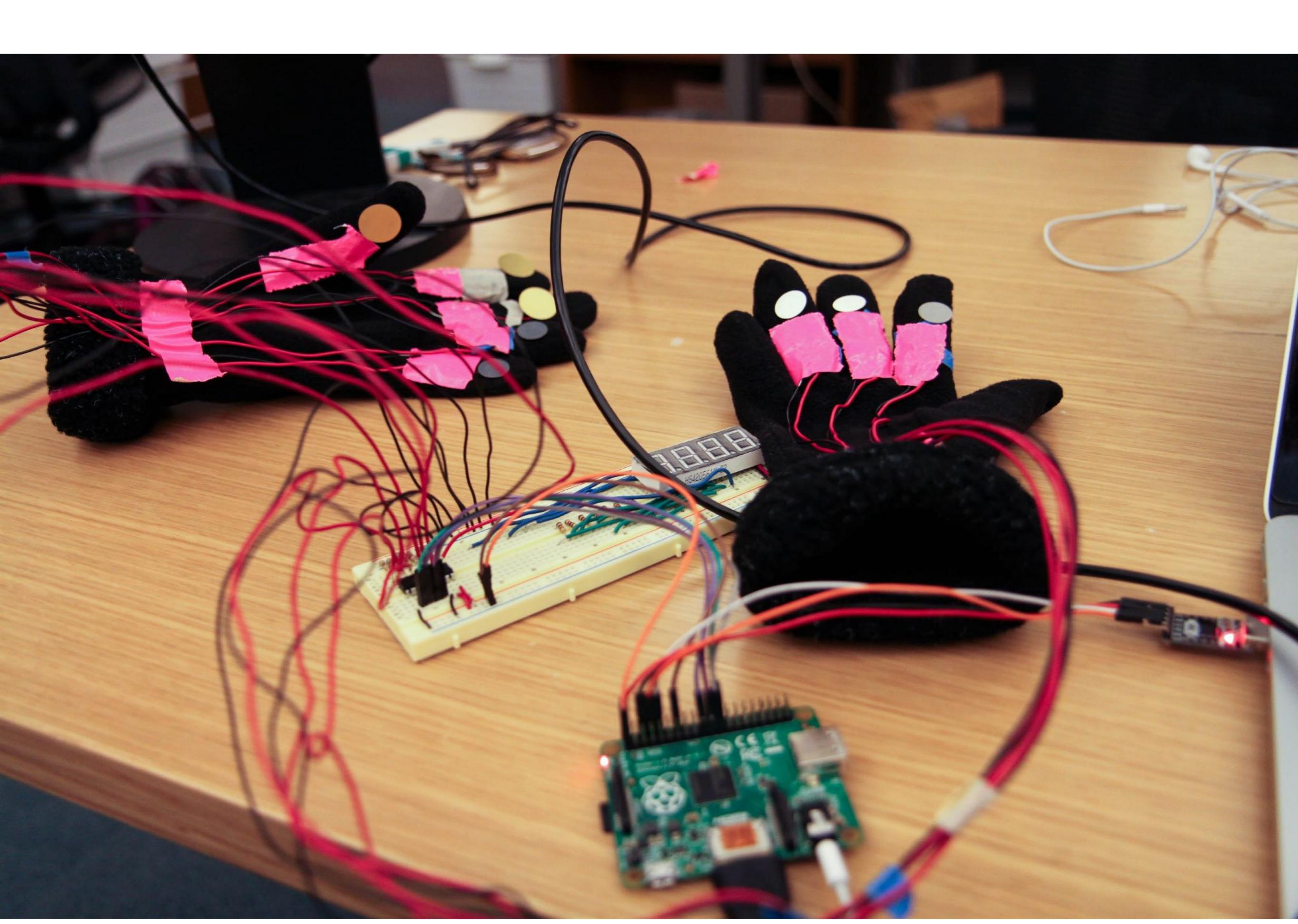
Two parts for each assignment

- Basic (required, tight spec, guided steps)
- Extension (optional, opportunity for your exploration/creativity)

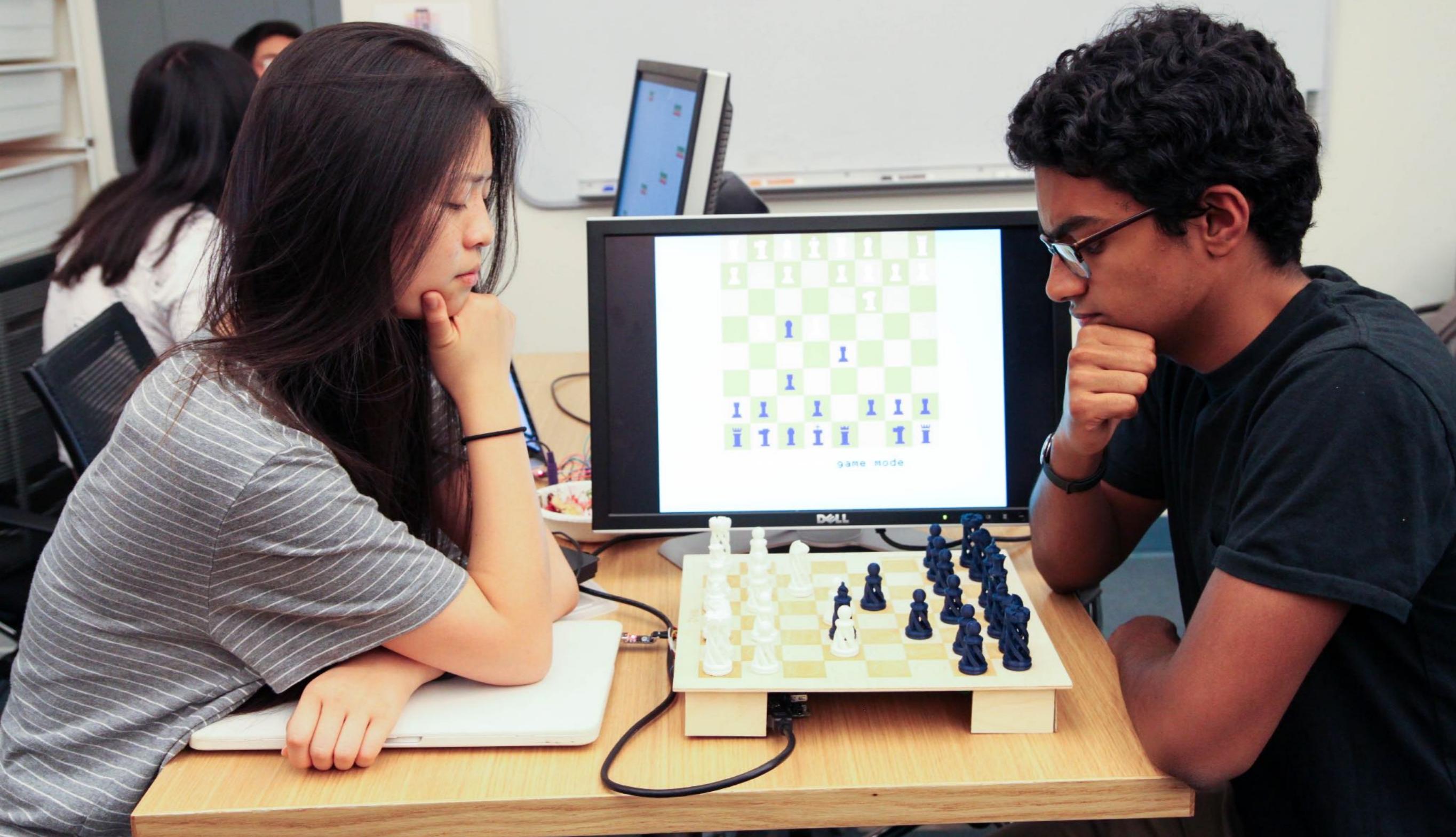
Final project demonstrations on Thursday, December 9

Scaled back due to lack of exam period, physical lab resources

- Encourage you to play with some hardware (e.g. sensors)

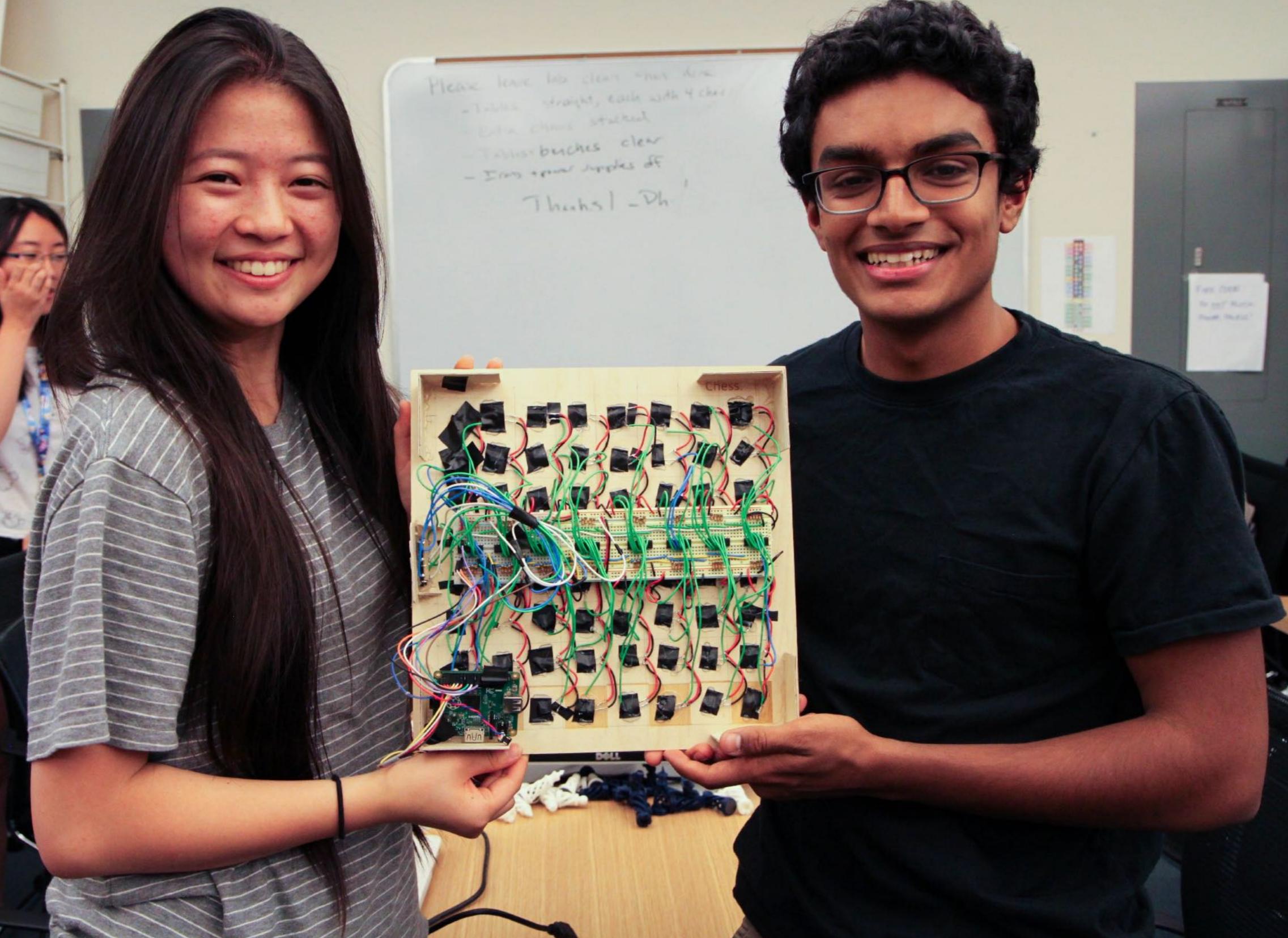
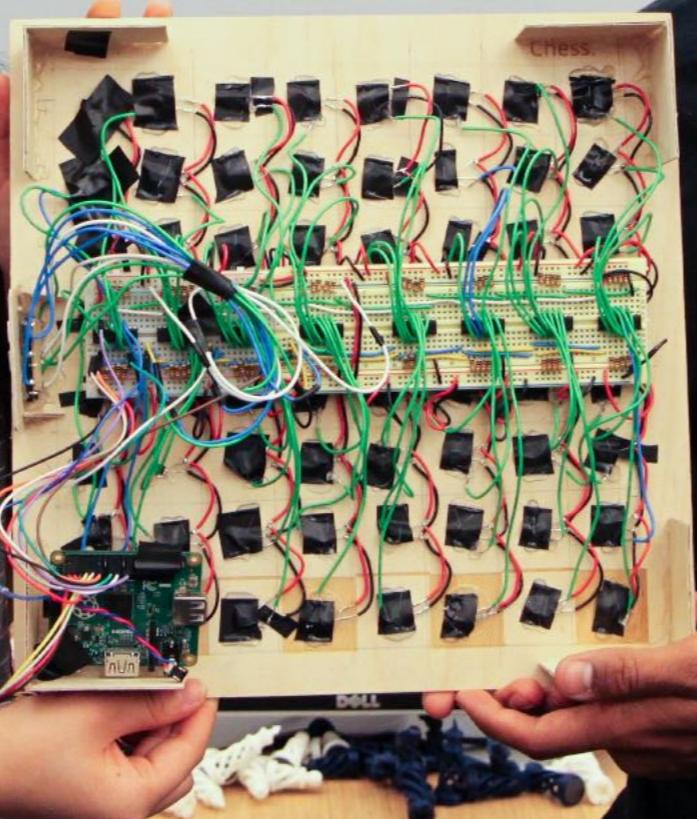


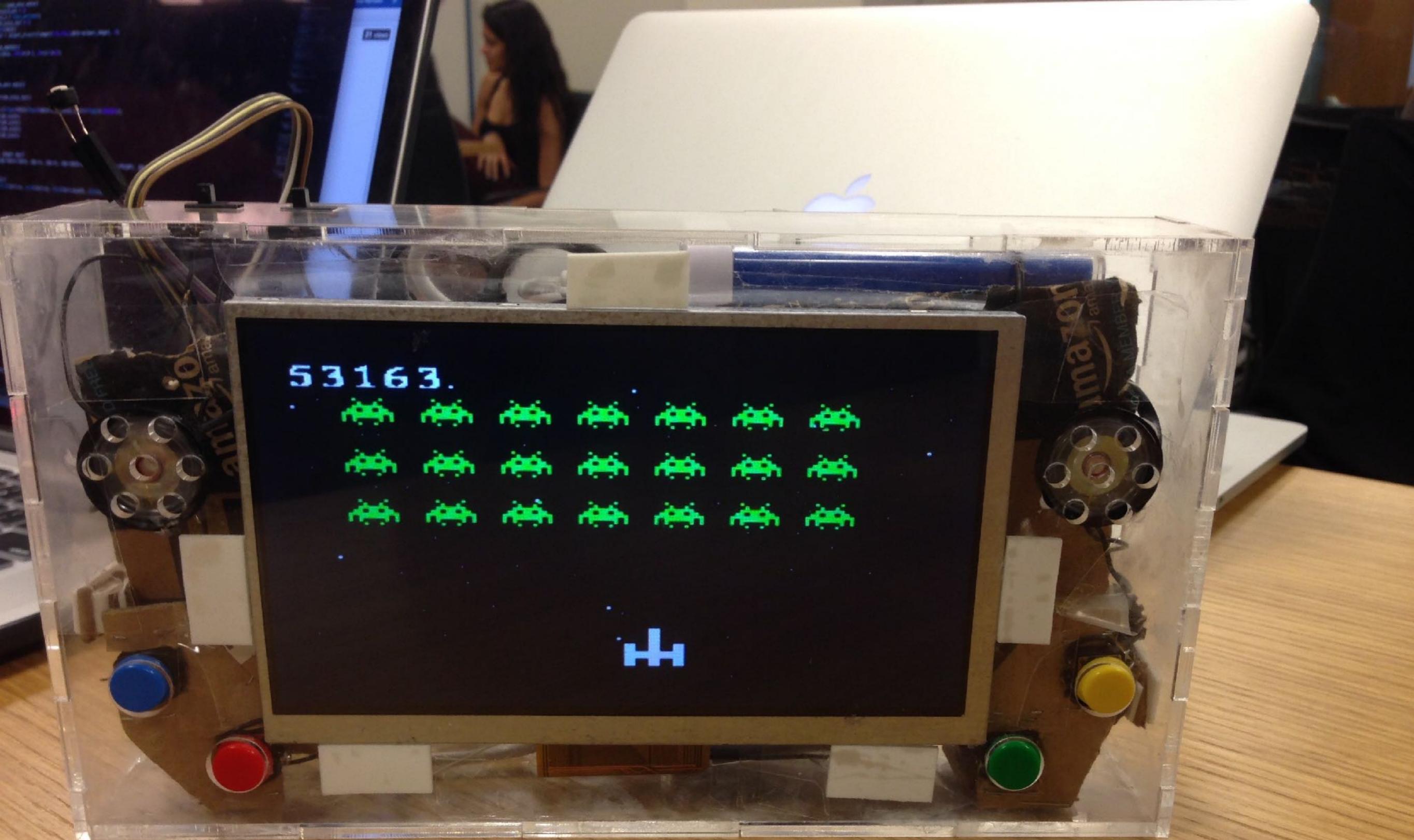




Please leave tea clean - no tea  
- Tables straight, each with 4 chairs  
- Extra chairs stacked  
- Paper bushes clear  
- Dirs equal widths of

Thanks! - Dh





# **First Week**

# Today

Fill out course application if you haven't already:

<https://web.stanford.edu/class/cs107e/>

We will decide on enrollment (capped at 40) by Tuesday, September 27th (tomorrow). You will receive an email about enrollment by then.

# Assignment 0

- Join forum [https://edstem.org/us/courses/29339/  
discussion/](https://edstem.org/us/courses/29339/discussion/)
- Read and understand our guides on basic topics:  
electricity, numbers, and UNIX
- Create github account and send us your GitHub id
- Install/setup your development environment
- Fill out lab time poll (will be posted on EdStem)

# Class Meeting Protocol I

Class attendance is expected. The slides are not intended to be a replacement for being in class. There are a lot of conceptually difficult topics, and having you there to ask us to stop and clarify is important.

In our experience teaching this class, students who stop regularly attending lectures struggle greatly and spend the last two weeks trying to earn more points back by fixing bugs and resubmitting.

# **Class Meeting Protocol 2**

I will likely screencast the lectures, and they will *only* be available on a case-by-case basis for students who have a legitimate reason for missing class. Legitimate reasons include:

- COVID isolation
- Away sporting / academic event

Illegitimate reasons include:

- Don't want to attend lecture / too tired
- Leaving for returning from a weekend trip that isn't sports/academic

# **Dealing with COVID**

Stanford requires masks are worn inside at all times unless you are speaking in a class. We will be masked in lab.

- Please wear them well and carefully! Even if you are alone in lab.

If you feel sick or have been exposed, get tested.

# What is a computer?

You've taking CSI06A / 106B, and possibly some hardware-esque classes (e.g., ENGR 40M, EE 101A/B, EE108, etc.), but you probably haven't taken a course where you discussed what a computer really is.

Almost all computers you use today (including the Raspberry Pi, your phone, and your laptop/desktop, but not FPGAs) are built using the *von Neumann architecture*, which was laid out by John von Neumann et al. in a 1945 paper on the EDVAC computer.

# The von Neumann architecture

The original architecture designed by von Newmann has the following features (see Wikipedia)

- A processing unit that contains an arithmetic logic unit and processor registers
- A control unit that contains an instruction register and program counter
- Memory that stores data and instructions
- External mass storage
- Input and output mechanisms

A critical part is the idea that instructions and data are both kept in the same memory

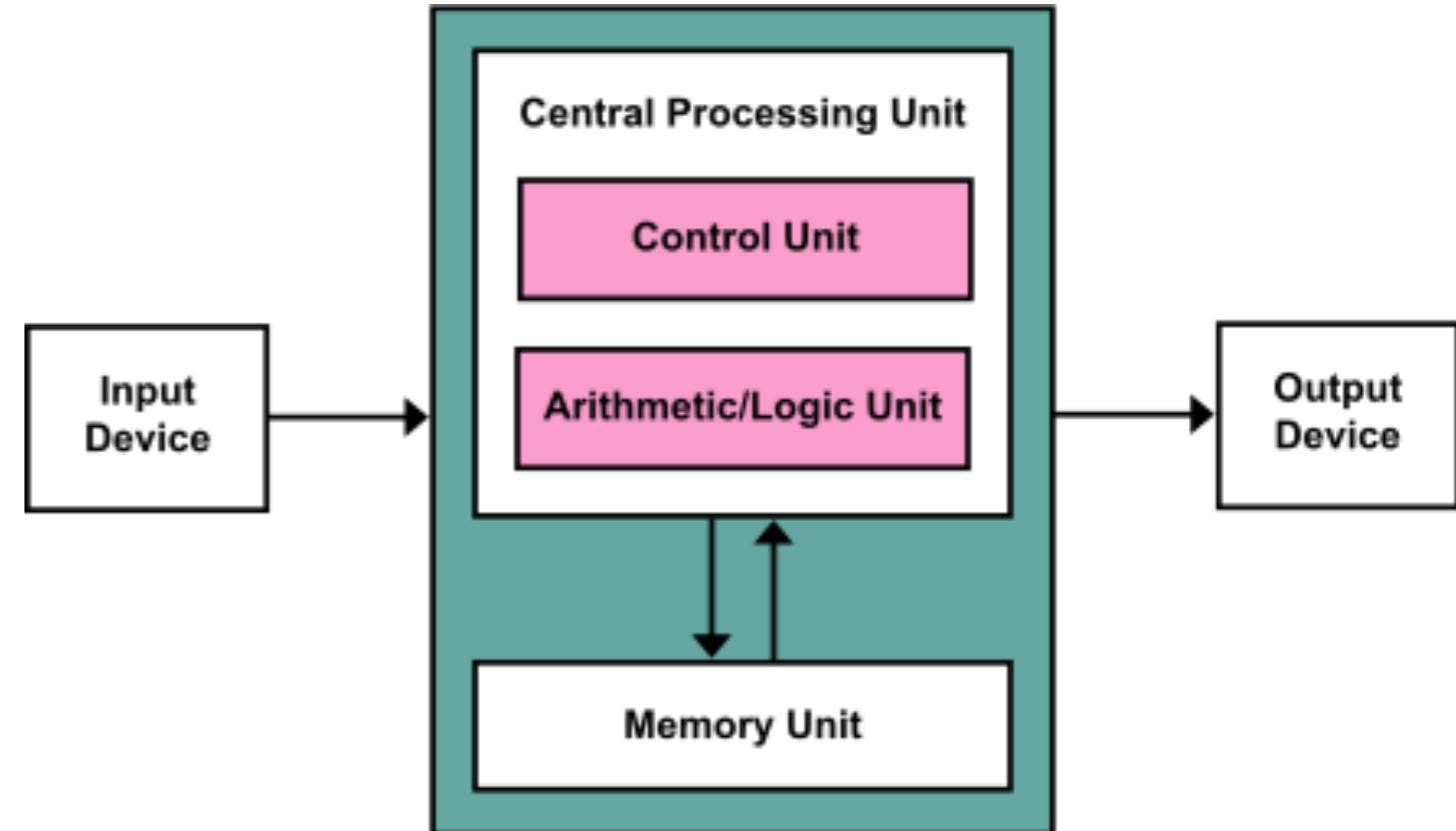
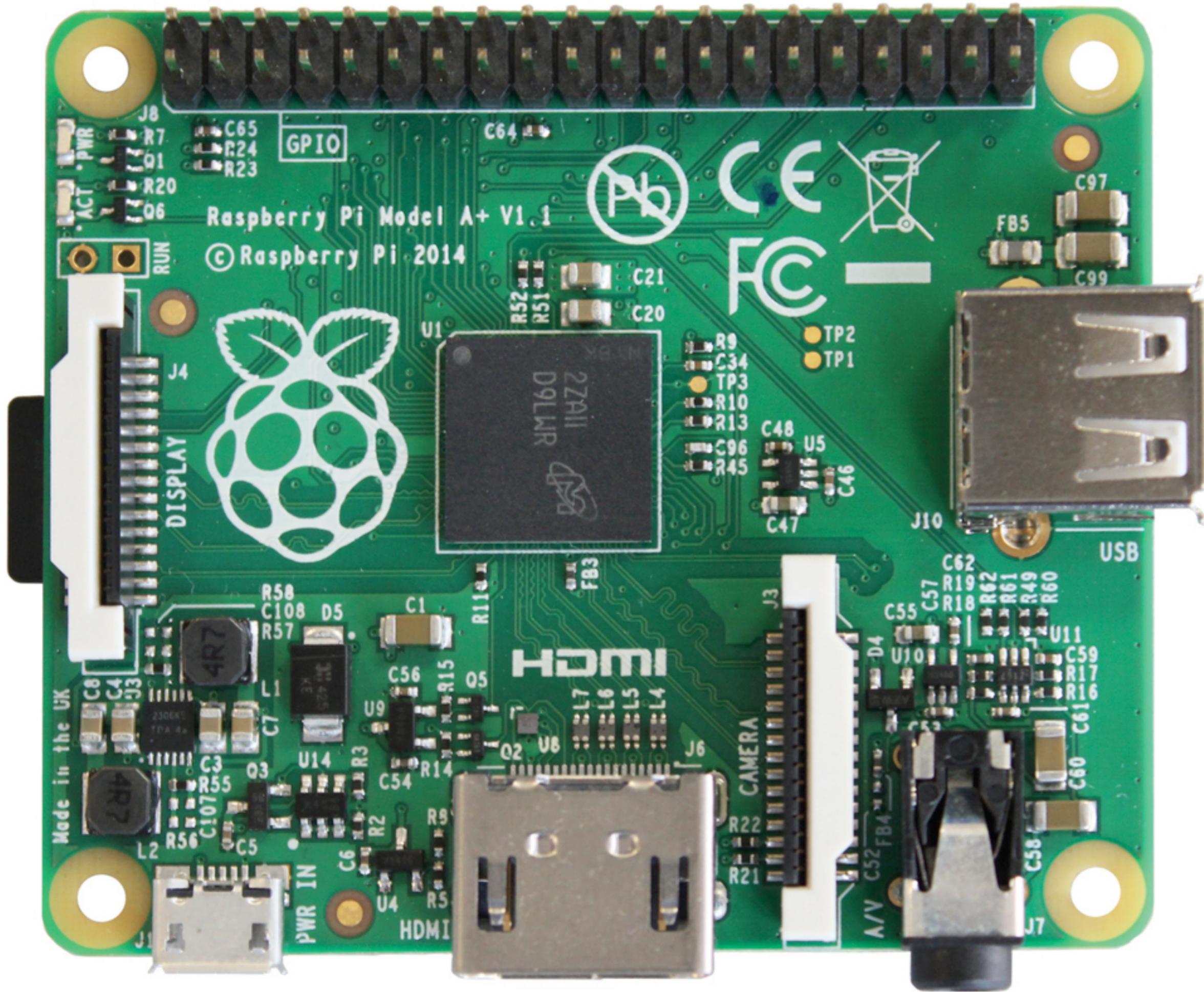


Image: [https://en.wikipedia.org/wiki/Von\\_Neumann\\_architecture#/media/File:Von\\_Neumann\\_Architecture.svg](https://en.wikipedia.org/wiki/Von_Neumann_architecture#/media/File:Von_Neumann_Architecture.svg)

# How is our Raspberry Pi a von Newmann architecture machine?

- A processing unit that contains an arithmetic logic unit and processor registers
  - The Raspberry Pi has an ARM processor with processor registers
- A control unit that contains an instruction register and program counter
  - The ARM processor has an instruction register (kind of — it is not something we can get access to) and a program counter ("r15")
- Memory that stores data and instructions
  - The Raspberry Pi A+ has 512MB of RAM
- External mass storage
  - The Raspberry Pi A+ has an SD card reader
- Input and output mechanisms
  - The Raspberry Pi A+ has USB (we won't use it), HDMI (we will use it), and GPIO pins (you better believe we will use them)

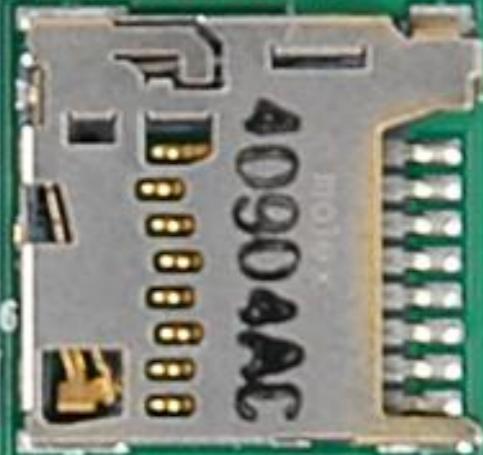


ARMKCE MC1  
V-OF3  
1439 1-6

PP10  
PP13



MICRO SD CARD



J1

C66

C2 R1 PP8 PP4

J9

PP7 PP1 PP2

F1 PP3

TRST\_N  
T01 T00 TMS TCK GND

J5

R12 C40 C17  
C95 FB2  
C94 C36  
C51 C49 C69  
C18 C14 C37  
R25  
C50 C9 C13 C12  
C35 C30  
C45 C29

PP40 PP39

PP38 PP37

PP30

PP32 PP29 PP34

PP33 PP31

PP36

PP35

PP23

PP22

PP21

PP15

PP18

PP16

PP17

PP19

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PP20

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PP11

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PP20

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PP11

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PP32

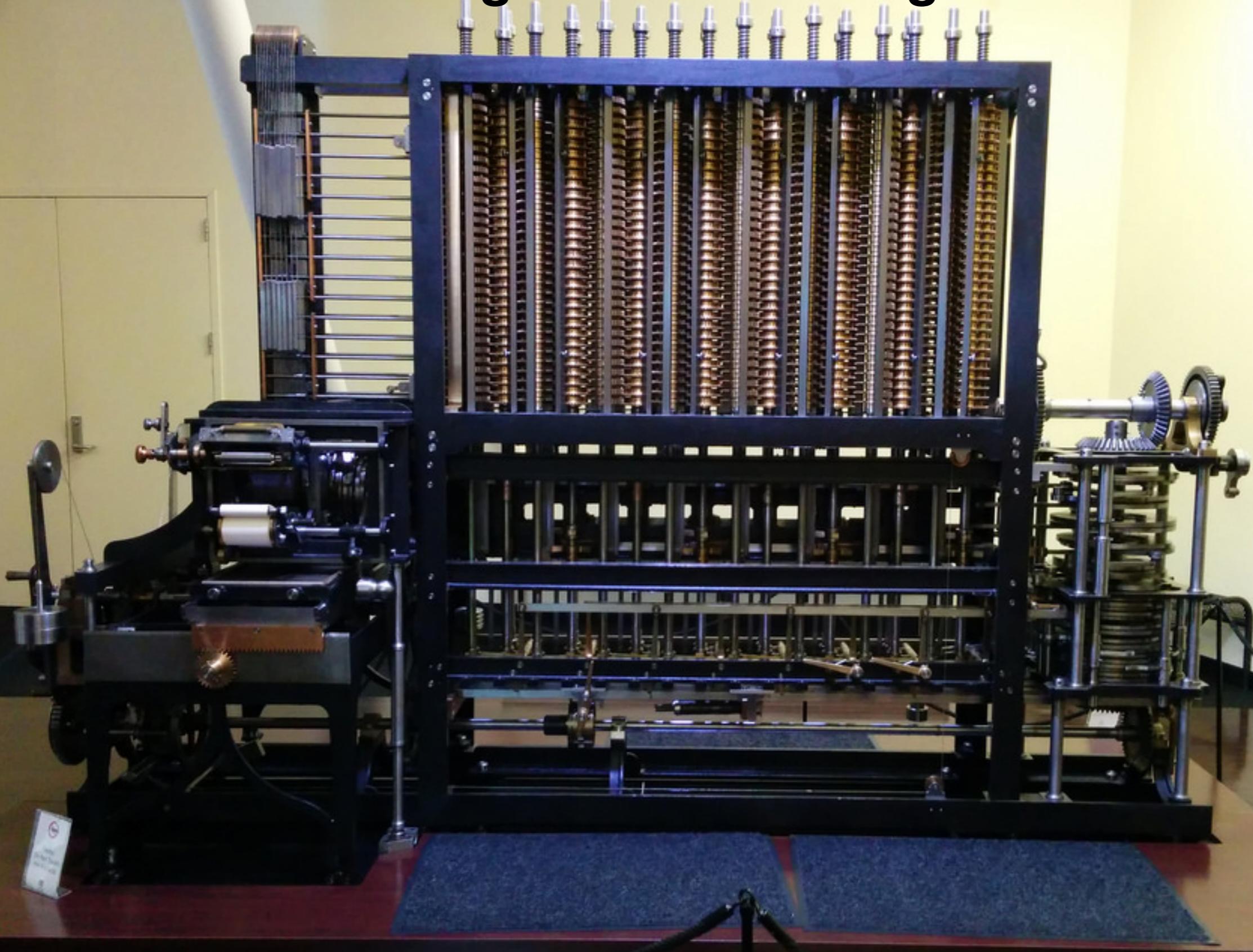
PP29

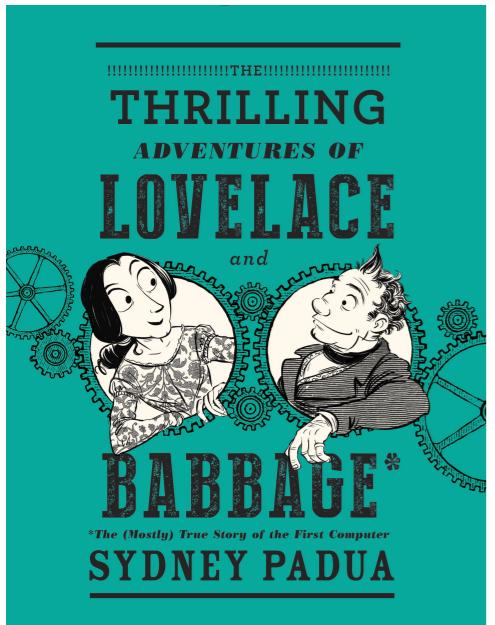
PP34

PP33

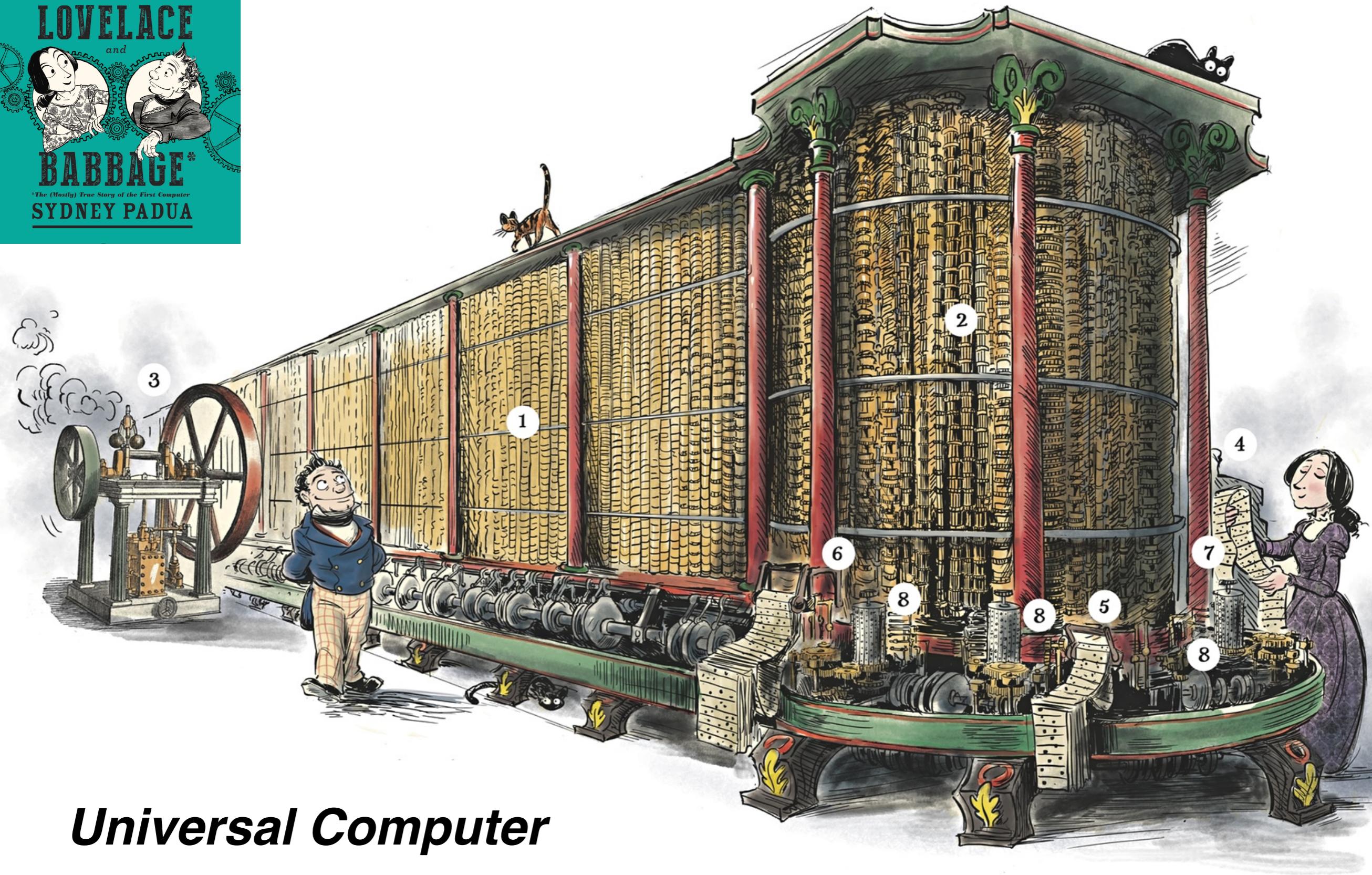
PP31

# Babbage Difference Engine



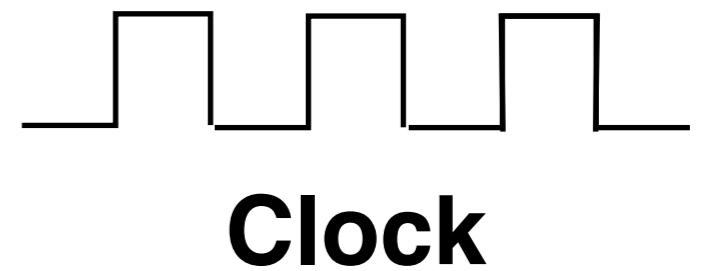
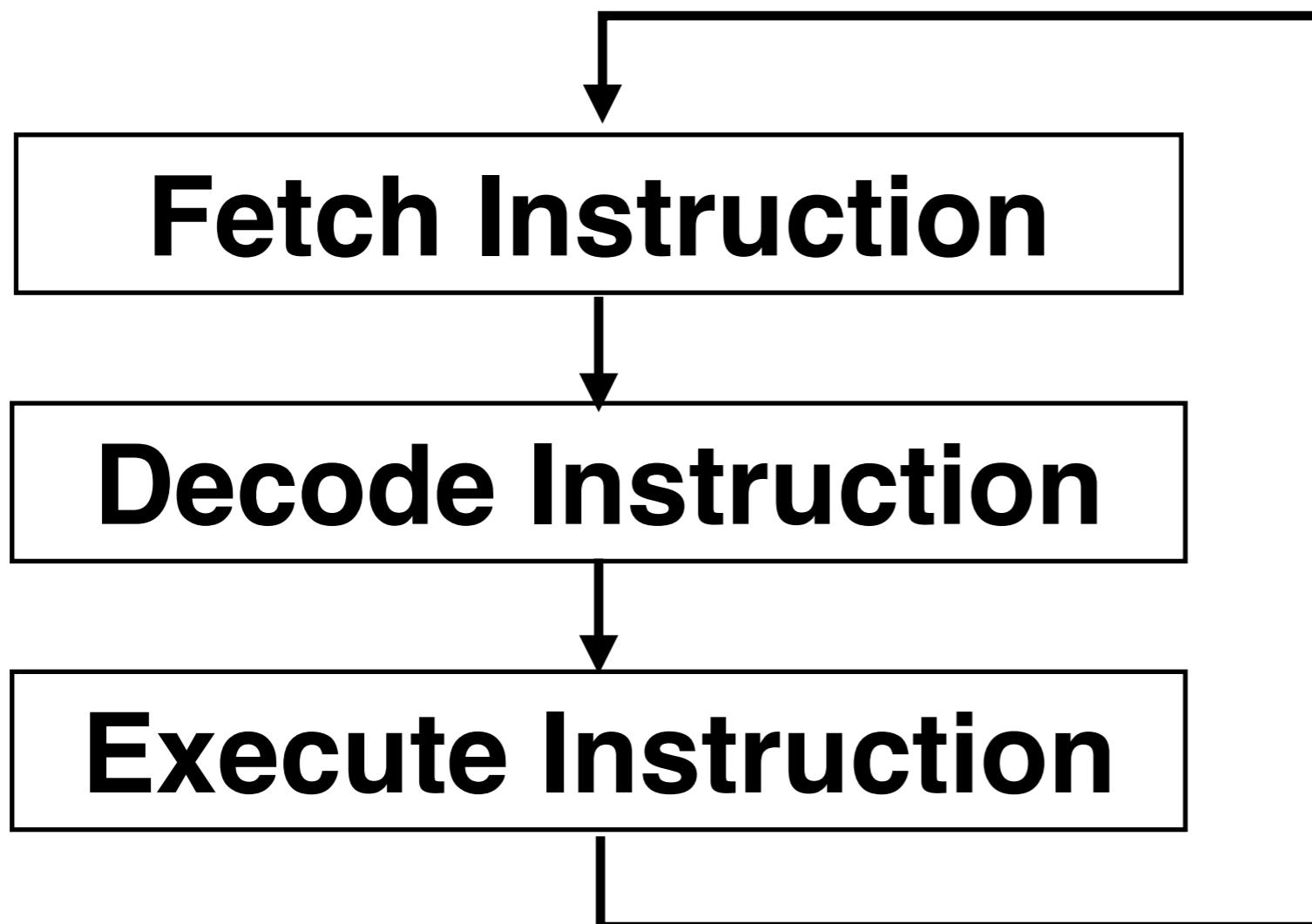


# Analytical Engine



## Universal Computer

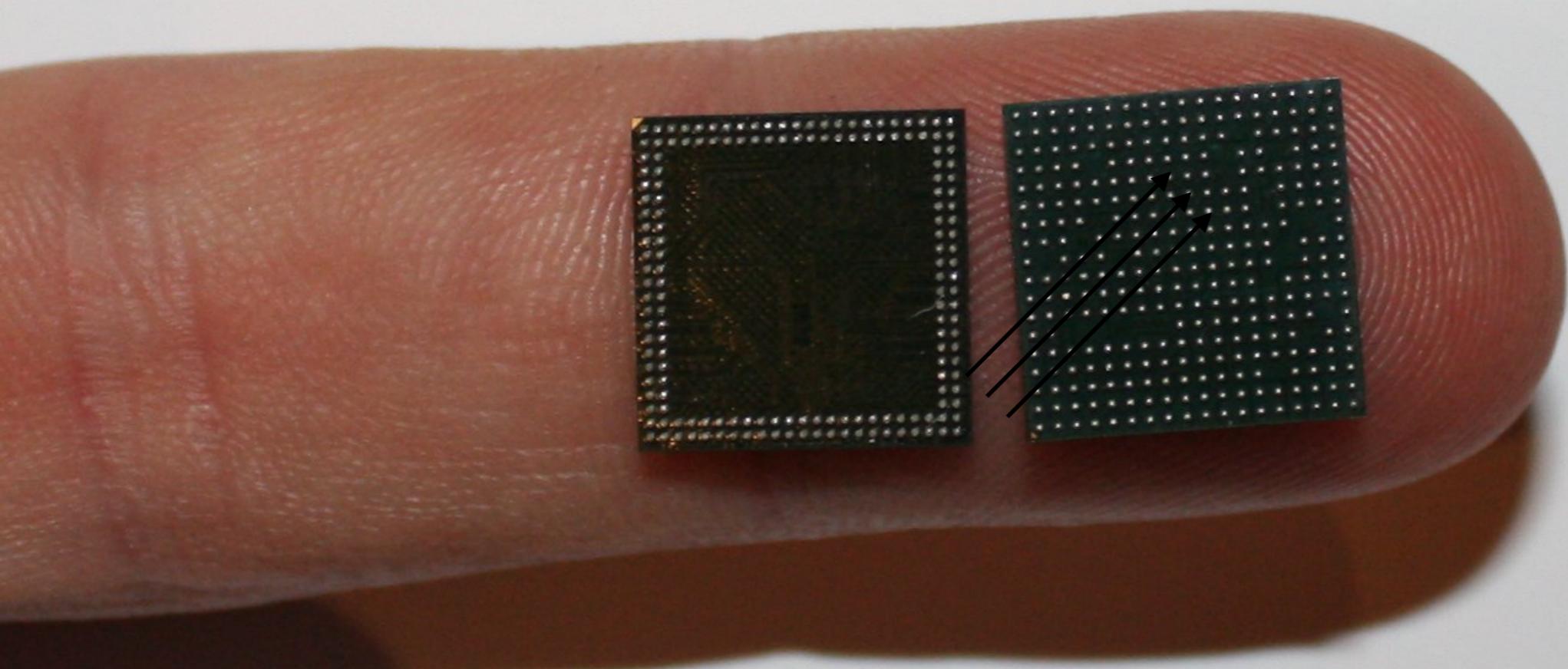
# Running a "Program"



Clock

# Package on Package

Broadcom 2865 ARM Processor



Samsung 4Gb SDRAM

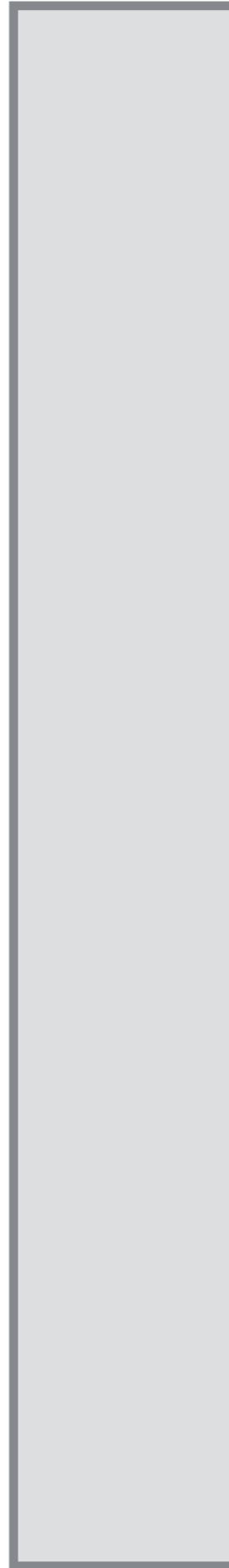
$10000000_16$

**Memory used to store both instructions and data**

**Storage locations are accessed using 32-bit addresses**

**Maximum addressable memory is 4 GB**

**Address refers to a *byte (8-bits)***



**Memory Map**

$00000000_16$

**10000000<sub>16</sub>**



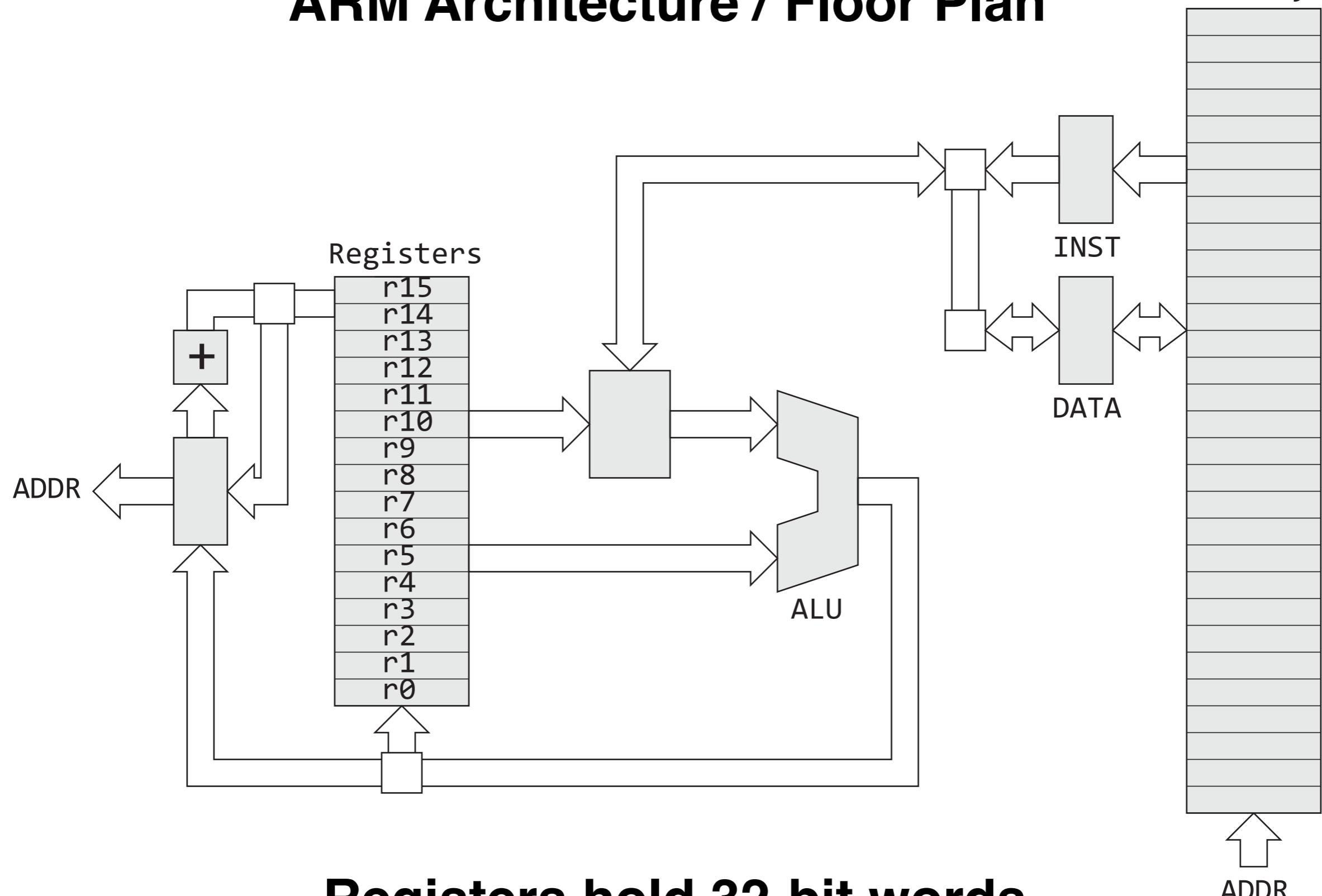
**Memory Map**

**512 MB Actual Memory**



**02000000<sub>16</sub>**

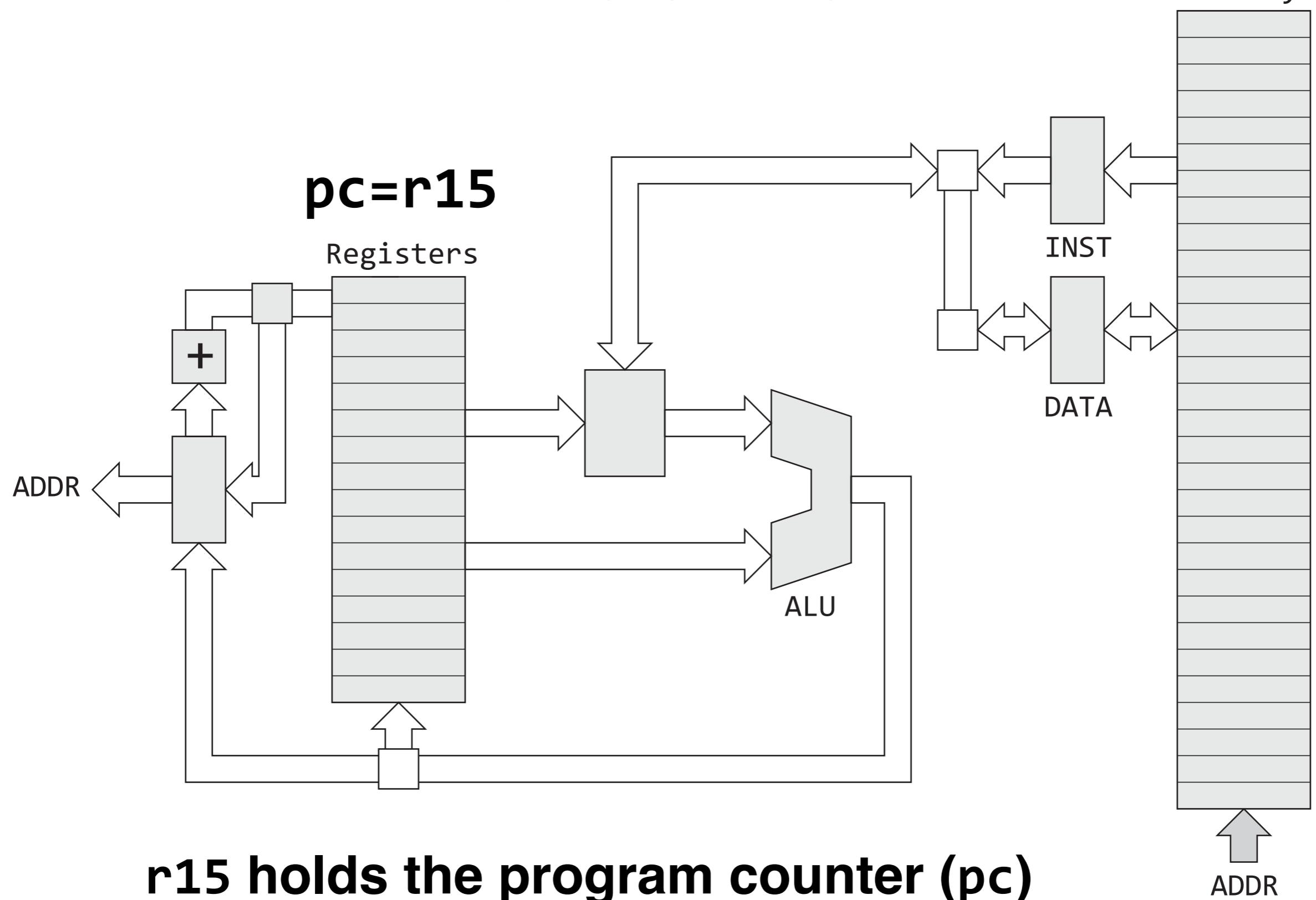
# ARM Architecture / Floor Plan



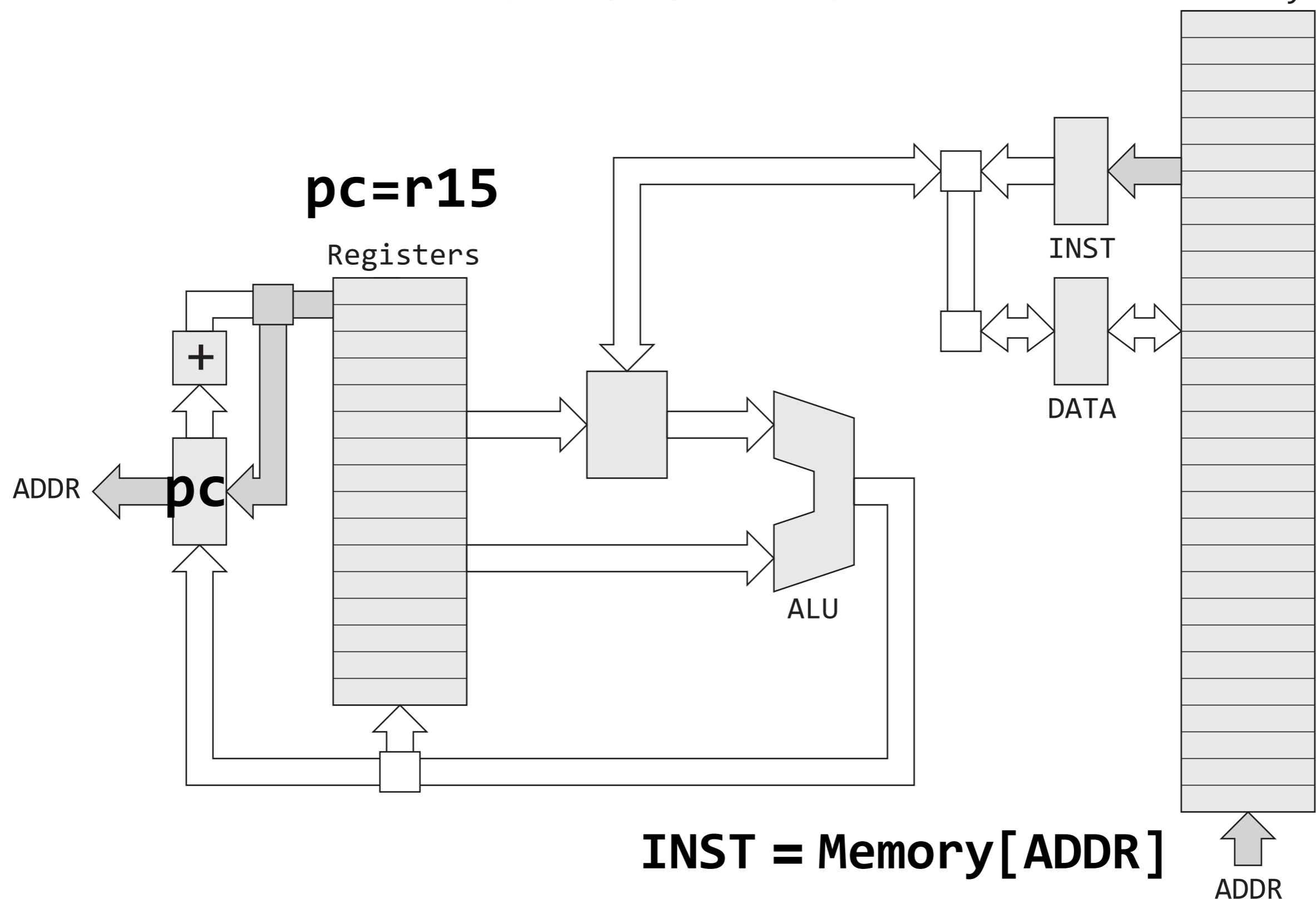
**Registers hold 32-bit words**

**Arithmetic-Logic Unit (ALU) operates on 32-bit words**

# Instruction Fetch

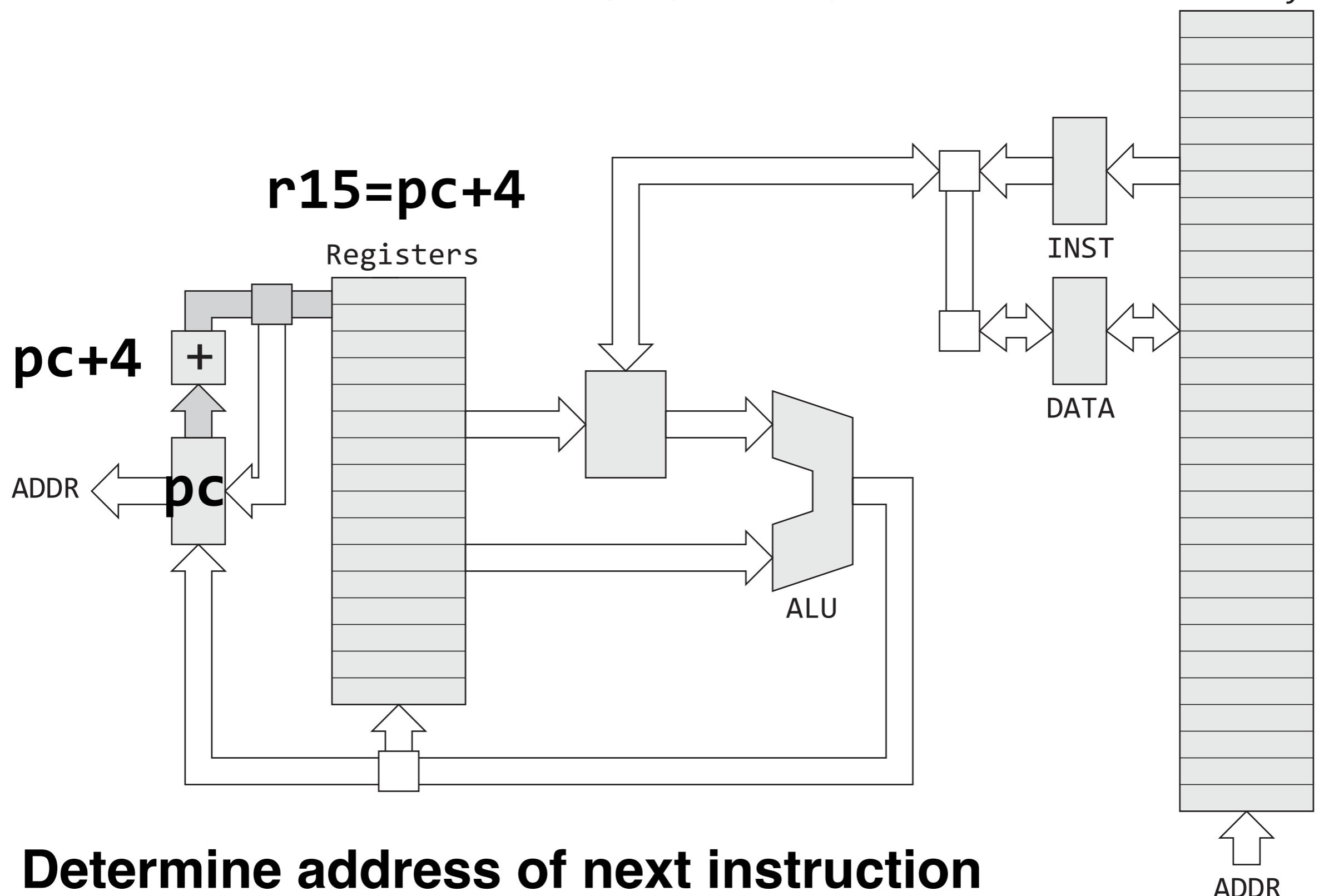


# Instruction Fetch



**Addresses and instructions are 32-bit words**

# Instruction Fetch



**Why pc+4?**