# Computer Organization

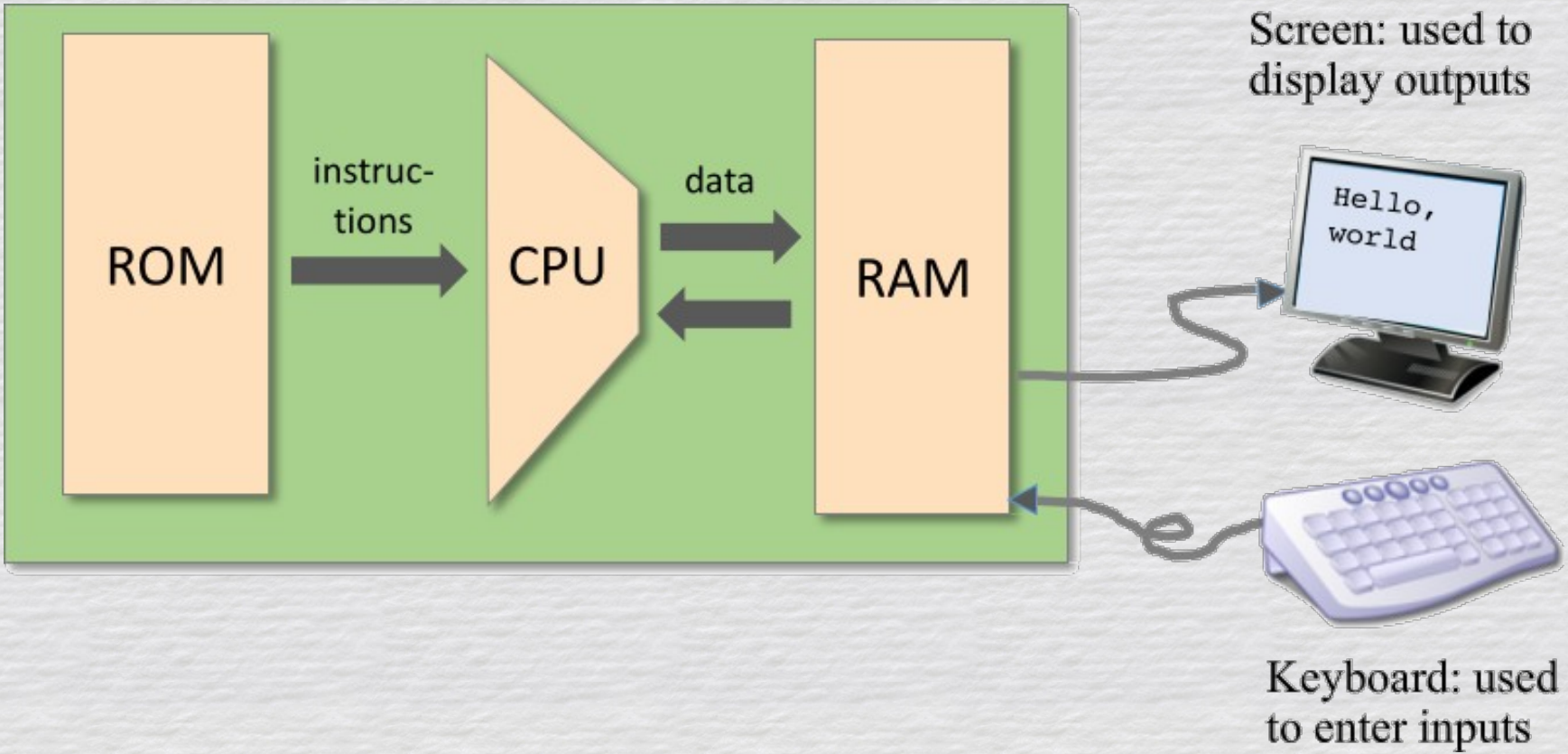
## HACK Input/Output

# Hack Instructions

- Now that we have gone over the entirety of the HACK assembly language's instructions, we can see how we utilize it to manipulate our computer's memory

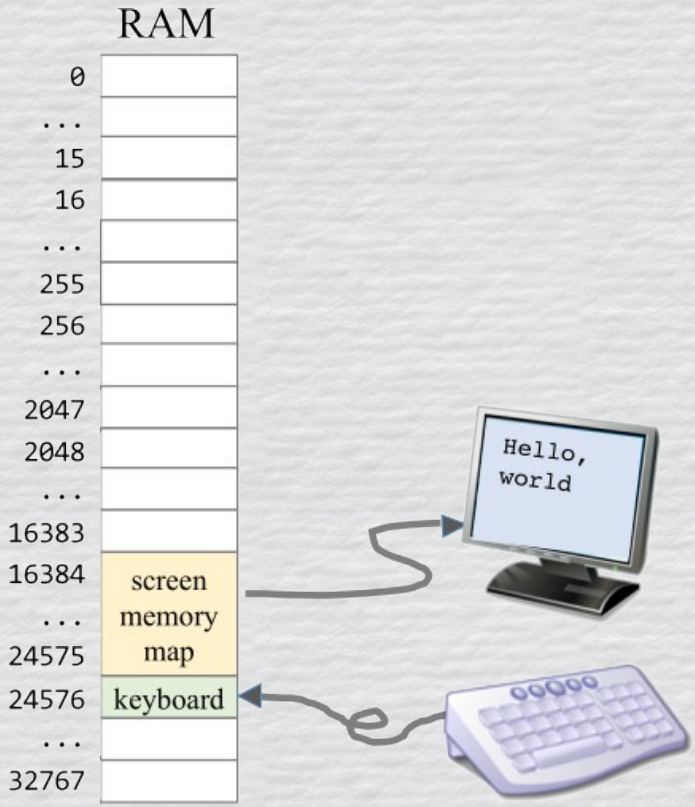
- This is broken down into 3 sections
  - RAM
  - Screen
  - Keyboard

# Hack System – Overview



# Hack Instructions

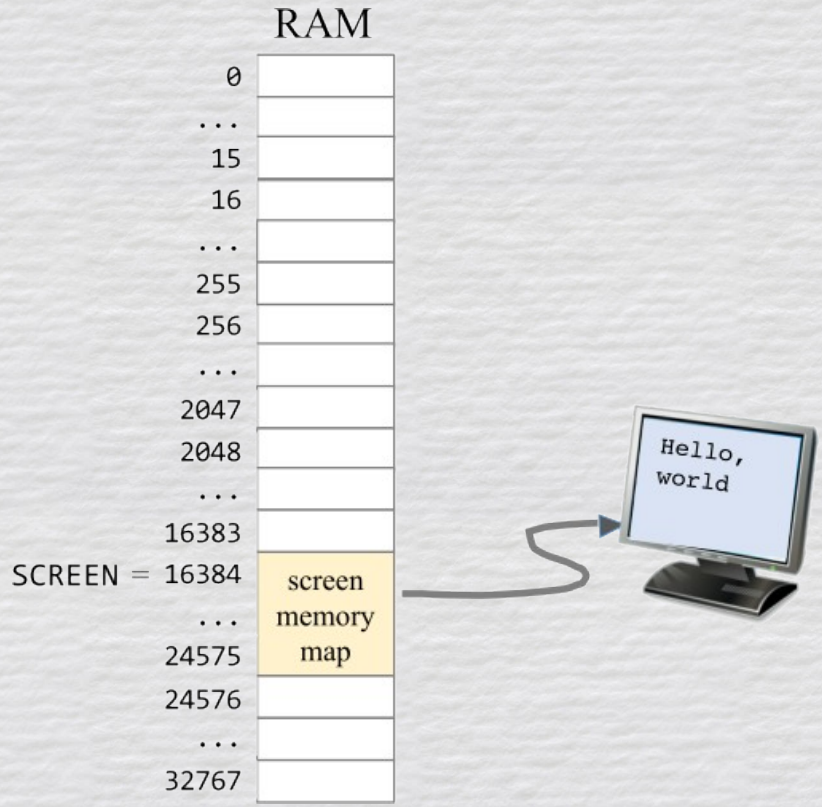
- RAM is derived from Chapter 3's **RAM16K** chip, so we will start with that chunk of memory to story data
- Following that, we have an 8K chunk of memory dedicated to the output of our **Screen**
- Finally, we have a single register directly after the screen to read in data from our **Keyboard**



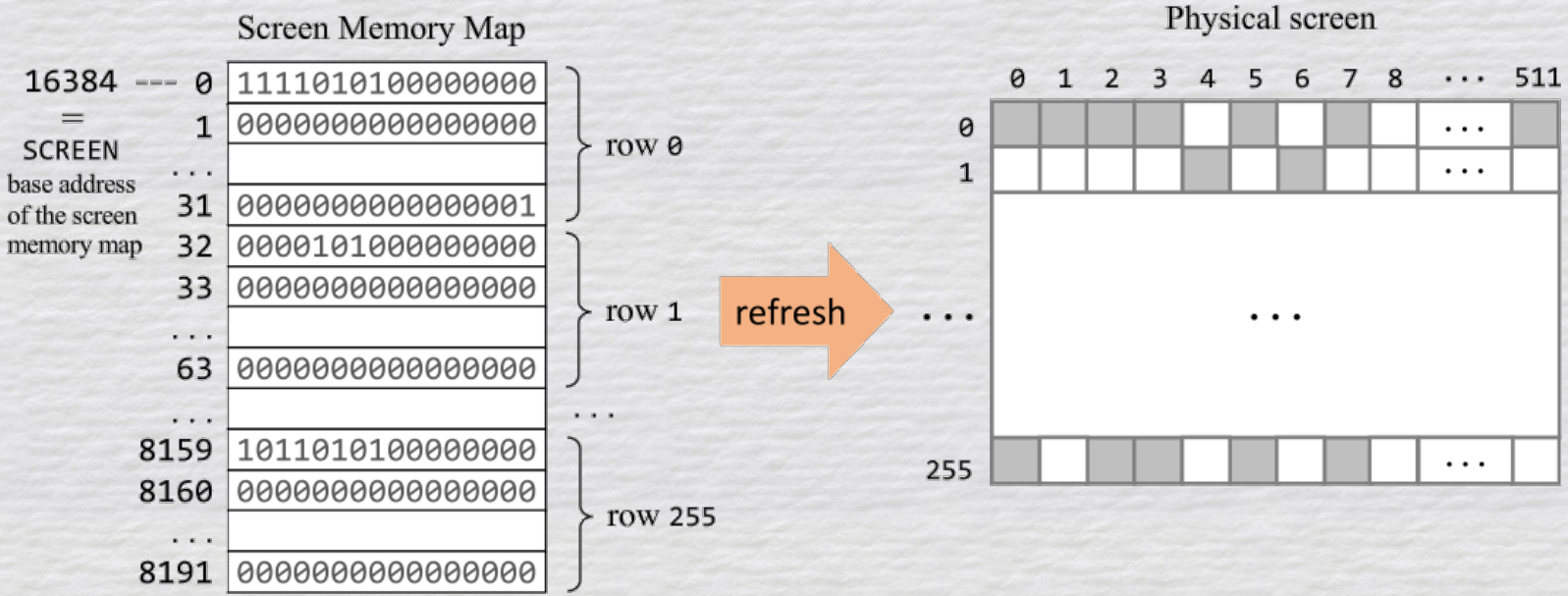
# Screen

- 8K memory bitmap used to display images via a black/white screen

- Starts at memory address 16384 which is known by the assembler as **SCREEN**



# Screen – Bitmap

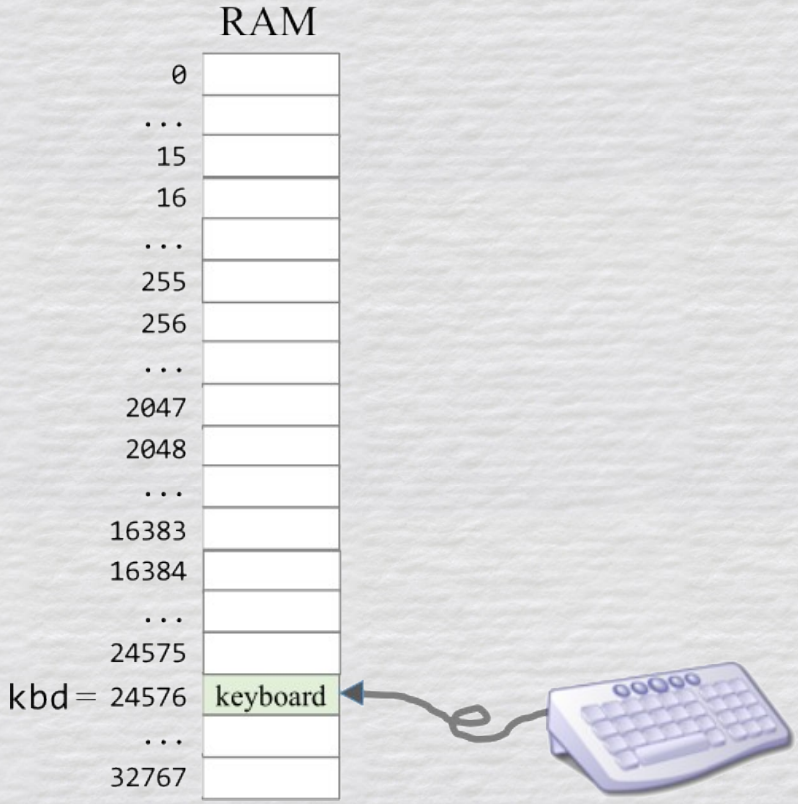



Mapping:

The pixel in location (*row*, *col*) in the physical screen is represented by the (*col* % 16)*th* bit in RAM address SCREEN + 32 * *row* + *col* / 16

# Screen

- Single register used to read data in from keyboard
- Resides directly after the screen block in a register known by the assembler as **KEYBOARD**



# Keyboard – Character Set

| key | code |
|---|---|
| (space) | 32 |
| ! | 33 |
| “ | 34 |
| # | 35 |
| $ | 36 |
| % | 37 |
| & | 38 |
| ‘ | 39 |
| ( | 40 |
| ) | 41 |
| * | 42 |
| + | 43 |
| , | 44 |
| - | 45 |
| . | 46 |
| / | 47 |

| key | code |
|---|---|
| 0 | 48 |
| 1 | 49 |
| … | … |
| 9 | 57 |

| key | code |
|---|---|
| : | 58 |
| ; | 59 |
| < | 60 |
| = | 61 |
| > | 62 |
| ? | 63 |
| @ | 64 |

| key | code |
|---|---|
| A | 65 |
| B | 66 |
| C | … |
| … | … |
| Z | 90 |

| key | code |
|---|---|
| [ | 91 |
| \ | 92 |
| ] | 93 |
| ^ | 94 |
| _ | 95 |
| ` | 96 |

| key | code |
|---|---|
| a | 97 |
| b | 98 |
| c | 99 |
| … | … |
| z | 122 |

| key | code |
|---|---|
| { | 123 |
| \| | 124 |
| } | 125 |
| ~ | 126 |

(Subset of Unicode)

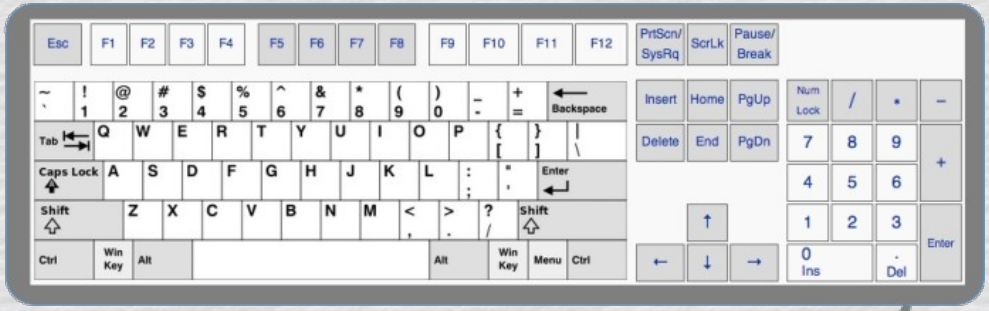
| key | code |
|---|---|
| newline | 128 |
| backspace | 129 |
| left arrow | 130 |
| up arrow | 131 |
| right arrow | 132 |
| down arrow | 133 |
| home | 134 |
| end | 135 |
| Page up | 136 |
| Page down | 137 |
| insert | 138 |
| delete | 139 |
| esc | 140 |
| f1 | 141 |
| . . . | . . . |
| f12 | 152 |

# Keyboard – No Input

RAM

24576 = KBD

base address of the keyboard memory map




| key | code |
|---|---|
| (space) | 32 |
| ! | 33 |
| “ | 34 |
| # | 35 |
| $ | 36 |
| % | 37 |
| & | 38 |
| ‘ | 39 |
| ( | 40 |
| ) | 41 |
| * | 42 |
| + | 43 |
| , | 44 |
| - | 45 |
| . | 46 |
| / | 47 |

| key | code |
|---|---|
| 0 | 48 |
| 1 | 49 |
| … | … |
| 9 | 57 |

| key | code |
|---|---|
| : | 58 |
| ; | 59 |
| < | 60 |
| = | 61 |
| > | 62 |
| ? | 63 |
| @ | 64 |

| key | code |
|---|---|
| A | 65 |
| B | 66 |
| C | … |
| … | … |
| Z | 90 |

| key | code |
|---|---|
| [ | 91 |
| \ | 92 |
| ] | 93 |
| ^ | 94 |
| _ | 95 |
| ` | 96 |

| key | code |
|---|---|
| a | 97 |
| b | 98 |
| c | 99 |
| … | … |
| z | 122 |

| key | code |
|---|---|
| { | 123 |
| \| | 124 |
| } | 125 |
| ~ | 126 |

(Subset of Unicode)

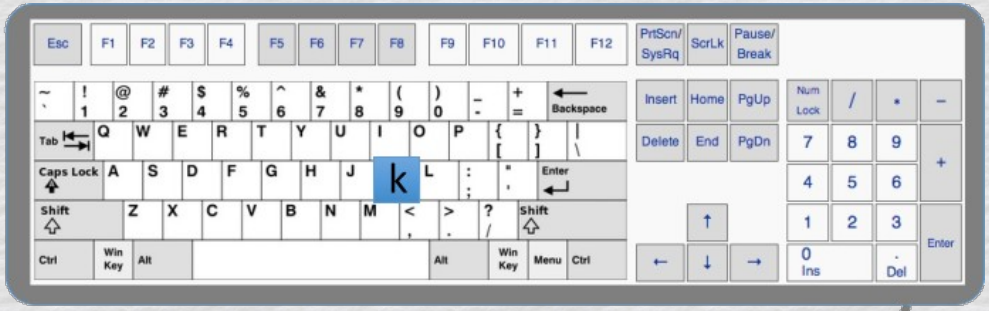
| key | code |
|---|---|
| newline | 128 |
| backspace | 129 |
| left arrow | 130 |
| up arrow | 131 |
| right arrow | 132 |
| down arrow | 133 |
| home | 134 |
| end | 135 |
| Page up | 136 |
| Page down | 137 |
| insert | 138 |
| delete | 139 |
| esc | 140 |
| f1 | 141 |
| … | … |
| f12 | 152 |

# Keyboard – Character

RAM

24576 = 0000000001001011

KBD
base address
of the keyboard
memory map




code('k') = 75

| key | code |
|---|---|
| (space) | 32 |
| ! | 33 |
| “ | 34 |
| # | 35 |
| $ | 36 |
| % | 37 |
| & | 38 |
| ‘ | 39 |
| ( | 40 |
| ) | 41 |
| * | 42 |
| + | 43 |
| , | 44 |
| - | 45 |
| . | 46 |
| / | 47 |

| key | code |
|---|---|
| 0 | 48 |
| 1 | 49 |
| … | … |
| 9 | 57 |

| key | code |
|---|---|
| : | 58 |
| ; | 59 |
| < | 60 |
| = | 61 |
| > | 62 |
| ? | 63 |
| @ | 64 |

| key | code |
|---|---|
| A | 65 |
| B | 66 |
| C | … |
| … | … |
| Z | 90 |

| key | code |
|---|---|
| [ | 91 |
| \ | 92 |
| ] | 93 |
| ^ | 94 |
| _ | 95 |
| ` | 96 |

| key | code |
|---|---|
| a | 97 |
| b | 98 |
| c | 99 |
| … | … |
| z | 122 |

| key | code |
|---|---|
| { | 123 |
| \| | 124 |
| } | 125 |
| ~ | 126 |

(Subset of Unicode)

| key | code |
|---|---|
| newline | 128 |
| backspace | 129 |
| left arrow | 130 |
| up arrow | 131 |
| right arrow | 132 |
| down arrow | 133 |
| home | 134 |
| end | 135 |
| Page up | 136 |
| Page down | 137 |
| insert | 138 |
| delete | 139 |
| esc | 140 |
| f1 | 141 |
| … | … |
| f12 | 152 |

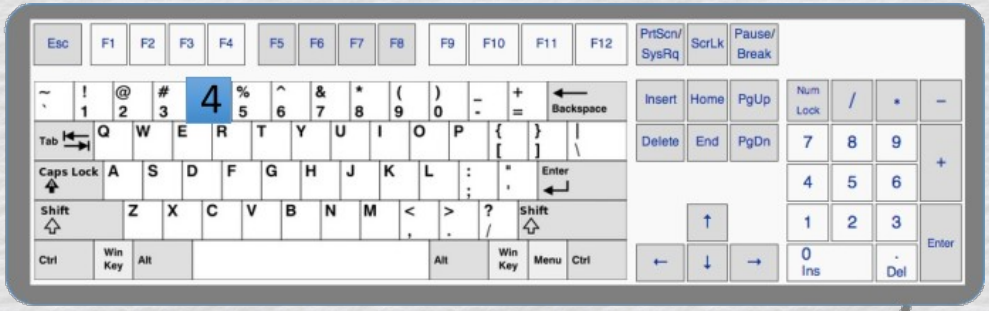
# Keyboard – Number

RAM

24576 = KBD

0000000000110100

base address of the keyboard memory map




code('4') = 52

| key | code |
|---|---|
| (space) | 32 |
| ! | 33 |
| " | 34 |
| # | 35 |
| $ | 36 |
| % | 37 |
| & | 38 |
| ' | 39 |
| ( | 40 |
| ) | 41 |
| * | 42 |
| + | 43 |
| , | 44 |
| - | 45 |
| . | 46 |
| / | 47 |

| key | code |
|---|---|
| 0 | 48 |
| 1 | 49 |
| … | … |
| 9 | 57 |

| key | code |
|---|---|
| : | 58 |
| ; | 59 |
| < | 60 |
| = | 61 |
| > | 62 |
| ? | 63 |
| @ | 64 |

| key | code |
|---|---|
| A | 65 |
| B | 66 |
| C | … |
| … | … |
| Z | 90 |

| key | code |
|---|---|
| [ | 91 |
| \ | 92 |
| ] | 93 |
| ^ | 94 |
| _ | 95 |
| ` | 96 |

| key | code |
|---|---|
| a | 97 |
| b | 98 |
| c | 99 |
| … | … |
| z | 122 |

| key | code |
|---|---|
| { | 123 |
| \| | 124 |
| } | 125 |
| ~ | 126 |

(Subset of Unicode)

| key | code |
|---|---|
| newline | 128 |
| backspace | 129 |
| left arrow | 130 |
| up arrow | 131 |
| right arrow | 132 |
| down arrow | 133 |
| home | 134 |
| end | 135 |
| Page up | 136 |
| Page down | 137 |
| insert | 138 |
| delete | 139 |
| esc | 140 |
| f1 | 141 |
| … | … |
| f12 | 152 |

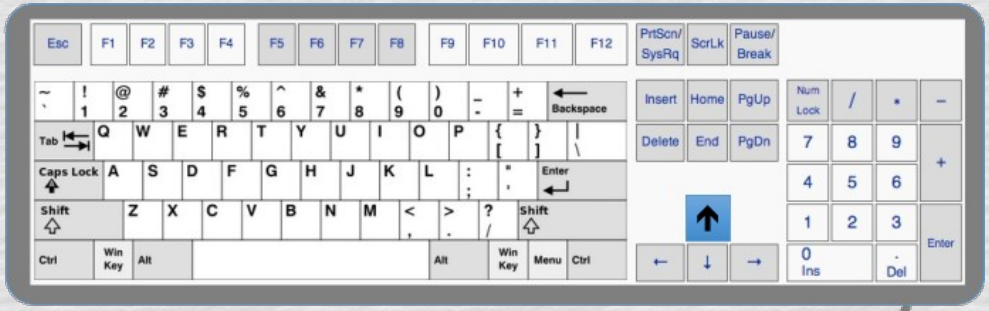
# Keyboard – Special Character

RAM

24576 = KBD

0000000010000011

base address of the keyboard memory map



code( '↑' ) = 131

| key | code |
|---|---|
| (space) | 32 |
| ! | 33 |
| “ | 34 |
| # | 35 |
| $ | 36 |
| % | 37 |
| & | 38 |
| ‘ | 39 |
| ( | 40 |
| ) | 41 |
| * | 42 |
| + | 43 |
| , | 44 |
| - | 45 |
| . | 46 |
| / | 47 |

| key | code |
|---|---|
| 0 | 48 |
| 1 | 49 |
| … | … |
| 9 | 57 |

| key | code |
|---|---|
| : | 58 |
| ; | 59 |
| < | 60 |
| = | 61 |
| > | 62 |
| ? | 63 |
| @ | 64 |

| key | code |
|---|---|
| A | 65 |
| B | 66 |
| C | … |
| … | … |
| Z | 90 |

| key | code |
|---|---|
| [ | 91 |
| \ | 92 |
| ] | 93 |
| ^ | 94 |
| _ | 95 |
| ` | 96 |

| key | code |
|---|---|
| a | 97 |
| b | 98 |
| c | 99 |
| … | … |
| z | 122 |

| key | code |
|---|---|
| { | 123 |
| \| | 124 |
| } | 125 |
| ~ | 126 |

(Subset of Unicode)

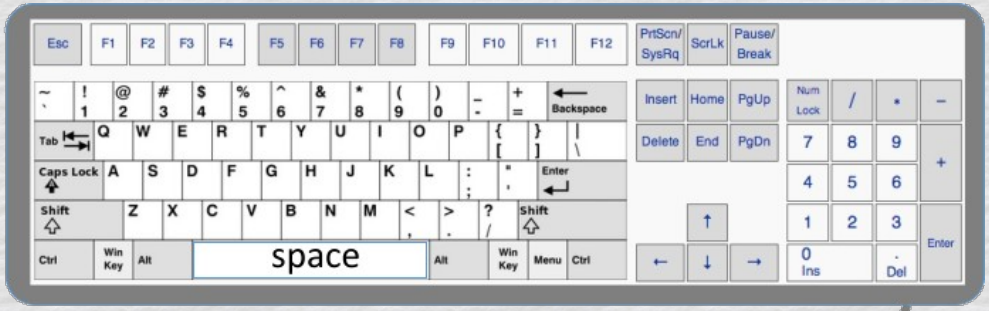
| key | code |
|---|---|
| newline | 128 |
| backspace | 129 |
| left arrow | 130 |
| up arrow | 131 |
| right arrow | 132 |
| down arrow | 133 |
| home | 134 |
| end | 135 |
| Page up | 136 |
| Page down | 137 |
| insert | 138 |
| delete | 139 |
| esc | 140 |
| f1 | 141 |
| . . . | . . . |
| f12 | 152 |

# Keyboard – Space

RAM

24576 = 0000000000100000

KBD base address of the keyboard memory map




code(' ') = 32

| key | code |
|---|---|
| (space) | 32 |
| ! | 33 |
| " | 34 |
| # | 35 |
| $ | 36 |
| % | 37 |
| & | 38 |
| ' | 39 |
| ( | 40 |
| ) | 41 |
| * | 42 |
| + | 43 |
| , | 44 |
| - | 45 |
| . | 46 |
| / | 47 |

| key | code |
|---|---|
| 0 | 48 |
| 1 | 49 |
| … | … |
| 9 | 57 |

| key | code |
|---|---|
| : | 58 |
| ; | 59 |
| < | 60 |
| = | 61 |
| > | 62 |
| ? | 63 |
| @ | 64 |

| key | code |
|---|---|
| A | 65 |
| B | 66 |
| C | … |
| … | … |
| Z | 90 |

| key | code |
|---|---|
| [ | 91 |
| \ | 92 |
| ] | 93 |
| ^ | 94 |
| _ | 95 |
| ` | 96 |

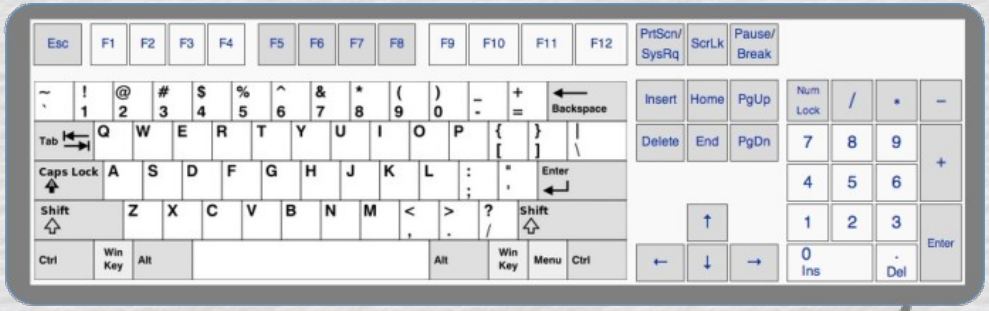
| key | code |
|---|---|
| a | 97 |
| b | 98 |
| c | 99 |
| … | … |
| z | 122 |

| key | code |
|---|---|
| { | 123 |
| \| | 124 |
| } | 125 |
| ~ | 126 |

(Subset of Unicode)

| key | code |
|---|---|
| newline | 128 |
| backspace | 129 |
| left arrow | 130 |
| up arrow | 131 |
| right arrow | 132 |
| down arrow | 133 |
| home | 134 |
| end | 135 |
| Page up | 136 |
| Page down | 137 |
| insert | 138 |
| delete | 139 |
| esc | 140 |
| f1 | 141 |
| … | … |
| f12 | 152 |

# Keyboard – Examples




| key | code |
|---|---|
| (space) | 32 |
| ! | 33 |
| " | 34 |
| # | 35 |
| $ | 36 |
| % | 37 |
| & | 38 |
| ' | 39 |
| ( | 40 |
| ) | 41 |
| * | 42 |
| + | 43 |
| , | 44 |
| - | 45 |
| . | 46 |
| / | 47 |

| key | code |
|---|---|
| 0 | 48 |
| 1 | 49 |
| … | … |
| 9 | 57 |
| : | 58 |
| ; | 59 |
| < | 60 |
| = | 61 |
| > | 62 |
| ? | 63 |
| @ | 64 |

| key | code |
|---|---|
| A | 65 |
| B | 66 |
| C | … |
| … | … |
| Z | 90 |
| [ | 91 |
| \ | 92 |
| ] | 93 |
| ^ | 94 |
| _ | 95 |
| ` | 96 |

| key | code |
|---|---|
| a | 97 |
| b | 98 |
| c | 99 |
| … | … |
| z | 122 |
| { | 123 |
| \| | 124 |
| } | 125 |
| ~ | 126 |

(Subset of Unicode)

| key | code |
|---|---|
| newline | 128 |
| backspace | 129 |
| left arrow | 130 |
| up arrow | 131 |
| right arrow | 132 |
| down arrow | 133 |
| home | 134 |
| end | 135 |
| Page up | 136 |
| Page down | 137 |
| insert | 138 |
| delete | 139 |
| esc | 140 |
| f1 | 141 |
| … | … |
| f12 | 152 |

Examples:

```
// Set D to the character code of
// the currently pressed key
@KBD
D=M
```

```
// If the currently pressed key is 'q', goto END
@KBD
D=M
@113   // 'q'
D=D-A
@END
D;JEQ
```