Mathematical Software Programming (02635)

Lecture 10 — November 15, 2018

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This week

Topics

- External libraries and testing

Learning objectives

- **Debug** and **test** mathematical software.
- Call external (third party) programs and libraries.
- Analyze the runtime behavior and the time and space complexity of simple programs.

Guidelines

- Design your program with testing in mind
- Do not try to construct a *full-featured* program from the beginning
- Start with specifications, data structures, and tests
- Implement and test one module/function at the time
- Use conditional compilation to include/exclude debugging code
- Use error checking and assertions
- Avoid (excessive) use of global variables
- Enable compiler **warnings** (`-Wall` and `-Wextra`)
- Aim for readability (as a rule of thumb, avoid `goto` statements)
- Use proper code indentation

Indentation

Proper indentation makes it easier to read and understand a program

Example 1

```
int x = 5;
while( x > 0 );
   x--;
```

How many times does the loop run? (Why?)

Indentation

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Example 1

```
int x = 5;
while( x > 0 );
   x--;
```

How many times does the loop run? (Why?)

Example 2

```
int x = 5;
while( x > 0 )
    ;
x--;
```

How many times does the loop run? (Why?)

Compiler toolchain

Preprocessing (`cpp`)

Processes *preprocessor directives* (`#include`, `#define`, `#ifdef`, ...)
`hello.c` → `hello.i` (*modified* source)

Compilation (`gcc -S`)

`hello.i` → `hello.s` (*assembly language* program)

Assembly (`as`)

`hello.s` → `hello.o` (*machine code*)

Linking (`ld`)

`hello.o`, *libraries*, ... → *executable*

The C preprocessor

Macros

```
#define BUFFER_SIZE 1024
#define PI 3.141592653589793
#define dmalloc(x) malloc(x*sizeof(double))
#define min(X, Y)  ((X) < (Y) ? (X) : (Y))
```

Beware of macro pitfalls!

Pre-defined macros

`__FILE__`, `__LINE__`, C99: `__DATE__`, `__TIME__`, `__func__`

System-specific macros

`_WIN32`, `_WIN64`, `__linux__`, `__APPLE__`, `__MACH__`, `__unix__`

Example: error handling

```c
#include <stdlib.h>
#include <stdio.h>
int main(void) {
    double *data = malloc(100*sizeof(*data));
    if ( data == NULL ) {
        fprintf(stderr, "Malloc failed in %s function,"
            " line %d\n",__func__,__LINE__);
        return EXIT_FAILURE;
    }

    /* .. some code that accesses the array .. */

    free(data);
    data = NULL;
    return EXIT_SUCCESS;
}
```

Assertions

Run-time assertions

- Boolean expressions that should be true *unless* there is a bug
- Useful for debugging, but should not replace error checking

```
#include <assert.h>
...

assert( expression );
```

Switching off assertions

- Define `NDEBUG` macro before including `assert.h` (`#define NDEBUG`)
- Define `NDEBUG` macro at compile time (add `-DNDEBUG` to `CPPFLAGS` in makefile)

```
$ gcc -Wall -DNDEBUG source.c -o my_program
```

Example: assertions

```c
#include <assert.h>
#include <stdlib.h>
void my_function(double *data, int size) {
    assert(data != NULL);
    assert(size > 0);
    /* Insert function body here */
    return;
}
int main(void) {
    my_function(NULL, 5);
    return 0;
}
```

```
$ ./example
Assertion failed: (data != NULL), function my_function,
   file example.c, line 4.
Abort trap: 6
```

Debugging

Compile program with -g flag to create "debug version" of executable

Terminal debuggers

- Set breakpoints and step through program
- Trace program and inspect variables
- GNU db (`gdb`), Intel db (`idb`), Sun db (`dbx`), LLVM db (`lldb`)

Integrated debuggers

- Set breakpoints and inspect variables directly in IDE

Conditionally compiled debugging code

- Augment program with debugging code (assertions, etc.)
- Print (selected) variables for debugging purposes

Common errors

Uninitialized pointer

```
double *pd;
...

*pd = 5.0;
```

Debugging: enable compiler warnings (`-Wall`)

Dereferencing `NULL`

```
int *pi = NULL;
...

*pi = 2;
```

Debugging: include assertion before dereferencing pointer

Common errors

Missing allocation

```
int n = 10;
double *A;
for (int i=0;i<n;i++) {
    A[i] = 1.0;
}
```

Debugging: initialize pointers (`double *A = NULL`) and use assertions

Memory leak (missing deallocation)

```
int my_function(size_t n) {
    int result=0, *p = malloc(n*sizeof(*p));
    /* Some code but no call to free() before end of scope */
    return result;
}
```

Debugging: check calls to `malloc` and `free`, or use memory profiler

Common errors

Memory leak (missing deallocation in “error branch”)

```c
int some_function(char * filename, int n, double * x) {

    double *y = malloc(n*sizeof(*y));
    if (y==NULL) return -1;
    FILE *fp = fopen(filename,"rb");
    if (fp == NULL) return -1;      // Memory leak! We forgot to free y...

    /* Do something with fp, y and input x */

    fclose(fp);
    free(y);
    return 0;
}
```

Common errors

Buffer overflow / index out of bounds

```c
/* Example 1 */
double data[10];
for (int i=0;i<=10;i++) {
    printf("data[%d] = %g\n",i,data[i]);
}

/* Example 2 */
char s[5];
s[5] = '\0';
```

Debugging: add assertions or use debugger

Common errors

Missing null-termination

```
char s[5];
s[0] = 'H'; s[1] = 'e'; s[2] = 'l'; s[3] = 'l'; s[4] = 'o';
puts(s);
```

Debugging: check `char` operations that operate on strings or use debugger

Unindended usage of preprocessor macro

```
#define cube(x) x*x*x
double d = cube(2+3);   // expands to 2+3*2+3*2+3, not (2+3)*(2+3)*(2+3)
```

Debugging: check macros / preprocessor output

Common errors

Stack overflow: automatic allocation of large arrays

```
double data[2097152]; // requires 16 MB of storage
```

Debugging: check size of automatically allocated data structures

Stack overflow: recursive function calls

```
long fibonacci(long n) {
   if ( n == 0 ) return 0;
   else if ( n == 1 ) return 1;
   else return fibonacci(n-1) + fibonacci(n-2);
}
```

What happens if `fibonacci()` is called with negative n?
Debugging: use a debugger to trace function calls

Today's exercises

- Use functions from external library `matrix_io`
- Extend `matrix_io` with additional functions
- Write test programs