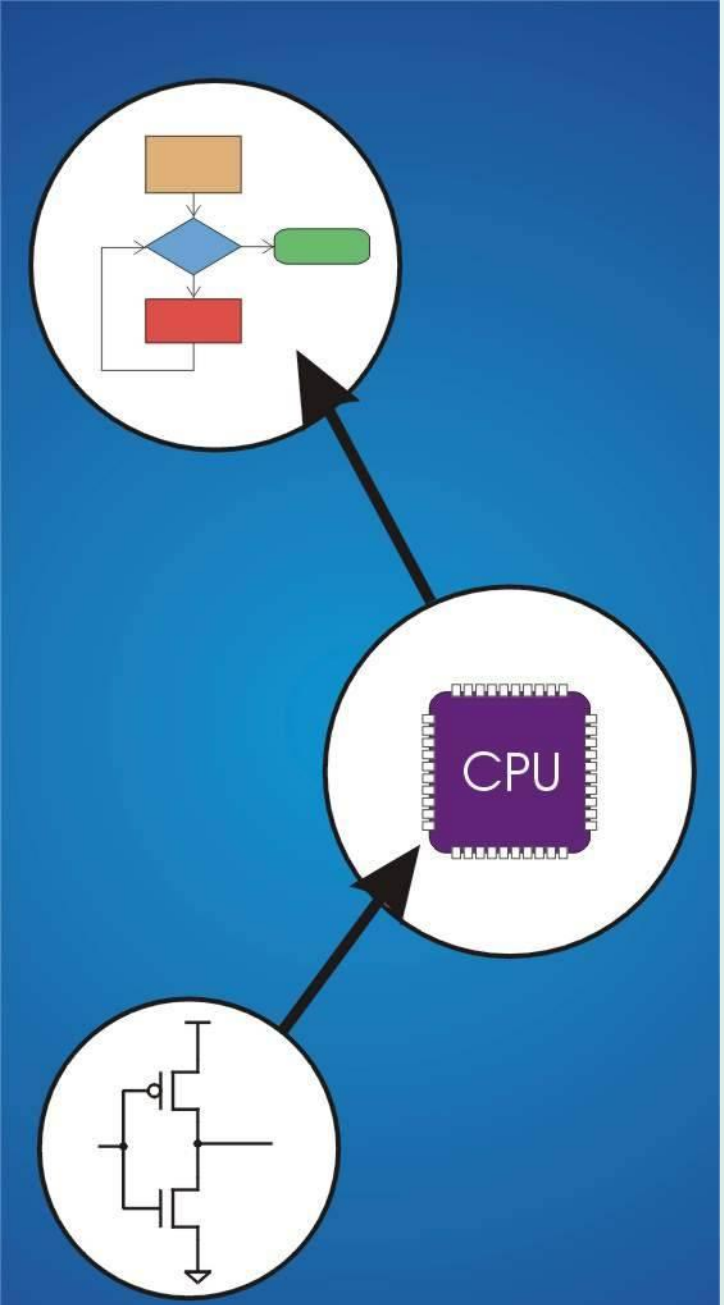


# Chapter 14
# **Functions**

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# 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 type
- In other languages, called procedures, subroutines, ...

# Example of High-Level Structure

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

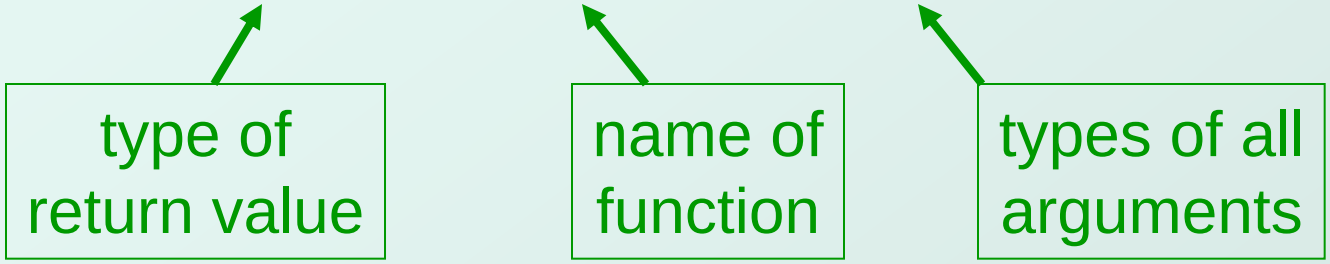
     /* Play game */
     do {
       WhitesTurn();
       BlacksTurn();
     } while (NoOutcomeYet());
   }
```

Structure of program is evident, even without knowing implementation.

# Functions in C

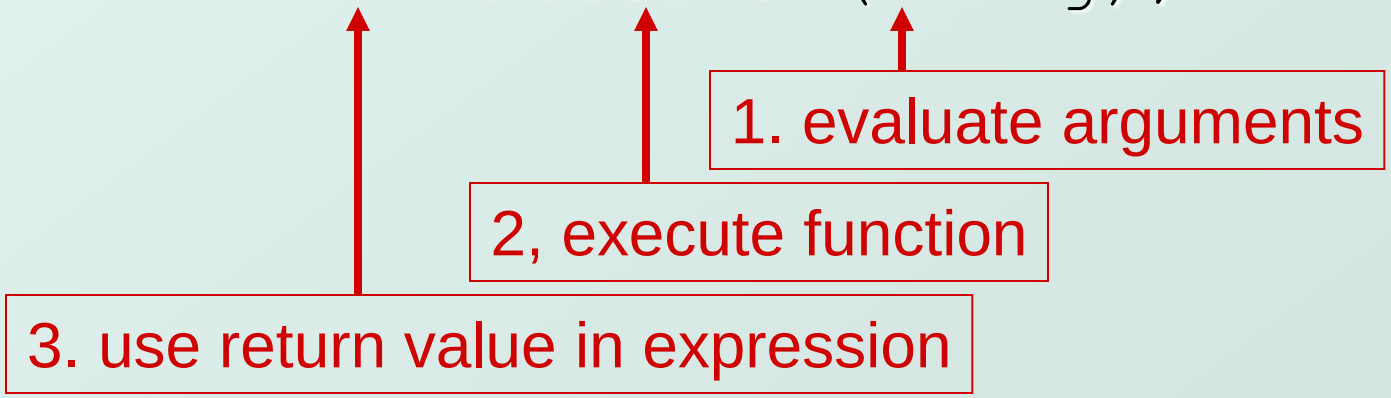
- **Declaration** (also called prototype)

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




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

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



# 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;
}
```

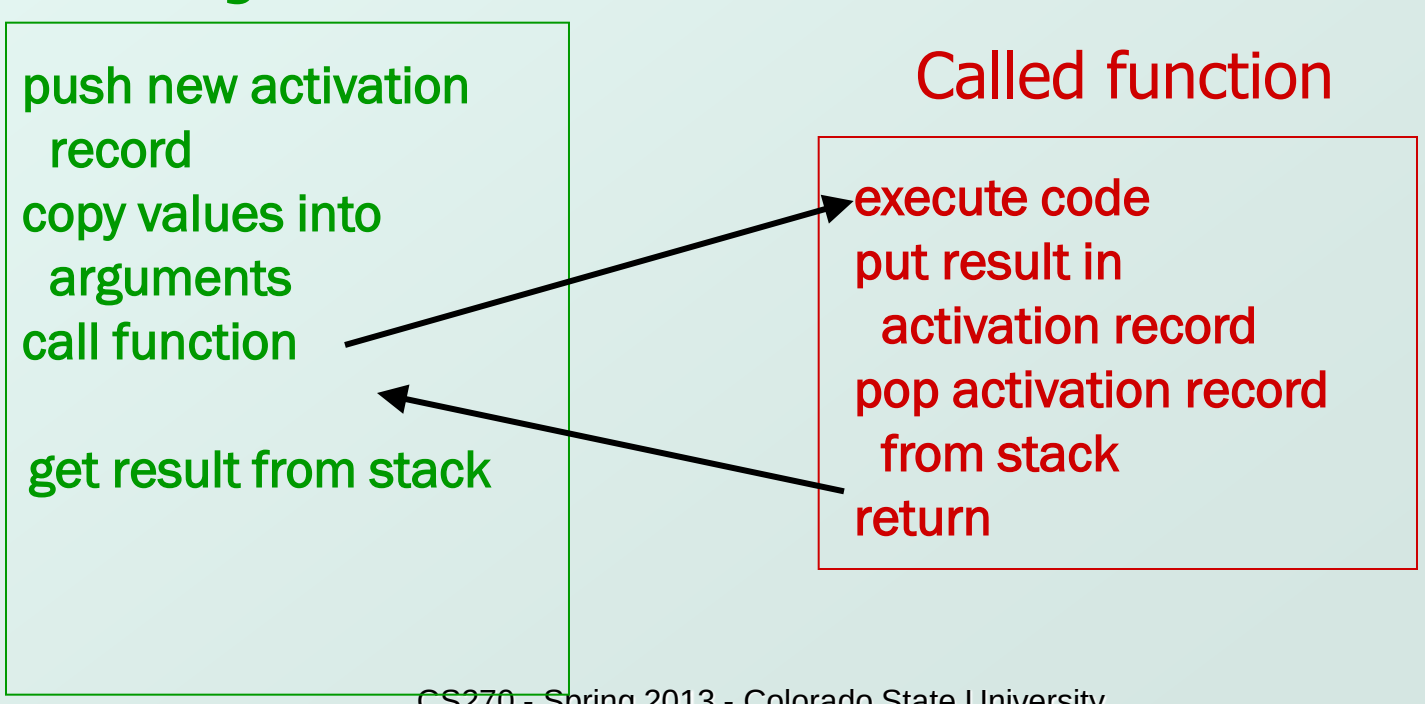
function declaration (prototype)

function call (invocation)

function definition (code)

# Implementing Functions: Overview

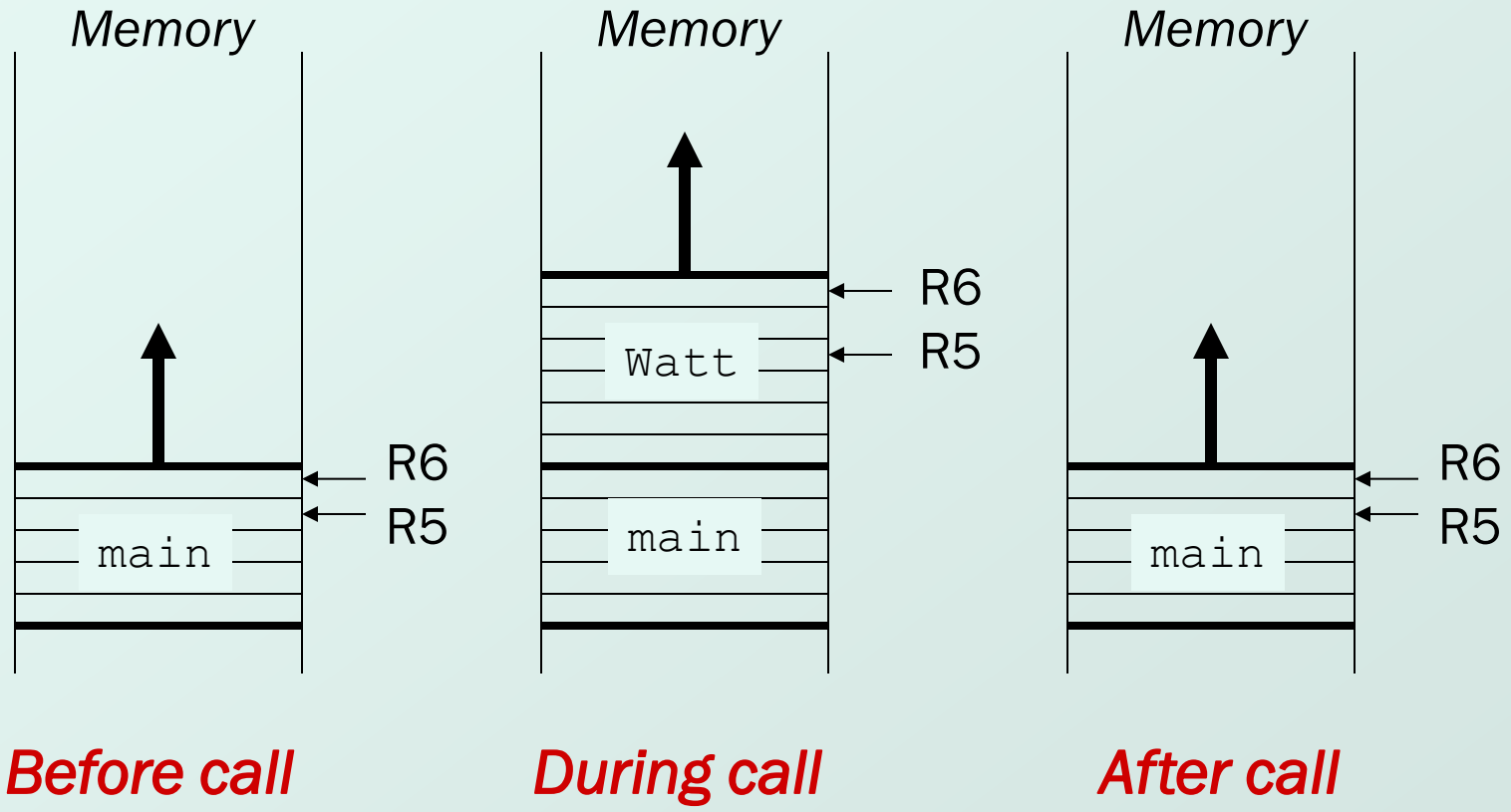
- Activation record (stack frame)
  - information about each function, including arguments and local variables
  - stored on run-time stack



# Run-Time Stack

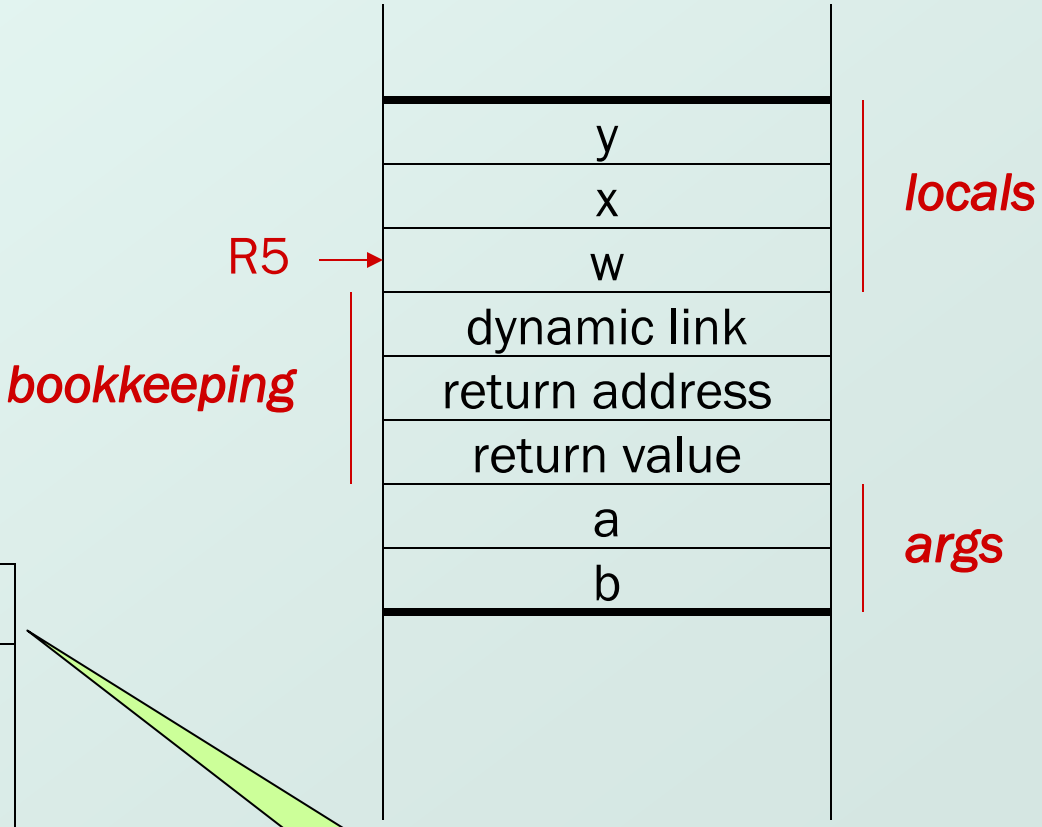
- Recall that local variables are stored on the run-time stack in an ***activation record***
- **Stack Pointer (R6)** is a pointer to the next free location in the stack, and is used to push and pop values on and off the stack.
- **Frame pointer (R5)** is a pointer to the beginning of a region of the 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 |

Symbol table

# 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

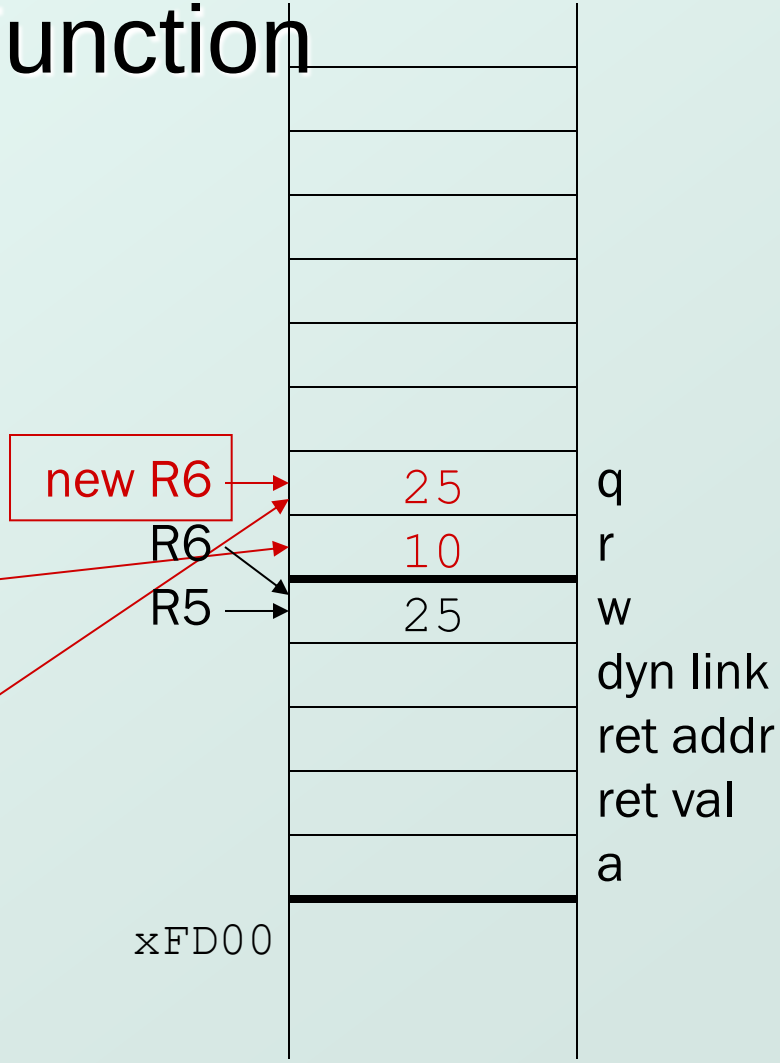
# Example Function Call

```
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

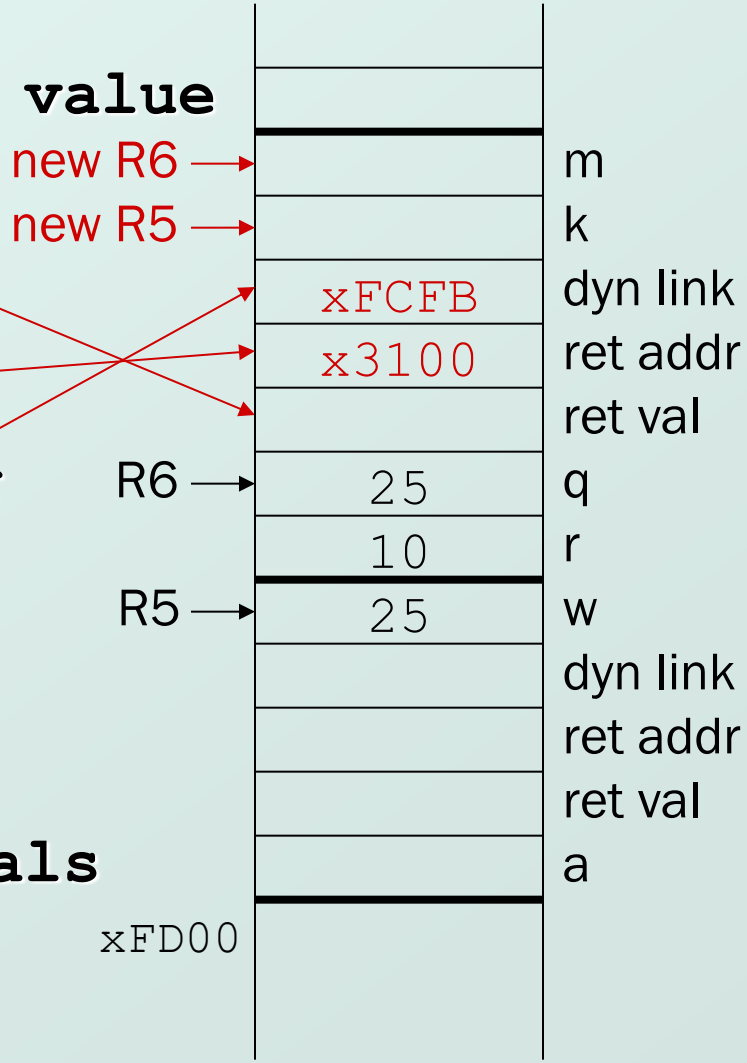
- `w = Volta(w, 10);`
- ```
  ; push second arg
  AND  R0, R0, #0
  ADD  R0, R0, #10
  ADD  R6, R6, #-1
  STR  R0, R6, #0
  ; push first argument
  LDR  R0, R5, #0
  ADD  R6, R6, #-1
  STR  R0, R6, #0
  ; call subroutine
  JSR  Volta
  ```




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

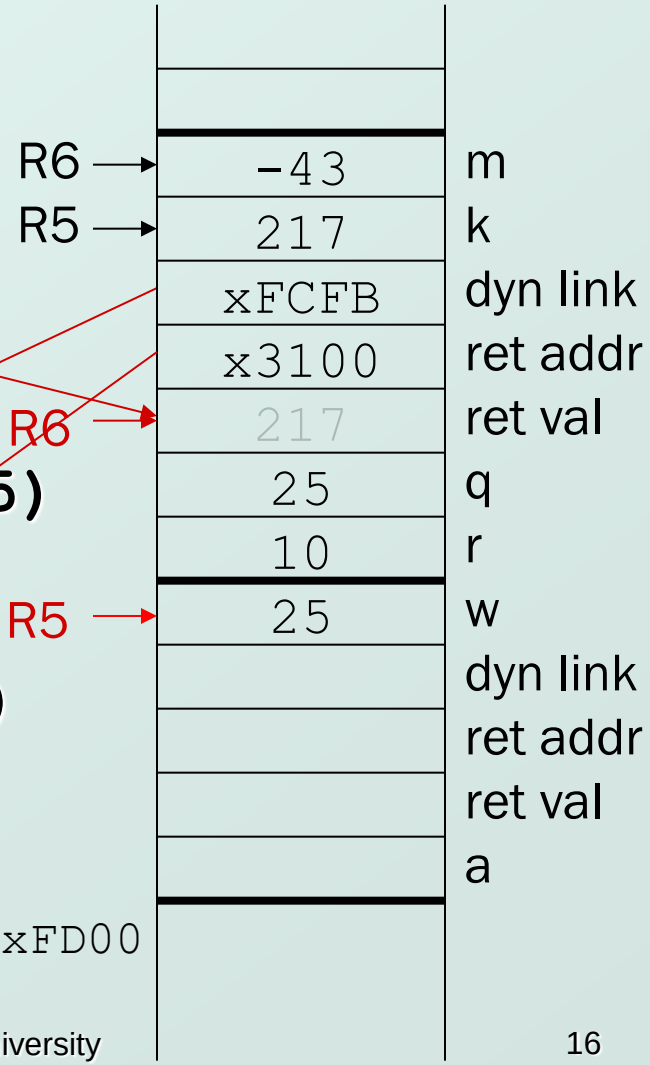
# Starting the Callee Function

```
; 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

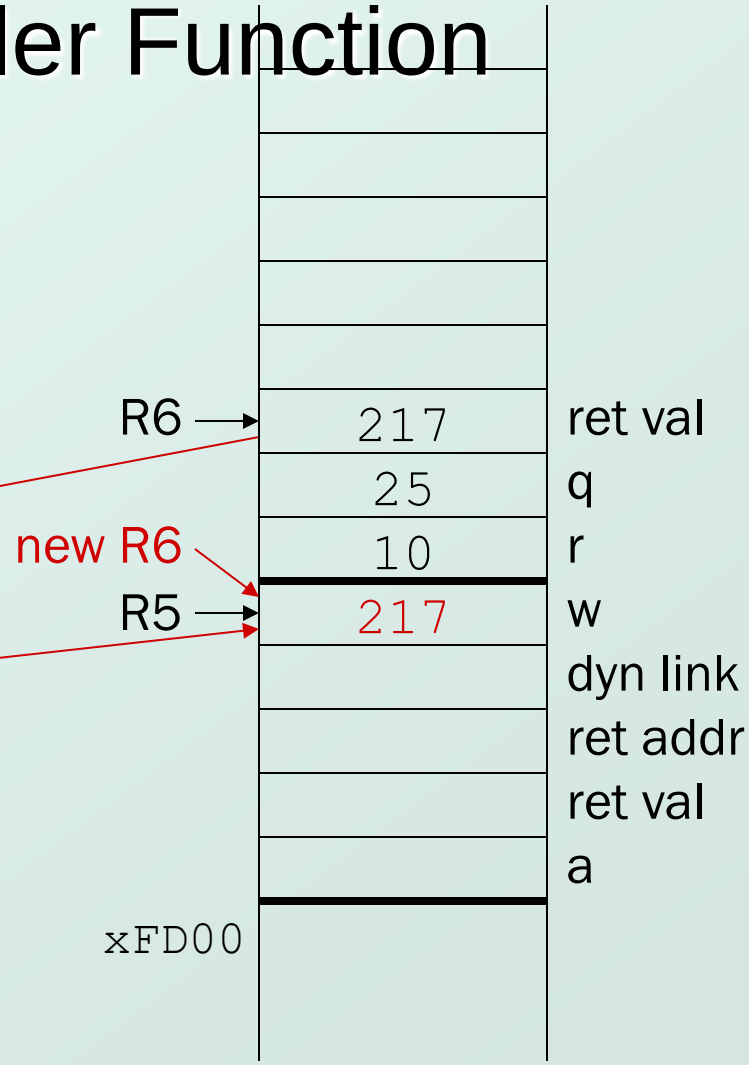
- `return k;`
- 
```
; copy k into return value
LDR  R0, R5, #0
STR  R0, R5, #3
; pop local variables
ADD  R6, R5, #1
; pop dynamic link (into R5)
LDR  R5, R6, #0
ADD  R6, R6, #1
; pop return addr (into R7)
LDR  R7, R6, #0
ADD  R6, R6, #1
; return control to caller
RET
```



# 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…