EECS 22: Advanced C Programming

Lecture 5

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Lecture 5: Overview

- Review of the C Programming Language
  - Functions
    - Introduction and concept
    - Declaration, definition, and function call
- Hierarchy of Functions
  - Example program **`Cylinder.c`**
  - Function call graph
  - Function call trace
  - Function call stack
  - Long Jump
- Recursion
  - Concept of recursion
  - Example program **`Fibonacci.c`**

Review of the C Programming Language

- Functions
  - Support for essential programming concepts
    - Hierarchy
    - Encapsulation
    - Information hiding
    - Divide and conquer
  - Software reuse
    - Don't re-invent the wheel!
  - Program composition
    - C program = Set of functions
      - starting point: function named **`main`**
    - Libraries = Set of functions
      - predefined functions (often written by somebody else)

Functions

- C programming language distinguishes 3 constructs around functions
  - *Function declaration*
    - declaration of function name, parameters, and return type
  - *Function definition*
    - extension of a function declaration with a function body
    - definition of the function behavior
  - *Function call*
    - invocation of a function

Functions

- Function Declaration
  - aka. *function prototype* or *function signature*
  - declares
    - function name
    - function parameters
    - type of return value
- Example:

```
double CircleArea(double r);
```

  - function is named **`CircleArea`**
  - function takes one parameter **`r`** of type **`double`**
  - function returns a value of type **`double`**

Functions

- Function Definition
  - extends a function declaration with a function body
  - defines the statements executed by the function
  - may use local variables for the computation
  - returns result value via **`return`** statement (if any)
- Example:

```
double CircleArea(double r)
{
  const double pi = 3.1415927;
  double a;
  a = pi * r * r;
  return a;
}
```

Functions

- Function Call
  - expression invoking a function
  - supplies arguments for formal parameters
  - invokes the function
  - result is the value returned by the function
- Example:

```
double a, b = 10.0;
a = CircleArea(b);
```

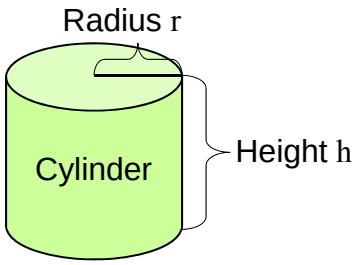
  - function **`CircleArea`** is called
  - argument **`b`** is passed for parameter **`r`** (by value)
  - value returned by the function is assigned to **`a`**

Functions

- C Programming Language distinguishes 3 Constructs
  - Function declaration
    - declaration of function name, parameters, and return type
  - Function definition
    - extension of a function declaration with a function body
    - definition of the function behavior
  - Function call
    - invocation of a function
- C Program Rules
  - A function must be declared before it can be called.
  - Multiple function declarations are allowed (if they match).
  - A function definition is an implicit function declaration.
  - A function must be defined exactly once in a program.
  - A function may be called any number of times.

Functions

- Hierarchy of Functions
  - functions call other functions
- Example:
  Cylinder calculations
    - given radius and height
    - calculate surface and volume



- Circle constant $\pi = 3.14159265...$
- Circle perimeter $f_p(r) = 2 \times \pi \times r$
- Circle area $f_a(r) = \pi \times r^2$
- Cylinder surface $f_s(r, h) = f_p(r) \times h + 2 \times f_a(r)$
- Cylinder volume $f_v(r, h) = f_a(r) \times h$

Functions

- Program example: **`Cylinder.c`** (part 1/3)

```
/* Cylinder.c: cylinder functions       */
/* author: Rainer Doemer                */
/* modifications:                       */
/* 10/25/05 RD  initial version         */

#include <stdio.h>

/* cylinder functions */

double pi(void)
{
    return(3.1415927);
}

double CircleArea(double r)
{
    return(pi() * r * r);
}
...
```

Functions

- Program example: **`Cylinder.c`** (part 2/3)

```
...
double CirclePerimeter(double r)
{
    return(2 * pi() * r);
}

double Surface(double r, double h)
{
    double side, lid;

    side = CirclePerimeter(r) * h;
    lid  = CircleArea(r);

    return(side + 2*lid);
}

double Volume(double r, double h)
{
    return(CircleArea(r) * h);
}
...
```


Functions

- Program example: **`Cylinder.c`** (part 3/3)

```
...
/* main function */

int main(void)
{   double r, h, s, v;

    /* input section */
    printf("Please enter the radius: ");
    scanf("%lf", &r);
    printf("Please enter the height: ");
    scanf("%lf", &h);

    /* computation section */
    s = Surface(r, h);
    v = Volume(r, h);

    /* output section */
    printf("The surface area is %f.\n", s);
    printf("The volume is %f.\n", v);

    return 0;
} /* end of main */
```

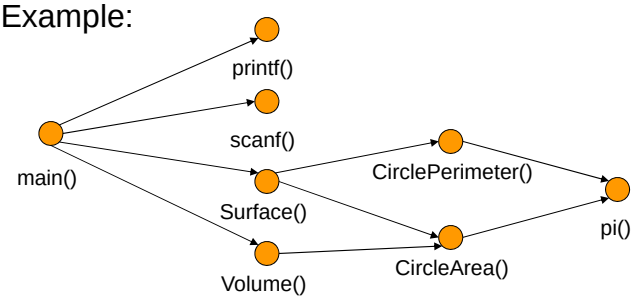
Functions

- Example session: **`Cylinder.c`**

```
% vi Cylinder.c
% gcc Cylinder.c -o Cylinder -Wall -ansi
% Cylinder
Please enter the radius: 5.0
Please enter the height: 8.0
The surface area is 408.407051.
The volume is 628.318540.
%
```


Function Call Graph

- Graphical Representation of Function Calls
  - Directed Graph
    - Nodes: Functions
    - Edges: Function calls
  - Shows dependencies among functions
  - Example:

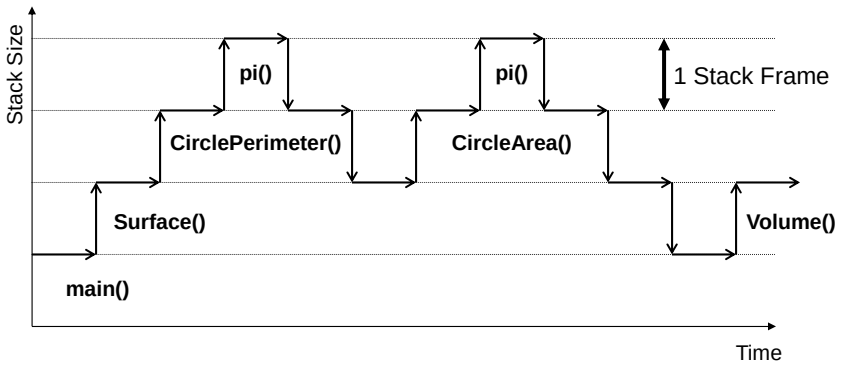


Function Call Trace

- Sequence of Function Calls
  - shows execution order of functions at run-time
- Example:
  - `main()`
    - `printf()`
    - `scanf()`
    - `printf()`
    - `scanf()`
    - `Surface()`
      - `CirclePerimeter()`
        - » `pi()`
      - `CircleArea()`
        - » `pi()`
    - `Volume()`
      - `CircleArea()`
        - » `pi()`
    - `printf()`
    - `printf()`

Function Call Stack

- Stack Frames
  - Keep track of active function calls
    - Stack grows by one frame with each function call
    - Stack shrinks by one frame with each completed function



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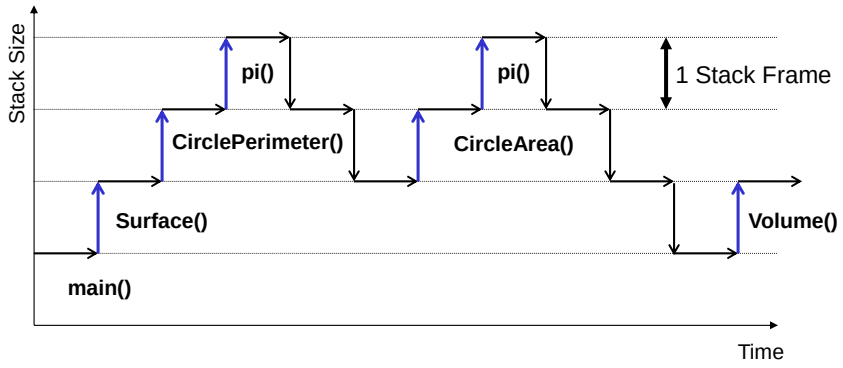

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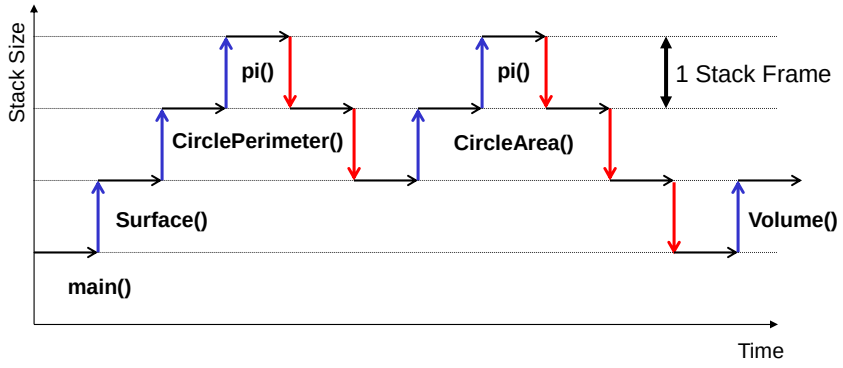

Non-Local Goto: Long Jump

- *Long Jump*: Returning to a previous stack frame
  - Useful, for example, when dealing with errors (or interrupts) in a low-level function of a program.
    - However, long jumps are hard to understand and maintain!
    - Same as goto, avoid long jumps, if possible!
  -
```
#include <setjmp.h>
int setjmp(jmp_buf env);
```
    - saves current stack context in **env** for later use by **longjmp()**
    - stack context in **env** is valid until the function which called **setjmp()** returns
  -
```
void longjmp(jmp_buf env, int val);
```
    - non-local jump (return) to a saved stack context **env**
    - **longjmp()** restores the stack context saved by **setjmp()**
    - after **longjmp()**, program execution continues as if the call of **setjmp()** had just returned the value **val**

Non-Local Goto: Long Jump

- *Long Jump*: Returning to a previous stack frame
- Example:

```
#include <setjmp.h>
jmp_buf env;        /* storage for stack context */
void error(void)    /* error, return to main! */
{
  longjmp(env, 1);
}
int main(void)
{
  if (setjmp(env))  /* store current stack context */
  { /* long jump arrives here! */
    return 10;
  }
  work(...); /* call tree can call error at any time */
  return 0;
}
```

Recursion

- Introduction
  - *Recursion* is often an alternative to *Iteration*
  - Recursion is a very simple concept, yet very powerful
  - Recursion is present in nature
    - Trees have branches, which have branches, which have branches, ... which have leaves.
  - Recursion is traversal of hierarchy
    - *Traverse* (climb) a tree to the top:
      - start at the root
      - at a leaf, stop
      - at a branch, *traverse* one branch
    - *Traverse* a file system on a computer
      - start at the current directory
      - at a file, process the file
      - at a directory, *traverse* the directory

Recursion

- Recursive Function
  - Function that calls itself ...
    - ... directly, or
    - ... indirectly

```
int f(...)
  { ...
    f(...);
    ...
  }
```

```
int a(...)
  { ...
    b(...);
    ...
  }
int b(...)
  { ...
    a(...);
    ...
  }
```

- Concept of Recursion
  - Trivial *base case*
    - Return value defined for simple case
    - Example: `if (arg == 0) {return 1; }`
  - *Recursion step*
    - Reduce the problem towards the base case
    - Make a recursive function call
    - Example: `if (arg > 0) { return ...fct(arg-1); }`
- Termination of Recursion
  - Converging of recursive calls to the base case
  - Recursive call must be “simpler” than current call

Recursion

- Example: Fibonacci series
  - Sequence of integers
    - 0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233, 377, 610, 987, ...
  - Mathematical properties
    - The first two numbers are 0 and 1
    - Every subsequent Fibonacci number is the sum of the previous two Fibonacci numbers
  - Ratio of successive Fibonacci numbers is ...
    - ... converging to constant value 1.618...
    - ... called *Golden Ratio* or *Golden Mean*
  - Recursive definition:
    - Base case: *fibonacci(0) = 0*
fibonacci(1) = 1
    - Recursion step: *fibonacci(n) = fibonacci(n-1) + fibonacci(n-2)*

Recursion

- Program example: **`Fibonacci.c`** (part 1/2)

```
/* Fibonacci.c: example demonstrating recursion */
/* author: Rainer Doemer                        */
/* modifications:                               */
/* 11/14/04 RD  initial version                 */

#include <stdio.h>

/* function definition */

long fibonacci(long n)
{
   if (n <= 1)  /* base case */
      { return n;
       } /* fi */
   else         /* recursion step */
      { return fibonacci(n-1) + fibonacci(n-2);
       } /* esle */
} /* end of fibonacci */

/* main function */
...
```

Recursion

- Program example: **`Fibonacci.c`** (part 2/2)

```
...
int main(void)
{
   /* variable definitions */
   long int n, f;

   /* input section */
   printf("Please enter value n: ");
   scanf("%ld", &n);

   /* computation section */
   f = fibonacci(n);

   /* output section */
   printf("The %ld-th Fibonacci number is %ld.\n", n, f);

   /* exit */
   return 0;
} /* end of main */

/* EOF */
```


Recursion

- Example session: **`Fibonacci.c`**

```
% cp Factorial.c Fibonacci.c
% vi Fibonacci.c
% gcc Fibonacci.c -o Fibonacci -Wall -ansi
% Fibonacci
Please enter value n: 1
The 1-th Fibonacci number is 1.
% Fibonacci
Please enter value n: 10
The 10-th Fibonacci number is 55.
% Fibonacci
Please enter value n: 20
The 20-th Fibonacci number is 6765.
% Fibonacci
Please enter value n: 30
The 30-th Fibonacci number is 832040.
% Fibonacci
Please enter value n: 40
The 40-th Fibonacci number is 102334155.
%
```