CPSC 213

Introduction to Computer Systems

Unit 0

Introduction

About the Course

- its all on the web page ...
  - http://www.cs.ubc.ca/~feeley/cs213
  - *Lecture Notes Companion*
  - *Piazza*
- marks
  - in-class clicker questions (**you will need a clicker**)
  - labs
  - quizzes
  - midterm
  - final
- work together! ***but don't cheat!***
  - never present anyone else's work as your own
    - it is your responsibility to provide *proper attribution*
  - anything you hand in in this course should follow this rule **anything**
  - but, don't let this stop you from helping each other learn ...

Overview of the course

- Hardware context of a single executing program
  - hardware context is CPU and Main Memory
  - develop CPU architecture to implement C and Java
  - differentiate compiler (static) and runtime (dynamic) computation
- System context of multiple executing programs with IO
  - extend context to add IO, concurrency and system software
  - thread abstraction to hide IO asynchrony and to express concurrency
  - synchronization to manage concurrency
  - virtual memory to provide multi-program, single-system model
  - hardware protection to encapsulate operating system
  - message-passing to communicate between processes and machines

GOAL: To develop a model of computation that is rooted in what really happens when programs execute.

What you will get out of this ...

- Become a better programmer by
  - deepening your understand of how programs execute
  - learning to build concurrent and distributed programs
- Learn to design real systems by
  - evaluating design trade-offs through examples
  - distinguish static and dynamic system components and techniques
- Impress your friends and family by
  - telling them what a program ***really*** is

What do you know now?

What happens what a program runs

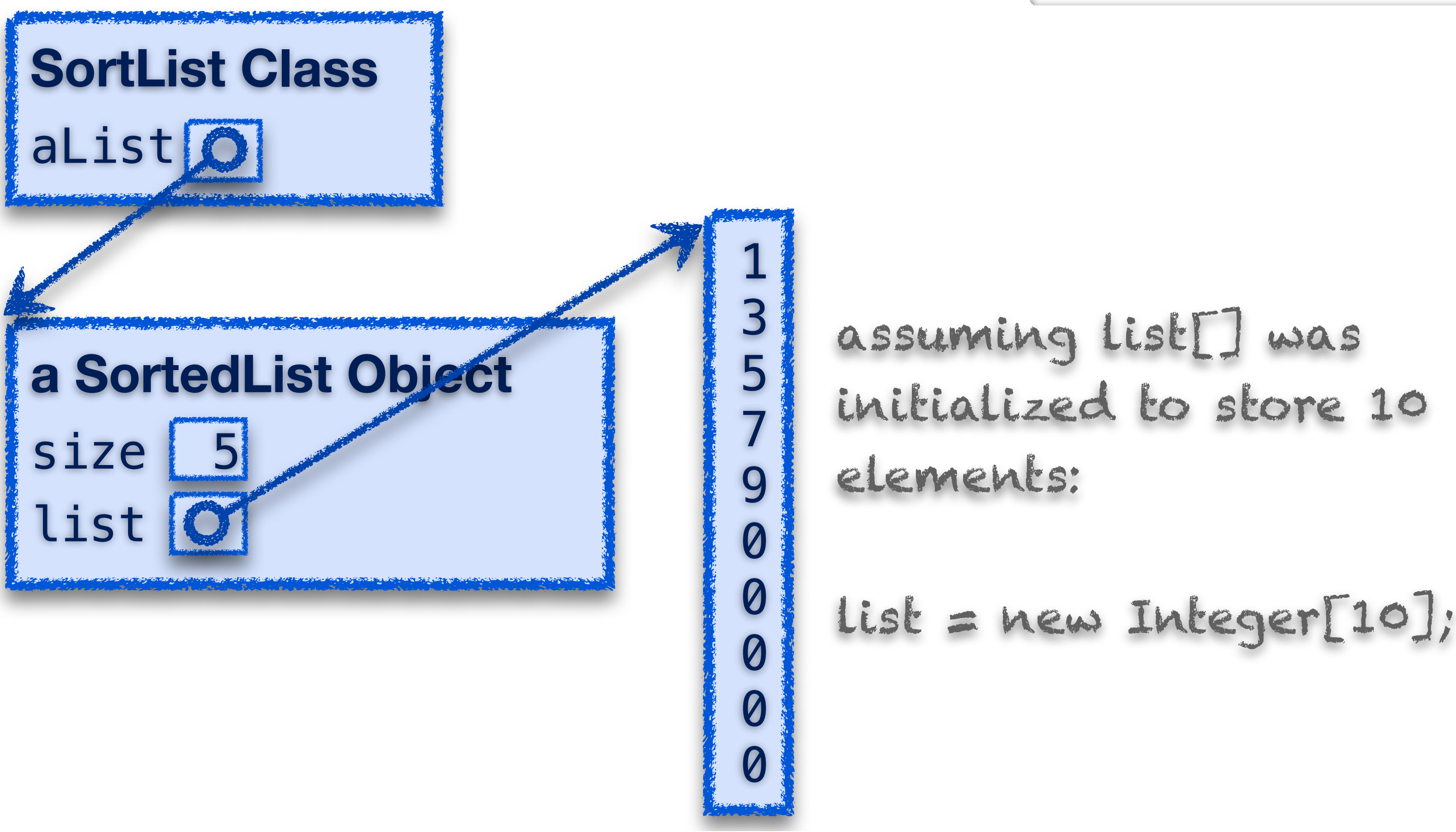
- Here’s a program

```
class SortedList {
  static SortedList aList;
  int    size;
  int    list[];

  void insert (int aValue) {
    int i = 0;
    while (list[i] <= aValue)
      i++;
    for (int j=size-1; j>=i; j--)
      list[j+1] = list[j];
    list[i] = aValue;
    size++;
  }
}
```

- What do you understand about the execution of **`insert`**?

- Example
  - list stores { 1, 3, 5, 7, 9 }
  - `SortedList.aList.insert(6)` is called
- Data structures
  - draw a diagram of the data structures
  - as they exist just before `insert` is called

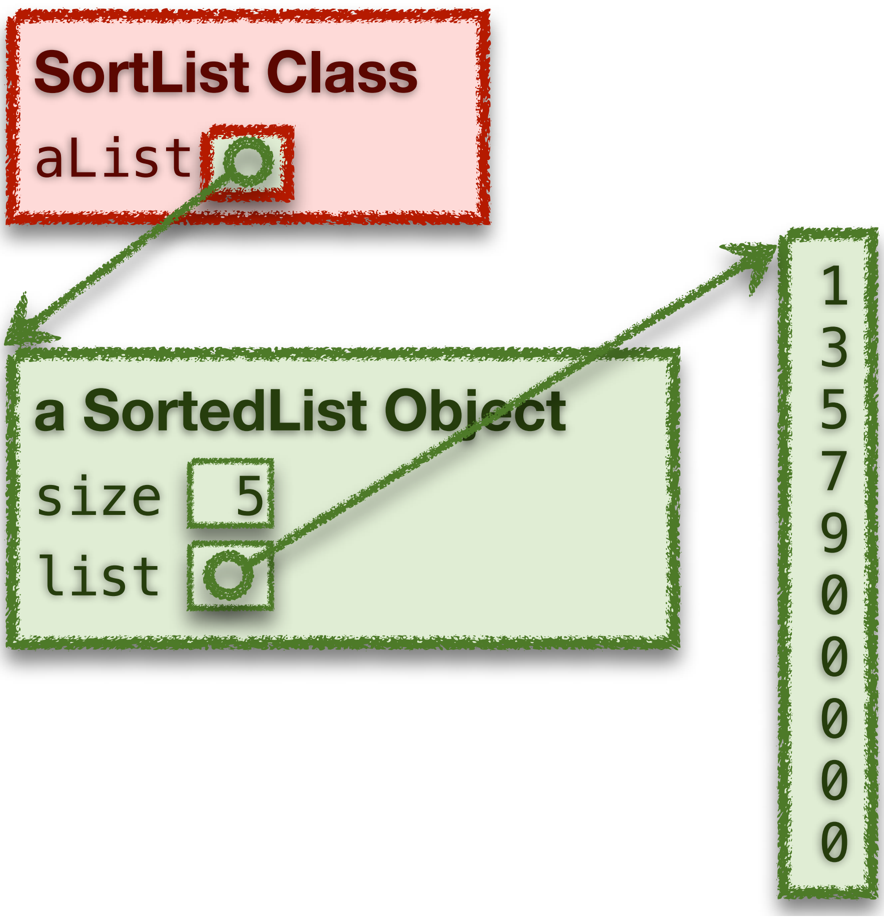
```
class SortedList {
  static SortedList aList;
  int    size;
  int    list[];

  void insert (int aValue) {
    int i = 0;
    while (list[i] <= aValue)
      i++;
    for (int j=size-1; j>=i; j--)
      list[j+1] = list[j];
    list[i] = aValue;
    size++;
  }
}
```



Data structures

- lets dig a little deeper
- which of these existed before program started?
  - these are the ***static*** features of the program
- which were created by execution of program?
  - these are the ***dynamic*** features of the program

```
class SortedList {
  static SortedList aList;
  int     size;
  int     list[];

  void insert (int aValue) {
    int i = 0;
    while (list[i] <= aValue)
      i++;
    for (int j=size-1; j>=i; j--)
      list[j+1] = list[j];
    list[i] = aValue;
    size++;
  }
}
```



Static:

* class and aList variable (sort of - clearer in C)

Dynamic:

* SortedList object
* size and list variables
* value of aList, size and list
* list of 10 integers

Execution of insert

- how would you describe this execution?
- carefully, step by step?

```
class SortedList {
  static SortedList aList;
  int    size;
  int    list[];

  void insert (int aValue) {
    int i = 0;
    while (list[i] <= aValue)
      i++;
    for (int j=size-1; j>=i; j--)
      list[j+1] = list[j];
    list[i] = aValue;
    size++;
  }
}
```

Sequence of Instructions

* program order
* changed by control-flow structures

```
             save location of SortedList.aList.insert(6)
             aValue = 6
             i = 0
             goto end-while if list[i]>aValue (1>6)
             i = 0+1 (1)
             goto end-while if list[i]>aValue (3>6)
             i = 1+1 (2)
             goto end-while if list[i]>aValue (5>6)
             i = 2+1 (3)
             goto end-while if list[i]>aValue (7>6)
end-while:   j = size-1 (4)
             goto end-if if j<i (4<3)
             list[i+1] = list[i] (list[5]=9)
             j = 5-1 (3)
             goto end-if if j<i (3<3)
             list[i+1] = list[i] (list[4]=7)
             j = 4-1 (2)
             goto end-if if j<i (2<3)
end-if:      list[i] = aValue (list[3] = 6)
             size = size+1 (6)
             statement after SortedList.aList.insert(6)
```

Instruction Types?

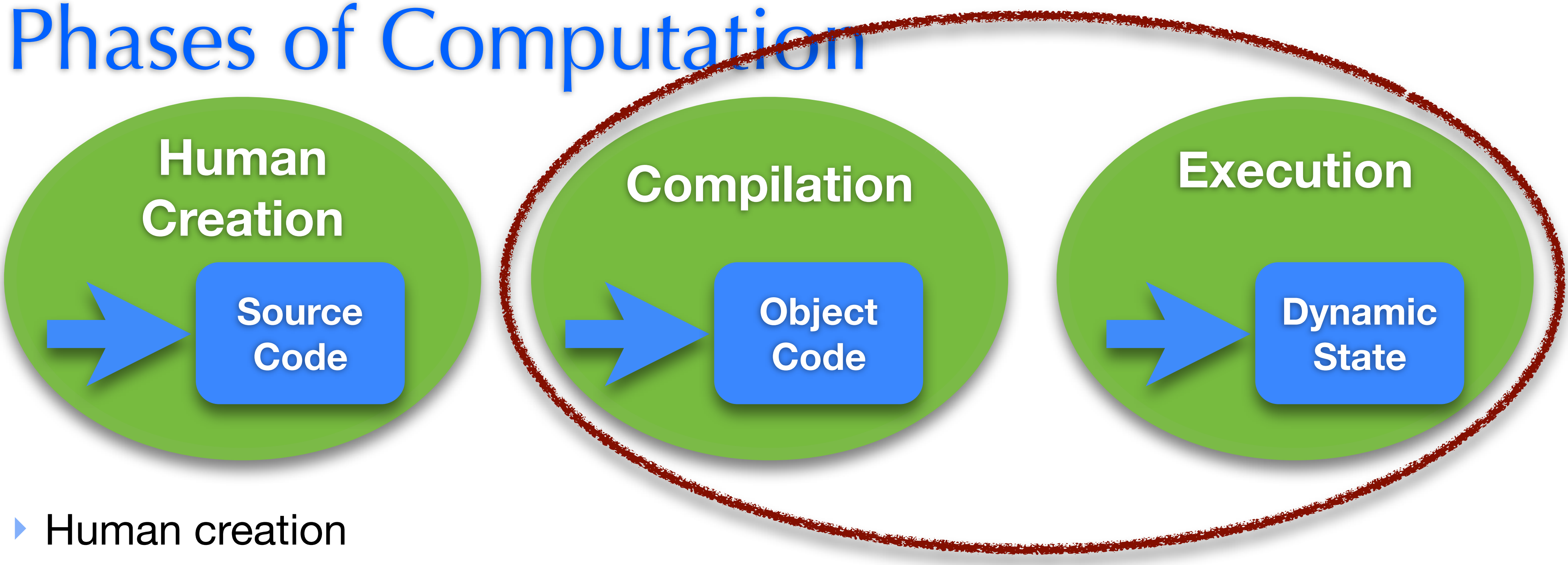
* read/write variable
* arithmetic
* conditional goto

Execution: What you Already Knew

- Data structures
  - variables have a storage location and a value
  - some variables are created before the program starts
  - some variables are created by the program while it runs
  - variable values can be set before program runs or by the execution
- Execution of program statements
  - execution is a sequence of steps
  - sequence-order can be changed by certain program statements
  - each step executes an instruction
  - instructions access variables, do arithmetic, or change control flow

An Overview of Computation

Phases of Computation



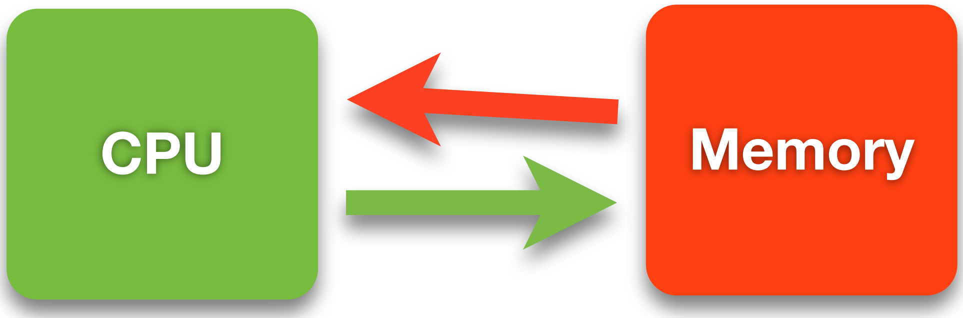
- Human creation
  - design program and describe it in high-level language
- Compilation
  - convert high-level, human description into machine-executable text
- Execution
  - a physical machine executes the text
  - parameterized by input values that are unknown at compilation
  - producing output values that are unknowable at compilation
- Two important initial definitions
  - anything that can be determined **before execution** is called ***static***
  - anything that can only be determined **during execution** is called ***dynamic***

Examples of Static vs Dynamic State

- Static state in Java

- Dynamic state in Java

A Simple Machine that can Compute

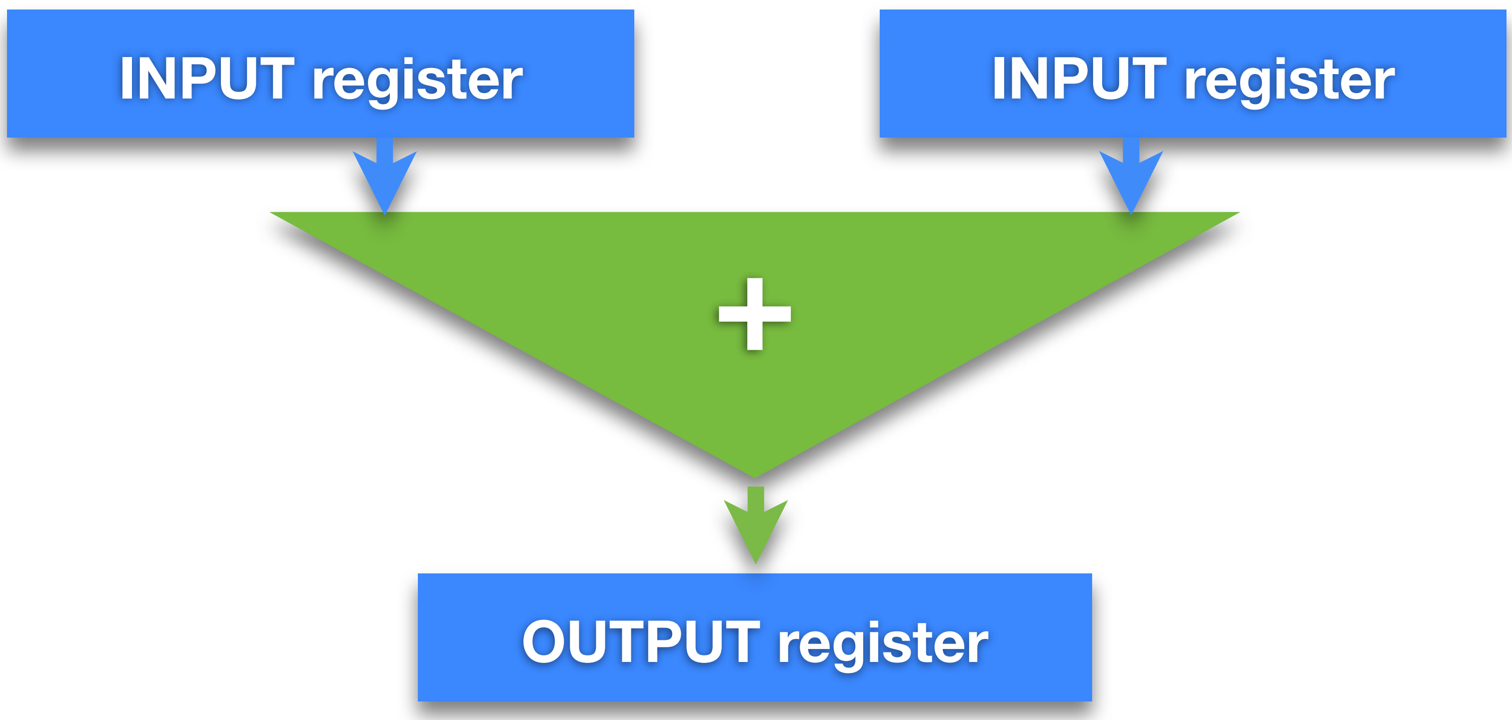


- Memory
  - stores programs and data
  - everything in memory has a unique name: its memory location (***address***)
  - two operations: read or write value at location X
- CPU
  - machine that executes programs to transform memory state
  - loads program from memory on demand one step at a time
  - each step may also read or write memory
- Not in the Simple Machine
  - I/O Devices such as mouse, keyboard, graphics, disk and network
  - we will deal with these other things in the second half of the course

The Simple Machine Model
A Closer Look

How do we start?

- One thing we need to do is add integers
  - you already know how to do this from 121 (hopefully :))
- A 32-bit Adder
  - implemented using logic gates implemented by transistors
  - it adds bits one at a time, with carry-out, just like in grade 2.



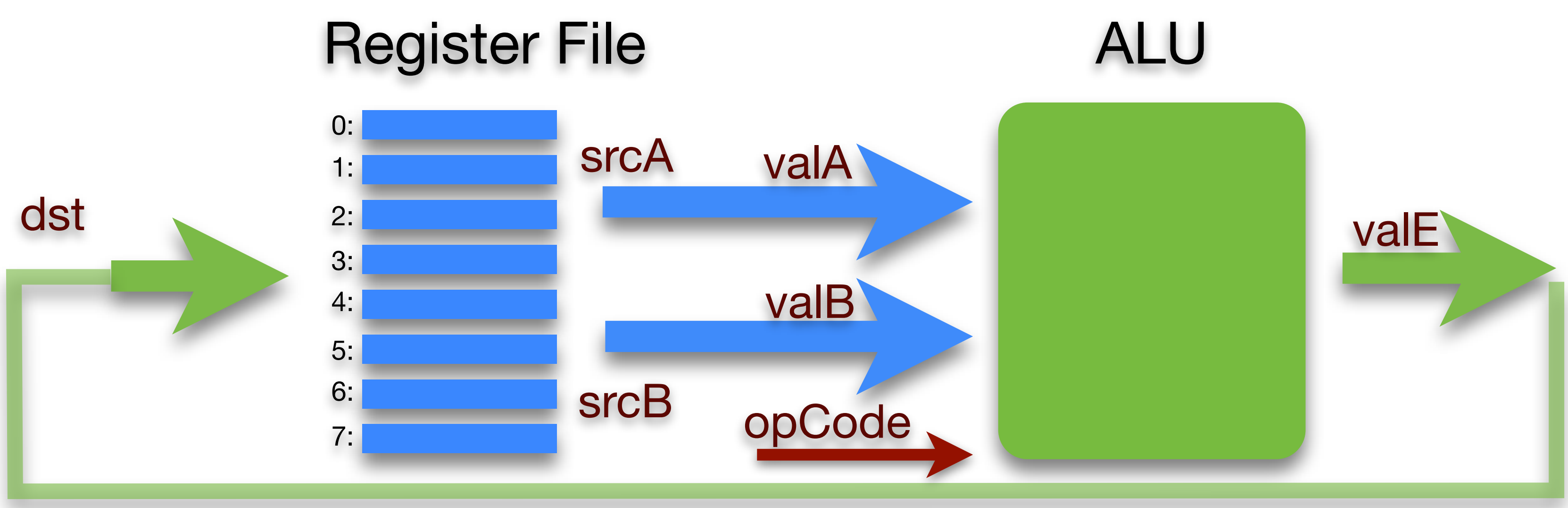
Generalizing the Adder

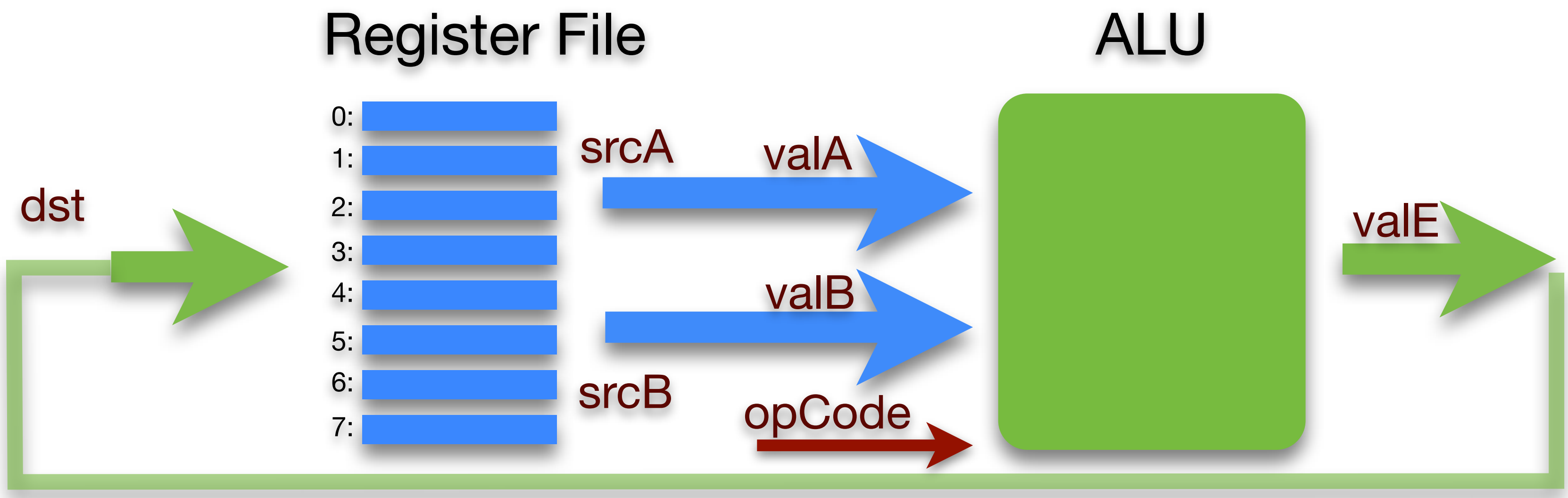
- What other things do we want to do with Integers

- What do we do with the value in the output register

Register File and ALU

- Arithmetic and Logic Unit (ALU)
  - generalizes ADDER to perform many ***operations*** on integers
  - three inputs: two source ***operands*** (valA, valB) and a ***operation code*** (opCode)
  - output value (valE) = operation-code (operand$_0$, operand$_1$)
- Register File
  - generalizes input and output registers of ADDER
  - a single bank of registers that can be used for input or output
  - registers ***named*** by ***numbers***: two source (srcA, srcB) and one destination (dst)

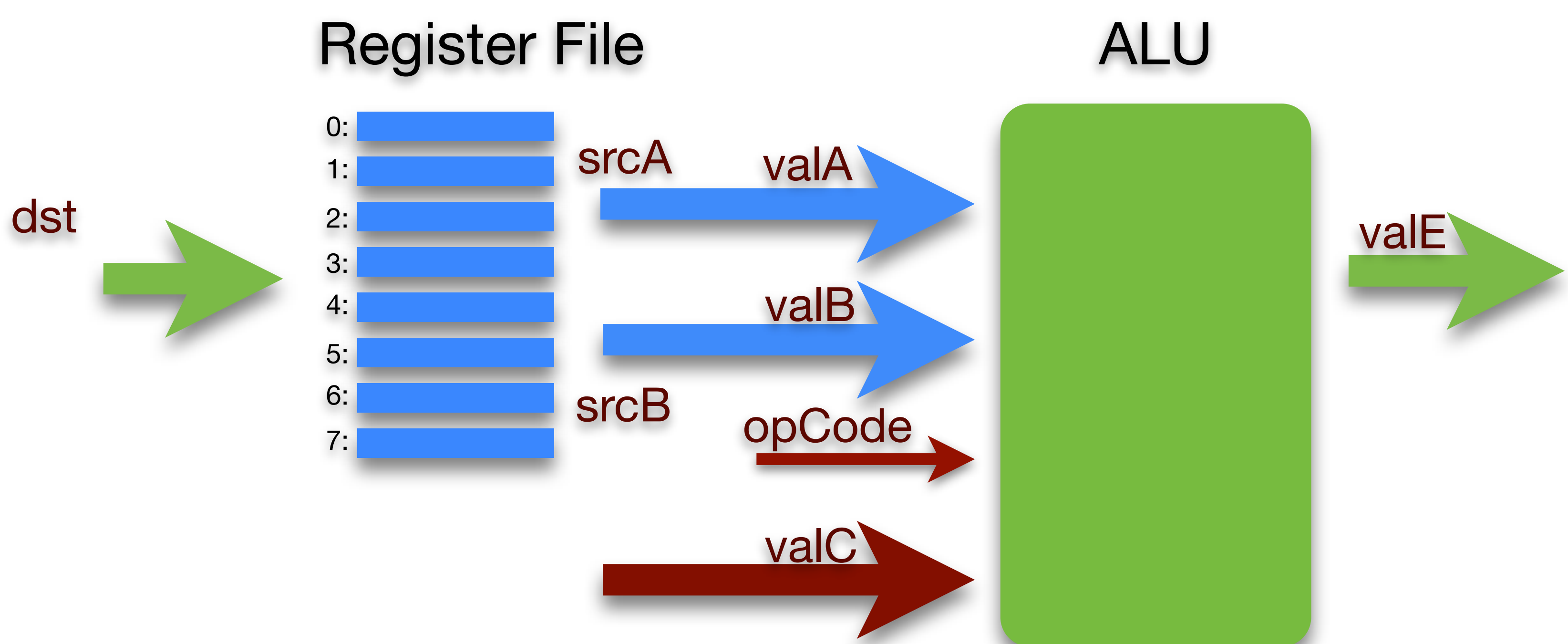


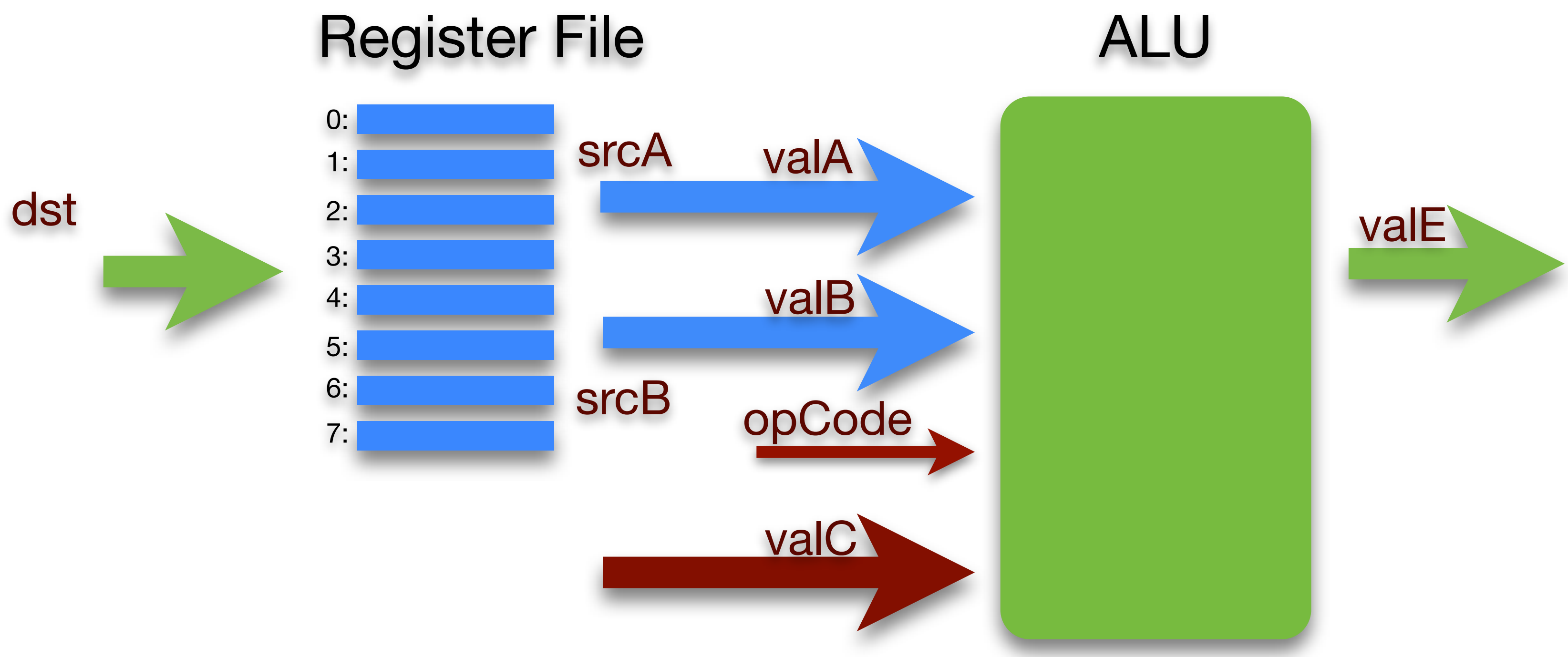


- Functional View
  - input for one step: opCode, srcA, srcB, and dst
  - a program is a sequence of these steps (and others)

Putting Initial Values into Registers

- Current model is too restrictive
  - to add two numbers the numbers must be in registers
  - programs must specify values explicitly
- Extend model to include *immediates*
  - an ***immediate value*** is a constant specified by a program instruction
  - extend model to allow some instructions to specify an immediate (valC)

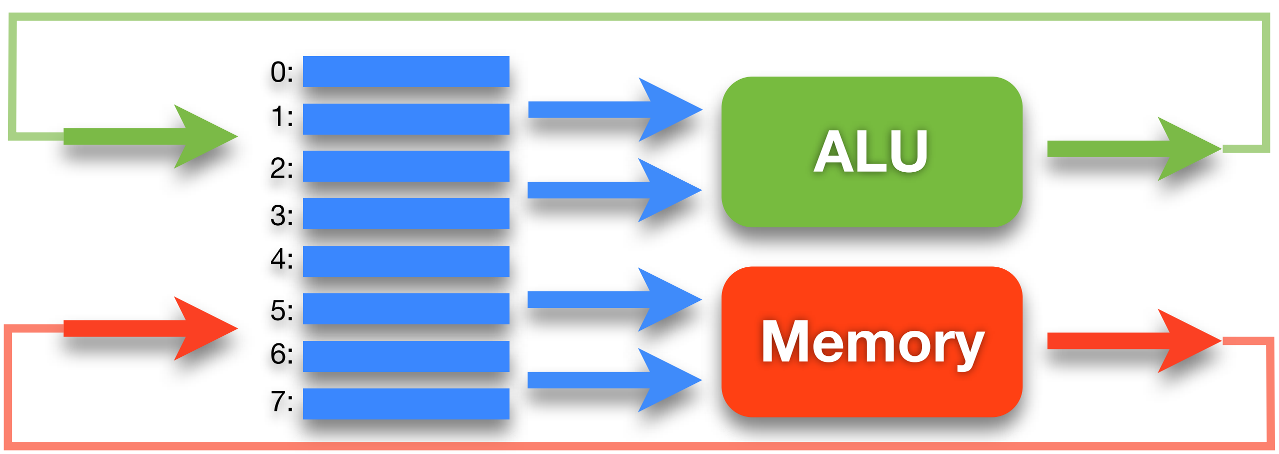




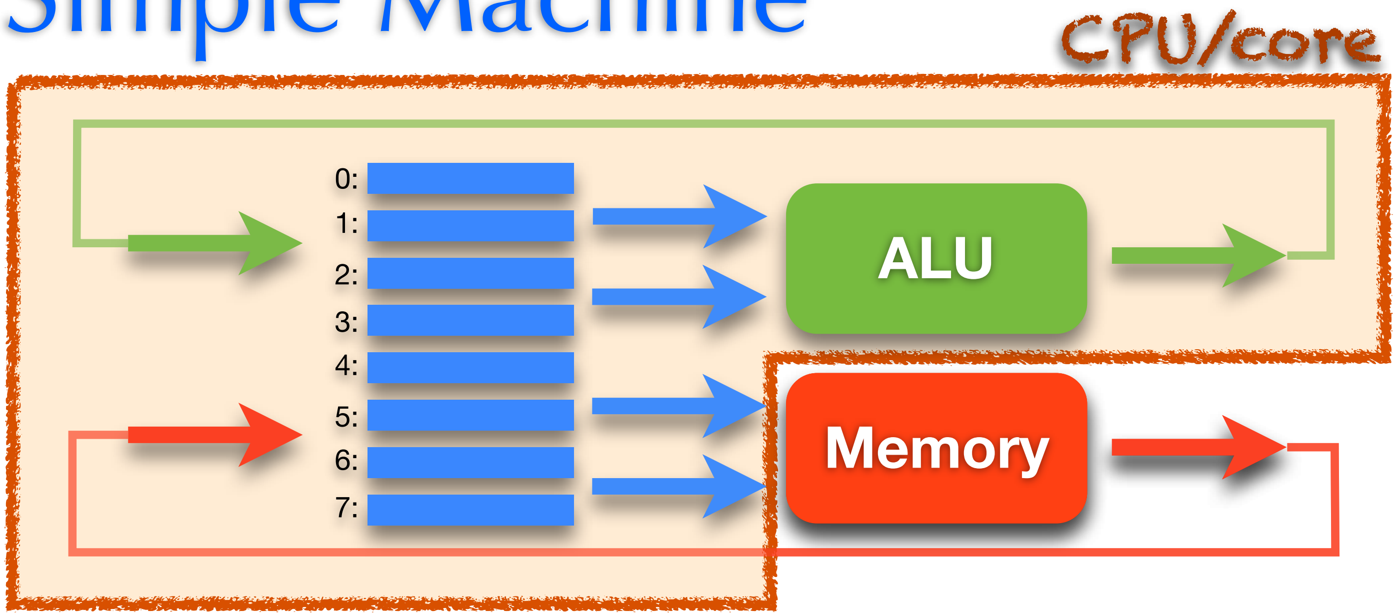
- Functional View
  - we now have an additional input, the immediate value, valC

Memory Access

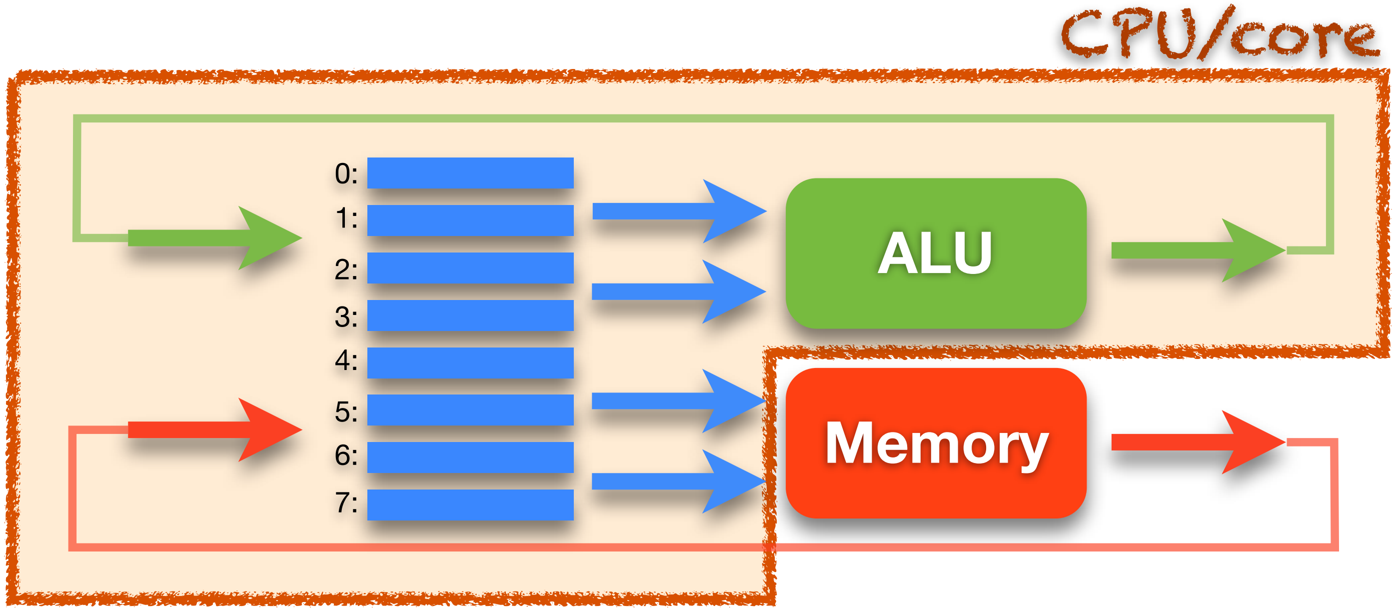
- Memory is
  - an array of bytes, indexed by byte ***address***
- Memory access is
  - restricted to a transfer between registers and memory
  - the ALU is thus unchanged, it still takes operands from registers
  - *this is approach taken by Reduced Instruction Set Computers (RISC)*
- Extending model to include RISC-like memory access
  - opcode selects from set of memory-access and ALU operations
  - memory address and value are in registers



The Simple Machine



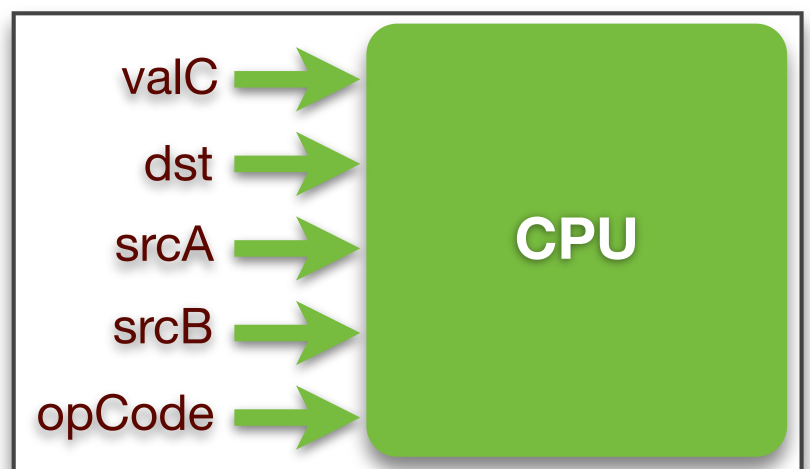
- Central Processing Unit or Core (CPU)
  - a register file
  - logic for ALU, memory access and control flow
  - a clock to sequence instructions
  - memory ***cache*** of some active parts of memory (e.g., instructions)
- Memory
  - is too big to fit on the CPU chip, so its stored off chip
  - much slower than registers or cache (200 x slower than registers)



- A Program
  - sequence of instructions stored in memory
- An Instruction
  - does one thing: math, memory-register transfer, or flow control
  - specifies a value for each of the functional inputs

A Program

```
0: valC=?, dst=?, srcA=?, srcB=?, opCode=?
1: valC=?, dst=?, srcA=?, srcB=?, opCode=?
2: valC=?, dst=?, srcA=?, srcB=?, opCode=?
3: valC=?, dst=?, srcA=?, srcB=?, opCode=?
```



Instruction Set Architecture (ISA)

- The ISA is the "interface" to a processor implementation
  - defines the instructions the processor implements
  - defines the format of each instruction
- Instruction format
  - is a set of bits (a number)
  - an opcode and set of operand values
- Types of instruction
  - math
  - memory access
  - control transfer (gotos and conditional gotos)
- Design alternatives
  - simplify compiler design (CISC such as Intel Architecture 32)
  - simplify processor implementation (RISC
- Assembly language
  - symbolic representation of machine code

Example Instruction: ADD

- Description
  - opCode = 61
  - two source operands in registers: srcA = rA, srcB = rB
  - put destination in register: dst = rB
- Assembly language
  - general form: `add rA, rB`
  - e.g., `add r0, r1`
- Instruction format
  - 16 bit number, divided into 4-bit chunks: `61sd`
  - high-order 8 bits are opCode (61)
  - next 4 bits are srcA (s)
  - next 4 bits are srcB/dst (d)

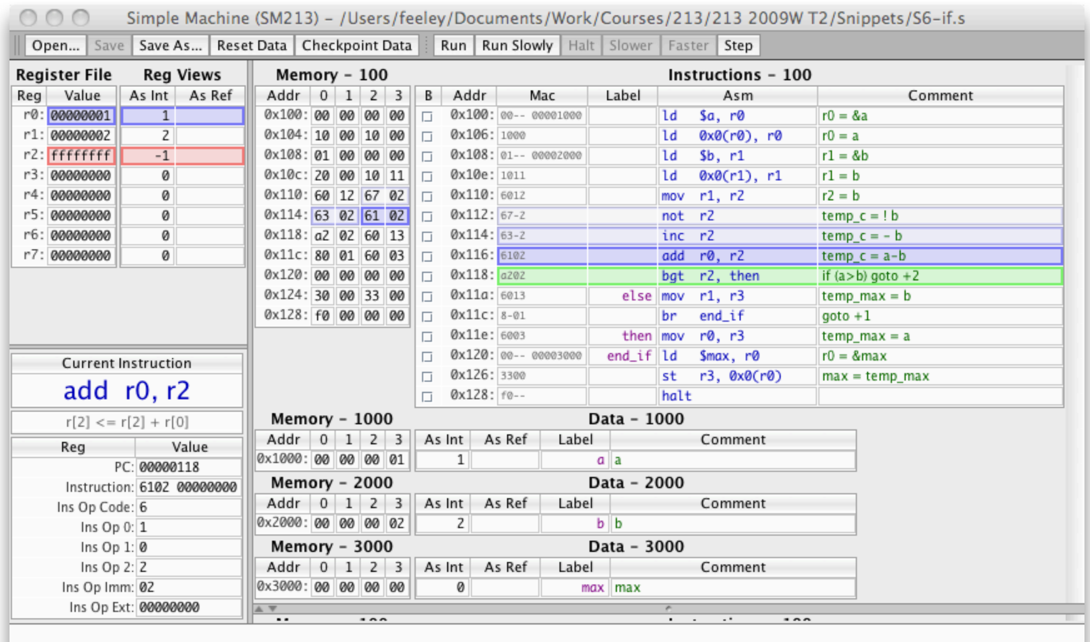
`add rA, rB`

0110	0001	ssss	dddd

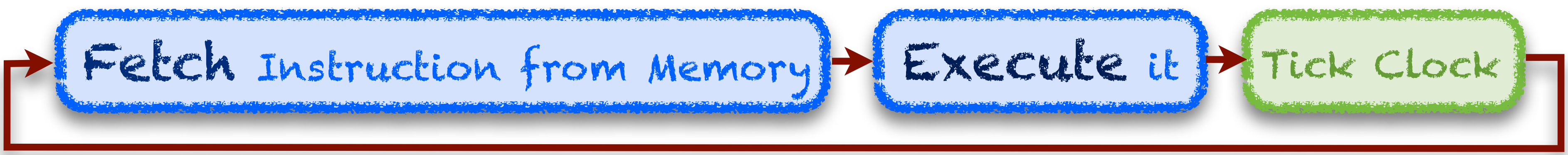
`add r0, r1`

0110	0001	0000	0001

Simulating a Processor Implementation



- Java simulator
  - edit/execute assembly-language
  - see register file, memory, etc.
- You will implement
  - the ***fetch*** + ***execute*** logic
  - for every instruction in SM213 ISA



- SM213 ISA
  - developed as we progress through key language features
  - patterned after *MIPS* ISA, one of the 2 first RISC architectures