EECS 10: Computational Methods in Electrical and Computer Engineering

Lecture 14

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Lecture 14: Overview

- Course Administration
  - Reminder: Midterm course evaluation
- Functions
  - Terms and concepts
  - Hierarchy of functions
    - Example **`Cylinder.c`**
    - Function call graph
    - Function call trace
    - Function call stack
    - Navigating stack frames in the debugger
  - Scoping
    - Scope rules
    - Example **`Scope.c`**
    - Viewing scopes in the debugger

Course Administration

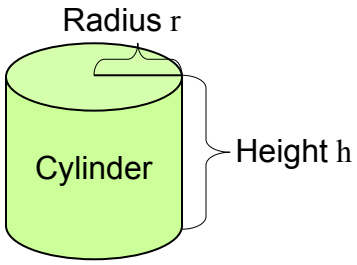
- Midterm Course Evaluation
  - This week!
  - Monday, Oct. 26, 9am – Sunday, Nov. 1, noon
  - Online via EEE Evaluation application
- Feedback from students to instructors
  - Completely voluntary
  - Completely anonymous
  - Very valuable
    - Help to improve this class!
- Mandatory Final Course Evaluation
  - expected for week 10 (TBA)

Functions

- Review: Terms and Concepts
  - Function declaration
    - function prototype with name, parameters, and return type
  - Function definition
    - extended declaration, defines the behavior in function body
  - Function call
    - expression invoking a function with supplied arguments
  - Function arguments
    - arguments passed to a function call (initial values for parameters)
  - Function parameters
    - formal parameters holding the data supplied to a function
  - Local variables
    - variables defined locally in a function body
  - Return value
    - result computed by a function call

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);
}
...
```

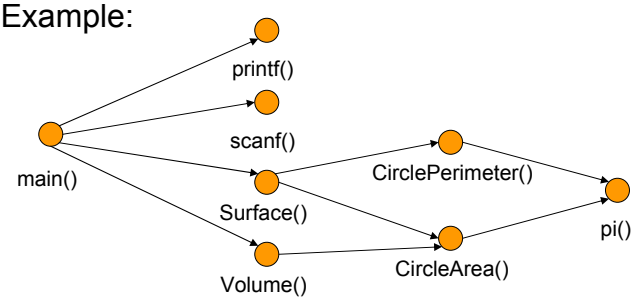

Functions

- 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 */
```

Function Call Graph

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

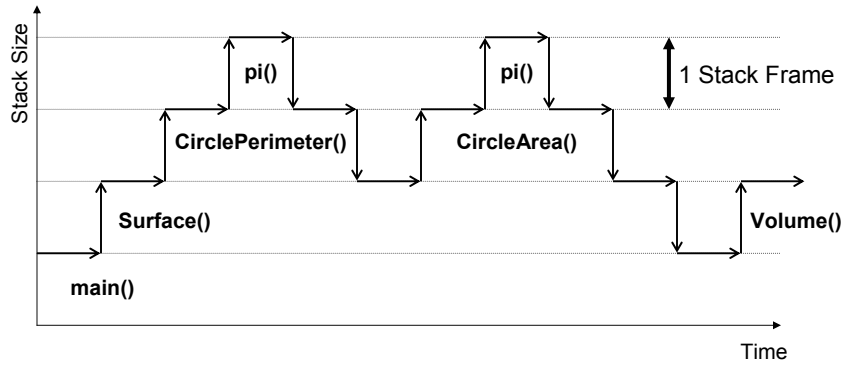


Function Call Trace

- 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



Function Call Stack

- Stack Frames
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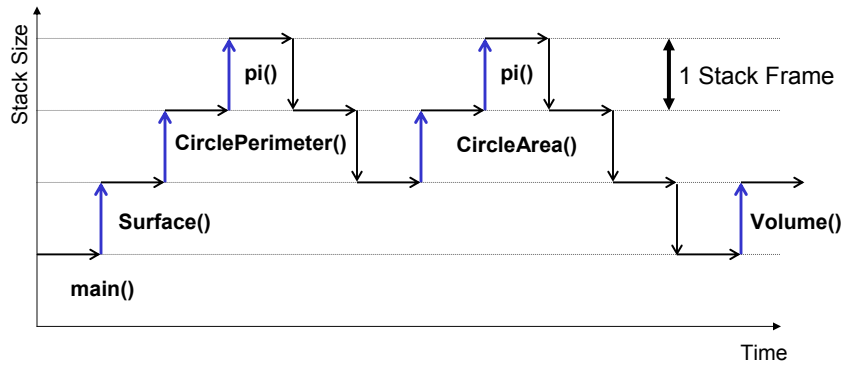

Function Call Stack

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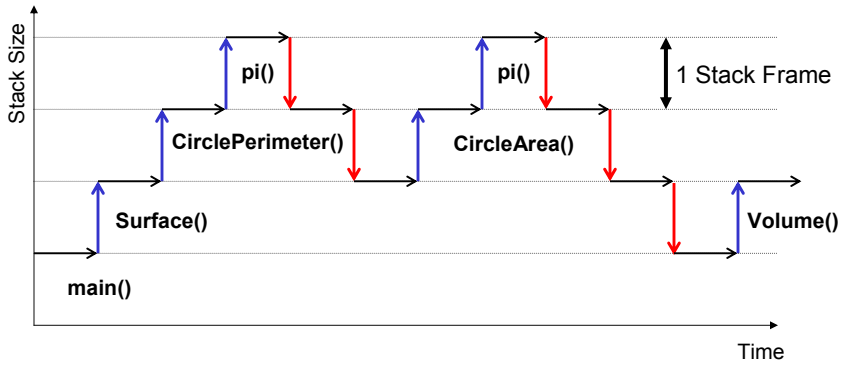


Debugging

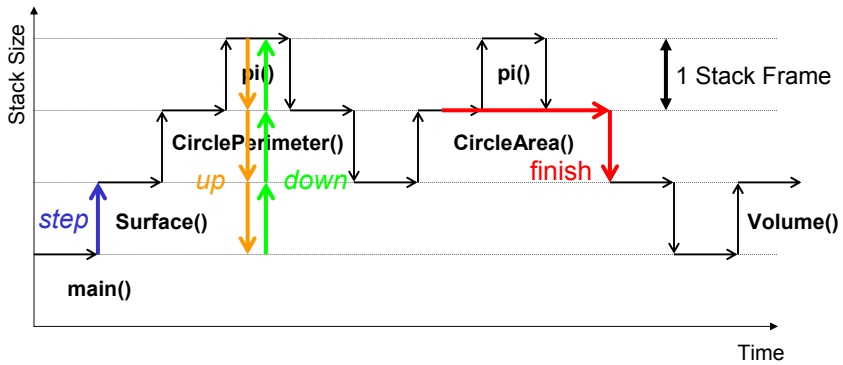
- Source-level Debugger **`gdb`**
  - Basic **`gdb`** commands
    - **`run`**
      - starts the execution of the program in the debugger
    - **`break`** ***`function_name`***
      - inserts a breakpoint at ***`function_name`***
      - program execution will stop at the breakpoint
    - **`list`** ***`line_numbers`***
      - lists the current or specified ***`line_numbers`***
    - **`print`** ***`variable_name`***
      - prints the current value of the variable ***`variable_name`***
    - **`next`**
      - executes the next statement (one statement at a time)
    - **`quit`**
      - exits the debugger (and terminates the program)
    - **`help`**
      - provides helpful details on debugger commands

Debugging

- Source-level Debugger **`gdb`** (continued)
  - Additional **`gdb`** commands
    - **`step`**
      - steps into a function call
    - **`finish`**
      - continues execution until the current function is finished
    - **`where`**
      - shows where in the function call hierarchy you are
      - prints a *back trace* of current *stack frames*
    - **`up`**
      - steps up one stack frame (up into the caller)
    - **`down`**
      - steps down one stack frame (down into the callee)

Function Call Stack

- Navigating Stack Frames in the Debugger
  - *step*: execute and step into a function call
  - up, down: navigate stack frames
  - finish: resume execution until the end of the current function



Functions

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

```
% vi Cylinder.c
% gcc Cylinder.c -o Cylinder -Wall -ansi -g
% gdb Cylinder
GNU gdb 6.3
(gdb) break 55
Breakpoint 1 at 0x108d0: file Cylinder.c, line 55.
(gdb) run
Starting program: /users/faculty/doemer/eecs10/Cylinder/Cylinder
Please enter the radius: 10
Please enter the height: 10
Breakpoint 1, main () at Cylinder.c:56
56          s = Surface(r, h);
(gdb) step
Surface (r=10, h=10) at Cylinder.c:31
31          side = CirclePerimeter(r) * h;
(gdb) step
CirclePerimeter (r=10) at Cylinder.c:24
24          return(2 * pi() * r);
...
```


Functions

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

```
(gdb) step
pi () at Cylinder.c:14
14          return(3.1415927);
(gdb) where
#0  pi () at Cylinder.c:14
#1  0x000107bc in CirclePerimeter (r=10) at Cylinder.c:24
#2  0x000107f8 in Surface (r=10, h=10) at Cylinder.c:31
#3  0x000108e0 in main () at Cylinder.c:56
(gdb) up
#1  0x000107bc in CirclePerimeter (r=10) at Cylinder.c:24
24          return(2 * pi() * r);
(gdb) up
#2  0x000107f8 in Surface (r=10, h=10) at Cylinder.c:31
31          side = CirclePerimeter(r) * h;
(gdb) up
#3  0x000108e0 in main () at Cylinder.c:56
56          s = Surface(r, h);
...
```

Functions

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

```
(gdb) down
#2  0x000107f8 in Surface (r=10, h=10) at Cylinder.c:31
31          side = CirclePerimeter(r) * h;
(gdb) down
#1  0x000107bc in CirclePerimeter (r=10) at Cylinder.c:24
24          return(2 * pi() * r);
(gdb) down
#0  pi () at Cylinder.c:14
14          return(3.1415927);
(gdb) finish
Run till exit from #0  pi () at Cylinder.c:14
0x000107bc in CirclePerimeter (r=10) at Cylinder.c:24
24          return(2 * pi() * r);
Value returned is $1 = 3.1415926999999999
(gdb) finish
Run till exit from #0  CirclePerimeter (r=10) at Cylinder.c:24
0x000107f8 in Surface (r=10, h=10) at Cylinder.c:31
31          side = CirclePerimeter(r) * h;
...
```


Functions

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

```
Value returned is $2 = 62.831854
(gdb) next
32          lid  = CircleArea(r);
(gdb) step
CircleArea (r=10) at Cylinder.c:19
19          return(pi() * r * r);
(gdb) finish
Run till exit from #0  CircleArea (r=10) at Cylinder.c:19
0x00010818 in Surface (r=10, h=10) at Cylinder.c:32
32          lid  = CircleArea(r);
Value returned is $3 = 314.15926999999999
(gdb) cont
Continuing.
The surface area is 1256.637080.
The volume is 3141.592700.
Program exited normally.
(gdb) quit
%
```

Functions

- *Scope* of an identifier
  - Portion of the program where the identifier can be referenced
  - aka. accessability, visibility
- Scope rules
  - Global variables: *file scope*
    - Declaration outside any function (at global level)
    - Scope in entire source file after declaration
  - Function parameters: *function scope*
    - Declaration in function parameter list
    - Scope limited to this function body (entirely)
  - Local variables: *block scope*
    - Declaration inside a compound statement (i.e. function body)
    - Scope limited to this compound statement block (entirely)

Scope Rules: Example

```
#include <stdio.h>
int square(int a);
int add_y(int x);
int x = 5,
    y = 7;
int square(int a)
{  int s;
   s = a * a;
   return s;
}
int add_y(int x)
{  int s;
   s = x + y;
   return s;
}
int main(void)
{  int z;
   z = square(x);
   z = add_y(z);
   printf("%d\n", z);
   return 0;
}
```

Header file inclusion

Function declarations

Global variables

Function definition
Local variable

Function definition
Local variable

Function definition
Local variable

Scope Rules: Example

```
#include <stdio.h>
int square(int a);
int add_y(int x);
int x = 5,
    y = 7;
int square(int a)
{  int s;
   s = a * a;
   return s;
}
int add_y(int x)
{  int s;
   s = x + y;
   return s;
}
int main(void)
{  int z;
   z = square(x);
   z = add_y(z);
   printf("%d\n", z);
   return 0;
}
```

Scope of global functions **`printf()`**, **`scanf()`**, etc.

Scope Rules: Example

```
#include <stdio.h>
int square(int a);
int add_y(int x);
int x = 5,
    y = 7;
int square(int a)
{  int s;
   s = a * a;
   return s;
}
int add_y(int x)
{  int s;
   s = x + y;
   return s;
}
int main(void)
{  int z;
   z = square(x);
   z = add_y(z);
   printf("%d\n", z);
   return 0;
}
```

Scope of global function **`square()`**

Scope Rules: Example

```
#include <stdio.h>
int square(int a);
int add_y(int x);
int x = 5,
    y = 7;
int square(int a)
{  int s;
   s = a * a;
   return s;
}
int add_y(int x)
{  int s;
   s = x + y;
   return s;
}
int main(void)
{  int z;
   z = square(x);
   z = add_y(z);
   printf("%d\n", z);
   return 0;
}
```

Scope of global function **`add_y()`**

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Scope Rules: Example

```
#include <stdio.h>
int square(int a);
int add_y(int x);
int x = 5,
    y = 7;
int square(int a)
{  int s;
   s = a * a;
   return s;
}
int add_y(int x)
{  int s;
   s = x + y;
   return s;
}
int main(void)
{  int z;
   z = square(x);
   z = add_y(z);
   printf("%d\n", z);
   return 0;
}
```

Scope of global variable **`x`**

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Scope Rules: Example

```
#include <stdio.h>
int square(int a);
int add_y(int x);
int x = 5,
    y = 7;
int square(int a)
{  int s;
   s = a * a;
   return s;
}
int add_y(int x)
{  int s;
   s = x + y;
   return s;
}
int main(void)
{  int z;
   z = square(x);
   z = add_y(z);
   printf("%d\n", z);
   return 0;
}
```

Scope of global variable **y**

Scope Rules: Example

```
#include <stdio.h>
int square(int a);
int add_y(int x);
int x = 5,
    y = 7;
int square(int a)
{  int s;
   s = a * a;
   return s;
}
int add_y(int x)
{  int s;
   s = x + y;
   return s;
}
int main(void)
{  int z;
   z = square(x);
   z = add_y(z);
   printf("%d\n", z);
   return 0;
}
```

Scope of parameter **a**

Scope Rules: Example

```
#include <stdio.h>
int square(int a);
int add_y(int x);
int x = 5,
    y = 7;
int square(int a)
{  int s;
   s = a * a;
   return s;
}
int add_y(int x)
{  int s;
   s = x + y;
   return s;
}
int main(void)
{  int z;
   z = square(x);
   z = add_y(z);
   printf("%d\n", z);
   return 0;
}
```

Scope of local variable **s**

Scope Rules: Example

```
#include <stdio.h>
int square(int a);
int add_y(int x);
int x = 5,
    y = 7;
int square(int a)
{  int s;
   s = a * a;
   return s;
}
int add_y(int x)
{  int s;
   s = x + y;
   return s;
}
int main(void)
{  int z;
   z = square(x);
   z = add_y(z);
   printf("%d\n", z);
   return 0;
}
```

Local variables are independent!
(unless their scopes are nested)

Scope of local variable **s**

Scope of local variable **s**

Scope Rules: Example

```
#include <stdio.h>
int square(int a);
int add_y(int x);
int x = 5,
    y = 7;
int square(int a)
{  int s;
   s = a * a;
   return s;
}
int add_y(int x)
{  int s;
   s = x + y;
   return s;
}
int main(void)
{  int z;
   z = square(x);
   z = add_y(z);
   printf("%d\n", z);
   return 0;
}
```

Local variables are independent!
(unless their scopes are nested)

Scope of local variable **s**

Scope of local variable **s**

Scope of local variable **z**

Scope Rules: Example

```
#include <stdio.h>
int square(int a);
int add_y(int x);
int x = 5,
    y = 7;
int square(int a)
{  int s;
   s = a * a;
   return s;
}
int add_y(int x)
{  int s;
   s = x + y;
   return s;
}
int main(void)
{  int z;
   z = square(x);
   z = add_y(z);
   printf("%d\n", z);
   return 0;
}
```

Scope of parameter **x**

Scope Rules: Example

```
#include <stdio.h>
int square(int a);
int add_y(int x);
int x = 5,
    y = 7;
int square(int a)
{  int s;
   s = a * a;
   return s;
}
int add_y(int x)
{  int s;
   s = x + y;
   return s;
}
int main(void)
{  int z;
   z = square(x);
   z = add_y(z);
   printf("%d\n", z);
   return 0;
}
```

Shadowing!
In nested scopes,
inner scope takes precedence!

Scope of global variable **x**

Scope of parameter **x**

Debugging

- Source-level Debugger **gdb** (continued)
  - Additional **gdb** commands
    - **step**
      - steps into a function call
    - **finish**
      - continues execution until the current function is finished
    - **where**
      - shows where in the function call hierarchy you are
      - prints a *back trace* of current *stack frames*
    - **up**
      - steps up one stack frame (up into the caller)
    - **down**
      - steps down one stack frame (down into the callee)
    - **info locals**
      - lists the local variables in the current function (current stack frame)
    - **info scope *function_name***
      - lists the variables in scope of the ***function_name***

Scope Rules: Example

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

```
/* Scope.c: example demonstrating scope rules   */
/* author: Rainer Doemer                        */
/* modifications:                               */
/* 10/30/04 RD  initial version                 */

#include <stdio.h>

int square(int a);      /* global function declarations */
int add_y(int x);

int x = 5,              /* global variables */
    y = 7;

int square(int a)       /* global function definition */
{
   int s;               /* local variable */

   s = a * a;
   return s;
}
...
```


Scope Rules: Example

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

```
...
int add_y(int x)        /* global function definition */
{
   int s;               /* local variable */

   s = x + y;
   return s;
}

int main(void)          /* main function definition */
{
   int z;               /* local variable */

   z = square(x);
   z = add_y(z);

   printf("%d, %d, %d\n", x, y, z);
   return 0;
}

/* EOF */
```

Scope Rules: Example

- Example session: **`Scope.c`** (part 1/3)

```
% vi Scope.c
% gcc Scope.c -o Scope -Wall -ansi -g
% Scope
5, 7, 32
% gdb Scope
GNU gdb 5.0
[...]
(gdb) break main
Breakpoint 1 at 0x1079c: file Scope.c, line 36.
(gdb) run
Starting program: /users/faculty/doemer/eecs10/Scope/Scope

Breakpoint 1, main () at Scope.c:36
36          z = square(x);
(gdb) step
square (a=5) at Scope.c:20
20          s = a * a;
(gdb) next
21          return s;
...
```


Scope Rules: Example

- Example session: **`Scope.c`** (part 2/3)

```
...
(gdb) next
22      }
(gdb) next
main () at Scope.c:37
37          z = add_y(z);
(gdb) step
add_y (x=25) at Scope.c:28
28          s = x + y;
(gdb) where
#0  add_y (x=25) at Scope.c:28
#1  0x107c4 in main () at Scope.c:37
(gdb) up
#1  0x107c4 in main () at Scope.c:37
37          z = add_y(z);
(gdb) down
#0  add_y (x=25) at Scope.c:28
28          s = x + y;
...
```

Scope Rules: Example

- Example session: **`Scope.c`** (part 3/3)

```
...
(gdb) finish
Run till exit from #0  add_y (x=25) at Scope.c:28
0x107c4 in main () at Scope.c:37
37          z = add_y(z);
Value returned is $1 = 32
(gdb) info locals
z = 25
(gdb) info scope square
Scope for square:
Symbol a is an argument at stack/frame offset 68, length 4.
Symbol s is a local variable at frame offset -20, length 4.
(gdb) info scope add_y
Scope for add_y:
Symbol x is an argument at stack/frame offset 68, length 4.
Symbol s is a local variable at frame offset -20, length 4.
(gdb) quit
%
```