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Let’s Write Our Own CHIP-8 Interpreter!

CON3584

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Hi There!

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- OpenJDK 8 Update Project Maintainer
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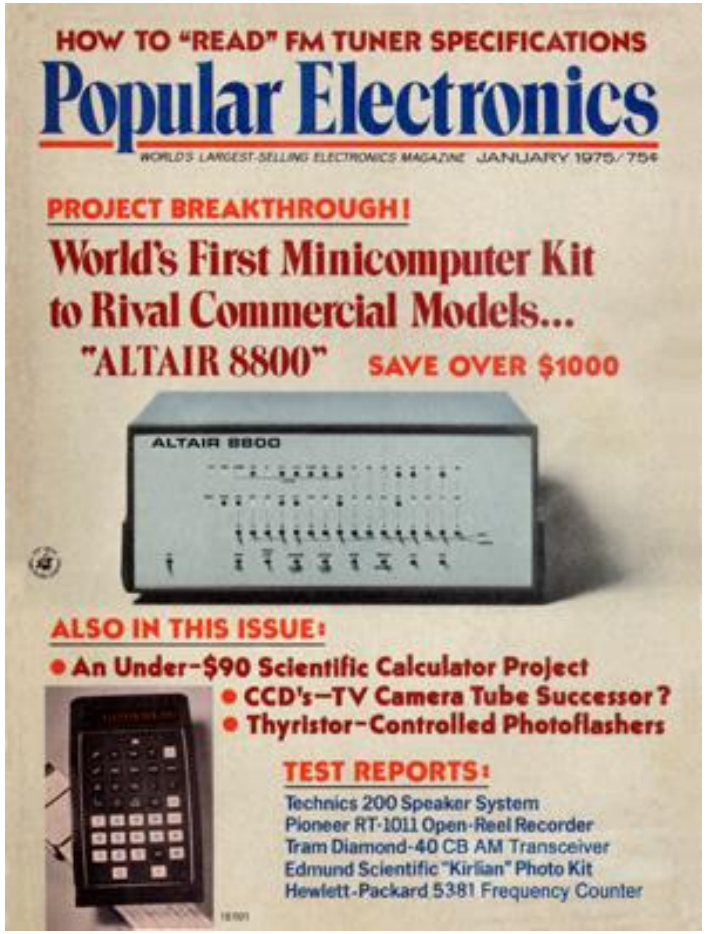
- https://blogs.oracle.com/buck/

Agenda

1. CHIP-8 History
2. CHIP-8 Architecture
3. Emulating CHIP-8
4. Advanced Emulation Topics

Introducing CHIP-8

Before CHIP-8



HOW TO "READ" FM TUNER SPECIFICATIONS

Popular Electronics

WORLD'S LARGEST-SELLING ELECTRONICS MAGAZINE JANUARY 1975/75¢

PROJECT BREAKTHROUGH!

World's First Minicomputer Kit to Rival Commercial Models... "ALTAIR 8800" SAVE OVER $1000

ALSO IN THIS ISSUE:

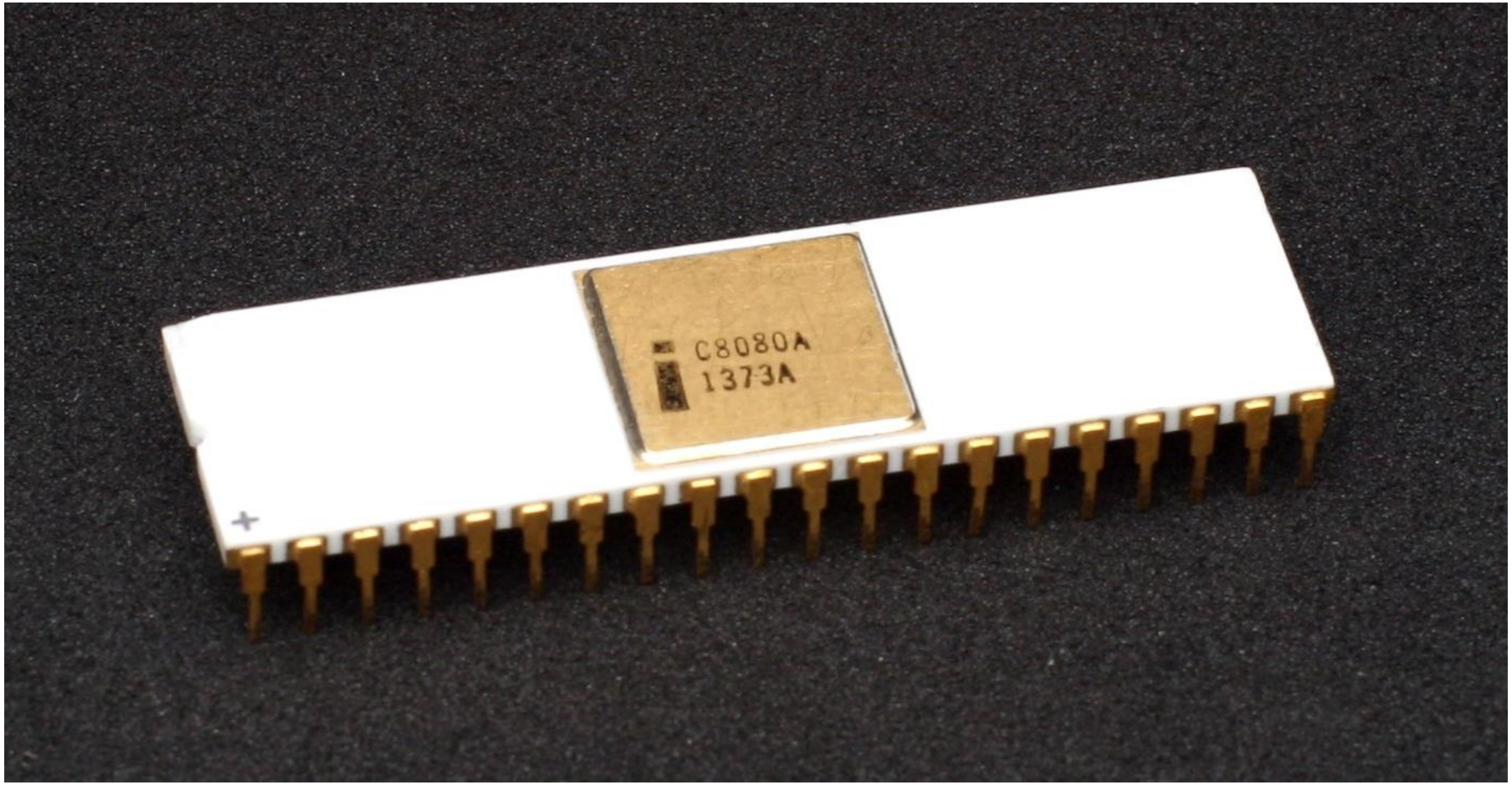
- An Under-$90 Scientific Calculator Project
- CCD's—TV Camera Tube Successor?
- Thyristor-Controlled Photoflashers

TEST REPORTS:

Technics 200 Speaker System
Pioneer RT-1011 Open-Reel Recorder
Tram Diamond-40 CB AM Transceiver
Edmund Scientific "Kirlian" Photo Kit
Hewlett-Packard 5381 Frequency Counter

https://en.wikipedia.org/w/index.php?curid=4327124

Intel 8080

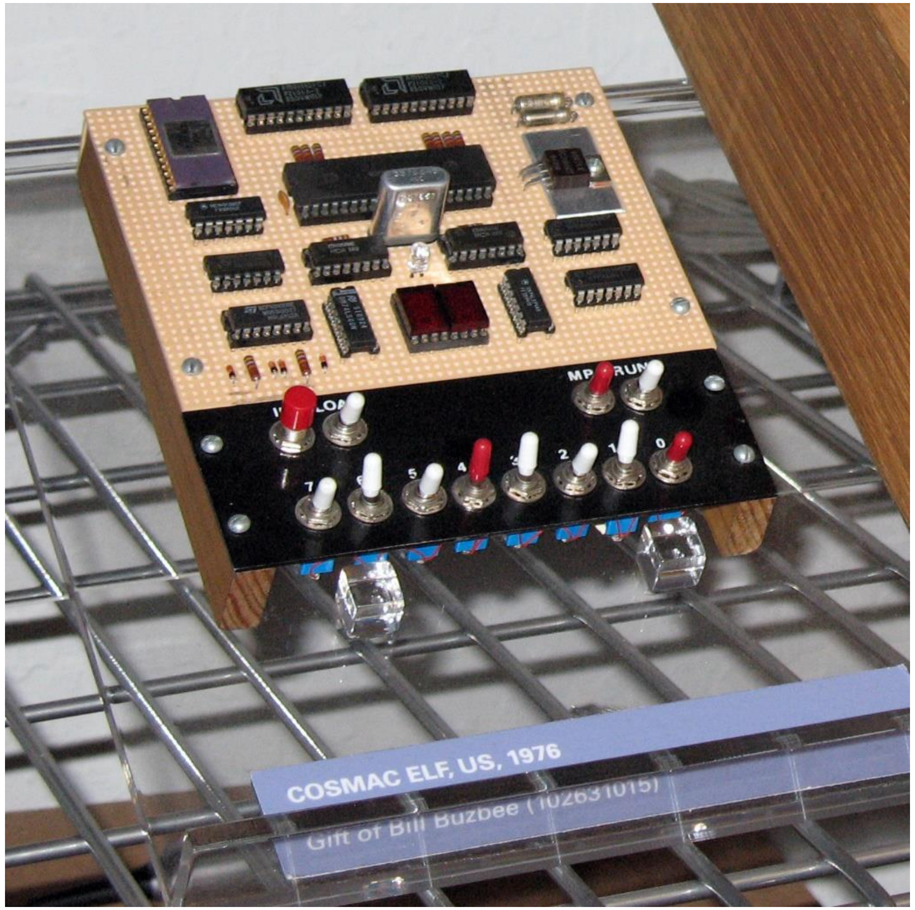


By Konstantin Lanzet - CPU collectionCamera: Canon EOS 400D, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=7028099

Not a Poor Nerd’s Hobby…

- 1975 kit price: 439 USD
- In 2017 currency: 1,997 USD

COSMAC ELF



By Swtpc6800 en:User:Swtpc6800 Michael Holley - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=3471056

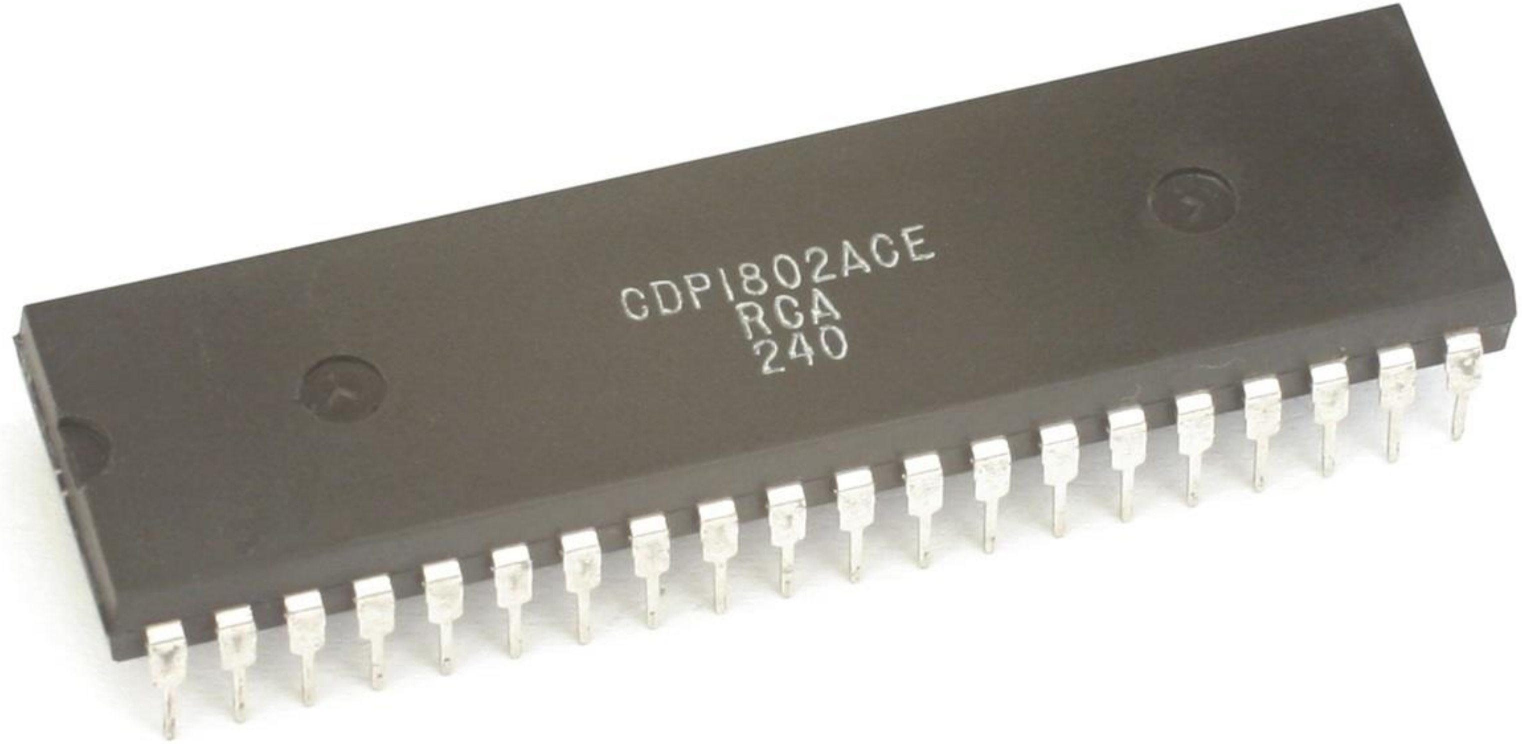
COSMAC ELF

- DIY project documented in Popular Electronics in 1976-1977
- Could be built for under 100 USD (1976 prices)
- Kits and pre-assembled boards offered from many vendors
- Very popular both then and now

Pixie

- RCA 1861 video generator IC
- 64 × 32 square pixels
- Needed 256 bytes of external RAM

RCA COSMAC 1802



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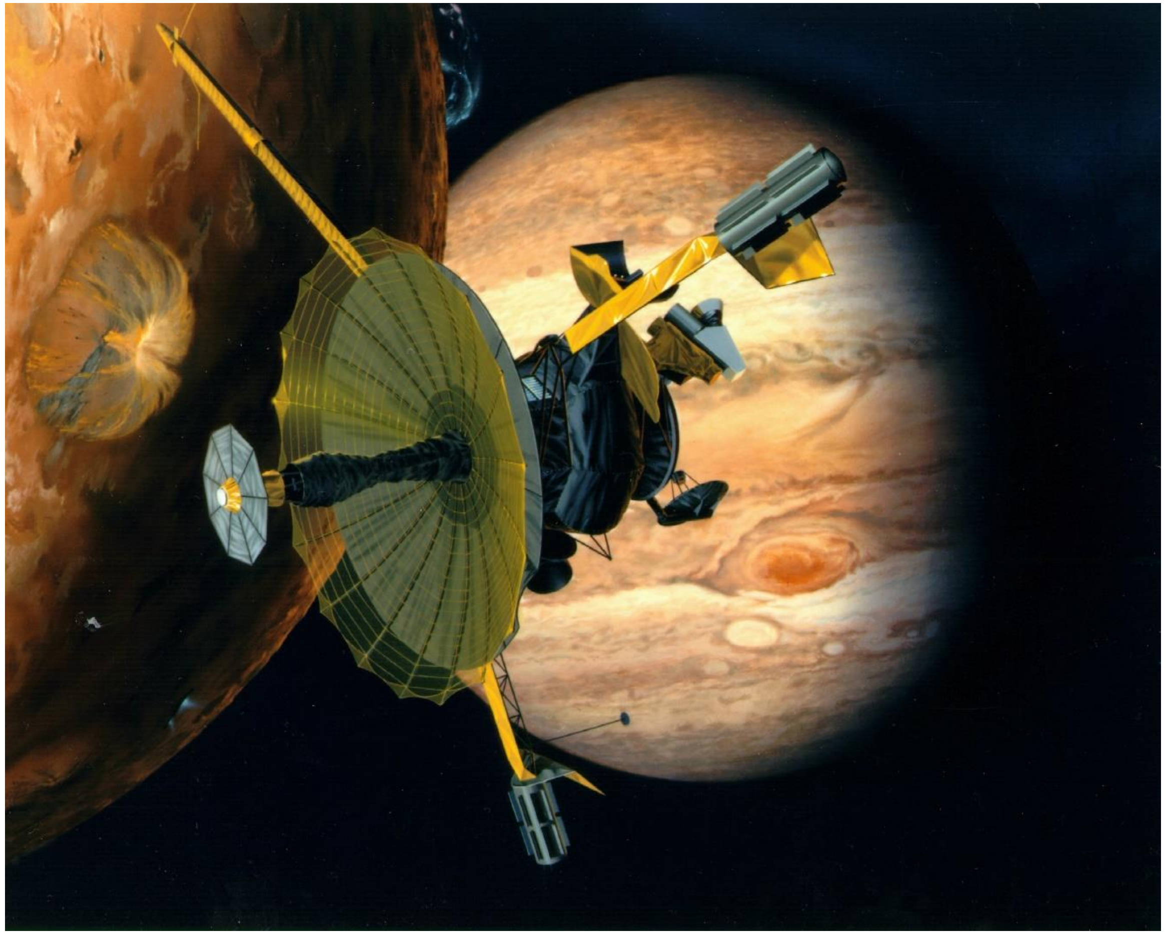
RCA COSMAC 1802

- Complementary Symmetry Monolithic Array Computer
- 1 chip revision of an earlier 2 chip design (1801)
- Very low cost compared to 8080
- Still in use in many applications today

Radiation Hardened Versions

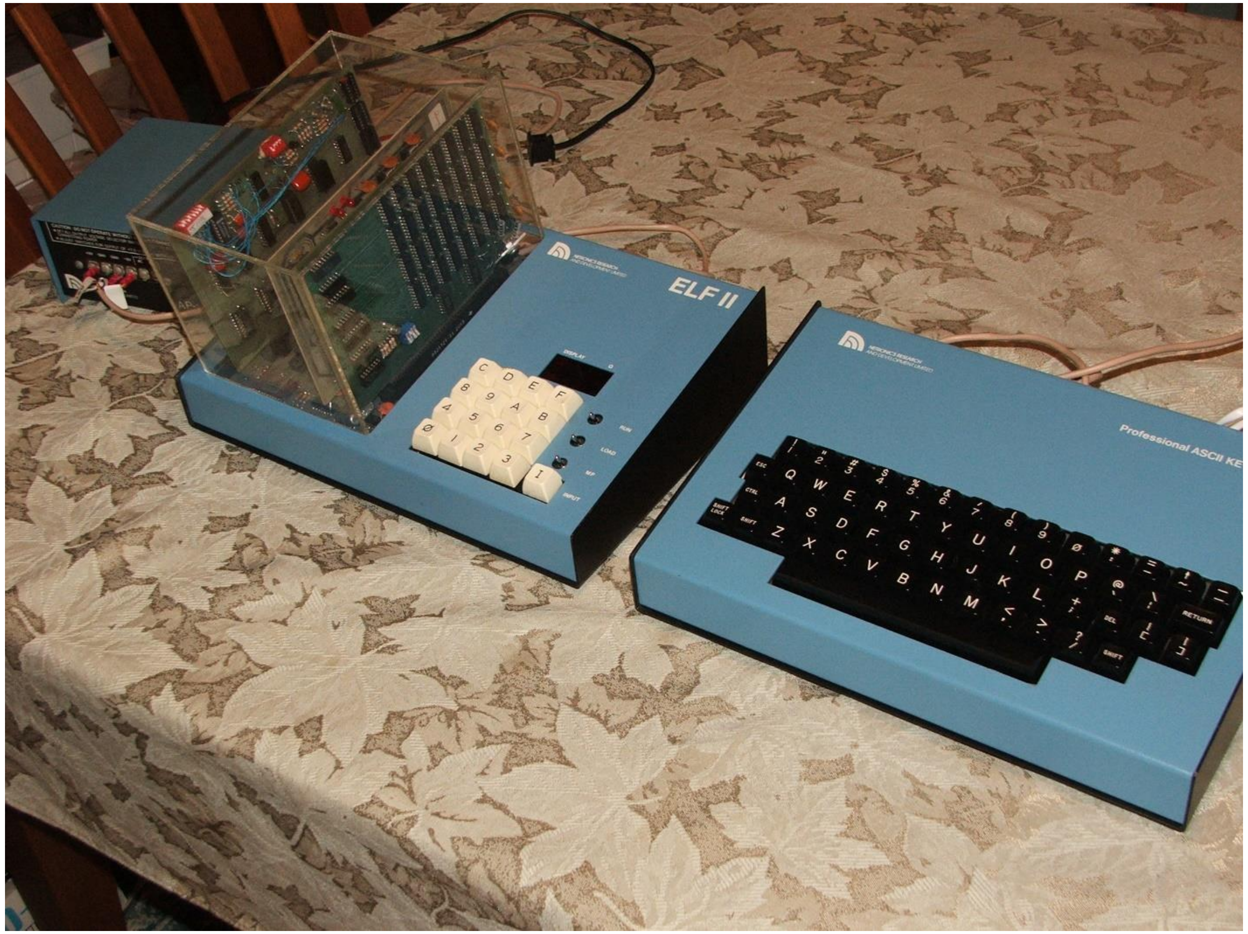


By NASA - http://solarsystem.nasa.gov/multimedia/display.cfm?IM_ID=2071 (image link)http://photojournal.jpl.nasa.gov/catalog/PIA18176 (image link) Public Domain, https://commons.wikimedia.org/w/index.php?curid=408298

COSMAC VIP

- Developed by Joseph Weisbecker
- Version of the ELF targeting the video game market
- Came pre-assembled
- Hex-keyboard was standard

Hex Keyboard



By John crane 59 - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=15795865

Hex Keyboard

1	2	3	C
4	5	6	D
7	8	9	E
A	0	B	F

COSMAC VIP

- CPU: 1802
- ROM: 512-byte
- RAM: 2k~4k on-board (up to 32k external)
- Cassette interface: 100 bps
- 40 years old this year!

Similar to “CPU Trainers” of the day…

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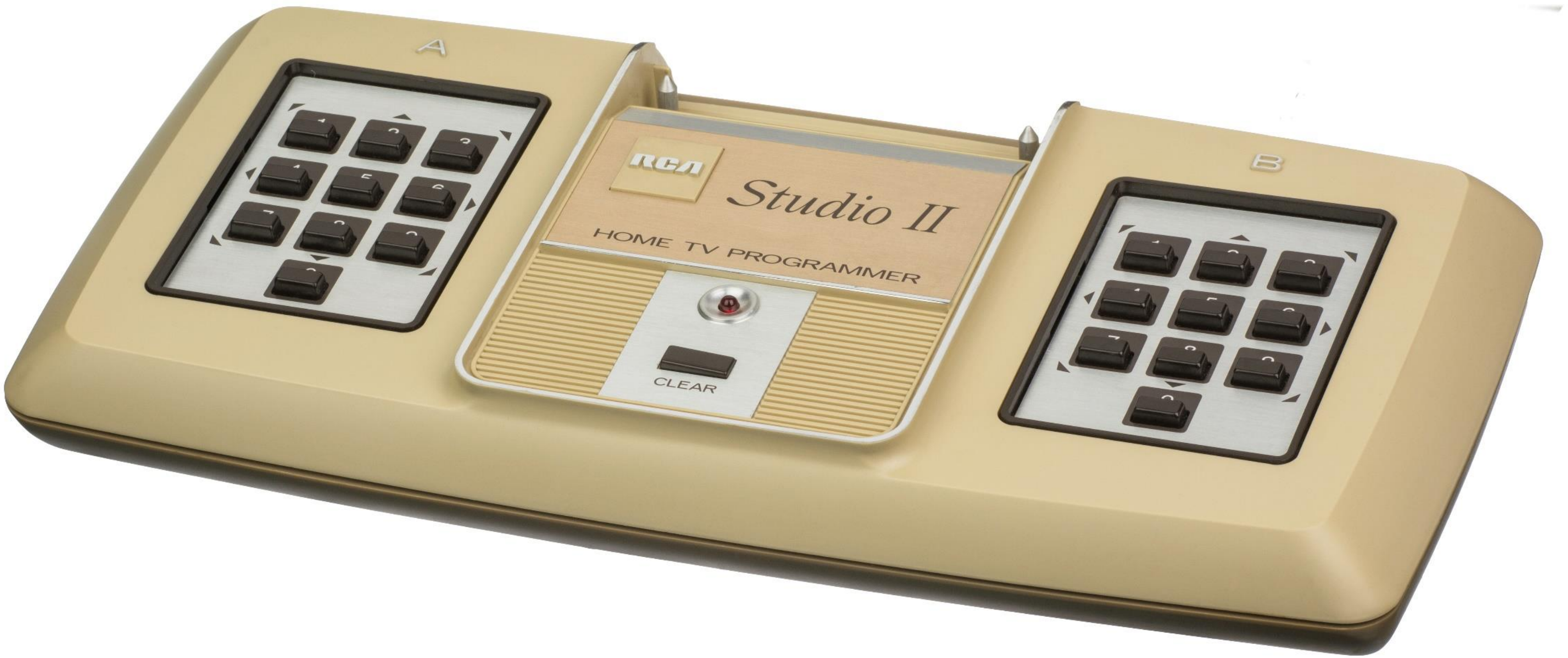
RCA-Studio II



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CHIP-8

- A “language” for programming video games
- Developed by Joseph Weisbecker for the VIP
- Interpreter built into the VIP ROM
- Made writing games for the VIP much easier

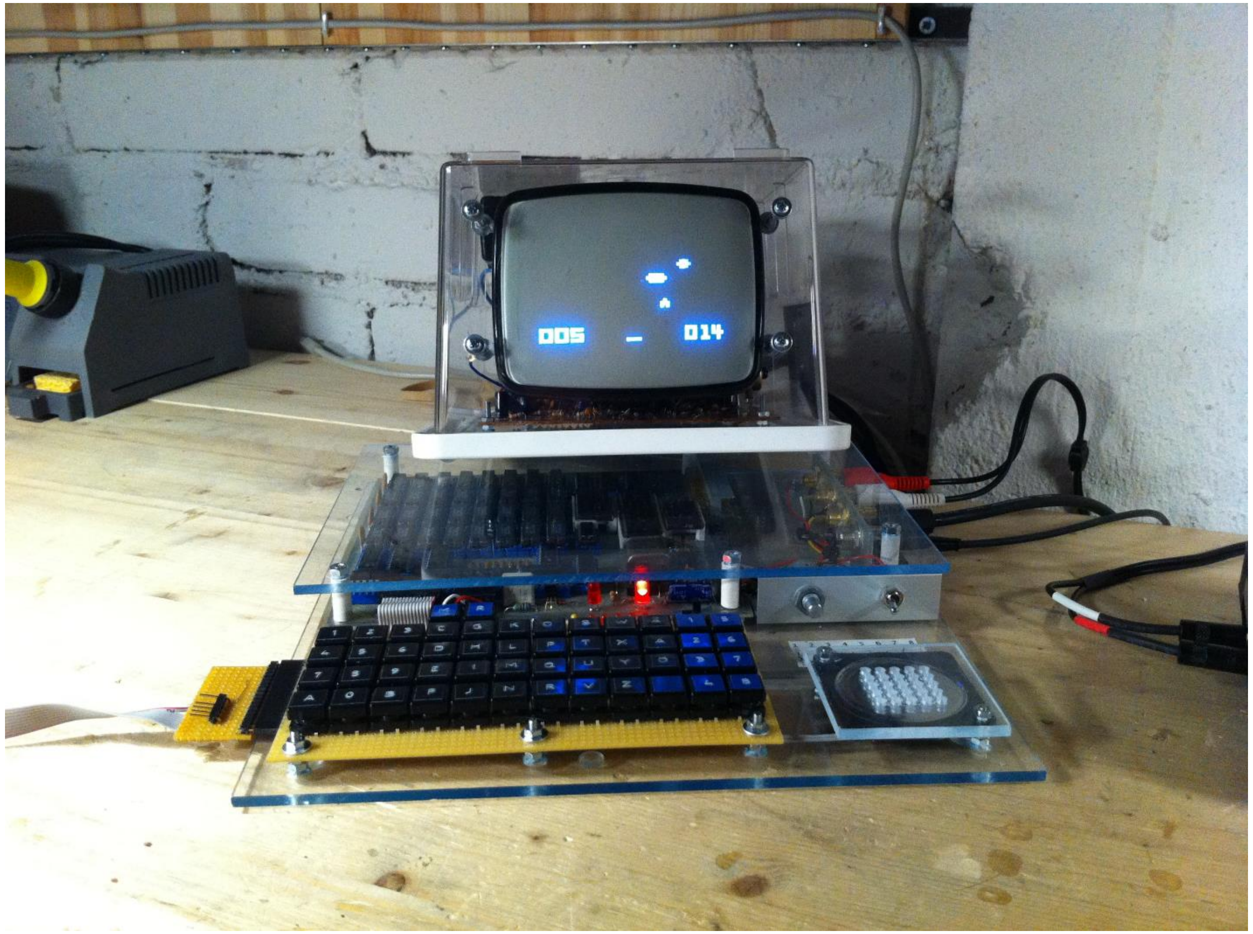
“Language”?

- Looks like machine code
- It was really a very early virtual machine specification

Why use a virtual machine?

- Abstract away much of the real hardware
  - Linier display buffer -> X,Y mapped grid
  - Sprite support
  - Sound support (q-line on 1802)
  - Key debouncing
- Very easy to program
- Very high code density

Other Platforms Followed (Telmac 1800)



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Fast Forward About 10 Years

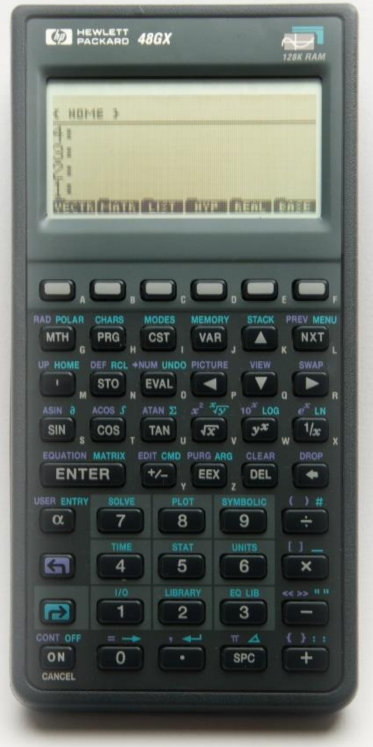
HP 28c released

- HP's first graphing calculator
- **Light-years** beyond anything else
  - RPL (lambda expressions!)
  - Symbolic math (CAS)

By Kurt Moerman (Kpmkpm) - Own work, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=4020998

The Legendary 48G

- Released in 1990
- HP’s most powerful calculator for almost a decade



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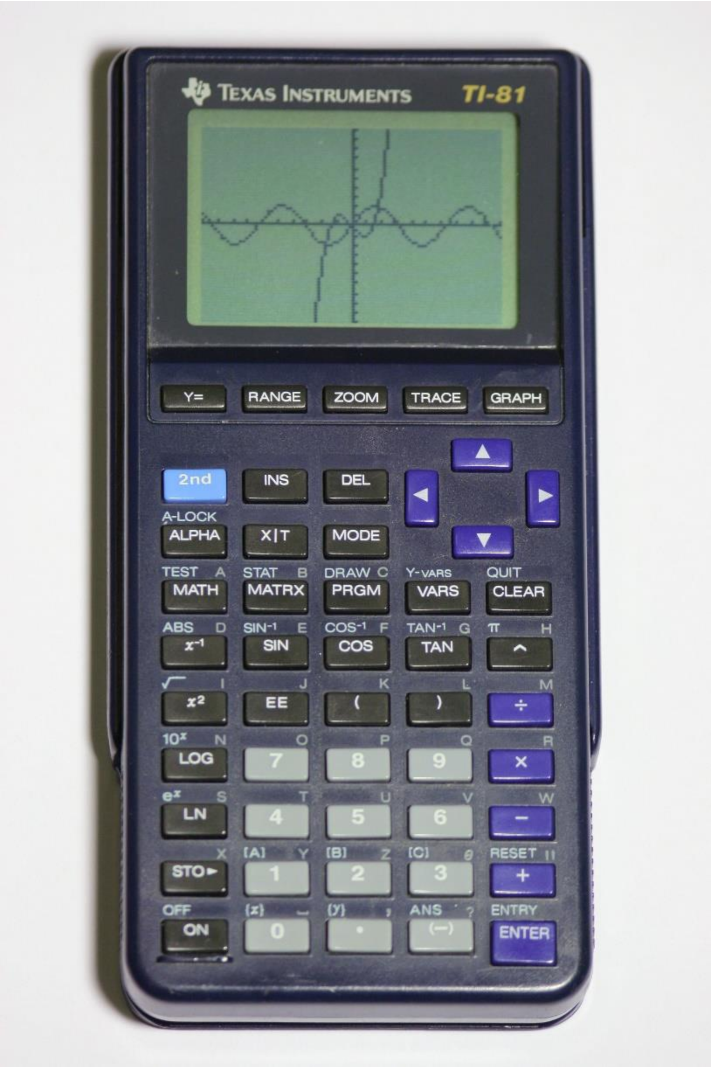
Meanwhile…

- TI-81
- Z80 based
- BASIC-like programming language
- Very easy to program
- Very easy to make games



By Calcvids - I took this photo of my TI-81, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=24252718

HP48G owners were jealous!

- RPL was **horrible** for gaming
  - Too abstract / high-level
  - Slow
  - Steep learning curve

CHIP-8 to the rescue!

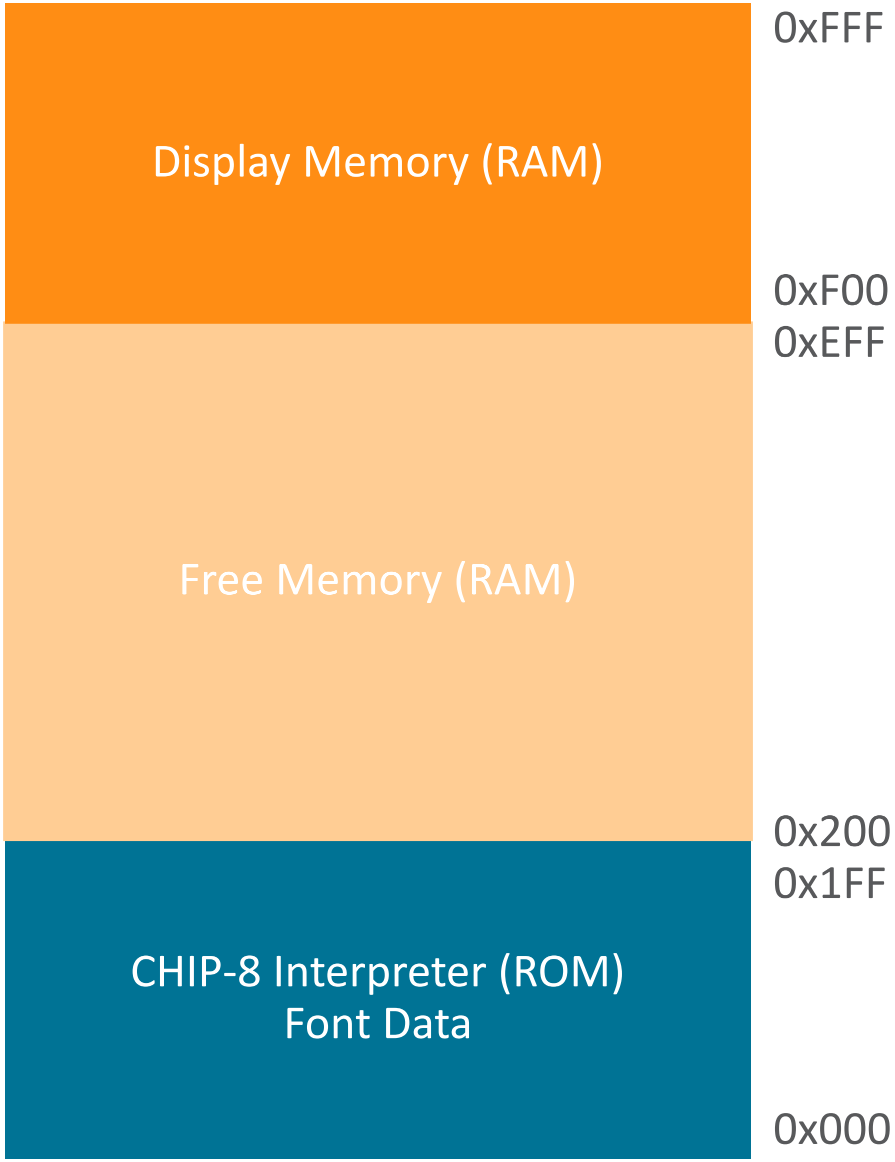
- Andreas Gustafsson wrote a CHIP-8 interpreter for the HP48
- HP48 users got access to library of preexisting software from the 70s
- New CHIP-8 software started to be written
- Super CHIP (SCHIP) expanded to take advantage of HP48 hardware

CHIP-8 Today

- A great way for future emulator authors to cut their teeth
- Probably the easiest platform to emulate that plays games
- Possibly the only platform with more emulators than native software

CHIP-8 Architecture

Memory Map


0xFFF
Display Memory (RAM)
0xF00
0xEFF
Free Memory (RAM)
0x200
0x1FF
CHIP-8 Interpreter (ROM)
Font Data
0x000

An Embarrassment of Registers

- 15 8-bit general registers (V0-VE)
- 1 8-bit “Flag” register (VF)
  - Only used for carry (ALU) and sprite hit detection
- 1 16-bit address register
  - Only 12-bit LSBs normally used
- 1 16-bit PC

Sound

- Write-only sound timer that decrements 60 ticks a second
- Buzzer / beeping sound plays until timer reaches zero
- No music here!

Display

- 64x32 monochrome pixels
- Sprites
  - 8 pixels wide
  - 1~15 pixels tall
  - Drawn to video memory by XOR:ing
  - Collision flag (FV) set (or cleared)

Timer

- Like sound timer, but no output.
- Decremented 60 ticks a second
- Stops at zero
- Can be both read or written to (unlike RO sound timer)

Opcodes

- AAA: address
- KK: 8-bit constant (byte)
- K: 4-bit constant (nibble)
- X, Y: 4-bit register identifier
- I, PC: 16bit register

Call instruction

- 0AAA – jump to 1802 code at AAA (not used in modern CHIP-8)

Display

- 00E0 CLS
- FX29 set I register to font for hex digit stored in X
- DXYK draw sprite K pixels high at X, Y coordinates

Flow Control Instructions

00EE	return from sub ★
1AAA	jump to AAA
2AAA	call sub at AAA ★
3XKK	if VX == KK skip next instruction
4XKK	if VX != KK skip next instruction
5XY0	if VX == VY skip next instruction

★ push and pop return address use implementation-defined stack

Loads / Stores / Moves

- 6XKK Vx = NN
- 8XY0 VX = VY
- AAAA I = AAA

ALU (Math) Instructions

- 7XKK Vx += KK
- 8XY1 Vx=Vx|Vy
- 8XY2 Vx=Vx&Vy
- 8XY3 Vx=Vx^Vy
- 8XY4 Vx += Vy
- 8XY5 Vx -= Vy
- 8XY6 Vx=Vy=Vy>>1
- 8XY7 Vx=Vy-Vx
- 8XYE Vx=Vy=Vy<<1

Input Instructions

- EX9E if (key()==Vx) skip next instruction
- EXA1 if (key()!=Vx) skip next instruction
- FX0A Vx = next key press (blocking wait)

Timers / Sound Instructions

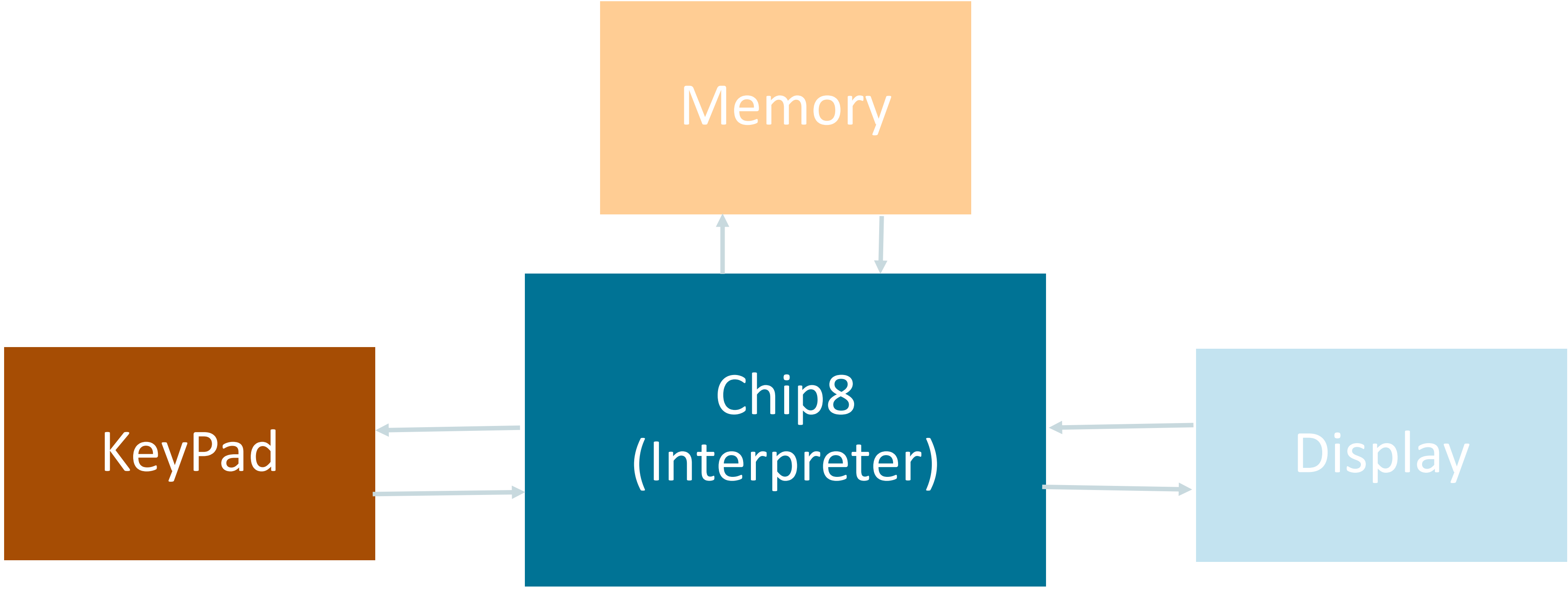
- FX07 Vx = delay_timer
- FX15 delay_timer = Vx
- FX18 sound_timer = Vx

Other Instructions

- CXKK Vx = random_number & KK
- FX33 stores 3 digits of BCD for value of Vx into I, I+1, I+2
- FX55 writes all V registers between V0 and Vx to I
- FX65 loads all V registers between V0 and Vx from I

Emulating CHIP-8

Overall Design



Overall Design

- Allows Display and KeyPad to be swapped out with different implementations
  - AWT
  - Swing
  - JavaFX
  - LWJGL
- Memory is isolated to be closer aligned to more advanced emulators

Memory

- One single 4K byte array
- Handles font data (must be initialized)
- Handles reading in of program (“rom”) during startup

Display

- ASCII ART inspired
- Appends characters to a StringBuilder
  - White Pixel ‘#’
  - Black Pixel ‘ ‘
- Note that screen buffer memory is independent from main memory
- Screen buffer is shared between Display and Chip8 (the interpreter)
- Screen refresh timing / method can have a huge performance impact

KeyPad

- Depends on enabling raw input from terminal
- Semantics of key press detection depend on automatic key repeat
  - By extension also depends on a very low repeat delay
- Shutdown hook is registered to restore terminal to useable state

Interpreter Loop

- Is a naive implementation
- Uses a simple series of nested switch statements
- Register values are stored in next larger primitive type
- Each iteration of the main loop updates timers as needed
- Each iteration of the main loop refreshes display as needed

Debugging

- You often want some way to debug what is running on the VM
  - Trace
  - Breakpoints
  - Memory dumps

Other General Emulation Tips

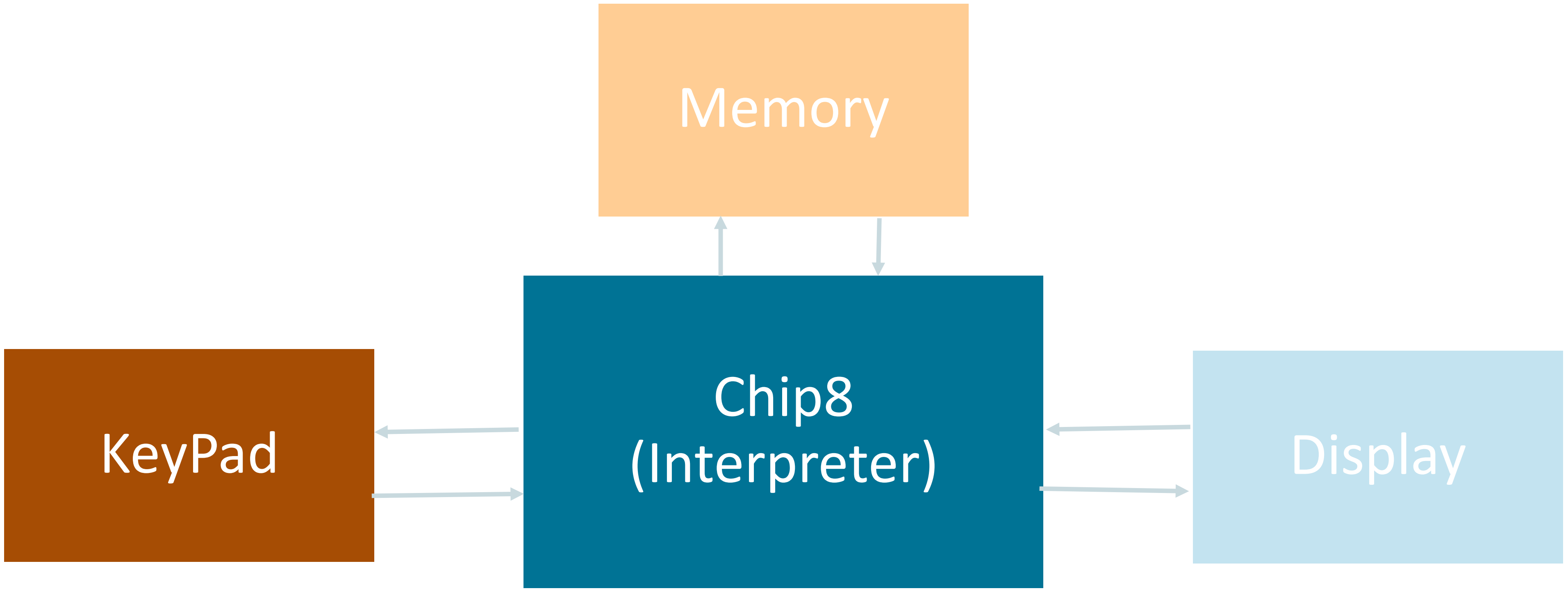
- Start with small test cases, not full games
- Write your own tests if you cannot find any
- Have some way to throttle execution speed
- Compare your emulator's behavior to other emulators

Advanced Emulation Topics

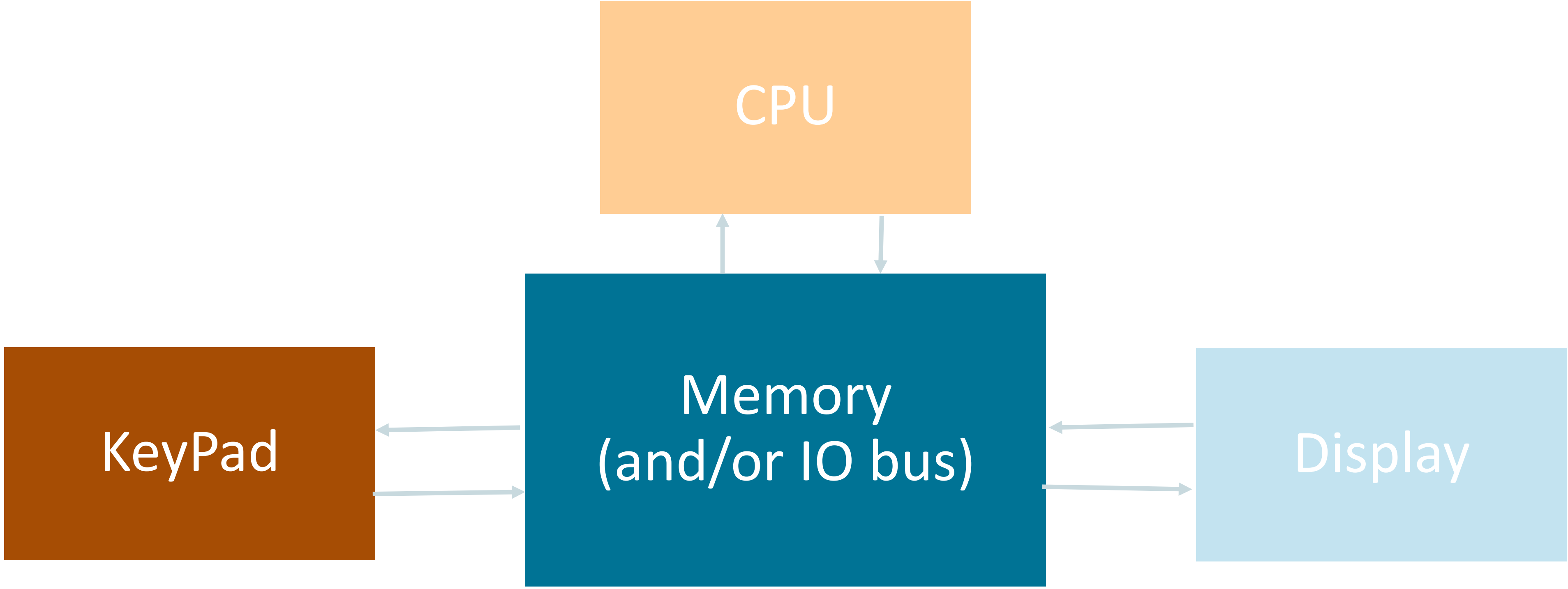
Your code should model the hardware

- Figure out how instructions are encoded / decoded (e.g. z80 decode)
- If there are multiple pieces of similar hardware, instantiating objects is probably best
- Multiple threads for interpreter loop / IO refresh (including display) may be the easiest design

My CHIP-8 Design



Typical Emulator Design



Dynamic Recompilation

- Use ASM to generate bytecode on the fly!
- Way easier than you might imagine
- Run your interpreter through ASMifier

  (temporarily refactoring each opcode implementation into its own method may help make things clearer)
- Write a new version of interpreter loop where implementation code is replaced by the corresponding ASMifier output
- The interpreter loop will now just linearly scan the “rom”, and generate corresponding bytecode.

Conclusions

- Emulation / Interpreters are fun to write in Java
- They are not as hard as many people imagine
- You can improve your general programming skillset by writing one
- Start out small. You can't get much simpler than CHIP-8

THANK YOU!

References

- Octo - Chip-8 Assembly Language & On-line IDE

https://johnearnest.github.io/Octo/

- Cowgod's Chip-8 Technical Reference

http://devernay.free.fr/hacks/chip8/C8TECH10.HTM

- Chip-8 Software for HP48 Archive

http://www.hpcalc.org/hp48/games/chip/

- Cosmac ELF

(A great fan site with a lots of ELF content)

http://www.cosmacelf.com/

- Matthew Mikolay's Retro Computing Site

(Has scans of VIPER magazine among a ton of other great information)

http://retro.mattmik.com/

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