EECS 10: Computational Methods in Electrical and Computer Engineering

Lecture 6

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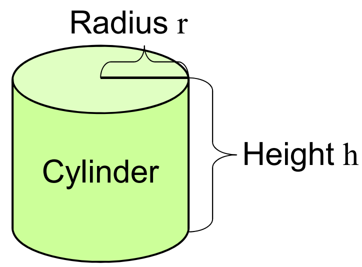
Lecture 6.1: Overview

- Functions
  - Hierarchy of functions
    - Example **`Cylinder.c`**
  - Function call graph
  - Function call trace
  - Function call stack
- Debugging
  - Navigating stack frames

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 $f_v(r, h) = f_a(r) \times h$

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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);
}
...
```

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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);
}
...
```

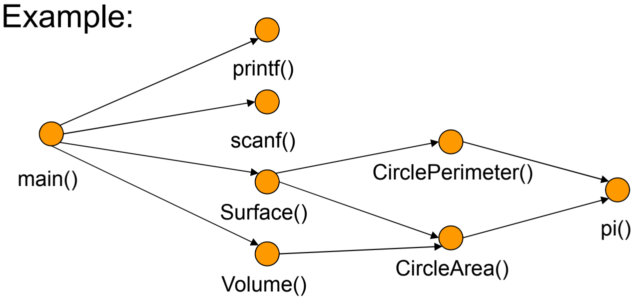

Functions

- 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
    - Vertices: Functions
    - Edges: Function calls
  - Shows dependencies among functions
  - Example:



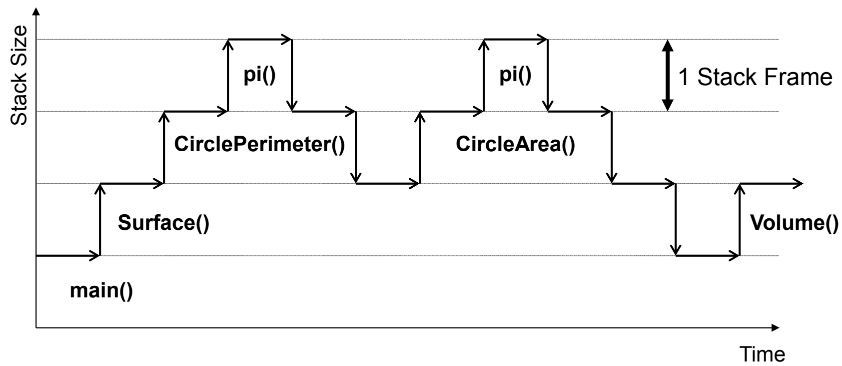
Function Call Trace

- 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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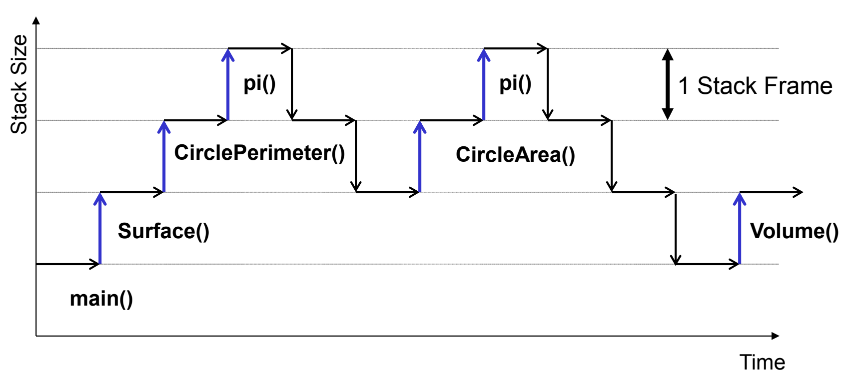

Function Call Stack

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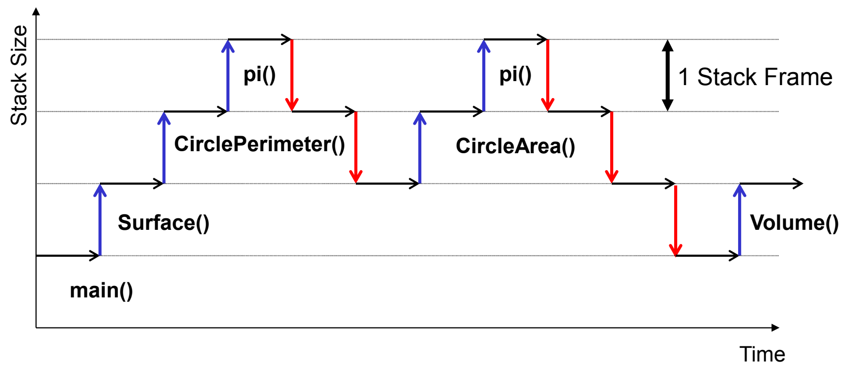

Debugging

- Source-level Debugger **gdb**
  - Basic **gdb** commands
    - **`run`**
      - starts the execution of the program in the debugger
    - **`break`** ***`function_name`*** *(or* ***`line_number`****)*
      - inserts a breakpoint; program execution will stop at the breakpoint
    - **`cont`**
      - continues the execution of the program in the debugger
    - **`list`** ***`from_line_number,to_line_number`***
      - lists the current or specified range of 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)

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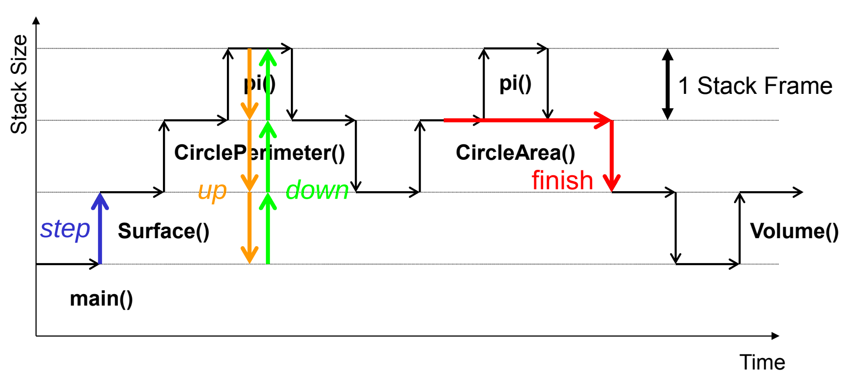
Debugging

- 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



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Debugging

- 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);
...
```

Debugging

- 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);
...
```

Debugging

- 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;
...
```

Debugging

- 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
%
```

Lecture 6.2: Overview

- Functions
  - Terms and concepts
  - Scope rules
  - Scope example
- Debugging
  - Scopes

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 parameters
    - Formal parameters holding the data supplied to a function
  - Function arguments
    - Arguments passed to a function call (initial values for parameters)
  - Local variables
    - Variables defined locally in a function body (or compound statement)
  - Global variables
    - Variables defined globally outside of any function

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>`	Header file inclusion
`int square(int a);` `int add_y(int x);`	Function declarations
`int x = 5,` `    y = 7;`	Global variables
`int square(int a)` `{   int s;` `    s = a * a;` `    return s;` `}`	Function definition Local variable
`int add_y(int x)` `{   int s;` `    s = x + y;` `    return s;` `}`	Function definition Local variable
`int main(void)` `{   int z;` `    z = square(x);` `    z = add_y(z);` `    printf("%d\n", z);` `    return 0;` `}`	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.

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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 function **square()**

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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 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

```c
#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**

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Scope Rules: Example

```c
#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**

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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 local variable **s**

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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;
}
```

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

Scope of local variable **s**

Scope of local variable **s**

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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;
}
```

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

Scope of local variable **s** (s = a * a; return s; })

Scope of local variable **s** (s = x + y; return s; })

Scope of local variable **z** (z = square(x); … return 0; })

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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 parameter **x** ({ int s; s = x + y; return s; })

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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;
}
```

Shadowing!
In nested scopes,
inner scope takes precedence!

Scope of global variable **x**

Scope of parameter **x**

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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`*** (or ***`line_number`***)
      - inserts a breakpoint; program execution will stop at the breakpoint
    - **`cont`**
      - continues the execution of the program in the debugger
    - **`list`** ***`from_line_number,to_line_number`***
      - lists the current or specified range of 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

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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`***

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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;
}
...
```

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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 */
```

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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
%
```

Lecture 6.3: Overview

- Functions
  - Math library functions
    - Example **`Function.c`**
  - Standard library functions
    - Example **`Dice.c`**

Math Library Functions

- C standard math library
  - standard library supplied with every C compiler
  - predefined mathematical functions
    - e.g. $cos(x)$, $sqrt(x)$, etc.
- Math library header file
  - contains math function declarations
  - **`#include <math.h>`**
- Math library linker file
  - contains math function definitions (pre-compiled)
    - library file **`libm.a`**
  - compiler needs to *link* against the math library
  - use option **`–l`*`libraryname`***
  - Example: **`gcc MathProgram.c –o MathProgram -lm`**

Math Library Functions

- Functions declared in **`math.h`** (part 1/2)
  - `double sqrt(double x);` $\sqrt{x}$
  - `double pow(double x, double y);` x^y
  - `double exp(double x);` e^x
  - `double log(double x);` $log(x)$
  - `double log10(double x);` $log_{10}(x)$
  - `double ceil(double x);` $\lceil x \rceil$
  - `double floor(double x);` $\lfloor x \rfloor$
  - `double fabs(double x);` $|x|$
  - `double fmod(double x, double y);` $x \bmod y$

Math Library Functions

- Functions declared in **`math.h`** (part 2/2)
  - `double cos(double x);` $cos(x)$
  - `double sin(double x);` $sin(x)$
  - `double tan(double x);` $tan(x)$
  - `double acos(double x);` $acos(x)$
  - `double asin(double x);` $asin(x)$
  - `double atan(double x);` $atan(x)$
  - `double cosh(double x);` $cosh(x)$
  - `double sinh(double x);` $sinh(x)$
  - `double tanh(double x);` $tanh(x)$

Math Library Functions

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

```
/* Function.c: compute a math function table    */
/*                                              */
/* author: Rainer Doemer                        */
/*                                              */
/* modifications:                               */
/* 10/28/04 RD  initial version                 */

#include <stdio.h>
#include <math.h>

/* function definition */

double f(double x)
{
    return cos(x);
} /* end of f */

...
```

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Math Library Functions

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

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

int main(void)
{
    /* variable definitions */
    double hi, lo, step;
    double x, y;

    /* input section */
    printf("Please enter the lower bound: ");
    scanf("%lf", &lo);
    printf("Please enter the upper bound: ");
    scanf("%lf", &hi);
    printf("Please enter the step size:   ");
    scanf("%lf", &step);

...
```

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Math Library Functions

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

```
...

    /* computation and output section */
    for(x = lo; x <= hi; x += step)
    {
        y = f(x);
        printf("f(%10g) = %10g\n", x, y);
    } /* rof */

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

/* EOF */
```


Math Library Functions

- Example session: **Function.c**

```
% vi Function.c
% gcc Function.c -o Function -Wall -ansi -lm
% Function
Please enter the lower bound: -0.5
Please enter the upper bound: 1.0
Please enter the step size:   .1
f(      -0.5) =   0.877583
f(      -0.4) =   0.921061
f(      -0.3) =   0.955336
f(      -0.2) =   0.980067
f(      -0.1) =   0.995004
f(-2.77556e-17) =          1
f(       0.1) =   0.995004
f(       0.2) =   0.980067
f(       0.3) =   0.955336
f(       0.4) =   0.921061
f(       0.5) =   0.877583
f(       0.6) =   0.825336
f(       0.7) =   0.764842
f(       0.8) =   0.696707
f(       0.9) =    0.62161
f(         1) =   0.540302
%
```

Standard Library Functions

- Standard C library
  - standard library supplied with every C compiler
  - predefined standard functions
    - e.g. **`printf()`**, **`scanf()`**, etc.
- C library header files
  - input/output function declarations **`#include <stdio.h>`**
  - standard function declarations **`#include <stdlib.h>`**
  - time function declarations **`#include <time.h>`**
  - etc.
- C library linker file
  - contains standard function definitions (pre-compiled)
    - library file **`libc.a`**
  - compiler *automatically links* against the standard library (no need to supply extra options)

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Standard Library Functions

- Functions declared in **`stdlib.h`** (partial list)
  - **`int abs(int x);`**
  - **`long int labs(long int x);`**
    - return the absolute value of a (long) integer **`x`**
  - **`int rand(void);`**
    - return a random value in the range **`0 – RAND_MAX`**
    - **`RAND_MAX`** is a constant integer (e.g. 32767)
  - **`void srand(unsigned int seed);`**
    - initialize the random number generator with value **`seed`**
  - **`void exit(int result);`**
    - exit the program with return value **`result`**
  - **`void abort(void);`**
    - abort the program (with an error result)

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Standard Library Functions

- Random number generation
  - Standard library provides *pseudo* random number generator
    - **`int rand(void);`**
  - Pseudo random numbers are a sequence of values seemingly random in the range **`0 – RAND_MAX`**
    - Computer is a *deterministic* machine
    - Sequence will always be the same
  - Start of sequence is determined by *seed* value
    - **`void srand(unsigned int seed);`**
  - Trick: Initialize random sequence with current time
    - header file **`time.h`** declares function **`unsigned int time()`**
    - **`time(0)`** returns number of seconds since Jan 1, 1970
    - at beginning of program, use:
      `srand(time(0));`

Standard Library Functions

- Program example: **`Dice.c`** (part 1/4)

```
/* Dice.c: roll the dice                        */
/* author: Rainer Doemer                        */
/* modifications:                               */
/* 10/28/04 RD  initial version                 */

#include <stdio.h>
#include <stdlib.h>
#include <time.h>

/* function definition */

int roll(void)
{
    int r;

    r = rand() % 6 + 1;
 /* printf("Rolled a %d.\n", r); */
    return r;
} /* end of roll */
...
```

Standard Library Functions

- Program example: **`Dice.c`** (part 2/4)

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

int main(void)
{
    /* variable definitions */
    int i, n;
    int count1 = 0, count2 = 0, count3 = 0,
        count4 = 0, count5 = 0, count6 = 0;

    /* random number generator initialization */
    srand(time(0));

    /* input section */
    printf("Roll the dice: How many times? ");
    scanf("%d", &n);

...
```


Standard Library Functions

- Program example: **`Dice.c`** (part 3/4)

```
... /* computation section */
    for(i = 0; i < n; i++)
       { switch(roll())
            { case 1:
                 { count1++; break; }
              case 2:
                 { count2++; break; }
              case 3:
                 { count3++; break; }
              case 4:
                 { count4++; break; }
              case 5:
                 { count5++; break; }
              case 6:
                 { count6++; break; }
              default:
                 { printf("INVALID ROLL!");
                   exit(10); }
             } /* hctiws */
        } /* rof */
...
```

Standard Library Functions

- Program example: **`Dice.c`** (part 4/4)

```
...

    /* output section */
    printf("Rolled a 1 %5d times.\n", count1);
    printf("Rolled a 2 %5d times.\n", count2);
    printf("Rolled a 3 %5d times.\n", count3);
    printf("Rolled a 4 %5d times.\n", count4);
    printf("Rolled a 5 %5d times.\n", count5);
    printf("Rolled a 6 %5d times.\n", count6);

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

/* EOF */
```


Standard Library Functions

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

```
% vi Dice.c
% gcc Dice.c -o Dice -Wall -ansi
% Dice
Roll the dice: How many times? 6000
Rolled a 1   963 times.
Rolled a 2   995 times.
Rolled a 3  1038 times.
Rolled a 4  1024 times.
Rolled a 5   984 times.
Rolled a 6   996 times.
% Dice
Roll the dice: How many times? 6000
Rolled a 1   977 times.
Rolled a 2  1043 times.
Rolled a 3  1012 times.
Rolled a 4  1001 times.
Rolled a 5   963 times.
Rolled a 6  1004 times.
%
```