IBCM 2.2
Principles of Operation

The Itty Bitty Computing Machine 2.2 is a very, very simple computer. In fact, it's so simple that no one in their right mind would build it using today's technology. Nevertheless — except for limits on problem size — any computation that can be performed on the most modern, sophisticated computer can also be performed on the IBCM 2.2. Its main virtue is that it can be taught quickly and will provide context for talking about more recent architectures.

CPU Characteristics:

single accumulator,
16-bit, fixed point, 2's complement arithmetic
the program counter, PC, generally points to the next instruction

Memory Characteristics:

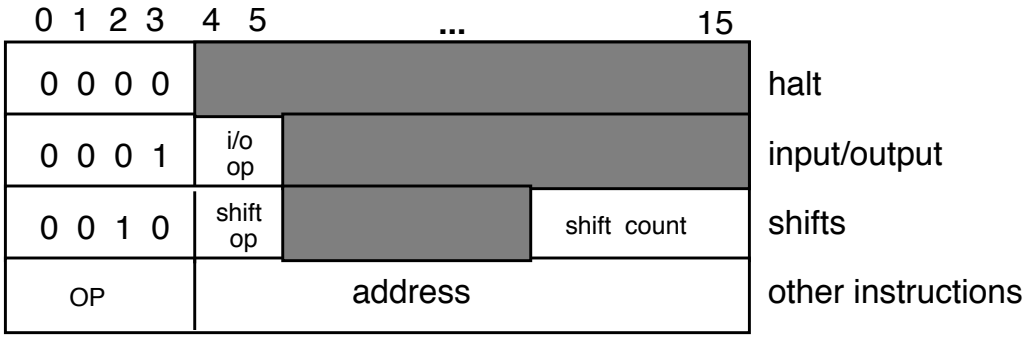
4096 16-bit "words"

I/O Characteristics

move numbers or characters from the accumulator to the screen, or from the keyboard to the accumulator.

Instruction Format:

Figure 1



The IBCM equivalent of "statements" in a higher level language are very simple instructions. Each instruction is encoded in a 16-bit word in one of the formats shown in Figure 1 (shaded areas in the Figure represent portions of the word whose value doesn't matter). So, for example, a word whose leftmost four bits are zero is an instruction to halt the computer.

Words with leftmost bits being 0001 and 0010 are input/output instructions and shift instructions respectively; we'll come back to those in a moment. All other bit combinations in the left-

most four bits either specify arithmetic or control — sort of like assignment statements and goto's in a high level language. These four bits are called the "op" field of the instruction; the value of this field is often called the "opcode". The "address" portion of the instruction generally specifies an address in memory where an operand (variable) will be found.

There are 13 IBCM operations of this form -- eight that manipulate data and five that perform control. The data manipulation operations all involve the "accumulator" and data from a memory location specified by the address portion of the instruction. The result of most data manipulation operations is recorded in the accumulator. Thus, the "add" instruction forms the arithmetic sum of the present contents of the accumulator with the contents of the memory location specified by "address" and puts the result back into the accumulator. So — it's like the very primitive assignment statement "`accumulator = accumulator + memory[address]`".

The control instructions determine the next instruction to be executed. The "jump" instruction, for example, causes the next instruction executed to be the one at the location contained in its address field. If you think of the address of a memory cell like a label in a high level language, then jump is just "`goto address`".

Two of the control instructions are conditional; they either cause a change in the control flow or not, depending on the nature of the contents of the accumulator. The simplest of the control instruction is "nop"; it does nothing.

The following table describes the function of each of the 16 IBCM instructions. Where possible, both English and programming language-like explanations are given for each instruction. In the latter, "a" is the accumulator, "addr" is the values of the address portion of the instruction, and "mem[]" is memory.

op	name	HLL-like meaning	English explanation
3_{16}	load	a:= mem[addr]	load accumulator from memory
4_{16}	store	mem[addr] := a	store accumulator into memory
5_{16}	add	a := a + mem[addr]	add memory to accumulator
6_{16}	sub	a := a - mem[addr]	subtract memory from accumulator
7_{16}	and	a := a & mem[addr]	logical 'and' memory into accumulator
8_{16}	or	a := a | mem[addr]	logical 'or' memory into accumulator
9_{16}	xor	a := a xor mem[addr]	logical 'xor' memory into accumulator
A_{16}	not	a := ~ a	logical complement of accumulator
B_{16}	nop		do nothing (no operation)
C_{16}	jmp	goto addr	jump to 'addr'
D_{16}	jmpe	if a = 0 goto addr	jump to 'addr' if accumulator equals zero
E_{16}	jmpl	if a < 0 goto addr	jump to 'addr' if accumulator less than zero
F_{16}	brl	a := PC; goto addr	jump (branch) to 'addr'; set accumulator to the value of the PC just before the jump (i.e., to the address following the brl). This instruction is often called "branch and link".

A few words of additional explanation are necessary for some of these operations (all of which are fairly standard for most computers).

1. Arithmetic operations may “overflow” or “underflow”; that is, the magnitude of the result may be larger than can be represented in 16 bits. The programmer is responsible for ensuring that this doesn't happen.

2. The “logical operations”, AND, OR, XOR and NOT perform bit-wise operations on the operands. The operations are defined by the following tables:

and	0	1
0	0	0
1	0	1

or	0	1
0	0	1
1	1	1

xor	0	1
0	0	1
1	1	0

not	
0	1
1	0

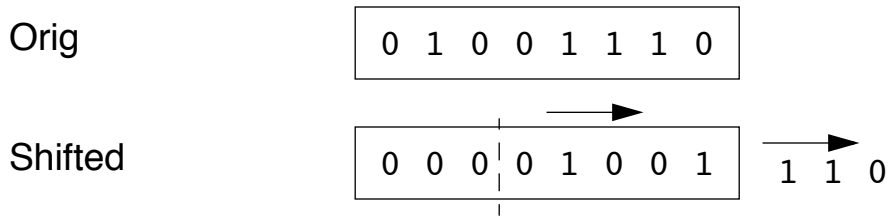
3. The branch and link instruction is used for subroutine calls, as will be discussed in class.

Now let’s return to the two classes of instructions that we skipped earlier, input/output and shifts.

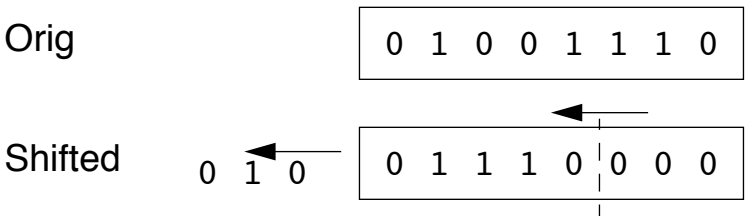
The input/output (or ‘io’) instructions move data between the accumulator and the computer ‘devices’ — the keyboard and screen. Data can be moved either as hexadecimal numbers or as a ascii character (in the later case, only the bottom 8 bits of the accumulator are involved). The four possibilities (in/out, hex/ascii) are specified by the bits 5 and 6 of the instruction word as follows:

bit 4	bit 5	operation
0	0	read a hexadecimal word (four digits) into the accumulator
0	1	read an ascii character into the accumulator bits 8-15
1	0	write a hexadecimal word (four digits) from the accumulator
1	1	write an ascii character from the accumulator bits 8-15

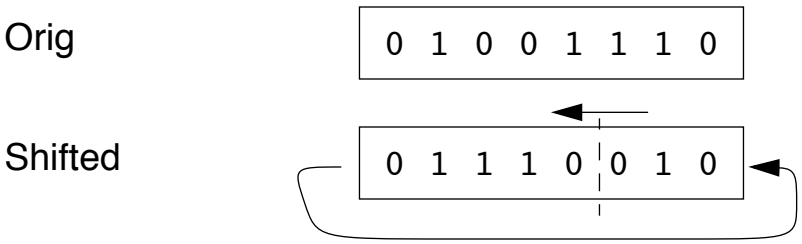
Shifting and rotating are common in computers. Shifting means moving data to the right or left; rotating is much the same thing except that bits that “fall off” one end are reinserted at the other. Diagrammatically, for example, a “right shift” of “n positions” looks like the following when n = 3:



Each bit is moved n positions to the right (three in this case). Alternatively, it is moved one bit to the right n times) This causes the original n rightmost bits to fall off the right end and n new (zero) bits to be inserted at the left. A "left shift" is much the same, except that bits move to the left:



As noted above, rotates are like shifts except that the bits don't fall off the end but are reinserted at the other end. Below, for example is a left rotation (we'll leave right rotates to your imagination).



Note that the shift instructions uses bits 5-6 to specify the shift operation (left/right, shift/rotate) as specified by the following table:

bit 4	bit 5	operation
0	0	shift left
0	1	shift right
1	0	rotate left
1	1	rotate right

In addition, bits 12-15 of the shift instructions specify the "shift count" — that is, the number of bits positions that the data is to be shifted (or rotated).

A Note on Using Hexadecimal Notation

IBCM is a *binary* computer. Internally all operations are performed on 16-bit binary values. However, because it's so tedious and error-prone for humans to write or read 16-bit quantities, all of IBCM's input/output is done either as ascii characters or 4-digit hexadecimal numbers. Remember that these are just external shorthands for the internal 16-bit values!

The IBCM Simulator/Debugger

The IBCM isn't a real computer, of course. One can, nonetheless, run programs written for it. The trick is that we have written a "simulator", a program that makes another computer behave more-or-less like the IBCM 2.2.

The IBCM 2.2 simulator will execute all the instructions of the machine and show the contents of memory locations and the accumulator as it executes. After you start the simulator by double-clicking on the `vb-ibcm.exe` file in Windows Explorer, you will see a screen with the following areas and buttons:

- The File pull-down menu in the upper left corner will let you Open an IBCM program file from disk, or Exit the simulator.
- The memory display table at the left shows all memory locations by address. The PC (program counter) arrow will point to the next instruction to be executed.
- The accumulator contents are displayed at the upper right.
- The memory watch table keeps a running display of the values in memory locations that you have specified by double-clicking an address in the memory display table. Double-clicking an entry in the watch table removes the entry.
- The Run key will run your program until it reaches a HALT instruction or pauses for input.
- The Step key will execute the next instruction and stop (very useful for debugging.)
- The Reset button will reset the PC and Accumulator to zero. Memory locations are not cleared.
- The large Input/Output area on the lower right is where you type input and see output displayed from the I/O instructions in IBCM.

When you load your program file using the File->Open menu item, it will be loaded starting at address zero in memory. The accumulator will be initialized to zero, as will the PC. Please note the following:

1. the format of your program file is very rigid -- the first four characters of each line are interpreted as a hexadecimal number. The number on the first line is loaded into location zero, the next into location one and so on. Characters after the first four on each line are ignored, so you should use them to comment the code; example code will be discussed in class.
2. when you execute a HALT, the simulator will halt with the PC pointing at the HALT.