Announcements

- Program #5 on the web
  - if you checked out before this morning, a file has been added so you need to do a
    - cvs update
  - unique port number for your project
  - overall view – picture at bottom of handout
- Reading
  - Notes

Recall Computer from Project 1

- Consider slight extensions (correction)
  - Load Rn Rm <value>
    - Rn = memory[Rm + <value>]
  - Store Rn Rm <value>
    - memory[Rm + <value>]= Rn
- Remember
  - R0 is always 0
  - Branch Rn Rm label
    - saves currentPC + 1 into Rn

Calling Functions

- When you call a function, eventually you return
  - Need to know where to return to
- Consider Machine from project #1
  - Branch instruction saved program counter to register
  - Can use that saved address to get back
  - Consider this code:

```
foo:    Branch R3 R0 bar
        Branch R4 R0 other
        Halt
bar:    Load R10 R0 #1234
        Branch R0 R3 0
other:  Load R10 R0 #5678
        Branch R3 R0 bar
        Output R10
        Branch R0 R4 0
```

Calling Functions

- Previous Code
  - Allows functions to call and return
  - But, need to coordinate which registers are used
    - caller and callee need to agree
    - what about recursion?
- Improved Solution
  - Keep a stack of return addresses for function
  - Dedicate a register to managing the stack
    - called stack pointer (R15)
  - Pick a standard register to save return address in
    - caller always uses this one (R14)
    - callee knows where return address is and saves it
      - push return address onto stack onto stack

Call Stack

- R15 contains address of top of stack
- Stack grows down from the end of memory
- Sample Code:
- Setup Stack
  - Load R15 R0 #65535
- Push R14 onto stack
  - Store R14 R15 0
  - Load R2 R0 #1
  - Negate R2
  - Add R15 R2 R15
- Pop top of Stack into R14
  - Load R2 R0 #1
  - Add R15 R2 R15
  - Load R14 R15 0

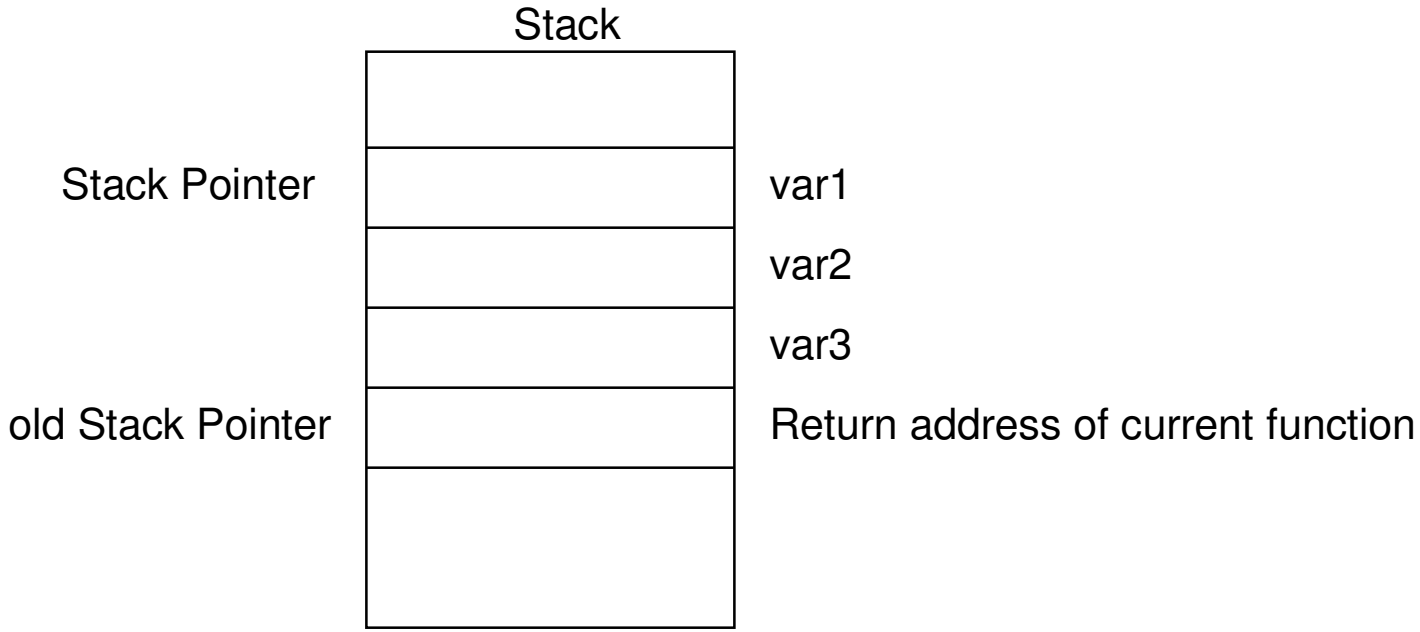
Improved Function Calls

```
main:   Load R15 R0 #65535
        Load R3 R0 #10
        Negate R3
        Branch R14 R0 foo
        Halt
foo:    Store R14 R15 0
        Load R2 R0 #1
        Negate R2
        Add R15 R2 R15
        Bnn R3 done
        Output R3
        Load R2 R0 #1
        Add R2 R3 R3
        Branch R14 R0 foo
done:   Load R2 R0 #1
        Add R15 R2 R15
        Load R14 R15 0
        Branch R0 R14 0
```

Local Variables

- Where to store variables local to a function?
  - Option 1:
    - in specific memory locations (like global vars)
    - what about recursion?
  - Option 2:
    - on the stack
    - specific address of a variables depends on call stack

Local Variables



- How to find local variables on the stack?
  - Use stack pointer to define relative position of items
  - When a function is called
    - save return address on stack
    - move stack pointer by size of locals plus return address

Local Variable Example

```
int main(void){
    foo();
}
void foo()
{
    int a, b, c, d;

    a = 30;
    b = 25;
    c = a + b;
    printf("%d\n", c);
}
```

```
0: Load R15 #65535
1: Branch R14 R0 3
2: Halt
3: Store R14 R15 0
4: Load R2 #5
5: Negate R2
6: Add R15 R2 R15
7: Load R5 #30
8: Store R5 R15 1
9: Load R6 #25
10: Store R6 R15 2
11: Add R5 R6 R7
12: Store R7 R15 3
13: Output R7
14: Load R2 #5
15: Add R15 R2 R15
16: Load R14 R15 0
17: Branch R0 R14 0
```

Passing Parameters

- Parameters are like local variables
  - values are only defined for lifetime of function
  - but, they have initial values
- Implementation
  - Option 1:
    - use stack just like local variables
    - copy initial values into locations prior to branch
  - Option 2:
    - put some parameters into registers
    - registers are faster than memory
    - finite number of them means still need option #1
      - put first n parameters into registers, then on stack

Return Values

- Also sort of like a local variable
- Return statement is an assignment to the variable
- Implementation
  - Option 1:
    - Put values on stack in well defined spot
    - Caller can access it after function returns
  - Option 2:
    - Dedicate a register for the return value
    - What about returning a struct?