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Input-Output and Assembler

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Lab Work

- Objectives:
  - Write a Hack assembly program for handling keyboard input and screen output.
  - Practice how to trace the execution of a Hack assembly language program.
  - Practice how to manually translate the Hack assembly program to binary machine language.
  - Develop an assembler using C language. (Optional)

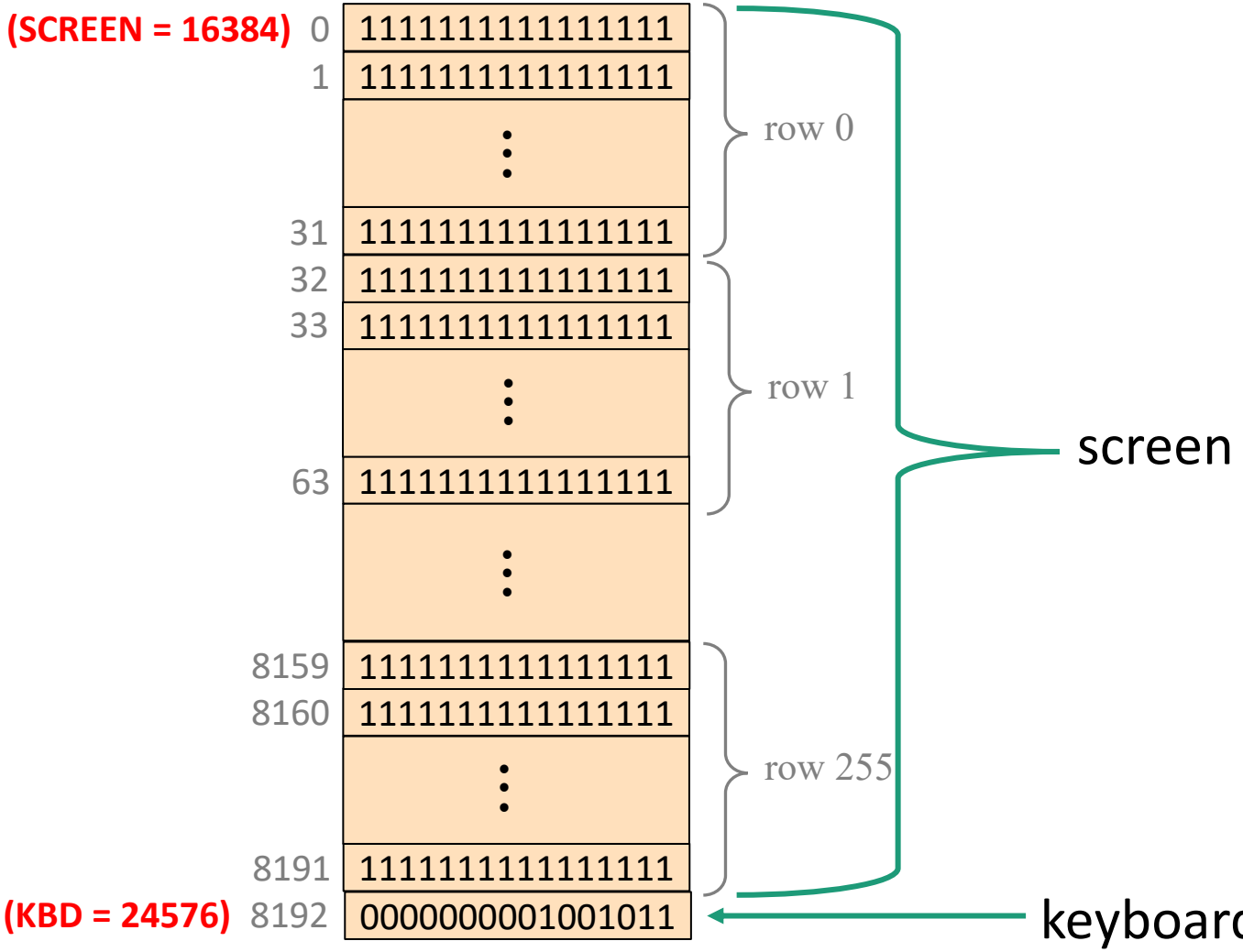
Task 1: fill a rectangle interactively

- `Fill`: a simple interactive program
  - Runs an infinite loop that listens to the keyboard input.
  - When a key is pressed (any key), the program blackens the screen,i.e. writes "black" in every pixel;
  - the screen should remain fully black as long as the key is pressed.
  - When no key is pressed, the program clears the screen, i.e. write "white" in every pixel;
  - the screen should remain fully clear as long as no key is pressed.

Task 1: Fill a Rectangle Interactively

- Implementation strategy
  - Listen to the keyboard
  - To blacken / clear the screen, write code that fills the entire screen memory map with either “white” or “black” pixels
  - Accessing the memory requires working with pointers
  - Hack computer is slow!!!
- Testing
  - Select “no animation”
  - Manual testing (no test scripts).

Task 1: Hints


(SCREEN = 16384)
0
1
31
32
33
63
8159
8160
8191
(KBD = 24576)
8192
1111111111111111
0000000001001011
row 0
row 1
row 255
screen
keyboard
scan-code of 'k' = 75

Task 2 – Trace Program Execution

```
@4
D=A
@R0
M=D
@R0
D=M
@n
M=D
@i
M=0
@sum
M=0
```

```
(LOOP)
 @i
 D=M
 @n
 D=D-M
 @STOP
 D;JGT
 @sum
 D=M
 @i
 D=D+M
 @sum
 M=D
 @i
 M=M+1
 @LOOP
 0;JMP
```

```
(STOP)
 @sum
 D=M
 @R1
 M=D
(END)
 @END
 0;JMP
```

Question:

Derive the value of RAM[1] after the execution of this piece of code.

Task 3 - Manually Translate Assembly Code

- Translate the symbolic assembly code to binary code.
  - **Add**.asm: Add two numbers, `// RAM[0] = 2 + 3`
  - Max.asm: `//RAM[2] = max(RAM[0],RAM[1])`
  - Rectangle.asm `//Draw a rectangle`

- You may find the binary code by choosing “Bin” option in “CPU Emulator”, but the objective of this lab is to **manually** convert the assembly code to binary code.

Task 3 - Test program: **Add**

Add.asm

```
// Computes RAM[0] = 2 + 3

@2
D=A
@3
D=D+A
@0
M=D
```

<u>Basic things to handle:</u>

- White space
- Instructions

Task 3 - Test program: **Max**

Max.asm

```
// Computes RAM[2] = max(RAM[0],RAM[1])

   @R0
   D=M           // D = RAM[0]
   @R1
   D=D-M         // D = RAM[0] - RAM[1]
   @OUTPUT_RAM0
   D;JGT         // if D>0 goto output RAM[0]

   // Output RAM[1]
   @R1
   D=M
   @R2
   M=D           // RAM[2] = RAM[1]
   @END
   0;JMP

(OUTPUT_RAM0)
   @R0
   D=M
   @R2
   M=D           // RAM[2] = RAM[0]

(END)
   @END
   0;JMP
```

with labels

MaxL.asm

```
// Symbol-less version

   @0
   D=M           // D = RAM[0]
   @1
   D=D-M         // D = RAM[0] - RAM[1]
   @12
   D;JGT         // if D>0 goto output RAM[0]

   // Output RAM[1]
   @1
   D=M
   @2
   M=D           // RAM[2] = RAM[1]
   @16
   0;JMP

   @0
   D=M
   @2
   M=D           // RAM[2] = RAM[0]

   @16
   0;JMP
```

without labels

Task 3 - Test program: **Rectangle**

Rectangle.asm

```
// Rectangle.asm

   @R0
   D=M
   @n
   M=D  // n = RAM[0]

   @i
   M=0  // i = 0

   @SCREEN
   D=A
   @address
   M=D  // base address of Hack
    screen

(LOOP)
   @i
   D=M
   @n
   D=D-M
   @END
   D;JGT  // if i>n goto END
```

with symbols

RectangleL.asm

```
// Symbol-less version

   @0
   D=M
   @16
   M=D   // n = RAM[0]

   @17
   M=0   // i = 0

   @16384
   D=A
   @18
   M=D   // base address of Hack screen

   @17
   D=M
   @16
   D=D-M
   @27
   D;JGT  // if i>n goto END
```

without symbols

Task 3 - Test program: **Rectangle**

Rectangle.asm

```
   @addr
   A=M
   M=-1  //RAM[addr]=1111111111111111

   @i
   M=M+1  // i = i + 1

   @32
   D=A   // D = 32
   @addr
   M=D+M  // addr = addr + 32
   @LOOP
   0;JMP  // goto LOOP

(END)
   @END   // progra
   0;JMP  // infinite loop
```

with symbols

RectangleL.asm

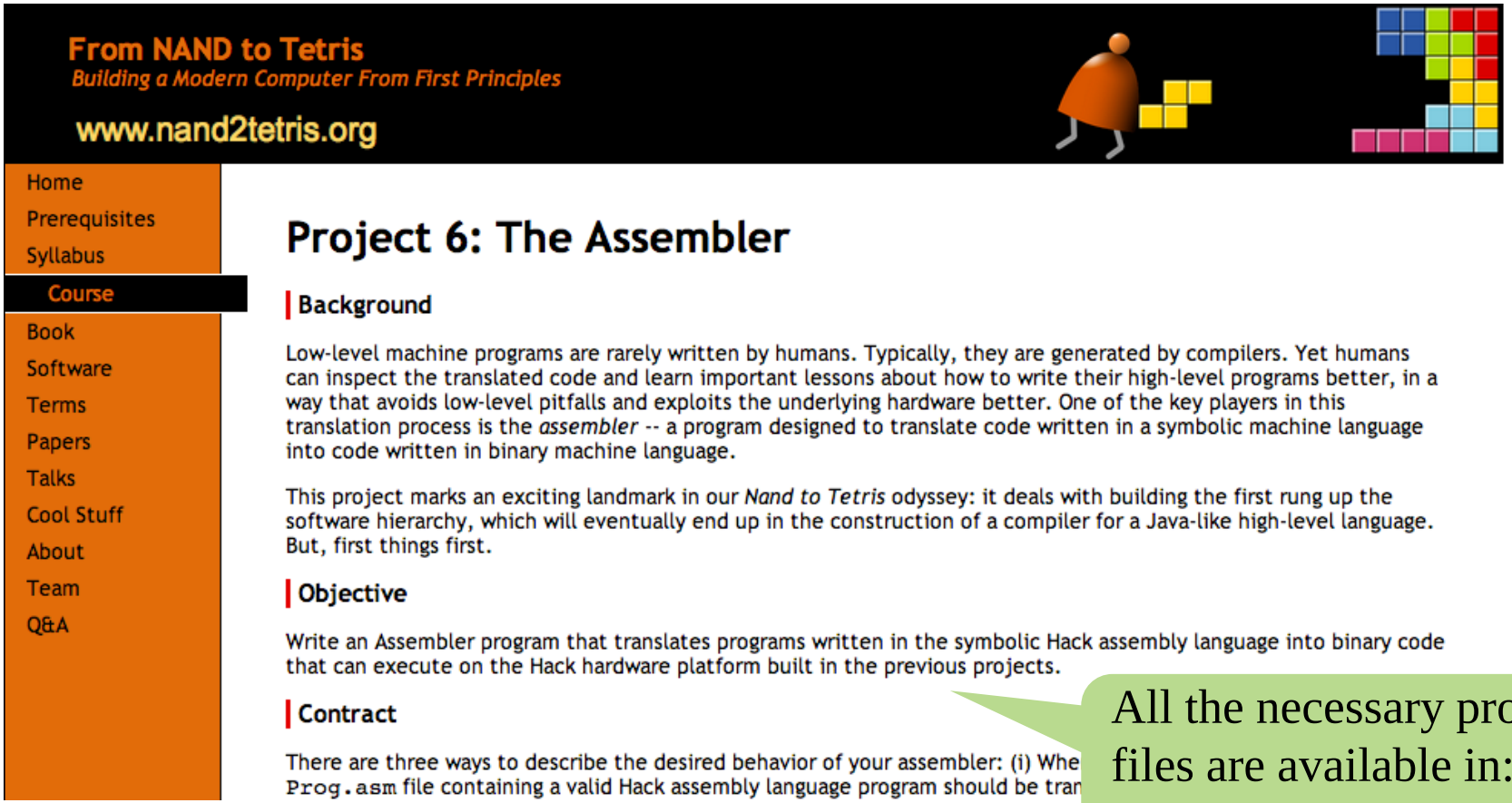
```
@16
A=M
M=-1  //RAM[addr]=1111111111111111

@18
M=M+1  // i = i + 1

@32
D=A   // D = 32
@16
M=D+M  // addr = addr + 32
@10
0;JMP  // goto LOOP


@27   // progra
0;JMP  // infinite loop
```

without symbols

Task 4 - Develop an Assembler (Optional)

- Develop an assembler using C language.
- Follow the modules defined in Page 35-37, e.g.
  - Parser module
  - Code module
  - SymbolTable module
- You may start with a symbol-free version first.

Project Resources



All the necessary project files are available in:

nand2tetris / projects / 06

Acknowlegement

- This set of lecture notes are based on the lecture notes provided by Noam Nisam / Shimon Schocken.
- You may find more information on: www.nand2tetris.org.