# Journey to the Center of the HP28C/S




by
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regarding the work of
Paul Courbis
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# Disclaimer

I am just the translator.
My French sucks.

# HP 28S




Photo by
Kurt Moerman

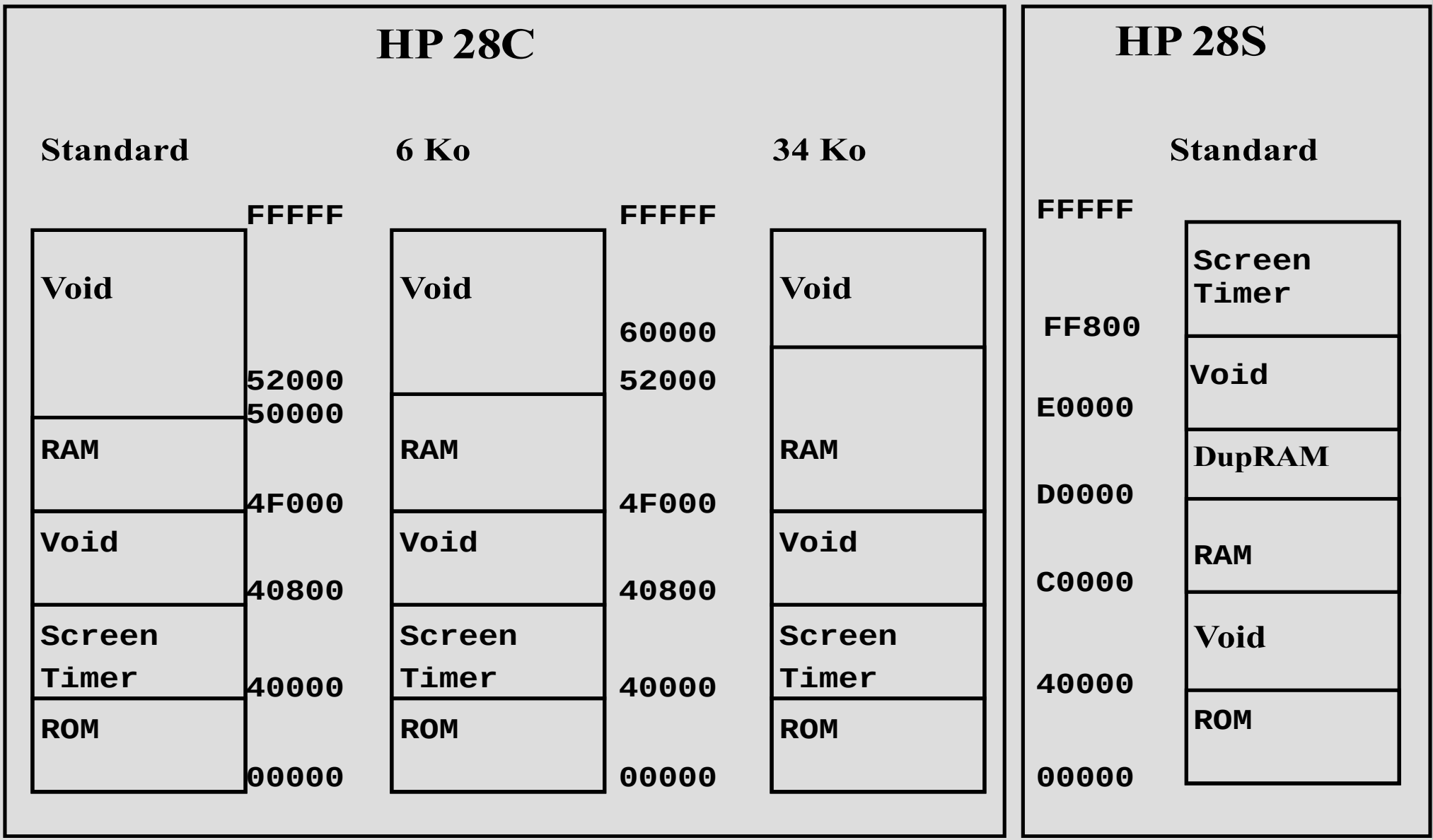
# Part 1: Software

- Objects: List and Structure
- I/O Zone
- RAM
- Accessing Machine Language
- Further Discoveries
- Useful Routines

# Introduction

- Three Models
  - HP28C-1BB
  - HP28C-1CC
  - HP28S-2BB
- HP SATURN architecture, same as HP 71b
- Nibble-wise Little Endian

# Memory Layout

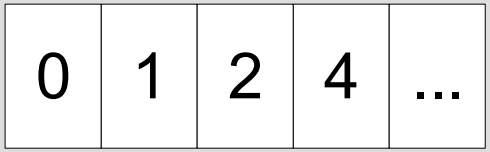


# Registers

| | | | |
|---|---|---|---|
| I/O | OUTPUT | INPUT | |
| | 12 | 16 | |
| Status | CARRY | HW Status | Status |
| | 1 | 4 | 16 |
| Pointers | P | D0,D1 | PC |
| | 20 | 20 each | 20 |
| Safeguard | RSTK | R0 to R4 | |
| | 20 by 8 | 64 each | |
| Working | A to D | | |
| | 64 each | | |

# Nybbles (Quartets)




- Byte
  - 0x00 to 0xFF
  - 0 to 255
- Nibble
  - 0 to F
  - BCD
    - 0 to 9

# Nybble Little Endian



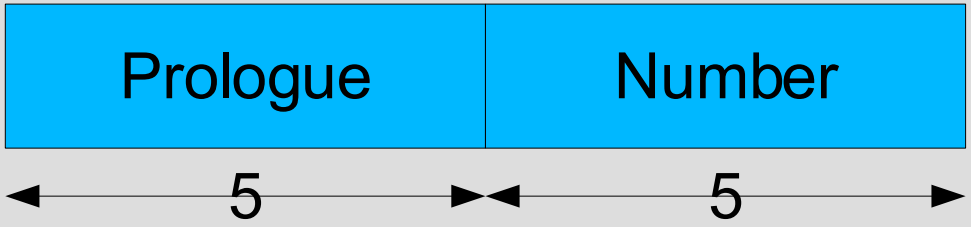
# Objects: List and Structure

- Prologue
  - 5 nibbles
  - Specifies Type
- Type
  - System or User
  - Implies Length

| Object | Prologue | Page |
|---|---|---|
| Short Integer[1] | #02991 | 10 |
| Real | #02933 | 11 |
| Extended Real[1] | #02955 | 11 |
| Complex | #02977 | 11 |
| Extended Complex[1] | #0299D | 12 |
| Byte[1] | #029BF | 12 |
| First Unknown Type[1] | #029E1 | 12 |
| Array | #02A0A | 13 |
| Second Unknown Type[1] | #02A2C | 13 |
| String | #02A4E | 14 |
| Binary Integer | #02A70 | 14 |
| List | #02A96 | 15 |
| ROM/RAM Pair[1] | #02AB8 | 15 |
| Algebraic | #02ADA | 19 |
| Program | #02C67 | 21 |
| Assembly Code[1] | #02C96 | 22 |
| Global Name | #02D12 | 22 |
| Local Name[1] | #02D37 | 22 |
| ROM Pointer[1] | #02D5C | 23 |

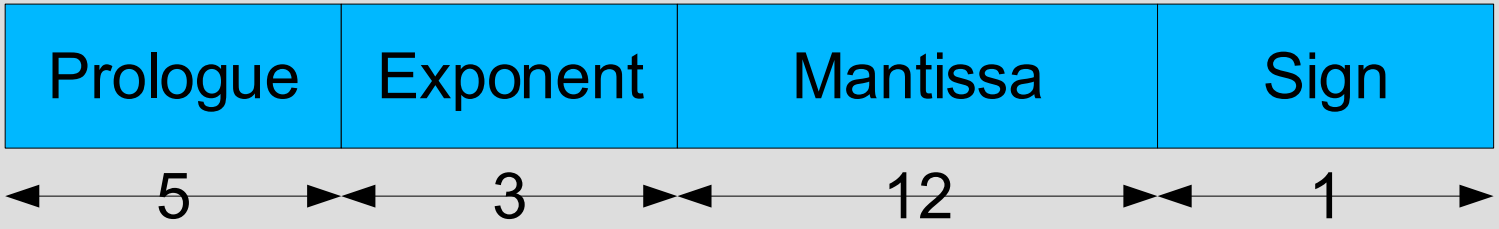
Table 2.1: Object Types and their Prologues

# Short Integer
# #02911




| | | |
|---|---|---|
| 00000 | 11920 | 00000 |
| 12345 | 11920 | 54321 |

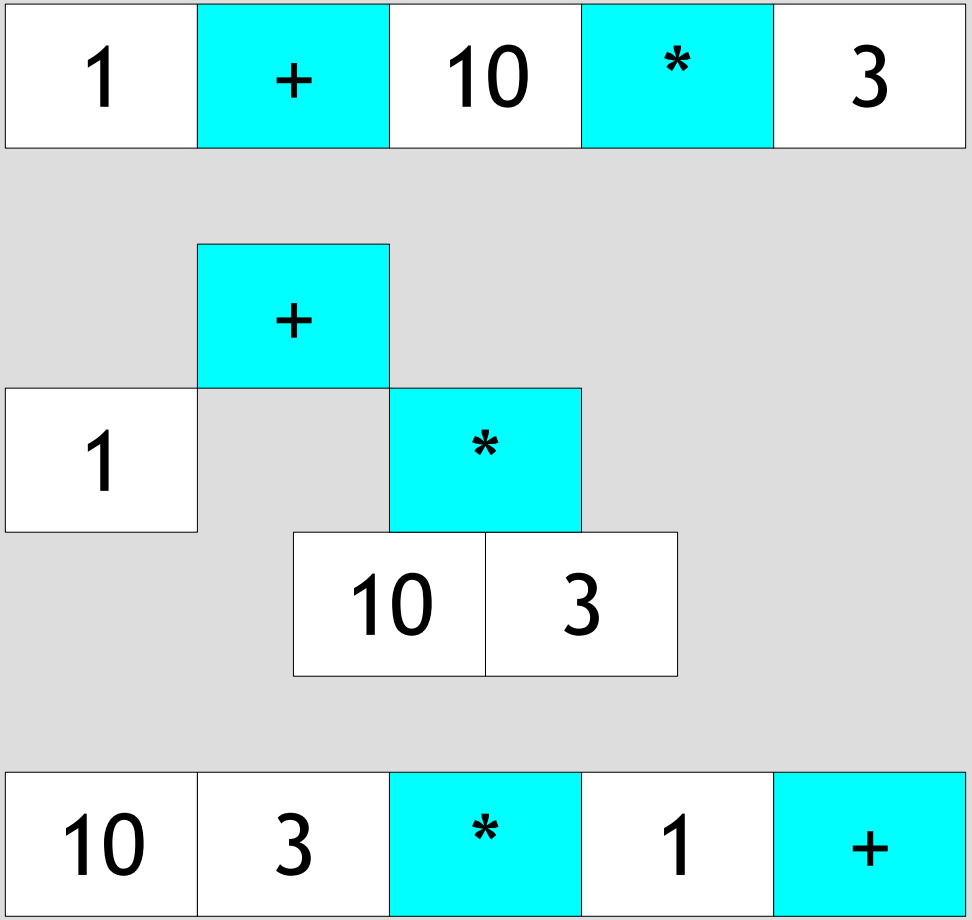
# Real
# #02933




| | | | | |
|---|---|---|---|---|
| | #02933 | 5 | 3.14159... | + |
| π*10^5 | 33290 | 500 | 953562**951413** | 0 |

# Reverse Polish Notation

- Stack Metaphor
- Left to right.
  - If value
    - PUSH onto stack.
  - If operator,
    - POP parameters.
    - PUSH result.
- No grouping symbols.
- Easy to interpret.



# RPN Interpretation

- Input

| 10 | 3 | * | 1 | + |
|---|---|---|---|---|


| 10 | 3 | * | 1 | + |
|---|---|---|---|---|


- Stack

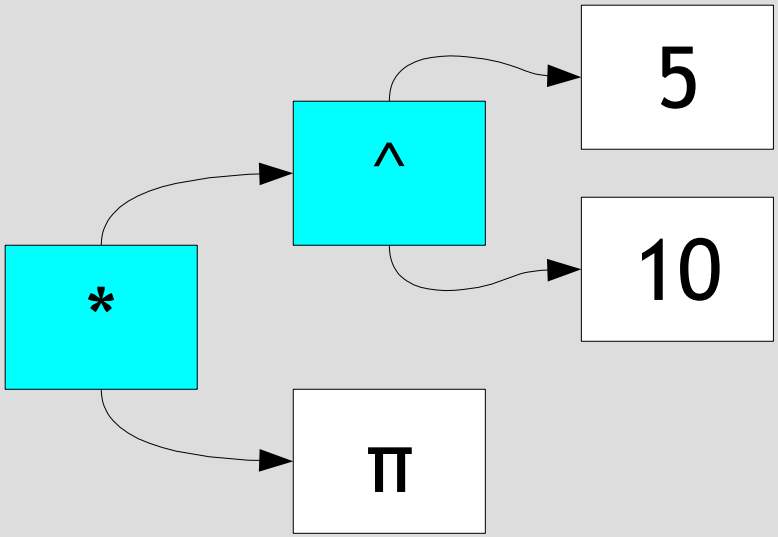
| 1 |
|---|
| 31 |

# Algebraic #02ADA

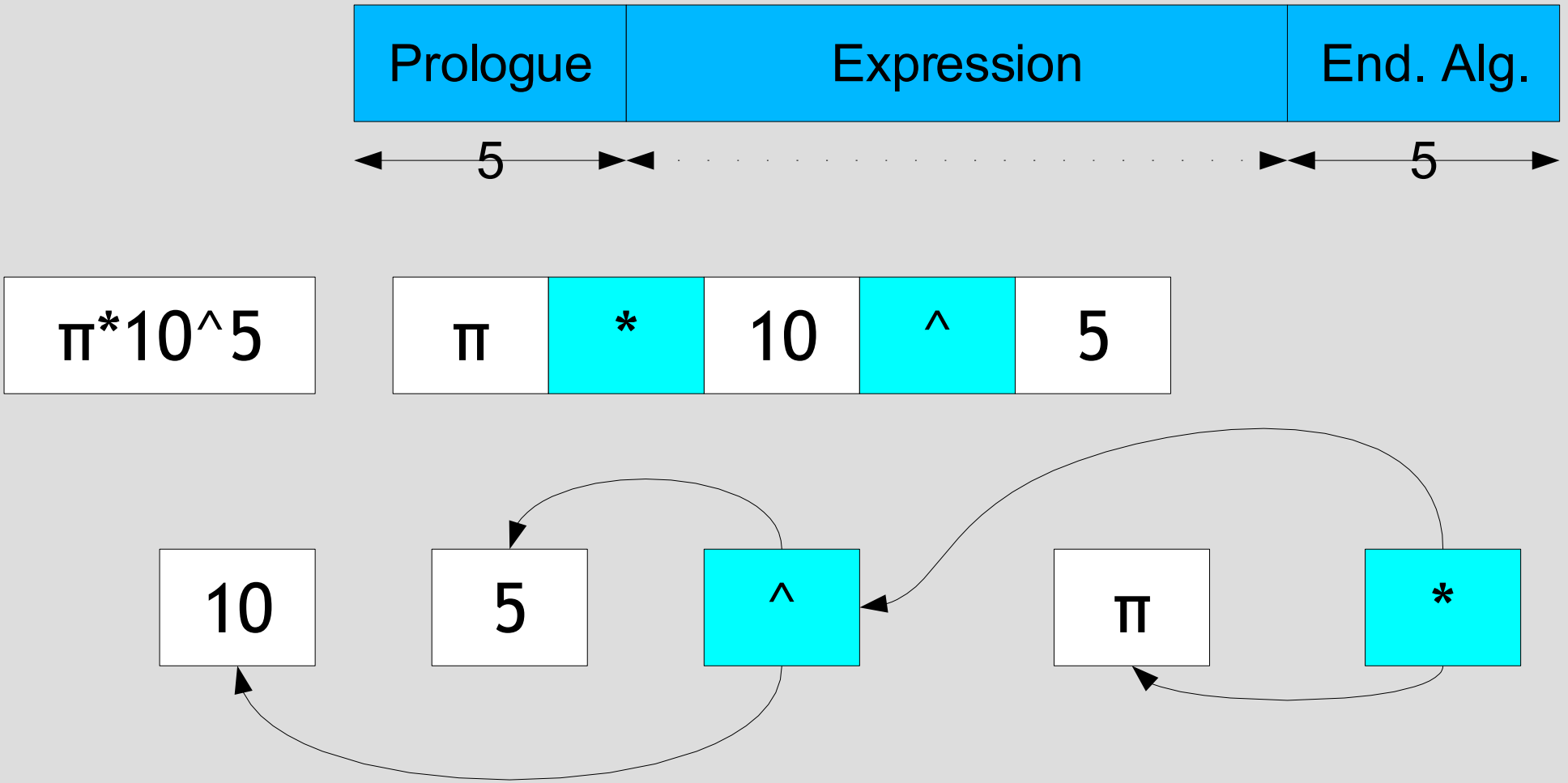



π*10^5



# Algebraic #02ADA

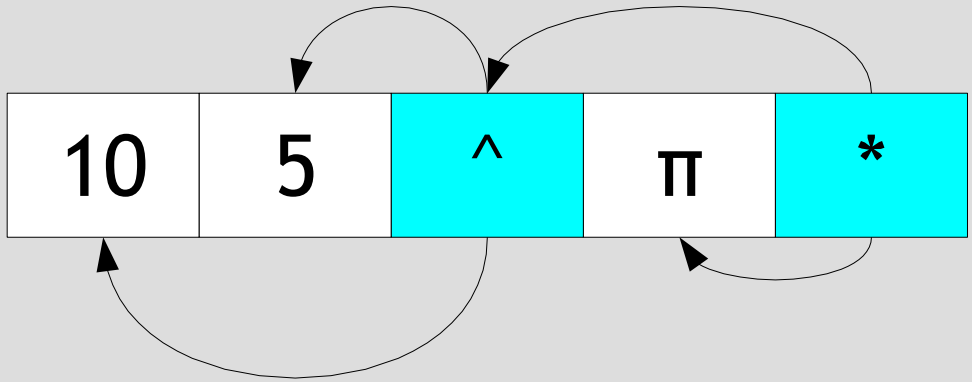


# Algebraic #02ADA



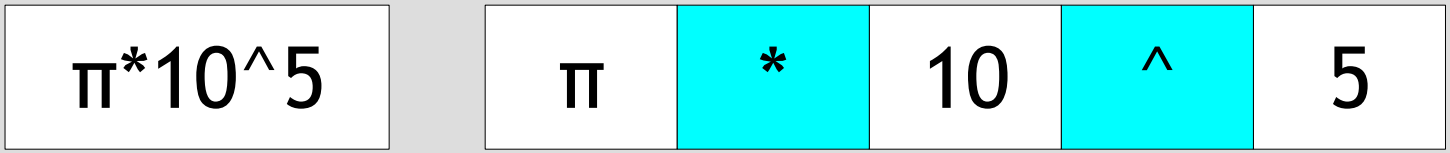

π*10^5

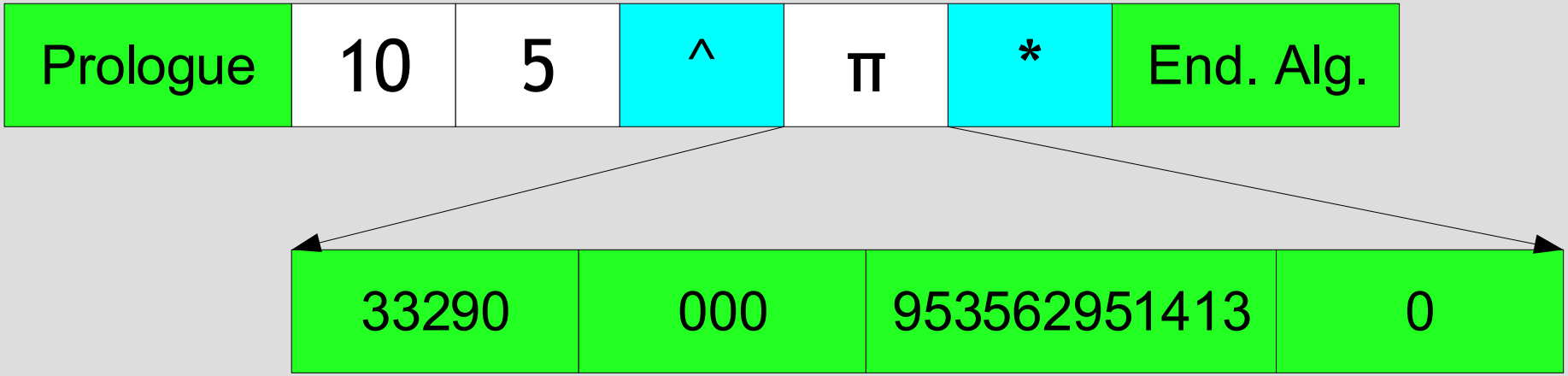


# Algebraic #02ADA



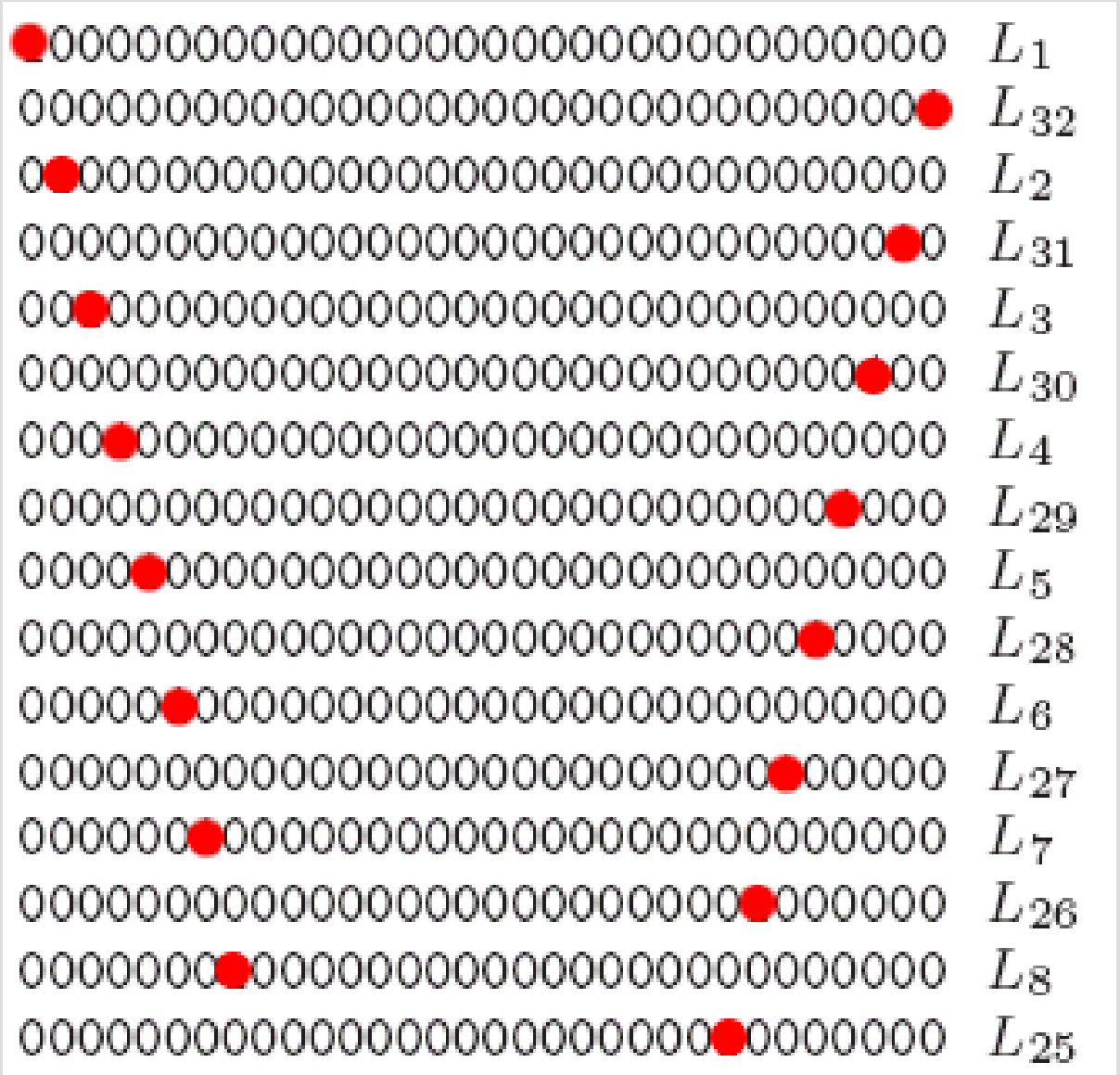
# I/O Zone

- IR in/out
- Timers
- Contrast
- Screen/Indicators
- Speed
  - 28S Only
- Row Driver Waveform
  - 28C Only

# Row Driver Waveform

- Maps logical lines to physical lines.
- Scrolling
  - Swap line-mappings, not data.
- Mirroring
  - Map the same logic line to many physical lines.
- Initialized at boot.
- Interpreted by software video driver.

# Row Driver Waveform

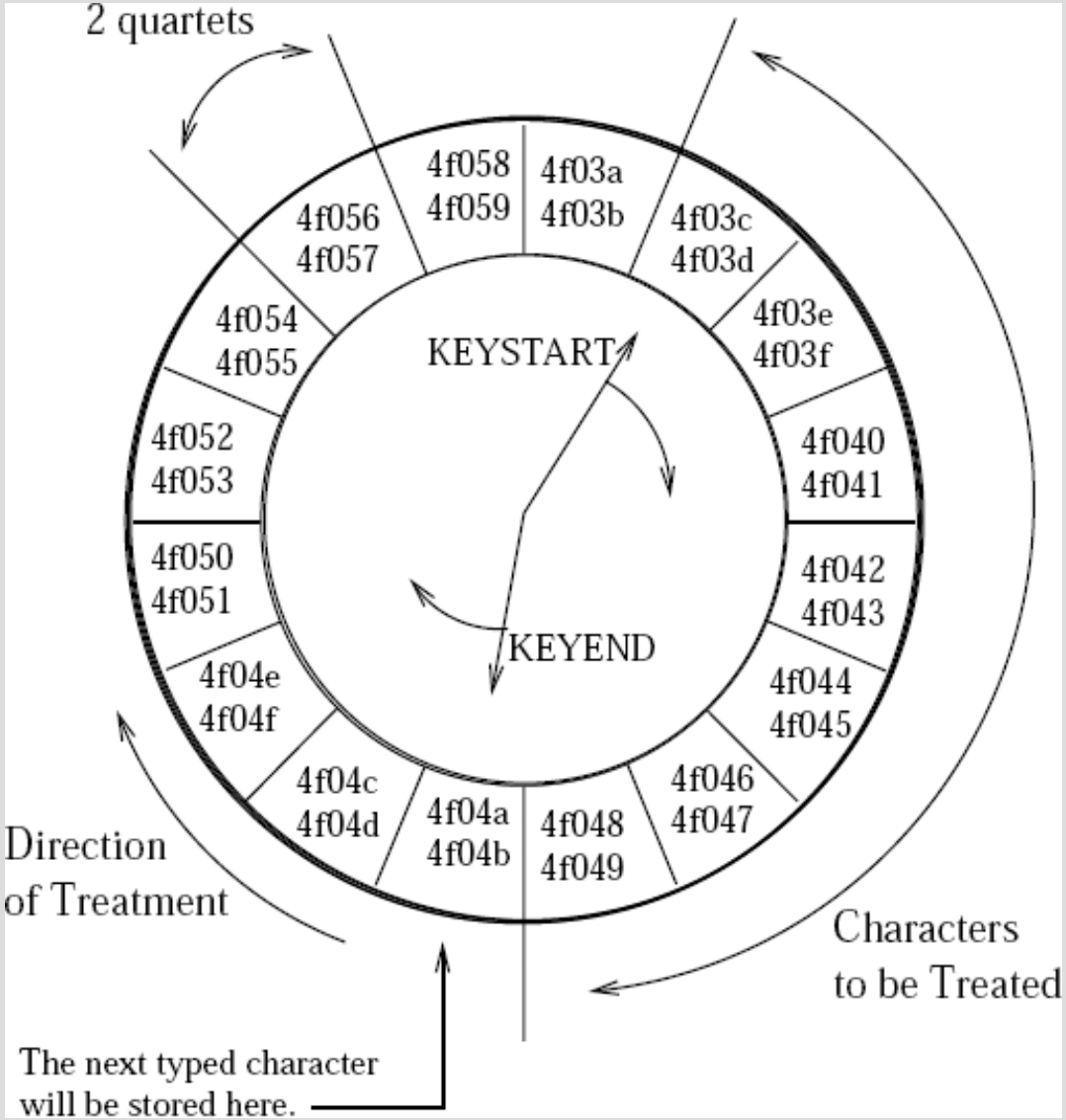


# RAM

- Polling
  - Background Processes Watch RAM
  - I/O-like Behavior
- Keyboard Buffer
- Flags
- Command-Line
- Stacks
- Temp Environment

# Keyboard Buffer

- Samples Keys
  - Not ASCII
- Clock
- KEYSTART
  - next to be handled
- KEYEND
  - next to be sampled



# Accessing Machine Language

- ML Program
  - is an Object Type (#02C96)
  - may not be created by the user.
- Bootstrapping
  - ASS
  - LASS

# LASS

- Takes as input an ML string.
- One character, one nybble.
- Assembles
  - ML String to ML Object
  - not Assembly String to ML Object
- Usage
  - Push string to stack.
  - LASS
  - Store resultant object to variable.

# INV.VID

# INV.VID

```
76C20   91C70   69C20   E5000   13310   334FD   2041F
87004   72203   4FD50   41F00   40470   10113   13114
21648   08C27   1531B   9C151   11771   33131   8BA9E
20010   9F20
```

- “76C2091C7...
- LASS
- `INV.VID' STO

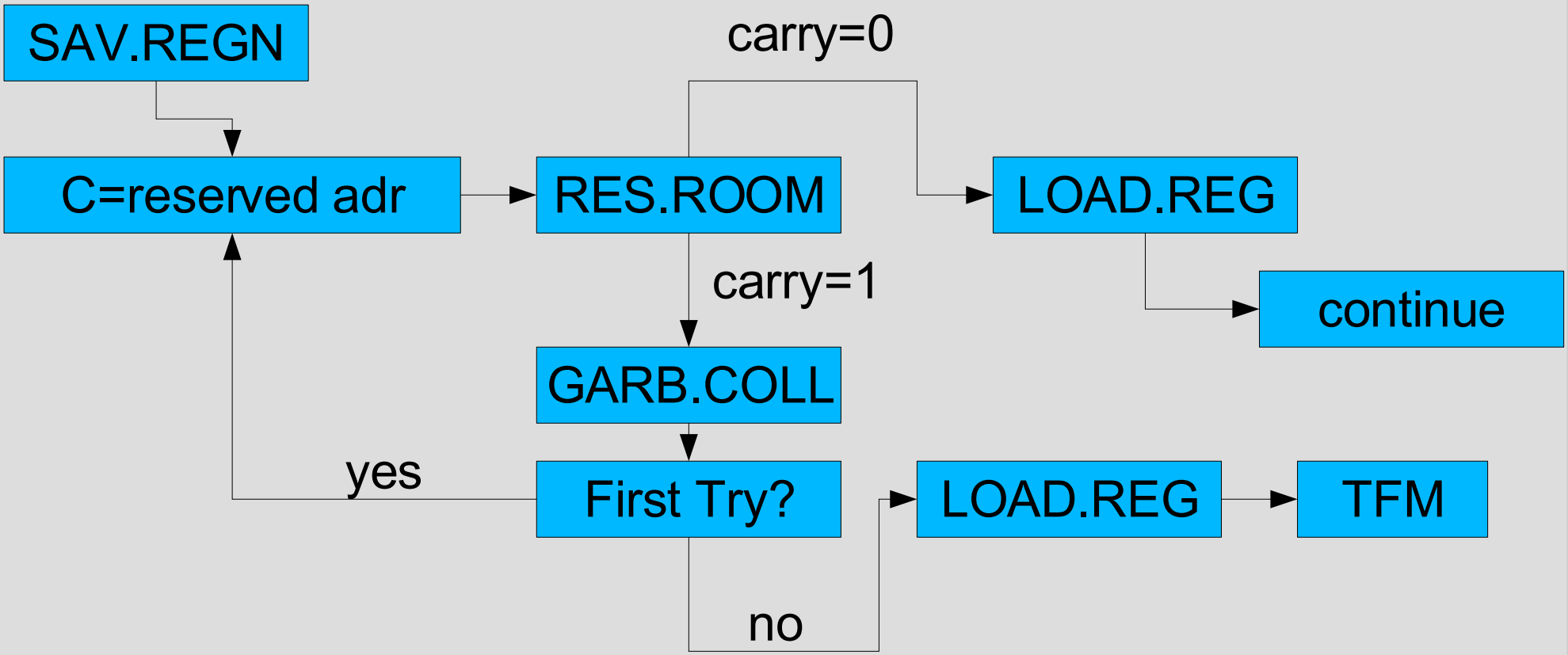
# Further Discoveries

- Search ROM
  - Strings Tables in Appendix
  - I/O or RAM addresses
- Systematic Disassembly
  - Disassembler Program
  - Dump to a Workstation

# Useful Routines

- SAV.REG
- LOAD.REG
- RES.ROOM
- GARB.COLL
  - Force Garbage Collection
- TFM
  - Too Few Memory
- ERROR
- BEEP

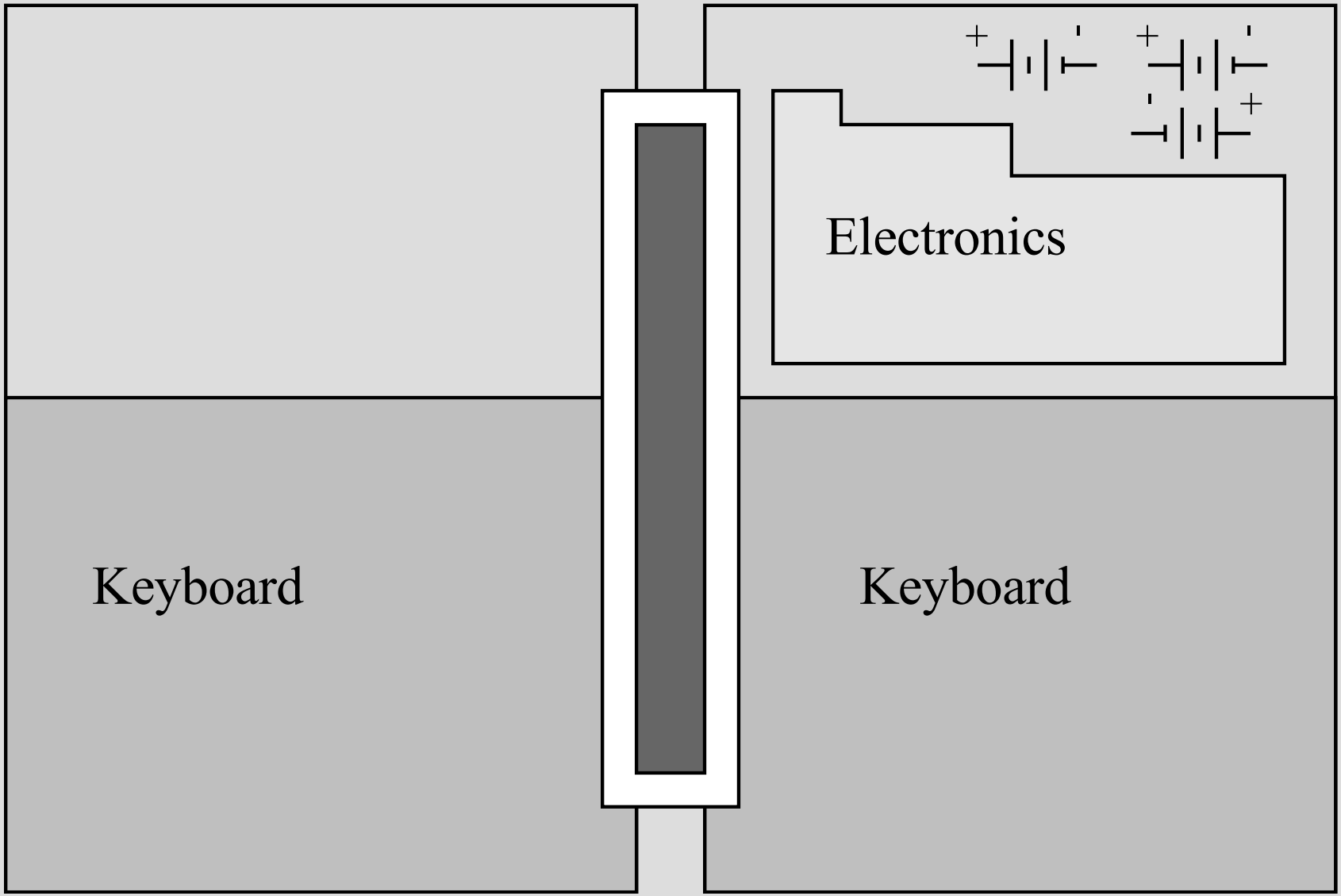
# Useful Routines



# Part 2: Hardware

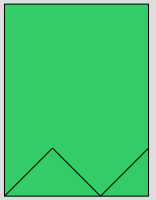
- Exterior Description
- Opening the Machine
- Interior Description
- Transformations
  - External Power Feed
  - Overclocking
  - Extended Memory
- The I/O Port
- Closing the Machine
- I/O Interfaces

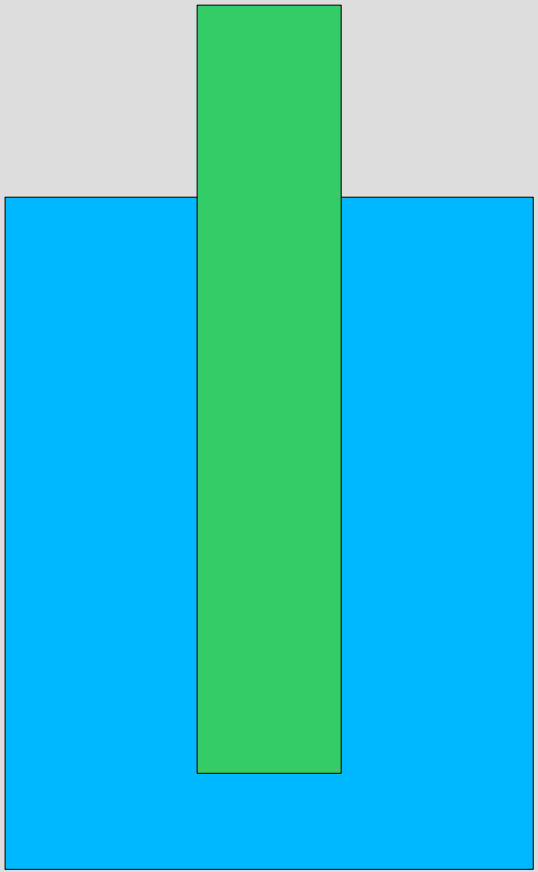
# Exterior Description

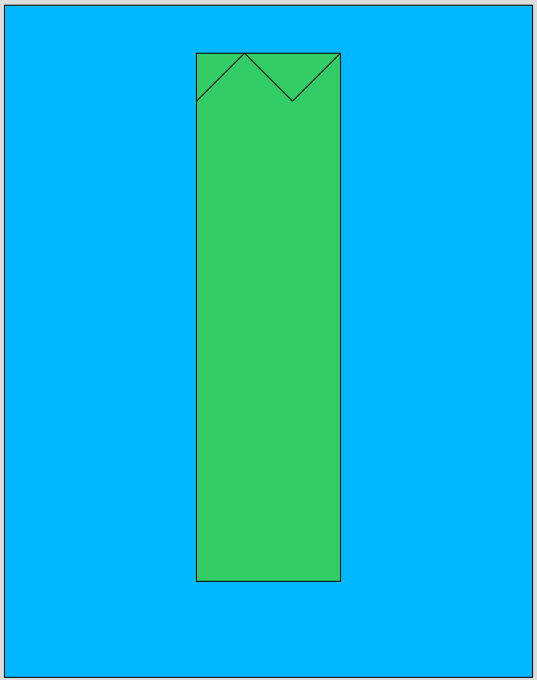


# Opening

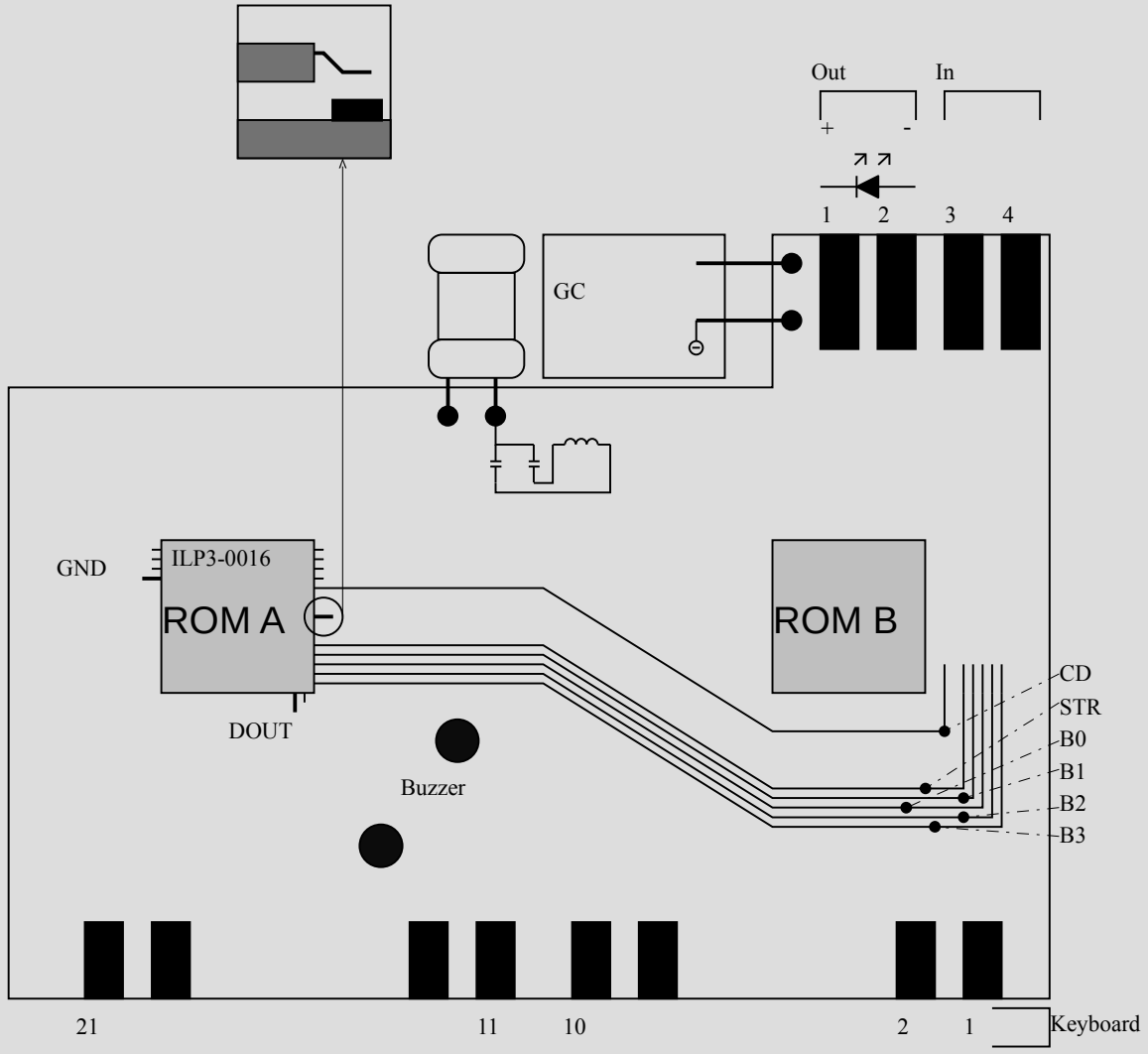
- No Screws!
- Gotta break some pins.







# Interior Description



# Transformations

- External Power Feed
- Overclocking
- Memory Upgrade

# Overclocking

- HP28C
  - Replace or Remove a Capacitor
  - Replace an Inductor
- HP28S
  - Overlocking in Software
  - SPEED Program

# Memory Upgrade

- HP71B Memory Module
- Installation
  - Cut Traces of Memory Bus
  - Patch in Upgrade Module

Educalc:

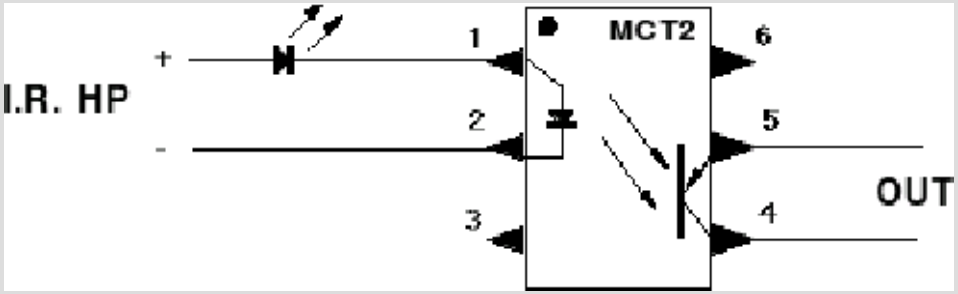
27953 Cabot Road
Laguna Niguel
CA 92677
U.S.A
Tel: 19-1-714-582-26-37

Module:

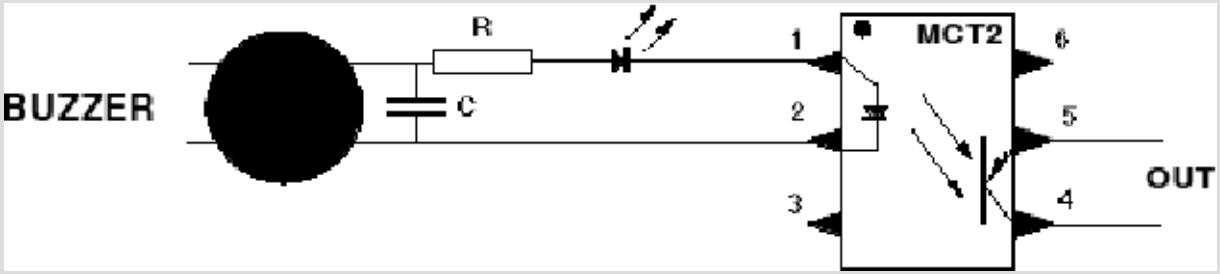
| | | |
|---|---|---|
| 64K RAM | #71-656B | $294.95 |
| 64K RAM | #71-656 | $149.95 |
| 4K RAM | #82-420 | $ 65.95 |

# I/O Ports

- Hack of the IR Led

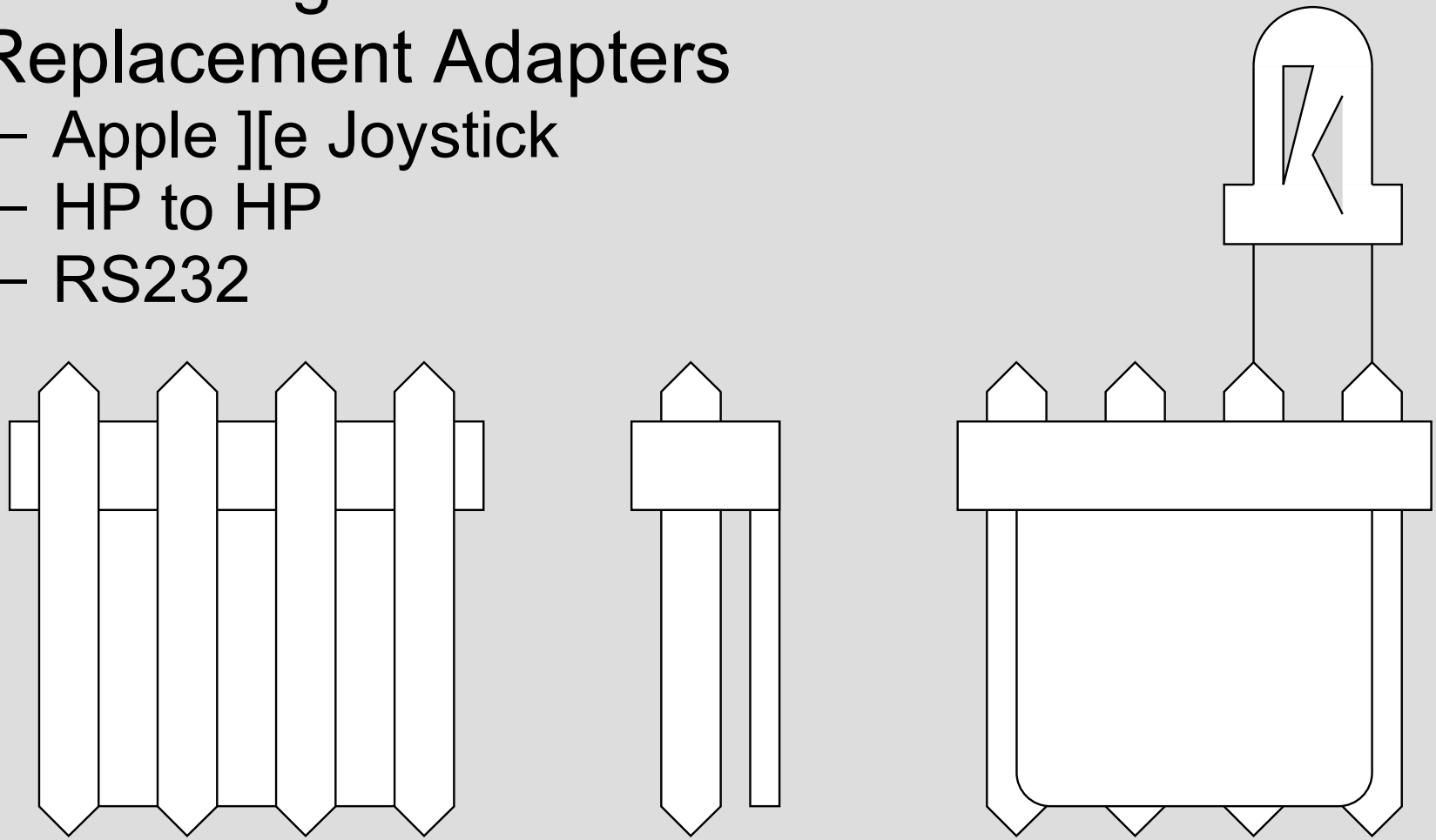



- Hack of the Buzzer



# I/O Ports

- IR Cartridge
- Replacement Adapters
  - Apple ][e Joystick
  - HP to HP
  - RS232



# HP28 Printer

- HP82240B



# Ideas!

- Add a Joystick
- Telephone Composer
  - Photocoupler and Relays
  - Provides click of a rotary phone.
  - Dial by counting digits, then waiting.
- Motor Control
- Robot
- Plotter

# Part 3: Appendices

- Machine Language
- SATURN Microprocessor
- SATURN Instructions
- Exhaustive List of Error Codes
- List of Objects and RPL Entry Points
- Library of Programs

# Epilogue

# HP28 Emulation

- Christoph Giesselink



# HP48 Series

- Memory Expansion
- IR I/O
- Serial Port
- Meta Kernel
  - Replacement OS




Photo by Heretiq

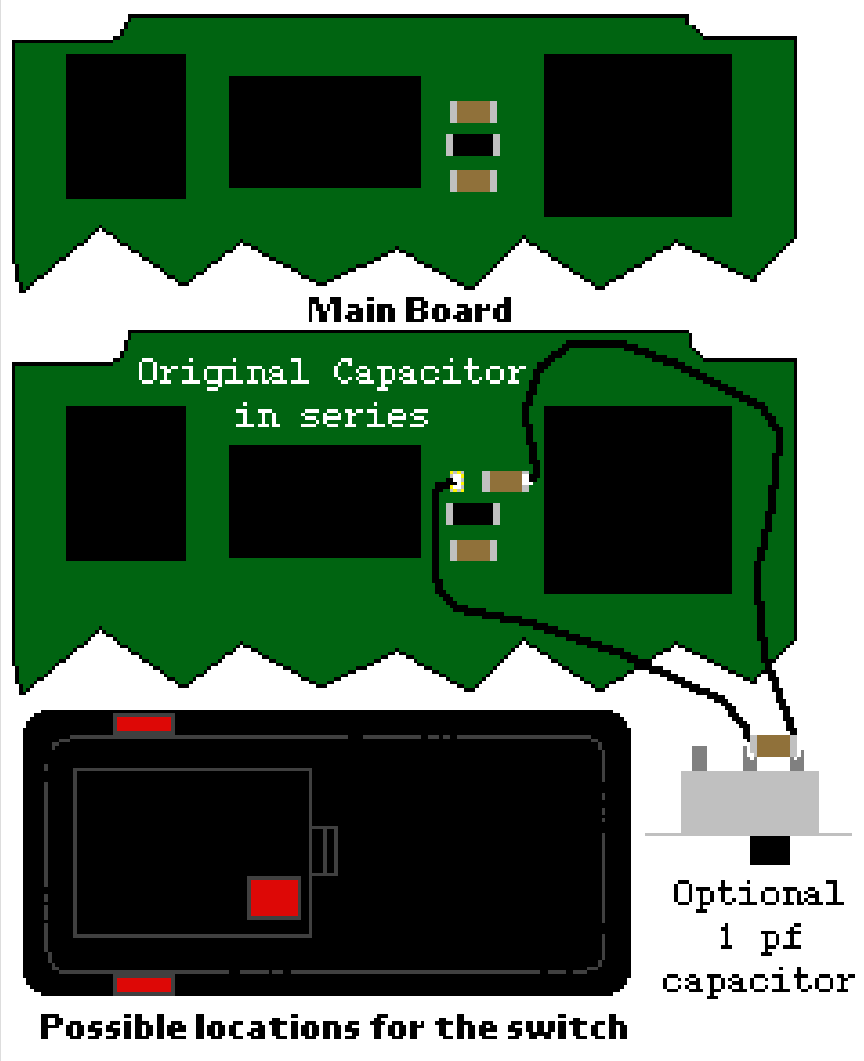
# HP49 Series

- SD Card Slot
- USB, IR, Serial
- ARM CPU
  - Emulates SATURN
- HPGCC
- Meta Kernel
  - Official OS




Photo by Nova dc

# TI Calculators







http://richfiles.solarbotics.net/

# Next Step: TI Nspire

- No ML Programming
- No Games
- No ROM Dump



# Questions?

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