Implementing Functions

Lecture 6
CS 212 – Fall 2007

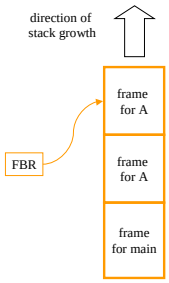
Announcements

- No section next week (Oct 8 and Oct 10) because of Fall Break
  - Class is in session on Oct 10, but we want to keep the sections in sync
- There will be a lecture as usual next week (Oct 10)
- Some comments about the Symbol Table
  - Symbol Table does not hold values

Basic Idea for Functions

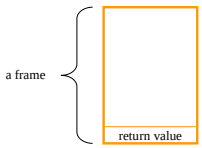
- A new *frame* (on the stack) is created for each function call
  - We use the FBR (Frame Base Register) to indicate the current frame
  - When a function returns it should "clean up" its frame

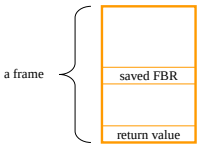
```
int main ( ):
    ...i = A( );...
    end

int A ( ):
    ...x = A( );...
    end
```



What's Kept in a Frame?

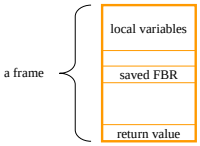
- We already have this principle:
  - When an expression is evaluated, the result is left on top of the stack
- What should be left on the stack after a function call?
- We know we have to change the FBR for each new frame
  - What do we do with the old FBR?

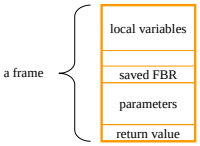




What Else is Kept in a Frame?

- Another principle:
  - Every time a function is called, it has its own local variables
- Thus it makes sense to keep a function's local variables in its frame
- The parameters of a function are also "local variables"
  - They can be kept in the frame, too

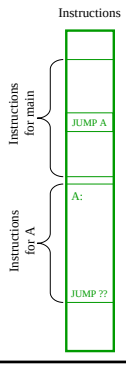




Is That It? Nothing Else in a Frame?

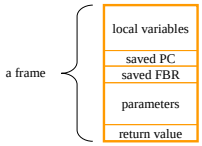
- Well, no; there's one more thing…
- We're using assembly language
  - If we want to jump somewhere and then come back then we must *remember* where to come back to

```
int main ( ):
    ...i = A( );...
    end

int A ( ):
    ...x = A( );...
    end
```



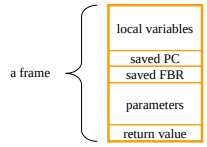
How Do We Jump Back?

- We can store the *return address* (i.e., a saved PC value) in the frame, too
- We have provided SAM instructions to store and restore the PC
  - JSR *address*
    - push PC+1 onto stack; set PC to *address*
    - Jump to SubRoutine
  - JUMPIND
    - set PC to value on top of stack
    - JUMP INDirect
- We also have instructions to save and restore the FBR
  - LINK
    - push value of FBR onto stack; set FBR to SP-1
  - UNLINK
    - set value of FBR to value on top of stack



Creating a Frame

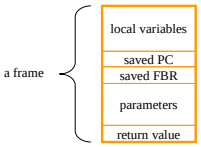
- Responsibility for creating a frame is shared by the *caller* (calling code) and the *callee* (the function's code)



- Caller's responsibilities
  - Push space for return value
  - Push arguments
  - Create new frame (use LINK = push current FBR and set FBR to SP–1)
  - JSR to callee (push PC+1 and jump to callee)
- Callee's responsibilities
  - Reserve space for local variables
  - Continue with callee's code

Clearing a Frame (Clean-up)

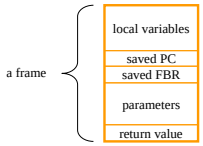
- Responsibility for clearing a frame is shared by the *callee* (the function's code) and the *caller* (calling code)



- Callee's responsibilities
  - Clear local variables from stack
  - JUMPIND to caller (clear the saved PC and jump back to calling code)
- Caller's responsibilities
  - Restore the FBR (UNLINK)
  - Clear the arguments from stack
  - Note: return value *remains on stack*

Access to Frame's Data

- Data stored in the frame are accessed via offset from the FBR
  - Let p be the number of parameters



The first local variable
- STOREOFF 2

The second local variable
- STOREOFF 3

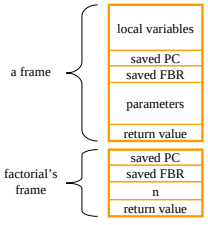
The first parameter
- STOREOFF –p

The second parameter
- STOREOFF –p + 1

The return value
- STOREOFF –p – 1

An Example

```
int factorial (int n) : :
   if n < 2 then return 1;
   else return n * factorial(n-1);
   endif
end
```




```
factorial: PUSHOFF -1
PUSHIMM 2
LESS
JUMPC true
JUMP false
true: PUSHIMM 1
STOREOFF -2          // Store return value
JUMPIND              // Return
false: PUSHOFF -1
ADDSP 1              // Space for return value
PUSHOFF -1
PUSHIMM 1
SUB                  // Argument is now on stack
LINK                 // Create new stack frame
JSR factorial        // Call the function
UNLINK               // Restore FBR
ADDSP -1             // Clear the argument
TIMES
STOREOFF -2          // Store return value
JUMPIND              // Return
```

Example Calling Code

```
program:
ADDSP 1              // Space for return value
PUSHIMM 5            // The argument
LINK                 // Create new stack frame
JSR factorial        // Call the function
UNLINK               // Restore FBR
ADDSP -1             // Clear the argument
WRITE                // Write result
STOP
```

- We need this "calling code" to help create factorial's initial frame

Code Pattern for Caller

func(*exp1*, *exp2*, *exp3*)

```
ADDSP 1          // Return value
code for exp1    // Push arguments
code for exp2
code for exp3
LINK             // Create new frame
JSR func         // Call func

UNLINK           // Restore FBR
ADDSP –3         // Remove arguments
```

- Caller's responsibilities (frame creation)
  - Push space for return value
  - Push arguments
  - Create new frame (LINK)
  - JSR to callee (push PC+1 and jump to callee)
- Caller's responsibilities (frame clean-up)
  - Restore the FBR (UNLINK)
  - Clear the arguments from stack

Code Pattern for Callee

retType func (*type1 exp1, type2 exp2, type3 exp3*):
local variables :
statements
return *exp*;
end

```
ADDSP v          // Space for v
                 // local variables
code for statements
code for exp     // Compute return value
JUMP endfunc     // Jump to clean-up
endfunc:
STOREOFF –4      // Store return value

ADDSP –v         // Clear local variables
JUMPIND          // Return to caller
```

- Callee's responsibilities (frame creation)
  - Push space for local variables
- Callee's responsibilities (frame clean-up)
  - Clear local variables from stack
  - JUMPIND to caller (clear the saved PC and jump back to calling code)

What About the "main" Function?

- The main function can be called by other functions
  - Thus, it needs to behave as a callee (i.e., it participates in building a frame)
  - We need some initial code to call main

```
program:
ADDSP 1          // Return value for main
LINK             // Create new frame
JSR main         // Call main
UNLINK           // Restore FBR

main:
ADDSP v          // Space for main's
                 // local variables
code for statements
code for exp     // Compute return value
JUMP endmain     // Jump to clean-up
endmain:
STOREOFF –1      // Store return value
ADDSP –v         // Clear local variables
JUMPIND          // Return to caller
```