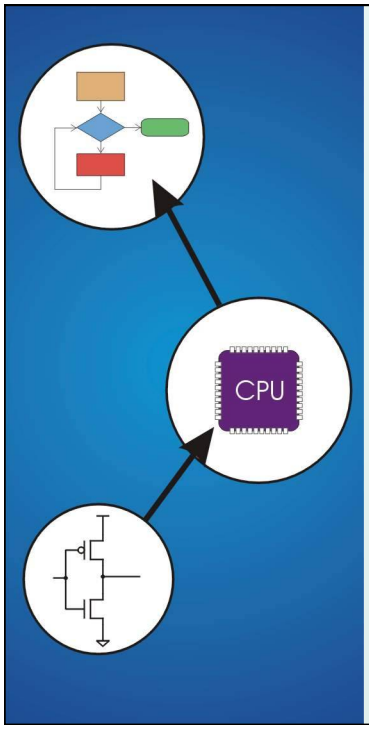


Chapter 14
Functions

Original slides from Gregory Byrd, North Carolina State University

Modified slides by C. Wilcox, S. Rajopadhye
Colorado State University

Function

- Smaller, simpler, subcomponent of program
- Provides abstraction
  - hide low-level details, give high-level structure
  - easier to understand overall program flow
  - enables separable, independent development
- C functions
  - zero or multiple arguments passed in
  - single result returned (optional)
  - return value is always a particular base type
- In other languages, called procedures, subroutines, ...

Example of High-Level Structure

```
main()
  {
    SetupBoard(); /* place pieces on board */
    DetermineSides(); /* choose black/white */

    /* Play game */
    do {
      WhitesTurn();
      BlacksTurn();
    } while (NoOutcomeYet());
  }
```

Structure of program is evident, even without knowing implementation.

Functions in C

- **Declaration** (also called prototype)

```
int Factorial(int n);
```

type of return value | name of function | types of all arguments

- **Function call** -- used in expression

```
a = x + Factorial(f + g);
```

1. evaluate arguments
2, execute function
3. use return value in expression

Function Definition

- State type, name, types of arguments
  - must match function declaration
  - give name to each argument (doesn't have to match declaration)

```
int Factorial(int n)
{
  int i;
  int result = 1;
  for (i = 1; i <= n; i++)
     result *= i;
  return result;
}
```

gives control back to calling function and returns value

Why Declaration?

- Since function definition also includes return and argument types, why is declaration needed?
- **Use might be seen before definition.** Compiler needs to know return and arg types and number of arguments.
- **Definition might be in a different file, written by a different programmer.**
  - include a "header" file with function declarations only
  - compile separately, link together to make executable

Example

```
double ValueInDollars(double amount, double rate);
main()
{
    ...
    dollars = ValueInDollars(francs,
                             DOLLARS_PER_FRANC);
    printf("%f francs equals %f dollars.\n",
           francs, dollars);
    ...
}
double ValueInDollars(double amount, double rate)
{
  return amount * rate;
}
```

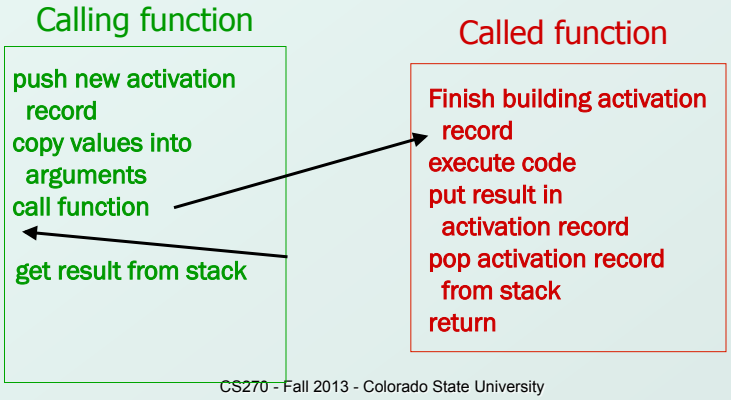
function declaration (prototype)

function call (invocation)

function definition (code)

Implementing Functions: Overview

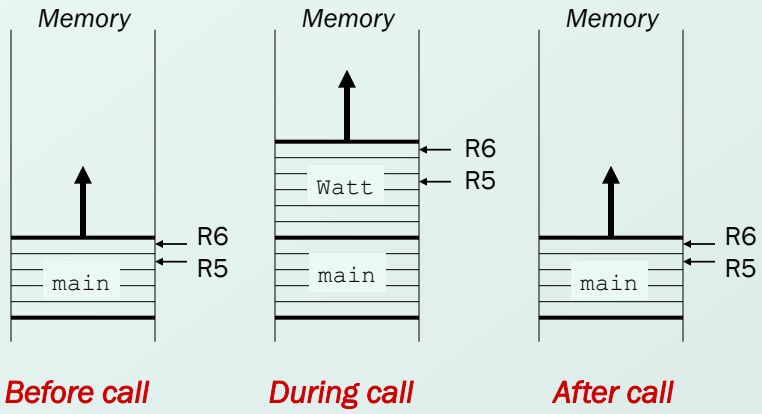
- Activation record (stack frame)
  - information about each function, including arguments and local variables
  - stored on run-time stack



Run-Time Stack

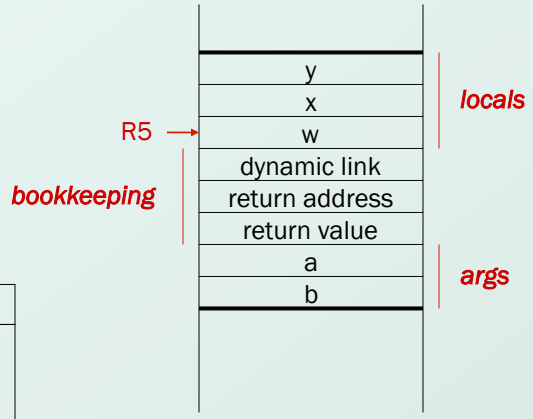
- Recall that local variables are stored on the run-time stack in an ***activation record***
- **Stack Pointer (R6)** is a pointer to the next free location in the stack, and is used to push and pop values on and off the stack.
- **Frame pointer (R5)** is a pointer to the beginning of a region of the activation record that stores local variables for the current function
- When a new function is **called**, its activation record is **pushed** on the stack; when it **returns**, its activation record is **popped** off of the stack.

Run-Time Stack



Activation Record

```
int NoName(int a, int b)
{
   int w, x, y;
   .
   .
   .
   return y;
}
```



Name	Type	Offset	Scope
a	int	4	NoName
b	int	5	NoName
w	int	0	NoName
x	int	-1	NoName
y	int	-2	NoName

Activation Record Bookkeeping

- **Return value**
  - space for value returned by function
  - allocated even if function does not return a value
- **Return address**
  - save pointer to next instruction in calling function
  - convenient location to store R7 in case another function (JSR) is called
- **Dynamic link**
  - caller's frame pointer
  - used to pop this activation record from stack

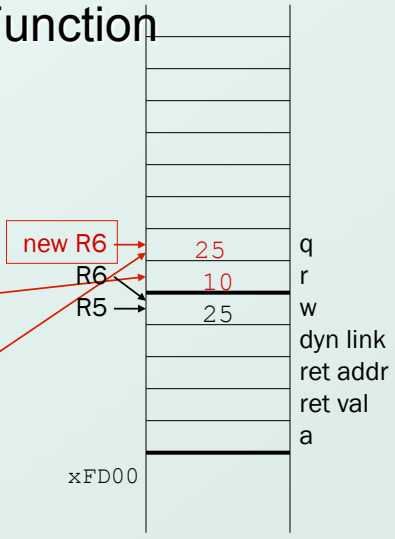
Example Function Call

```
int Volta(int q, int r)
{
  int k;
  int m;
  ...
  return k;
}

int Watt(int a)
{
  int w;
  ...
  w = Volta(w,10);
  ...
  return w;
}
```


Calling the Function

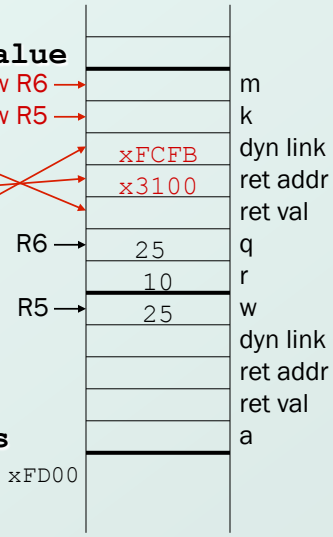
```
w = Volta(w, 10);
; push second arg
  AND  R0, R0, #0
  ADD  R0, R0, #10
  ADD  R6, R6, #-1
  STR  R0, R6, #0
  ; push first argument
  LDR  R0, R5, #0
  ADD  R6, R6, #-1
  STR  R0, R6, #0
  ; call subroutine
  JSR  Volta
```



Note: Caller needs to know number and type of arguments, doesn't know about local variables.

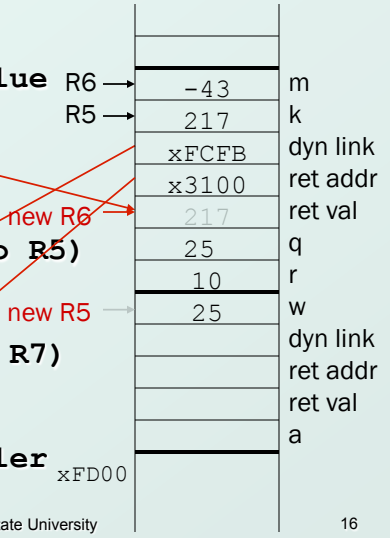
Starting the Callee Function

```
; leave space for return value
ADD  R6, R6, #-1
; push return address
ADD  R6, R6, #-1
STR  R7, R6, #0
; push caller's frame ptr
ADD  R6, R6, #-1
STR  R5, R6, #0
; set new frame pointer
ADD  R5, R6, #-1
; allocate space for locals
ADD  R6, R6, #-2
```



Ending the Callee Function

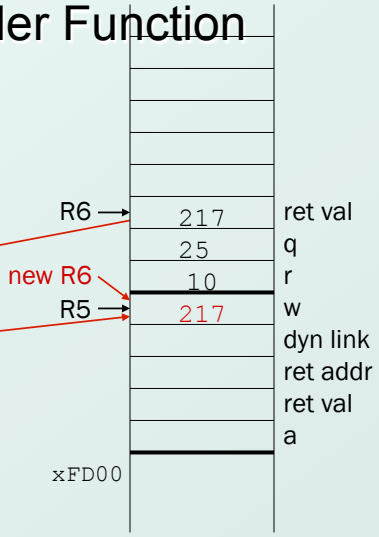
```
return k;
; copy k into return value
LDR  R0, R5, #0
STR  R0, R5, #3
; pop local variables
ADD  R6, R5, #1
; pop dynamic link (into R5)
LDR  R5, R6, #0
ADD  R6, R6, #1
; pop return addr (into R7)
LDR  R7, R6, #0
ADD  R6, R6, #1
; return control to caller
RET
```



Resuming the Caller Function

- `w = Volta(w,10);`
- `JSR  Volta`

```
  ; load return value
  ; from top of stack
  LDR  R0, R6, #0
  ; perform assignment
  STR  R0, R5, #0
  ; pop return value
  ADD  R6, R6, #1
  ; pop arguments
  ADD  R6, R6, #2
```



Summary of LC-3 Function Call Implementation

1. **Caller** pushes arguments (last to first).
2. **Caller** invokes subroutine (JSR).
3. **Callee** allocates return value, pushes R7 and R5.
4. **Callee** allocates space for local variables.
5. **Callee** executes function code.
6. **Callee** stores result into return value slot.
7. **Callee** pops local vars, pops R5, pops R7.
8. **Callee** returns (JMP R7).
9. **Caller** loads return value and pops arguments.
10. **Caller** resumes computation…