Chapter 14
Functions
**Function**

Smaller, simpler, subcomponent of program

Provides abstraction
- hide low-level details
- give high-level structure to program, 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

```c
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)

```c
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;
}
For each function call

- A stack-frame ("activation record") is inserted ("pushed") in the run-time stack.
- It holds:
  - local variables,
  - arguments
  - values returned
- If the function is recursive, for each iteration inserts a stack-frame.
- When a function returns, the corresponding stack-frame is removed ("popped").
- When a function returns, its local variables are gone.
Implementing Functions: Overview

Activation record

- information about each function, including arguments and local variables
- stored on run-time stack

Calling function

- push new activation record
- copy values into arguments
- call function
- get result from stack

Called function

- execute code
- put result in activation record
- pop activation record from stack
- return
How functions are implemented in LC-3

We skip the following slides. We will come to them after we have seen LC-3
Run-Time Stack

Recall that local variables are stored on the run-time stack in an *activation record*

Frame pointer (R5) points to the beginning of a region of 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

Before call

During call

After call
Activation Record

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

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Offset</th>
<th>Scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>int</td>
<td>4</td>
<td>NoName</td>
</tr>
<tr>
<td>b</td>
<td>int</td>
<td>5</td>
<td>NoName</td>
</tr>
<tr>
<td>w</td>
<td>int</td>
<td>0</td>
<td>NoName</td>
</tr>
<tr>
<td>x</td>
<td>int</td>
<td>-1</td>
<td>NoName</td>
</tr>
<tr>
<td>y</td>
<td>int</td>
<td>-2</td>
<td>NoName</td>
</tr>
</tbody>
</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

```c
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

```c
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 dyn link (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

\[ w = \text{Volta}(w, 10); \]

JSR Volta

; load return value (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

R6
new R6
R5
217
25
10
217

xFD00
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…