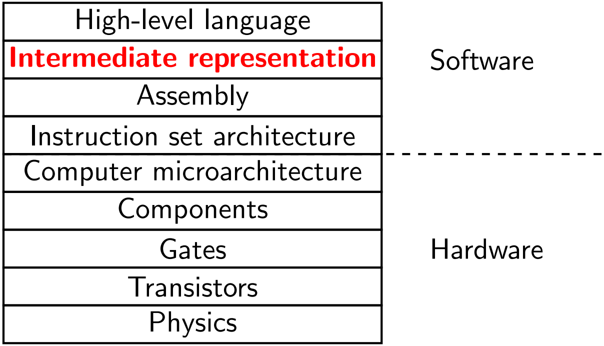
Extending Hack VM

John Lapinskas, University of Bristol

Our goals for this week



High-level language

Intermediate representation

Assembly

Instruction set architecture

Computer microarchitecture

Components

Gates

Transistors

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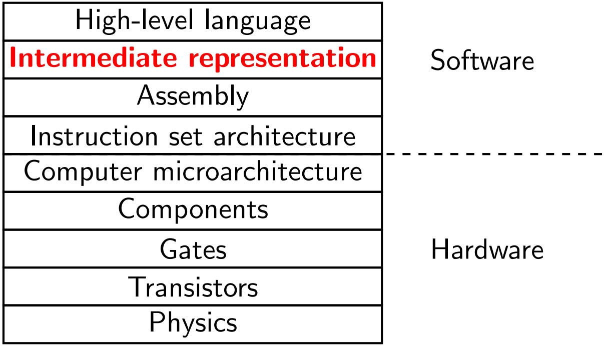

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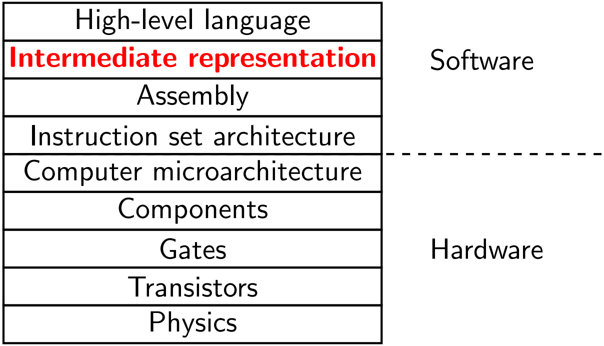
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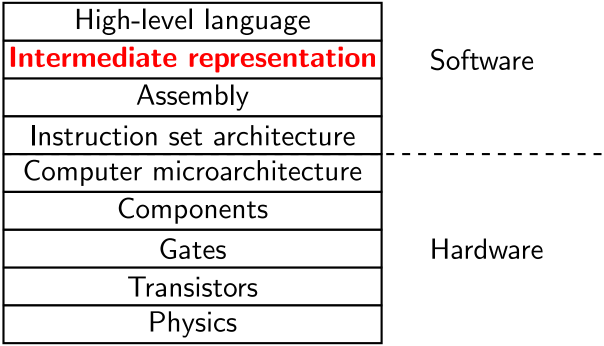

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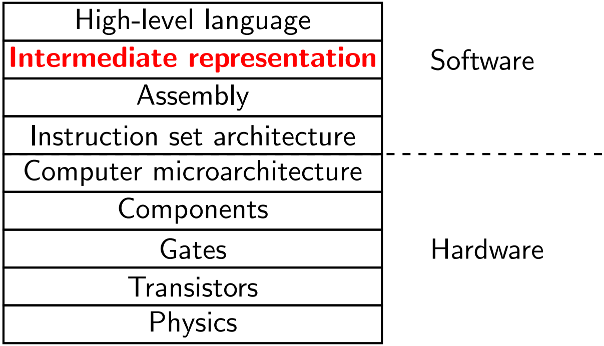

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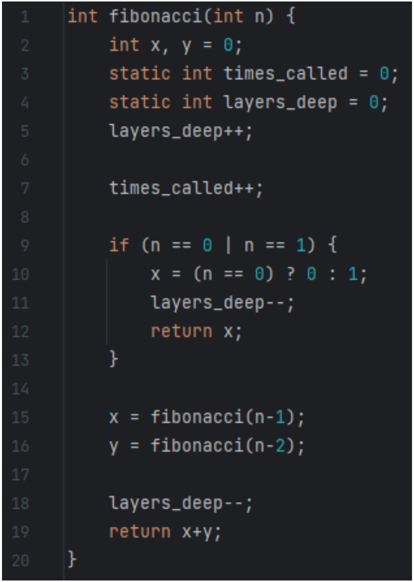
Next week, we'll be moving on to our high-level language — **Jack**.

How functions should behave: A case study



```c
int fibonacci(int n) {
    int x, y = 0;
    static int times_called = 0;
    static int layers_deep = 0;
    layers_deep++;

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    if (n == 0 | n == 1) {
        x = (n == 0) ? 0 : 1;
        layers_deep--;
        return x;
    }

    x = fibonacci(n-1);
    y = fibonacci(n-2);

    layers_deep--;
    return x+y;
}
```

Recall the (bad!) recursive algorithm from Programming in C to compute the Fibonacci sequence. The sequence is:

$$F_0 = 0, \quad F_1 = 1, \quad F_n = F_{n-1} + F_{n-2}.$$

So the algorithm is:

$$\texttt{fib}(n) = \begin{cases} 0 & \text{if } n = 0, \\ 1 & \text{if } n = 1, \\ \texttt{fib}(n-1) + \texttt{fib}(n-2) & \text{if } n \geq 2. \end{cases}$$

Here we have an implementation with some static variables to keep track of how many times the function has been called and how many calls deep we are into the recursion.

Summary of desired behaviour

On each call to `fibonacci`:

- Program flow jumps to the start of the function.
- The local variables `x` and `y` are cleared.
- The argument variable `n` is set by the call.
- The static variables `times_called` and `layers_deep` are unchanged.

On function return:

- Program flow returns to the line after the original function call.
- The local variables `x` and `y` return to their old values.
- The argument variable `n` returns to its old values.
- The static variables `times_called` and `layers_deep` are unchanged.

All of this must be robust for an arbitrary number of function calls within function calls (memory permitting), including recursive calls.

[See video for a demonstration in CLion with fibonacci-illustration.c.]

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    - This is analogous to main in C.
    - Sys.init will be provided for you in test code.
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- All functions in the file `abc.vm` (say) must have names starting with "`abc.`", e.g. `abc.print` or `abc.crash`.
  - This prevents name clashes between files, and our Jack compiler will enforce it by compiling a Jack function named `xyz` in a file named `abc` to a VM function named `abc.xyz`.

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  - This prevents name clashes between files, and our Jack compiler will enforce it by compiling a Jack function named `xyz` in a file named `abc` to a VM function named `abc.xyz`.
- If two instances of the same `static` address or `label` occur in different files, they should compile to different addresses.
  - Your VM translator already does this!

Jack and the “operating system”

Jack will come with what nand2tetris optimistically calls an “operating system”.

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- `Sys.vm` provides `Sys.init` and functions to halt, crash, or wait a certain number of milliseconds.
- `Memory.vm` provides functions for memory allocation (see later).
- `Array.vm` provides functions for an array data type.
- `String.vm` provides functions for a string data type.
- `Keyboard.vm` and `Screen.vm` provide functions for direct input and output.
- `Output.vm` provides functions for displaying and editing text.
- `Math.vm` provides functions for multiplication, division, minimum, maximum, and square root.

You will have access to Hack VM versions of these next week when writing the Jack compiler. The details can be found in Nisan and Schocken appendix 6.

None of them are examinable!

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The "OS" functions are mostly straightforward, and there are no new architecture ideas except for `Memory.vm` (which we'll talk about later this week).

That said, if you want practice with assembly/VM, they make good exercises!