# Course overview

*Introduction to Computer*

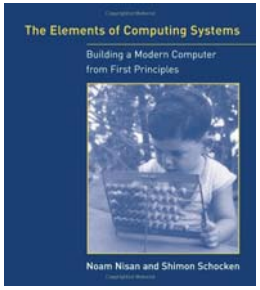
*Yung-Yu Chuang*

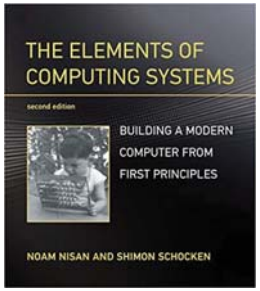
*with slides by Nisan & Schocken (www.nand2tetris.org)*

## Logistics

- **Meeting time**: 9:10am-12:00pm, Tuesday
- **Instructor**: 莊永裕 Yung-Yu Chuang
- **Webpage**: http://www.csie.ntu.edu.tw/~cyy/introcs

## Textbook




*The Elements of Computing Systems*, Noam Nisan, Shimon Schocken, MIT Press

Nand2Tetris on coursera

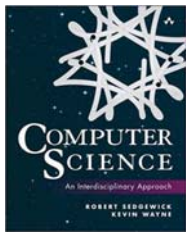
Nand2Tetris2 on coursera

## References (TOY)

**Princeton's Introduction to CS,** http://www.cs.princeton.edu/introcs/java/60machine/

http://www.cs.princeton.edu/introcs/java/70circuits/

Coursera course

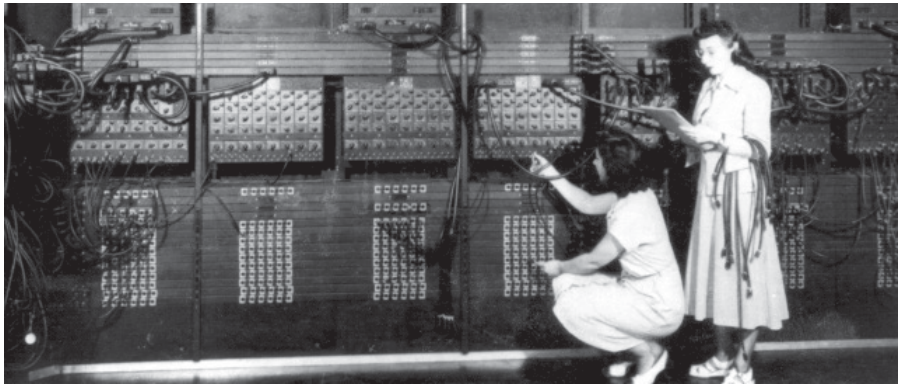



Computer Science: An Interdisciplinary Approach. Robert Sedgewick, Kevin Wayne

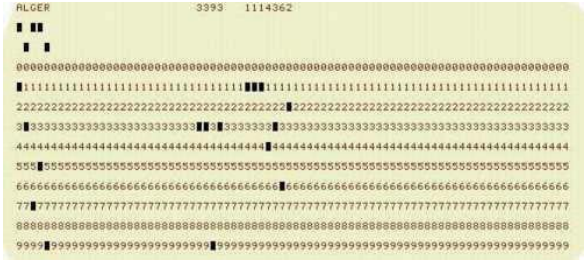
## Grading (subject to change)

- Assignments (5 projects+1 homework, 50%) from the accompanying website
- Class participation (5%)
- Midterm quiz (20%)
- Final project (25%)

## Early computers



## Early programming tools

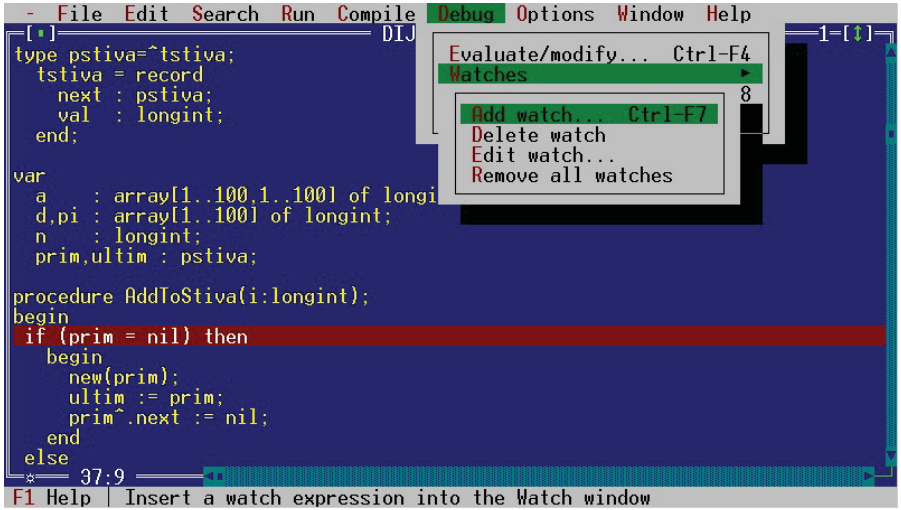



## First popular PCs

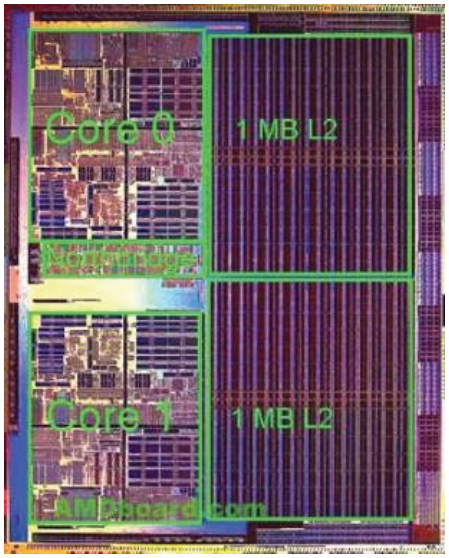

## Early PCs

- Intel 8086 processor
- 768KB memory
- 20MB disk
- Dot-Matrix printer (9-pin)

## GUI/IDE

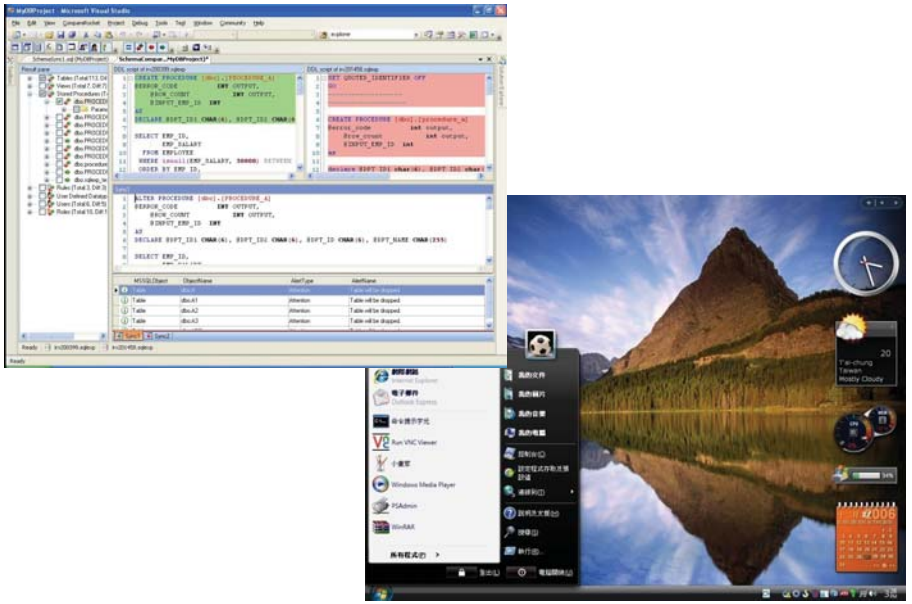



## More advanced architectures




- Pipeline
- SIMD
- Multi-core
- Cache

## More advanced software



## More “computers” around us


## My computers

Desktop
(Intel Core i7-6700
3.4GHz, GTX960)

MacBook Pro
(Intel Core i5, 2.3GHz)

Surface Pro 4
(Intel i5-6300 2.4GHz)

iPhone 11
Pro (A13,
ARMv8.3-A)

## The downside

- *“Once upon a time, every computer specialist had a gestalt understanding of how computers worked*. … As modern computer technologies have become increasingly more complex, this clarity is all but lost.” Quoted from the textbook

## How is it done?

```
// First Example in Programming 101
class Main {
  function void main () {
    do Output.printString("Hello World");
    do Output.println(); // New line
    return;
  }
}
```

## Main secret of computer science

implementation

Don't worry about the "how"

Only about the "what"

abstraction

what our programming language promises to do

- Extremely complicated system
- Information hiding

## Main secret of computer science

Don't worry about the "how"

But, someone has to, for example, you.

## Goal of the course


*"The best way to understand how computers work is to build one from scratch."* Quoted from the textbook

## The course at a glance

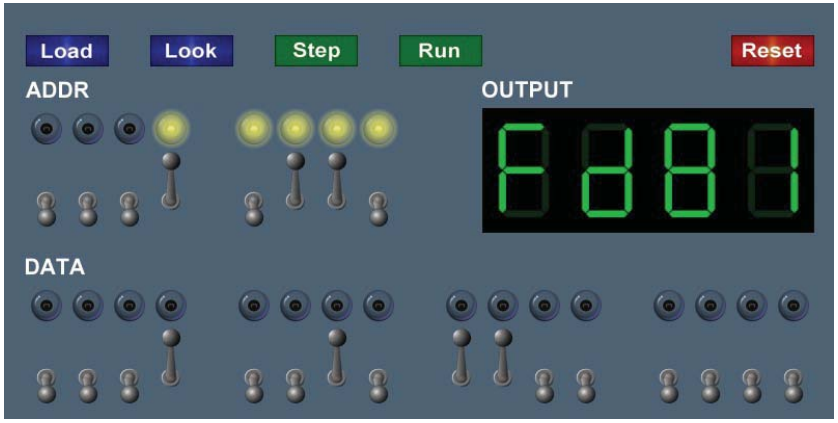
Objectives:

- Understand how hardware and software systems are built and how they work together
- Learn how to break complex problems into simpler ones
- Learn how large scale development projects are planned and executed
- Have fun

Methodology:

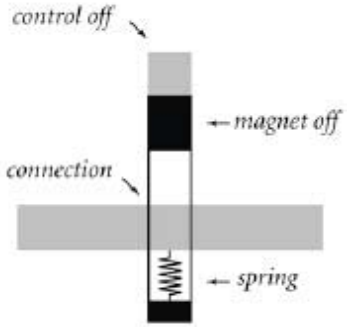
- Build a complete, general-purpose and working computer system
- Play and experiment with this computer, at any level of interest

## TOY machine

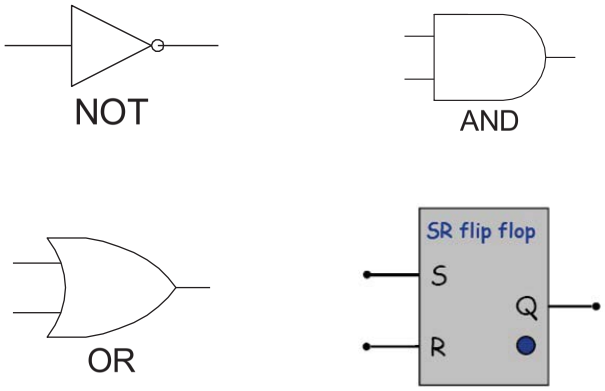



## TOY machine

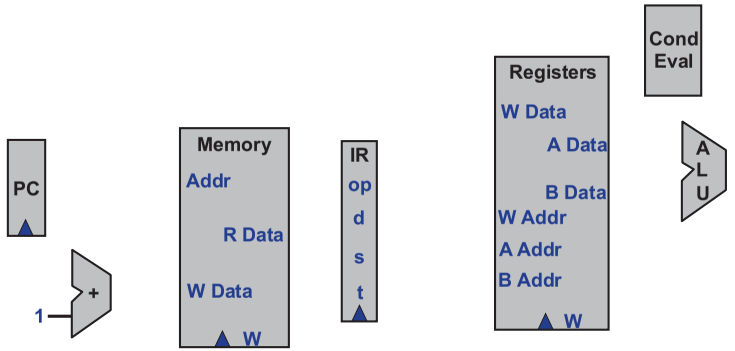
- Starting from a simple construct



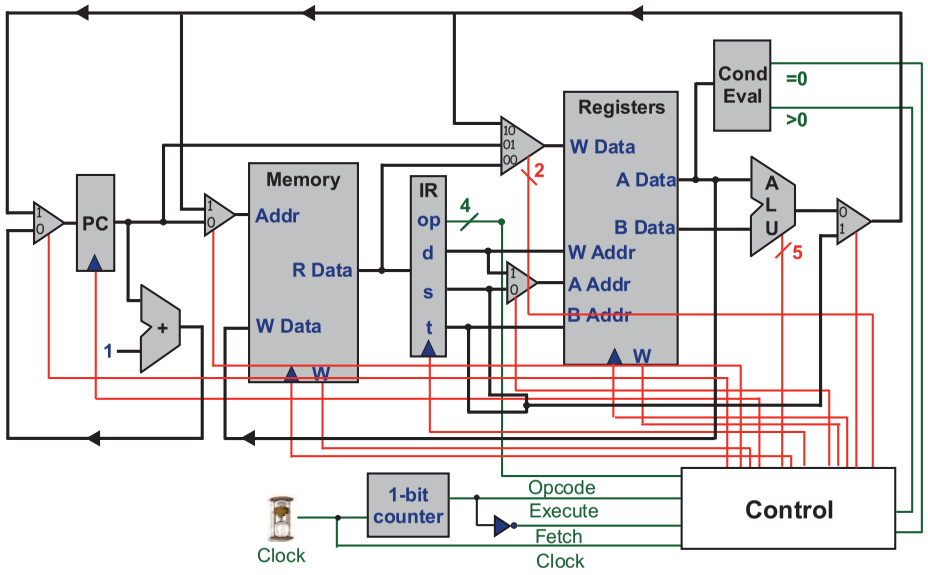

## Logic gates




## Components



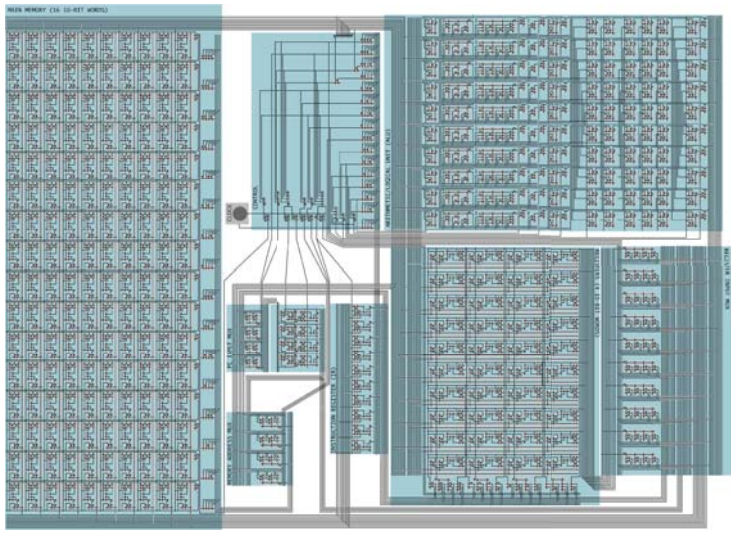
## Toy machine






## TOY machine

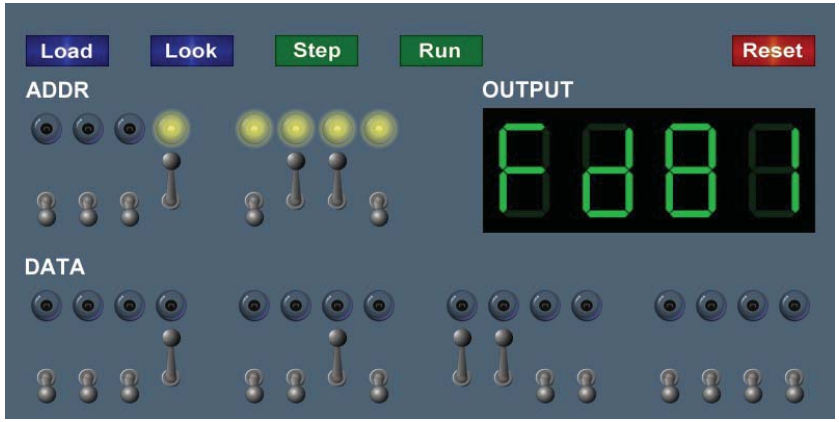
- Almost as good as any computers



## TOY machine

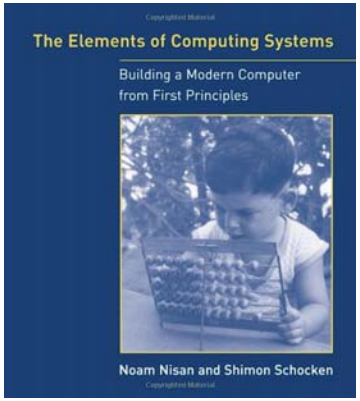
```
int A[32];          A     DUP   32        10: C020

                          lda   R1, 1     20: 7101
                          lda   RA, A     21: 7A00
i=0;                      lda   RC, 0     22: 7C00
Do {
  RD=stdin;         read  ld    RD, 0xFF  23: 8DFF
  if (RD==0) break;       bz    RD, exit  24: CD29
                          add   R2, RA, RC 25: 12AC
  A[i]=RD;                sti   RD, R2    26: BD02
  i=i+1;                  add   RC, RC, R1 27: 1CC1
} while (1);              bz    R0, read  28: C023

printr();           exit  jl    RF, printr 29: FF2B
                          hlt               2A: 0000
```

## TOY machine



## From NAND to Tetris

- The elements of computing systems
- Courses
- Software
- Cool stuffs

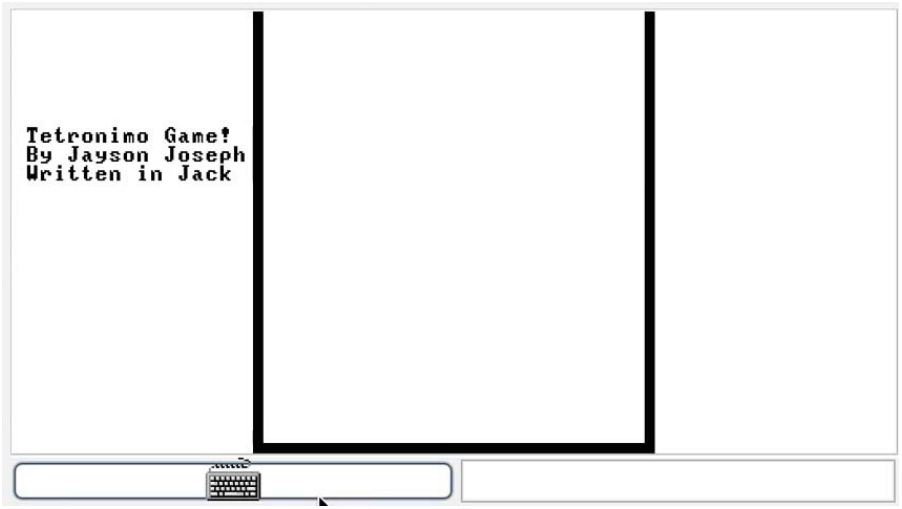



## Pong on the Hack computer

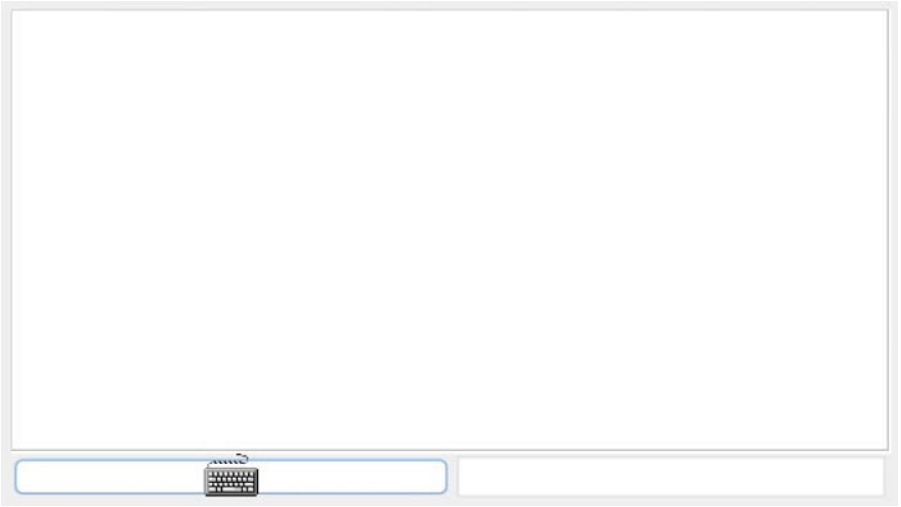

Pong, 1985

Pong, 2011

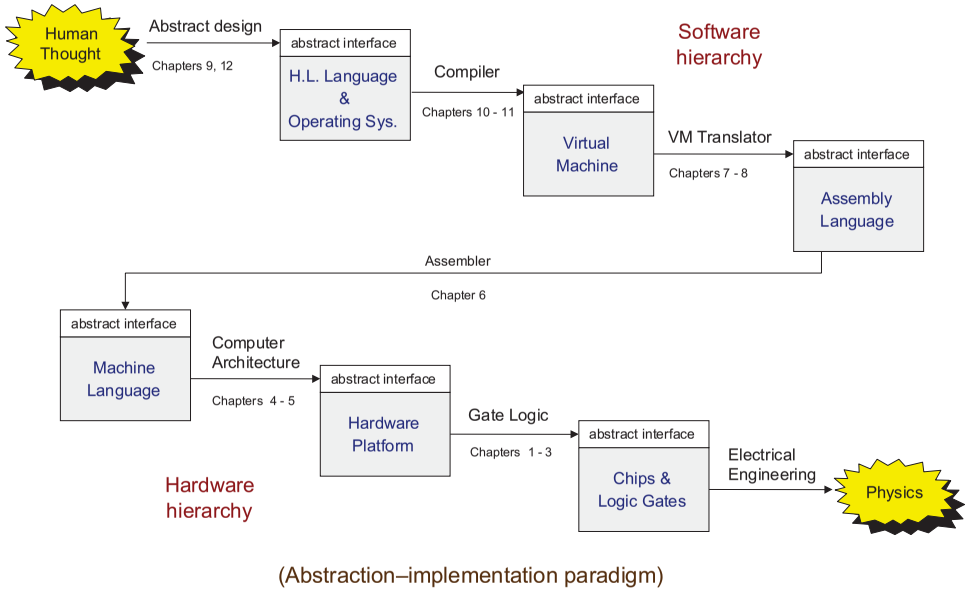

## Sample projects




## Sample projects

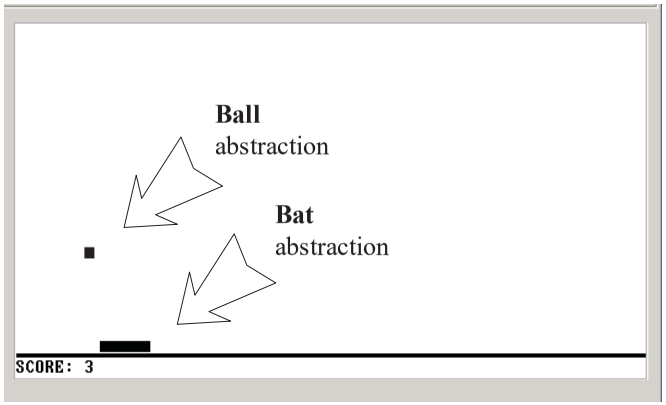


# Theme and structure of the book

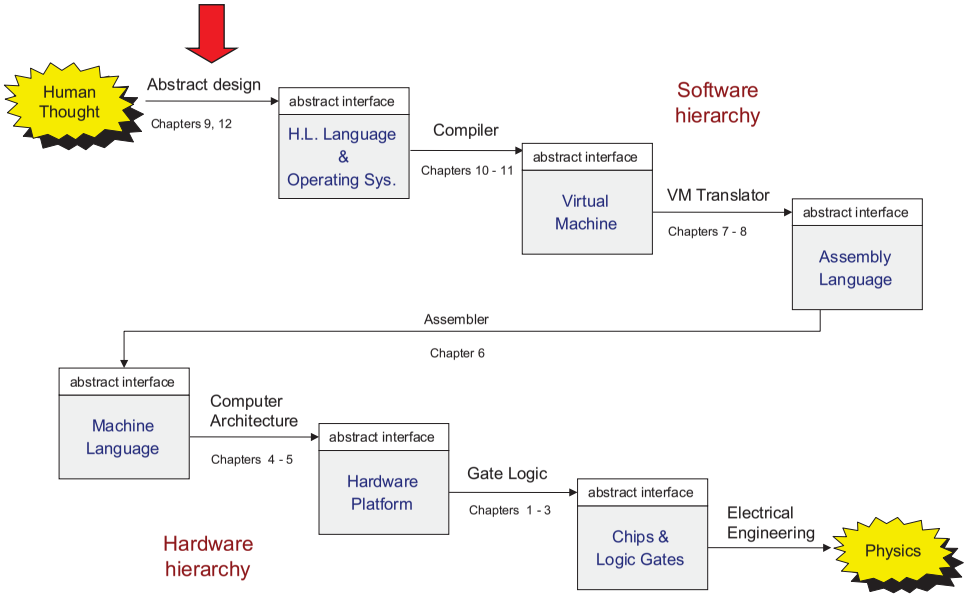



(Abstraction–implementation paradigm)

# Application level: Pong (an example)



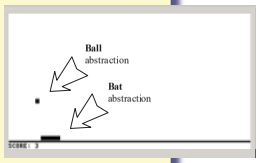

# The big picture




# High-level programming (Jack language)

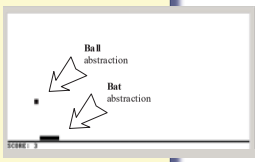
```
/** A Graphic Bat for a Pong Game */
class Bat {
    field int x, y;            // screen location of the bat's top-left corner
    field int width, height;   // bat's width & height

    // The class constructor and most of the class methods are omitted

    /** Draws (color=true) or erases (color=false) the bat */
    method void draw(boolean color) {
       do Screen.setColor(color);
       do Screen.drawRectangle(x,y,x+width,y+height);
       return;
    }

    /** Moves the bat one step (4 pixels) to the right. */
    method void moveR() {
       do draw(false);  // erase the bat at the current location
       let x = x + 4;   // change the bat's X-location
       // but don't go beyond the screen's right border
        if ((x + width) > 511) {
           let x = 511 - width;
       }
       do draw(true);  // re-draw the bat in the new location
       return;
    }
}
```

Typical call to an OS method

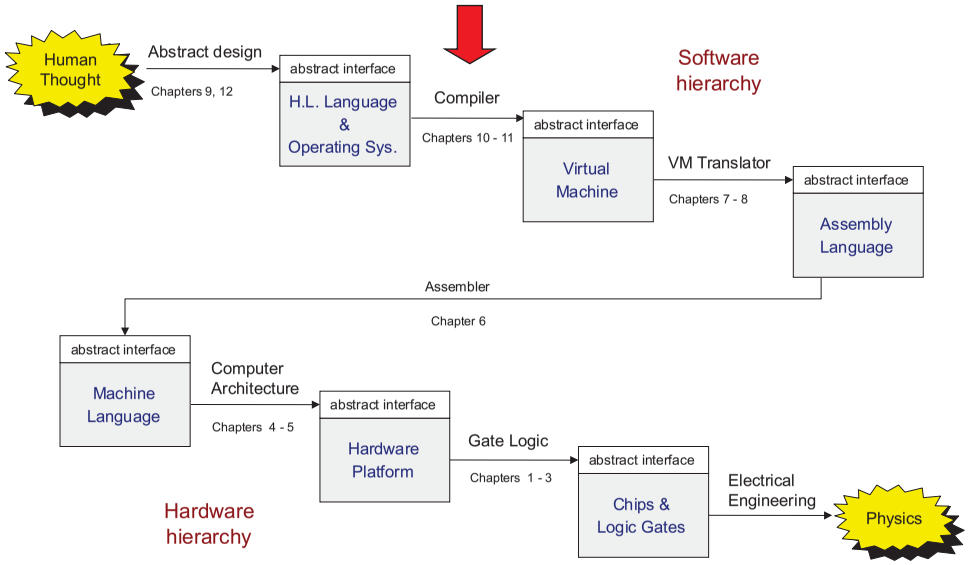


# Operating system level (Jack OS)

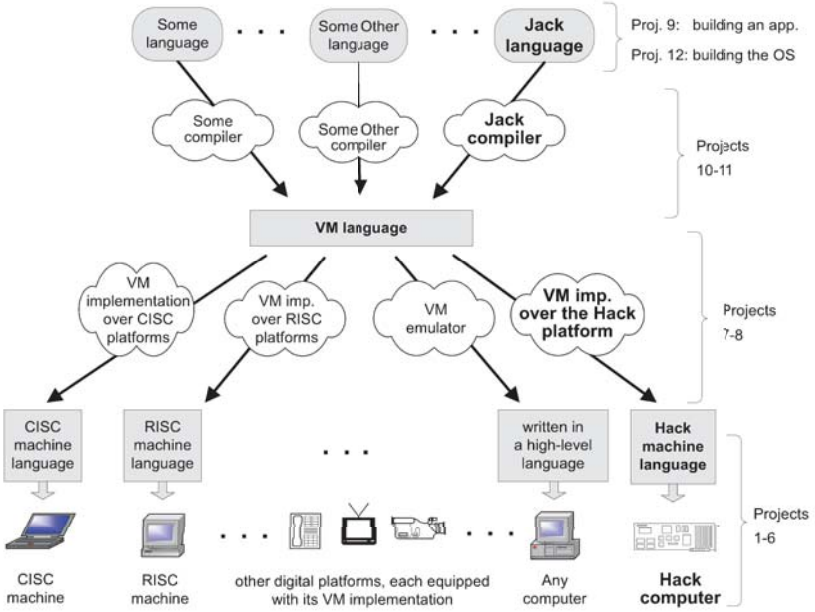
```
/** An OS-level screen driver that abstracts the computer's physical screen */
class Screen {
     static boolean currentColor;  // the current color

     // The Screen class is a collection of methods, each implementing one
     // abstract screen-oriented operation.  Most of this code is omitted.

     /** Draws a rectangle in the current color. */
     // the rectangle's top left corner is anchored at screen location (x0,y0)
     // and its width and length are x1 and y1, respectively.
     function void drawRectangle(int x0, int y0, int x1, int y1) {
         var int x, y;
         let x = x0;
         while (x < x1) {
             let y = y0;
             while(y < y1) {
                do Screen.drawPixel(x,y);
                let y = y+1;
             }
             let x = x+1;
         }
     }
}
```



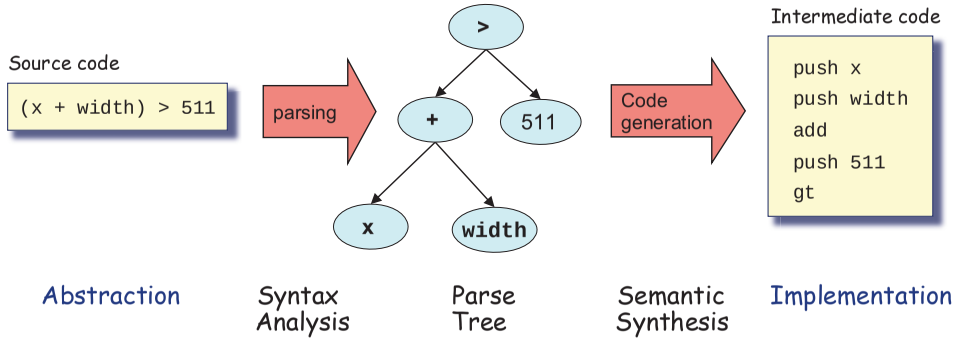

# The big picture




# A modern compilation model




# Compilation 101



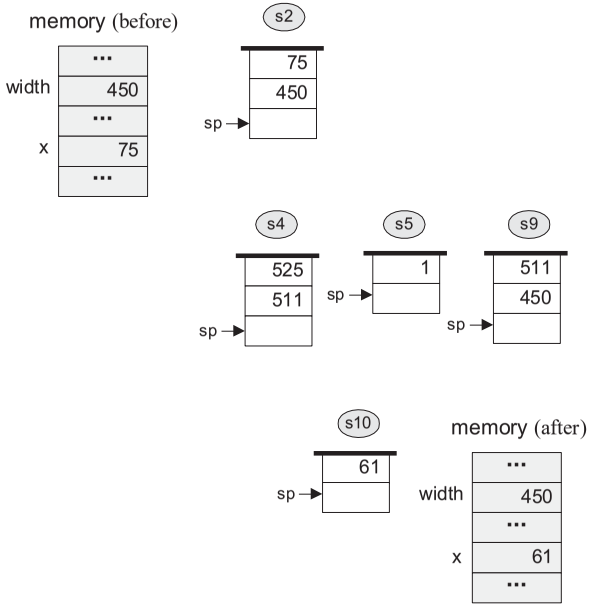

Observations:

- Modularity
- Abstraction / implementation interplay
- The implementation uses abstract services from the level below.

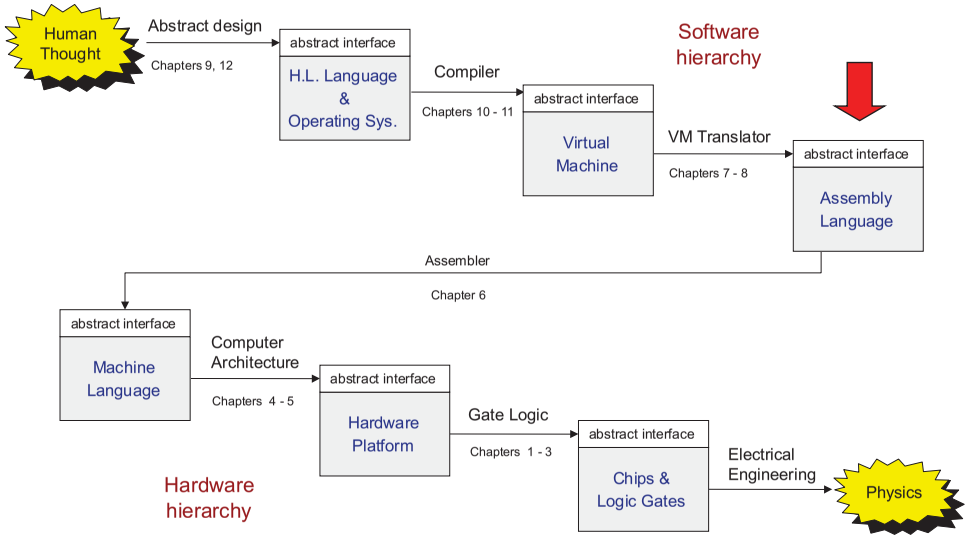
# The virtual machine (VM modeled after JVM)

```
if ((x+width)>511) {
   let x=511-width;
}
```

```
// VM implementation
   push x        // s1
   push width    // s2
   add           // s3
   push 511      // s4
   gt            // s5
   if-goto L1    // s6
   goto L2       // s7
L1:
   push 511      // s8
   push width    // s9
   sub           // s10
   pop x         // s11
L2:
...
```




# The big picture




# Low-level programming (on Hack)

**Virtual machine program**

```
...
   push x
   push width
   add
   push 511
   gt
   if-goto L1
   goto L2
L1:
   push 511
   push width
   sub
   pop x
L2:
...
```

# Low-level programming (on Hack)

**Virtual machine program**

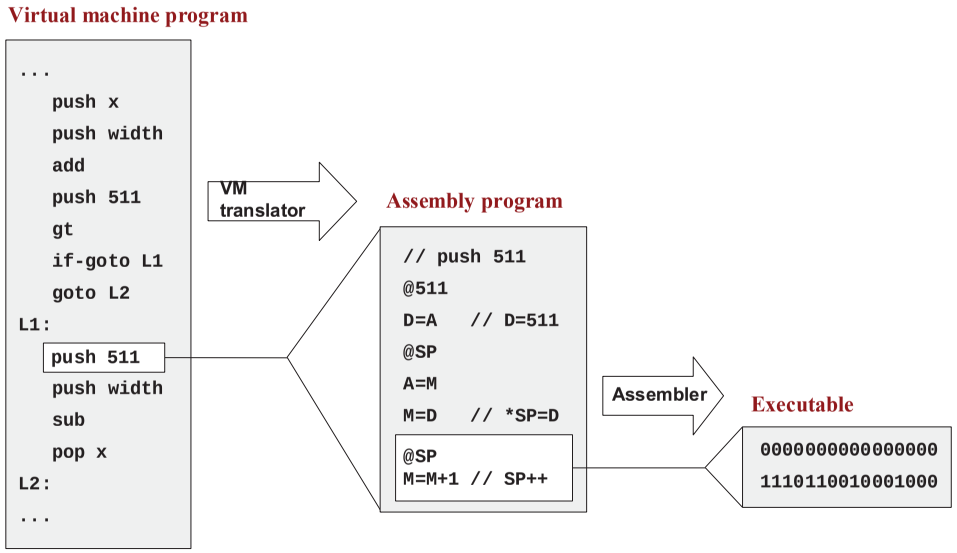
```
...
   push x
   push width
   add
   push 511
   gt
   if-goto L1
   goto L2
L1:
   push 511
   push width
   sub
   pop x
L2:
...
```

VM translator

**Assembly program**

```
// push 511
@511
D=A   // D=511
@SP
A=M
M=D   // *SP=D
@SP
M=M+1 // SP++
```

# Low-level programming (on Hack)

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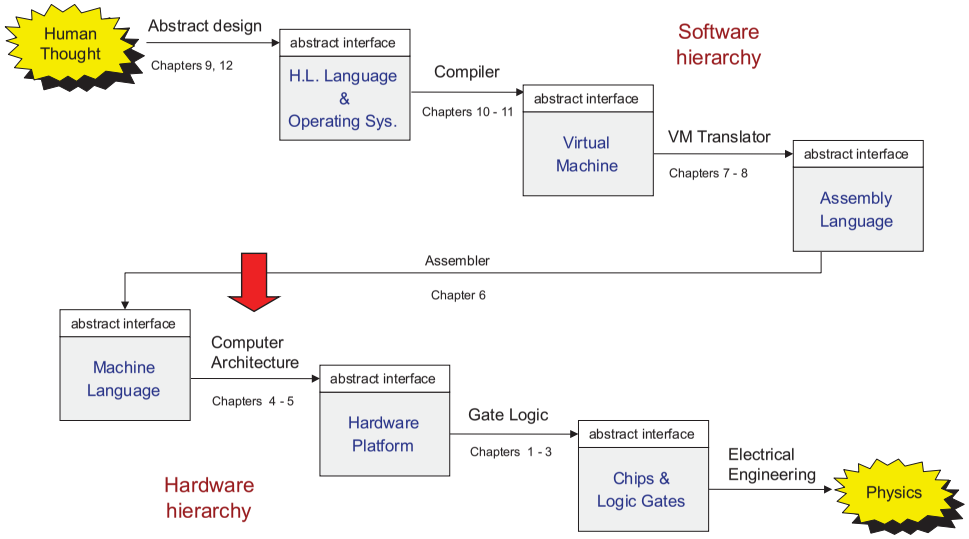
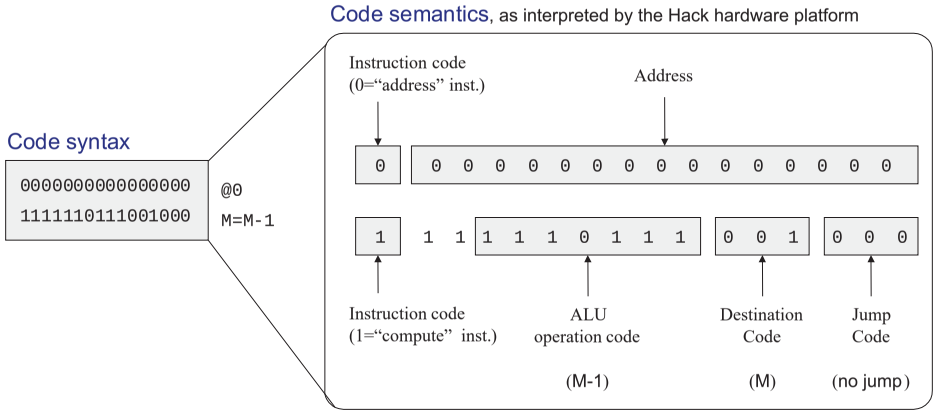
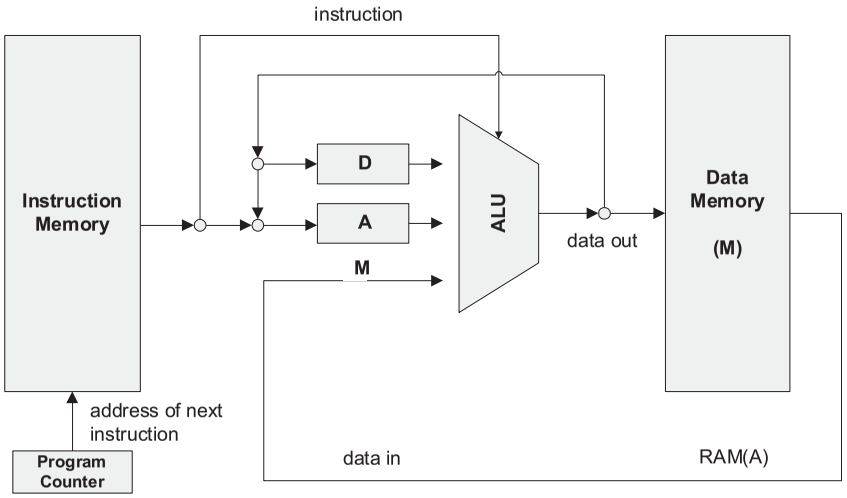



# Machine language semantics (Hack)



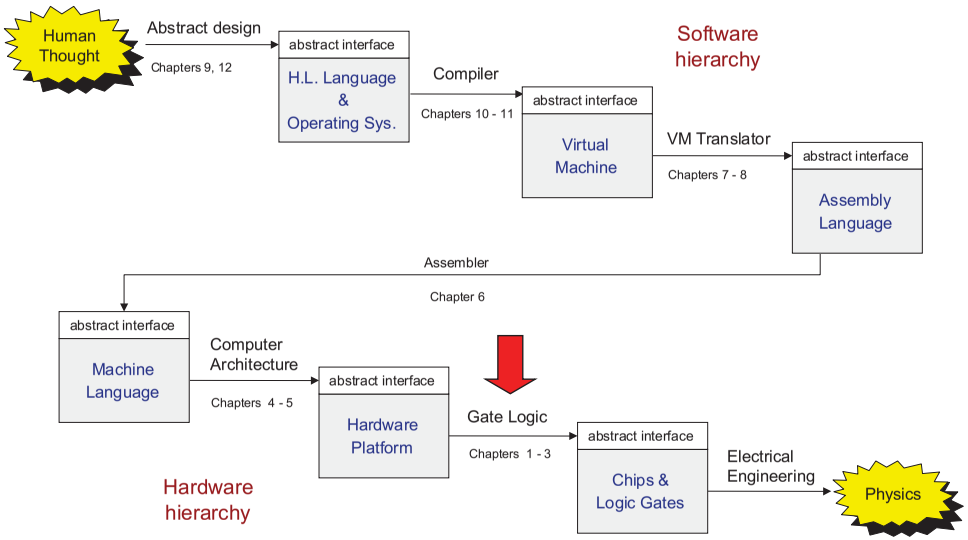

- We need a hardware architecture that realizes this semantics
- The hardware platform should be designed to:
  - Parse instructions, and
  - Execute them.

# Computer architecture (Hack)




- A typical Von Neumann machine

# The big picture




# Logic design

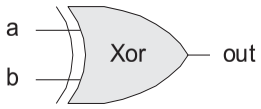
- Combinational logic (leading to an ALU)
- Sequential logic (leading to a RAM)
- Putting the whole thing together (leading to a computer)

Using ... gate logic

# Gate logic

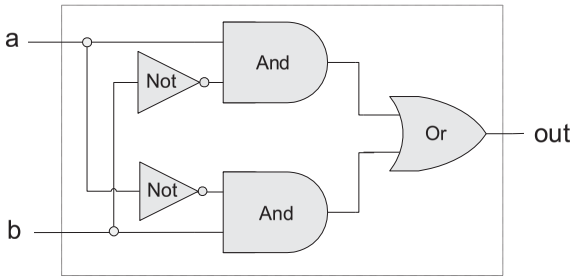
- Hardware platform = inter-connected set of chips
- Chips are made of simpler chips, all the way down to elemantary logic gates
- Logic gate = hardware element that implements a certain Boolean function
- Every chip and gate has an *interface*, specifying WHAT it is doing, and an *implementation*, specifying HOW it is doing it.

Interface

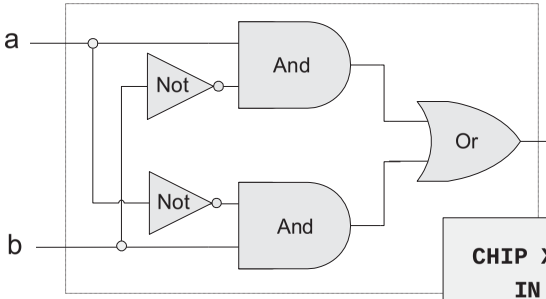



| a | b | out |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

Implementation



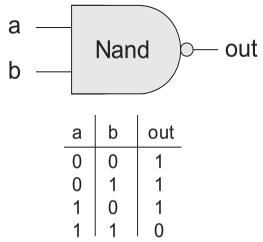

# Hardware description language (HDL)




```
CHIP Xor {
   IN a,b;
   OUT out;
   PARTS:
   Not(in=a,out=Nota);
   Not(in=b,out=Notb);
   And(a=a,b=Notb,out=w1);
   And(a=Nota,b=b,out=w2);
   Or(a=w1,b=w2,out=out);
}
```

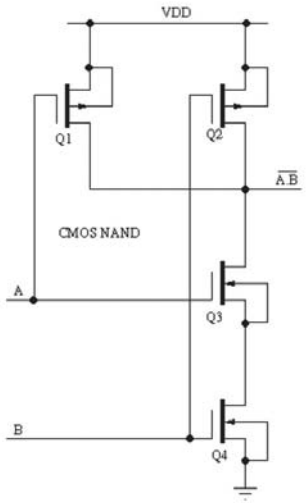
## The tour ends:

Interface

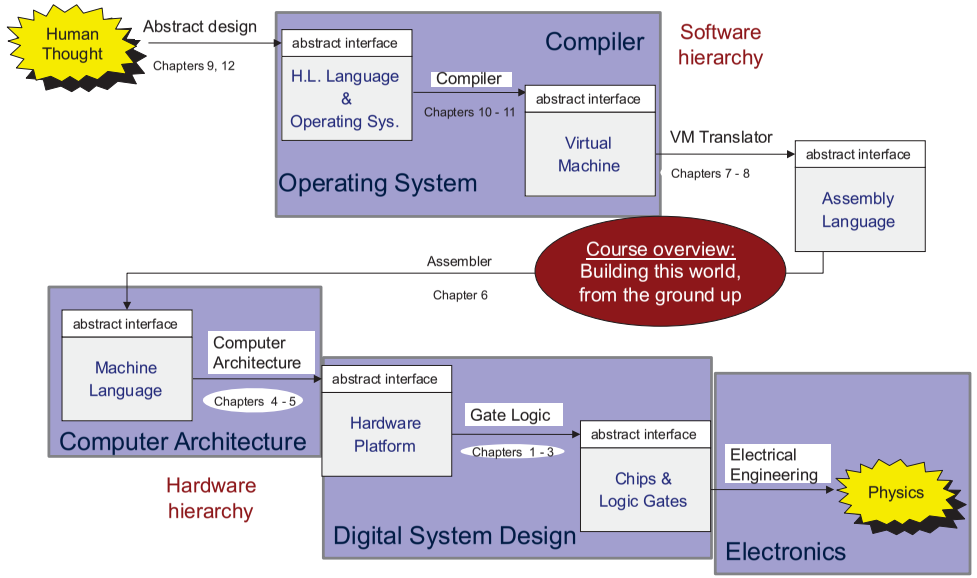



| a | b | out |
|---|---|---|
| 0 | 0 | 1 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

One implementation option (CMOS)




## The tour map, revisited




## What you will learn

- Number systems
- Combinational logic
- Sequential logic
- Basic principle of computer architecture
- Assembler
- Virtual machine
- High-level language
- Fundamentals of compilers
- Basic operating system
- Application programming

## In short