EECS 22: Advanced C Programming

Lecture 9

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Lecture 9: Overview

- Warm-up Quiz
- Course Administration
  - Midterm course evaluation
- Assertions
  - Using and disabling assertions
- Debugging
  - Source-level debugger **gdb**
  - Running a program under debugger control
  - Navigating and inspecting the stack
  - Inspecting and modifying variable values
  - Advanced commands for using break points
  - Data display debugger **ddd**

Quiz: Question 11

- Today's computers run at which clock speed?
  a) 85 MPH
  b) 1 kHz
  c) 1 ms
  d) 1 GHz
  e) 1 MHz

Quiz: Question 11

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  a) 85 MPH
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Quiz: Question 12

- Which of the following names are valid keywords in ANSI C?
  (Check all that apply!)
  a) `if`
  b) `when`
  c) `void`
  d) `main`
  e) `Int`

Quiz: Question 12

- Which of the following names are valid keywords in ANSI C?
  (Check all that apply!)
  a) `if`
  b) `when`
  c) `void`
  d) `main`
  e) `Int`

Quiz: Question 13

- Which of the following names are valid identifiers in ANSI C?
  (Check all that apply!)
  a) `xyz`
  b) `PC`
  c) `dollar amount`
  d) `My_Very_Long_Variable_Name`
  e) `2fast4you`

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  (Check all that apply!)
  a) `xyz`
  b) `PC`
  c) `dollar amount`
  d) `My_Very_Long_Variable_Name`
  e) `2fast4you`

Quiz: Question 14

- Which of the following constructs are valid type names in ANSI C?
  (Check all that apply!)
  a) `short char`
  b) `long double`
  c) `signed long long`
  d) `unsigned float`
  e) `signed`

Quiz: Question 14

- Which of the following constructs are valid type names in ANSI C?
  (Check all that apply!)
  a) `short char`
  b) `long double` ←
  c) `signed long long` ←
  d) `unsigned float`
  e) `signed` ←

Quiz: Question 15

- Which of the following constants is of type **`double`**? (Check all that apply!)
  a) **`42`**
  b) **`.42`**
  c) **`4e2`**
  d) **`4E2`**
  e) **`42f`**

Quiz: Question 15

- Which of the following constants is of type **`double`**? (Check all that apply!)
  a) **`42`**
  b) **`.42`**
  c) **`4e2`**
  d) **`4E2`**
  e) **`42f`**

Quiz: Question 16

- What is the value of the integer **x** after the following statement?

```
x = 3 << 2 >> 1;
```

a) **Syntax Error!**
b) **3**
c) **6**
d) **12**
e) **321**

Quiz: Question 16

- What is the value of the integer **x** after the following statement?

```
x = 3 << 2 >> 1;
```

a) **Syntax Error!**
b) **3**
c) **6**
d) **12**
e) **321**

Quiz: Question 17

- Which of the following expressions correctly computes the polynomial $p = 2x^2 - 3x + 4$? (Check all that apply!)

a) `p = 2x^2 - 3x + 4;`
b) `p = 2xx - 3x + 4;`
c) `p = x*x*2 - 3*x + 4.0;`
d) `p = 2*(x*x + 3)*x + 4;`
e) `p = (2*x - 3)*x + 4;`

Quiz: Question 17

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b) `p = 2xx - 3x + 4;`

c) `p = x*x*2 - 3*x + 4.0;`
d) `p = 2*(x*x + 3)*x + 4;`

e) `p = (2*x - 3)*x + 4;`

Quiz: Question 18

- What is the result of the evaluation of the following expression?

```
1 == 2 || 3 < 4 && 5 > 6
```

a) **123456**
b) **true**
c) **false**
d) **1**
e) **0**

Quiz: Question 18

- What is the result of the evaluation of the following expression?

```
1 == 2 || 3 < 4 && 5 > 6
```

a) **123456**
b) **true**
c) **false**
d) **1**
e) **0**

Quiz: Question 19

- Simple prime number test:
  The following code fragment iterates variable *i* over the range $2 \le i < x$ to find a divisor of *x.*
  What should go into box 1 in line 4?
  a) `i = 0;`
  b) `i = 1;`
  c) `i = 2;`
  d) `i = x;`
  e) `x = 0;`

```
int x, i;
printf("Please input a number: ");
scanf("%d", &x);
initialize variable i
while(i < x)
{ if(x % i == 0)
  { printf("%d is not prime\n", x);
    break;
  }
  i++;
}
if( none of the i is a divisor of x )
  { printf("%d is prime\n", x);
  }
```


Quiz: Question 19

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    break;
  }
  i++;
}
if( none of the i is a divisor of x )
  { printf("%d is prime\n", x);
  }
```

Quiz: Question 20

- Simple prime number test:
  The following code fragment iterates variable *i* over the range $2 \le i < x$ to find a divisor of *x.*
  What should go into box 2 in line 12?
  a) `x / i == 0`
  b) `x < i`
  c) `i / x == 0`
  d) `i + 1 == x`
  e) `i == x`

```
int x, i;
printf("Please input a number: ");
scanf("%d", &x);
initialize variable i
while(i < x)
{ if(x % i == 0)
  { printf("%d is not prime\n", x);
    break;
  }
  i++;
}
if( none of the i is a divisor of x )
  { printf("%d is prime\n", x);
  }
```


Quiz: Question 20

- Simple prime number test:
  The following code fragment iterates variable *i* over the range $2 \le i < x$ to find a divisor of *x.*
  What should go into box 2 in line 12?
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  b) `x < i`
  c) `i / x == 0`
  d) `i + 1 == x`
  e) `i == x`

```
int x, i;
printf("Please input a number: ");
scanf("%d", &x);
initialize variable i
while(i < x)
{ if(x % i == 0)
  { printf("%d is not prime\n", x);
    break;
  }
  i++;
}
if( none of the i is a divisor of x )
  { printf("%d is prime\n", x);
  }
```

Course Administration

- Midterm Course Evaluation
  - One week, starting this Sunday!
  - Sunday, Nov. 2, noon – Sunday, Nov. 9, 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)

Assertions

- Run-time Checks for Diagnostics and Debugging
  - Can be manually implemented

```
...
#ifdef DEBUG
if (value > 100)
   { printf("Something's wrong, value is >100!");
     abort();
   } /* fi */
#endif /* DEBUG */
...
```

  - Can be enabled at time of compilation (for development)

```
% gcc -DDEBUG program.c -o program
%
```

  - Can be disabled at time of compilation (for final release)

```
% gcc program.c -o program
%
```

Assertions

- *Assertions*: Diagnostics by the standard C library

```
#include <assert.h>
...
assert(value <= 100);
```

  - Header file **`assert.h`**
    - Defines **`assert(condition)`** (as a preprocessor macro)
  - Assertion failure
    - At run-time, if **`condition`** evaluates to **`false`**, the program is aborted with a corresponding diagnostic message

```
assertion: program.c:12: main: Assertion `value <= 100' failed.
Abort
```

  - Disabling assertions
    - If **`NDEBUG`** is defined when **`assert.h`** is included, the **`assert()`** macro is ignored (empty statement)

```
% gcc -DNDEBUG program.c -o program
%
```

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Assertions

- Example: Square Root Calculation **`Root.c`**

```
#include <assert.h>

double Root(double x) /* square root approximation */
{   double l, m, r, d;

    assert(x >= 0.0); /* caller must supply positive x */
    l = 0.0; r = x;
    do{ m = l + (r-l)/2.0;
        d = m * m - x;
        if (d < 0.0)
          { d = -d;
            l = m; }
        else
          { r = m; }
      } while (d > 1e-10);
    return m;
}
```

  - Assertion protects *contract* between caller and callee
    - Caller is in charge of ensuring positive argument to function call
    - Callee relies on this agreement (otherwise the loop will not terminate!)

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Assertions

- Advise on Using Assertions
  - ➢ Use assertions often
    - Confirm assumptions about parameters, calculated values, etc.
    - Assertions are cheap (low run-time overhead)!
  - ➢ Use assertions from beginning during software development
    - Diagnostic messages are very helpful in development
      - – Program aborts as soon as a value is out of expected range
      - – Location and problem condition are shown
    - This can avoid more serious problems later
  - ➢ Disable assertions for final program delivered to the user
    - Diagnostic messages are of no use to the end user!
      - – User has no idea about condition and source location
  - ➢ Beware of side-effects in assertions
    - Implemented as a macro!
    - Can lead to *Heisenbugs* which disappear when debugging is on!

Debugging

- Source-level Debugger **gdb**
  - – Debugging features
    - run the program under debugger control
    - follow the control flow of the program during execution
    - set breakpoints to stop execution at specific points
    - inspect (and adjust) the values of variables
    - find the point in the program where the “crash” happens
  - – Preparation:
    compile your program with debugging support on
    - Option **-g** tells compiler to add debugging information (symbol tables) to the generated executable file
    - **`gcc -g Program.c -o Program -Wall -ansi`**
    - **`gdb Program`**

Debugging

- Source-level Debugger **gdb**
  - Running the program under debugger control
    - **run**
      - starts the execution of the program in the debugger
    - **break *function_name*** *(or* **file:*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

- Example session: **Cylinder.c** (part 1/2)

```
% vi Cylinder.c
% gcc Cylinder.c -Wall -ansi -o Cylinder -g
% gdb Cylinder
GNU gdb (GDB) Red Hat Enterprise Linux (7.0.1-37.el5_7.1)
Copyright (C) 2009 Free Software Foundation, Inc.
...
Reading symbols from
/users/faculty/doemer/eecs22/lecture10/Cylinder...done.
(gdb) break main
Breakpoint 1 at 0x400654: file Cylinder.c, line 48.
(gdb) run
Starting program: /users/faculty/doemer/eecs22/lecture10/Cylinder
Breakpoint 1, main () at Cylinder.c:48
48          printf("Please enter the radius!\n");
(gdb) next
Please enter the radius!
49          scanf("%lf", &r);
...
```

Debugging

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

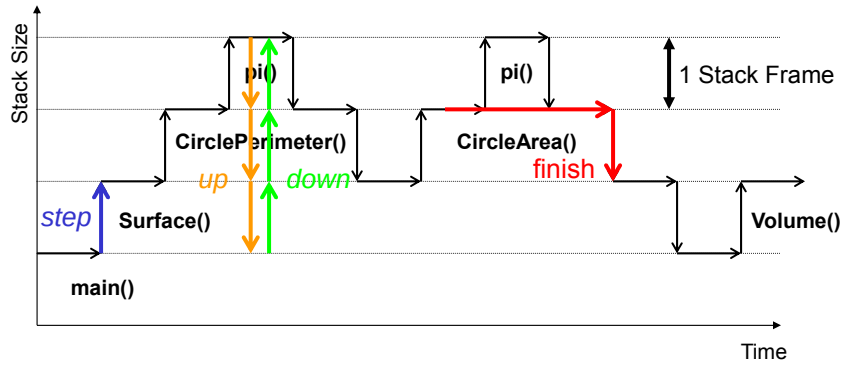
```
...
(gdb) next
5
50          printf("Please enter the height!\n");
(gdb) print r
$1 = 5
(gdb) cont
Continuing.
Please enter the height!
10
The surface area is 471.238905.
The volume is 785.398175.
Program exited normally.
(gdb) quit
%
```


Debugging

- Source-level Debugger **`gdb`** (continued)
  - Navigating the stack
    - **`step`**
      - steps into a function call
    - **`finish`**
      - continues execution until the current function has returned
    - **`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)

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



Debugging

- Example session: **`Cylinder.c`** (part 1/4)

```
% 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`** (part 2/4)

```
(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`** (part 3/4)

```
(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`** (part 4/4)

```
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
%
```


Debugging

- Source-level Debugger **`gdb`** (continued)
  - Inspecting the stack
    - **`info frame`**
      - displays information about the current stack frame
    - **`info locals`**
      - lists the local variables in the current function (current stack frame)
    - **`info scope`** ***`function`***
      - lists the variables in the scope of the specified function
  - Calling functions (outside of the regular control flow)
    - **`call`** ***`function(arguments)`***
      - calls the specified function with the specified arguments
  - Assembly level inspection
    - **`info registers`**
      - lists the CPU registers and their contents
    - **`disassemble`** ***`function`***
      - disassembles the function and lists its assembly code

Debugging

- Source-level Debugger **gdb** (continued)
  - Inspecting and modifying variable values
    - **`print variable_name`**
      - prints the current value of the variable ***`variable_name`***
    - **`set variable = value`**
      - sets the specified variable to the specified value
    - **`display variable`**
      - prints the value of a variable each time before the next command
    - **`info display`**
      - lists information on the displayed variables
    - **`undisplay variable`**
      - turns off the display of the specified variable

Debugging

- Source-level Debugger **gdb** (continued)
  - Advanced commands for using break points
    - **`info breakpoints`**
      - displays information about break points
    - **`tbreak function_name`** *(or* **`file:line_number`***)*
      - inserts a temporary breakpoint (valid only once)
    - **`watch variable`**
      - sets a watch point on the specified variable for write access
    - **`rwatch variable`**
      - sets a watch point on the specified variable for read access
    - **`ignore breakpoint n`**
      - skips the specified break point *n* times
    - **`enable`** *(or* **`disable`***)* **`breakpoint`** *(or* **`watchpoint`***)*
      - Enables (or disables) a break point (or watch point)
    - **`condition breakpoint condition`**
      - Specifies a condition for the given break point

Debugging

- Data Display Debugger **`ddd`**
  - Graphical frontend for **`gdb`**
    - Requires *X forwarding* and corresponding client (e.g. *Xming* in addition to *Putty*)
  - Provides menu bar and command buttons
  - Displays separate work windows
    - Graphical display area for data structures
    - Source code browser
    - Assembly code browser
    - Command line interface
  - Example: **`Cylinder.c`**