Module 36: Programming C++

Exceptions (Error handling in C): Part 1

Partha Pratim Das

Department of Computer Science and Engineering
Indian Institute of Technology, Kharagpur

ppd@cse.iitkgp.ernet.in

Tanwi Mallick
Srijoni Majumdar
Himadri B G S Bhuyan

Module Objectives

- Understand the Error handling in C

Module Outline

What are Exceptions?

- Conditions that arise
  - Infrequently and Unexpectedly
  - Generally betray a Program Error
  - Require a considered Programmatic Response
  - Run-time Anomalies – yes, but not necessarily
- Leading to
  - Crippling the Program
  - May pull the entire System down
  - Defensive Technique
    - Crashing Exceptions verses Tangled Design and Code

Exception Causes

- Unexpected Systems State
  - Exhaustion of Resources
    - Low Free Store Memory
    - Low Disk Space
  - Pushing to a Full Stack
- External Events
  - Ĉ
  - Socket Event
- Logical Errors
  - Pop from an Empty Stack
  - Resource Errors – like Memory Read/Write
- Run time Errors
  - Arithmetic Overflow / Underflow
  - Out of Range
- Undefined Operation
  - Division by Zero

Exception Handling?

- Exception Handling is a mechanism that separates the detection and handling of circumstantial Exceptional Flow from Normal Flow
- Current state saved in a pre-defined location
- Execution switched to a pre-defined handler

> Exceptions are C++'s means of separating error reporting from error handling
> – Bjarne Stroustrup

Types of Exceptions

- **Asynchronous Exceptions**:
  - Exceptions that come Unexpectedly
  - Example - an Interrupt in a Program
  - Takes control away from the Executing Thread context to a context that is different from that which caused the exception
- **Synchronous Exceptions**:
  - Planned Exceptions
  - Handled in an organized manner
  - The most common type of Synchronous Exception is implemented as a `throw`

Exception Stages

1. **Error Incidence**
   - Synchronous (S/W) Logical Error
   - Asynchronous (H/W) Interrupt (S/W Interrupt)
2. **Create Object & Raise Exception**
   - An Exception Object can be of any Complete Type
   - An int to a full blown C++ class object
3. **Detect Exception**
   - Polling Software Tests
   - Notification Control (Stack) Adjustments
4. **Handle Exception**
   - Ignore: hope someone else handles it, that is, Do Not Catch
   - Act: but allow others to handle it afterwards, that is, Catch, Handle and Re-Throw
   - Own: take complete ownership, that is, Catch and Handle
5. **Recover from Exception**
   - Continue Execution: If handled inside the program
   - Abort Execution: If handled outside the program

Exception Stages


```
int f() {
    int error;
    /* ... */
    if (error) /* Stage 1: error occurred */
        return -1; /* Stage 2: generate exception object */
    /* ... */
}

int main(void) {
    if (f() != 0) /* Stage 3: detect exception */
    {
        /* Stage 4: handle exception */
    }
    /* Stage 5: recover */
}
```

Support for Exceptions in C

- Language Features
  - Return Value & Parameters
  - Local `goto`
- Standard Library Support
  - Global Variables
  - Abnormal Termination
  - Conditional Termination
  - Non-Local `goto`
  - Signals

Return Value & Parameters

- Function Return Value Mechanism
  - Created by the Callee as Temporary Objects
  - Passed onto the Caller
  - Caller checks for Error Conditions
  - Return Values can be ignored and lost
  - Return Values are temporary
- Function (output) Parameter Mechanism
  - Outbound Parameters, bound to arguments, offer multiple logical Return Values

Example: Return Value & Parameters


```
int Push(int i) {
    if (top_ == size-1) // Incidence
        return 0; // Raise
    else
        stack_[++top_] = i;

    return 1;
}

int main() {
    int x;
    // ...
    if (!Push(x)) // Detect {
        // Handling
    }
    // Recovery
}
```

Local goto

- Local goto Mechanism
  - (At Source) Escapes: Gets Control out of a Deep Nested Loop
  - (At Destination) Refactors: Actions from Multiple Points of Error Inception
- A group of C Features
  - `goto Label;`
  - `break; & continue;`
  - `default switch case`

Example: Local goto


```
_PHNDLR _cdecl signal(int signum, _PHNDLR sigact)
{ // Lifted from VC98\CRT\SRC\WINSIG.C
...     /* Check for sigact support */
        if ( (sigact == ...) ) goto sigreterror;

        /* Not exceptions in the host OS. */
        if ( (signum == ... ) { ... goto sigreterror; }
    else { ... goto sigretok; }

        /* Exceptions in the host OS. */
        if ( (signum ...) ) goto sigreterror;
...
sigretok:
        return(oldsigact);

sigreterror:
        errno = EINVAL;
        return(SIG_ERR);
}
```

Example: Local goto


```
_PHNDLR __cdecl signal(int signum, _PHNDLR sigact)
{ // Lifted from VC98\CRT\SRC\WINSIG.C
...     /* Check for sigact support */
        if ( (sigact == ...) ) goto sigreterror;

        /* Not exceptions in the host OS. */
        if ( (signum == ... ) { ... goto sigreterror; }
       else { ... goto sigretok; }

        /* Exceptions in the host OS. */
        if ( (signum ...) ) goto sigreterror;
...
sigretok:
        return(oldsigact);

sigreterror:
        errno = EINVAL;
        return(SIG_ERR);
}
```

Example: Local goto


```
_PHNDLR __cdecl signal(int signum, _PHNDLR sigact)
{ // Lifted from VC98\CRT\SRC\WINSIG.C
...     /* Check for sigact support */
        if ( (sigact == ...) ) goto sigreterror;

        /* Not exceptions in the host OS. */
        if ( (signum == ... ) { ... goto sigreterror; }
       else { ... goto sigretok; }

        /* Exceptions in the host OS. */
        if ( (signum ...) ) goto sigreterror;
...
sigretok:
        return(oldsigact);

sigreterror:
        errno = EINVAL;
        return(SIG_ERR);
}
```

Example: Local goto


```
_PHNDLR __cdecl signal(int signum, _PHNDLR sigact)
{ // Lifted from VC98\CRT\SRC\WINSIG.C
...     /* Check for sigact support */
        if ( (sigact == ...) ) goto sigreterror;

        /* Not exceptions in the host OS. */
        if ( (signum == ... ) { ... goto sigreterror; }
       else { ... goto sigretok; }

        /* Exceptions in the host OS. */
        if ( (signum ...) ) goto sigreterror;
...
sigretok:
        return(oldsigact);

sigreterror:
        errno = EINVAL;
        return(SIG_ERR);
}
```

Global Variables

- GV Mechanism
  - Use a designated Global Error Variable
  - Set it on Error
  - Poll / Check it for Detection
- Standard Library GV Mechanism
  - `<errno.h > / <cerrno>`

Example: Global Variables


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

int main() {
    double x, y, result;
    /*... somehow set 'x' and 'y' ...*/
    errno = 0;

    result = pow (x, y);

    if (errno == EDOM)
        printf("Domain error on x/y pair \n");

    else if (errno == ERANGE)
        printf("range error in result \n");

    else
        printf("x to the y = %d \n", (int) result);

    return 0;
}
```

Abnormal Termination

- Program Halting Functions provided by
  - `<stdlib.h>` / `<cstdlib>`
- `abort()`
  - Catastrophic Program Failure
- `exit()`
  - Code Clean up via `atexit()` Registrations
- `atexit()`
  - Handlers called in reverse order of their Registrations

Example: Abnormal Termination


```
#include<stdio.h>
#include<stdlib.h>
static void atexit_handler_1(void) {
    printf("within 'atexit_handler_1' \n");
}

static void atexit_handler_2(void) {
    printf("within 'atexit_handler_2' \n");
}

int main(){
    atexit(atexit_handler_1);
    atexit(atexit_handler_2);
    exit(EXIT_SUCCESS);

    printf("This line should never appear \n");

    return 0;
}
/* On Execution Output: within 'atexit_handler_2'
                        within 'atexit_handler_1'
   and returns a success code to calling environment */
```

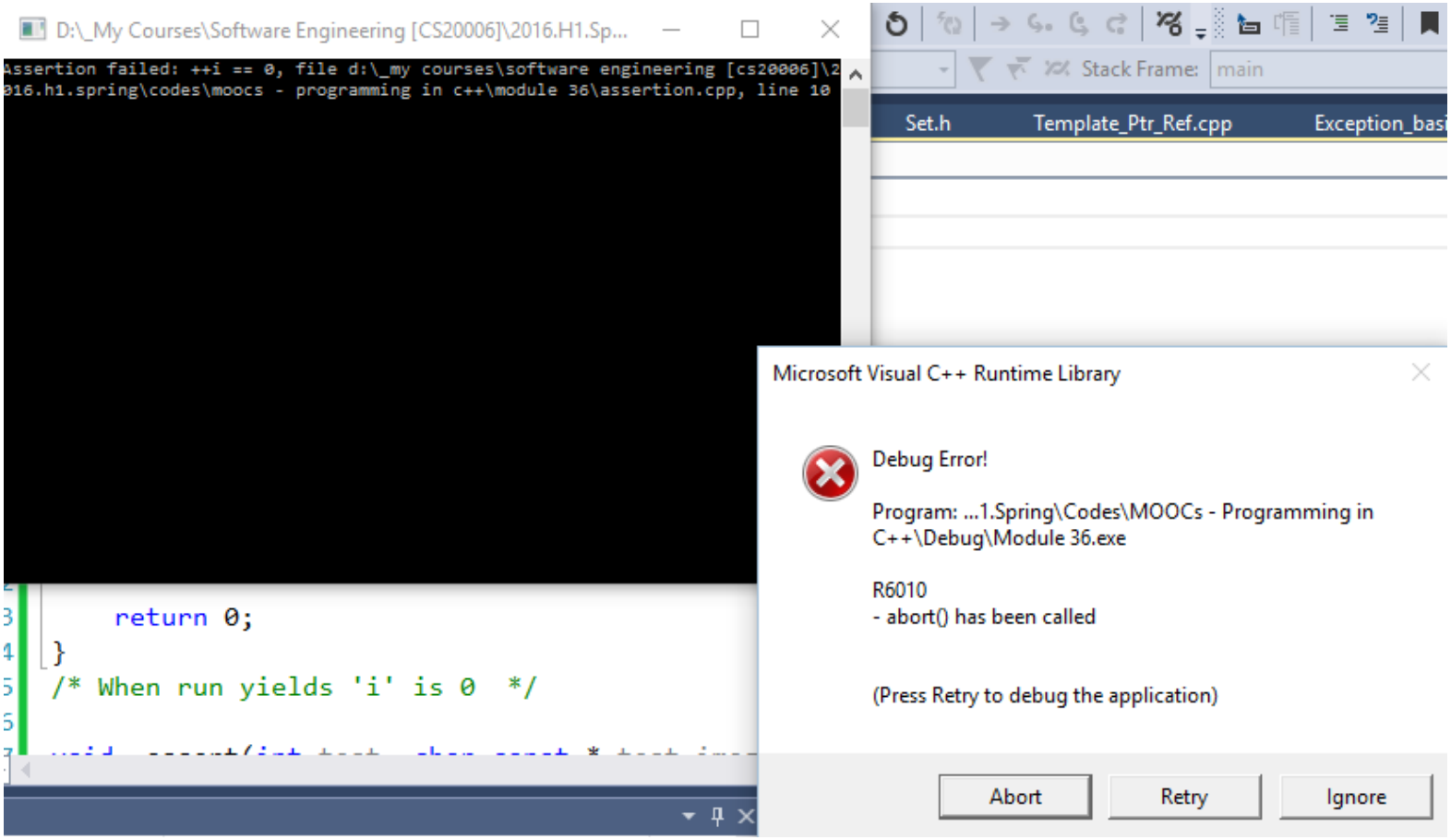
Conditional Termination

- Diagnostic ASSERT macro defined in
  - `<assert.h>` / `<cassert>`
- Assertions valid when `NDEBUG` macro is not defined (debug build is done)
- Assert calls internal function, reports the source file details and then Terminates

Example: Conditional Termination


```
/* Debug version */
//#define NDEBUG
#include <cassert>
#include <cstdlib>
#include <cstdio>
using namespace std;

int main() {
    int i = 0;
    assert(++i == 0); // Assert 0 here

    printf(" i is %d \n", i);

    return 0;
}
/* When run - Asserts  */

void _assert(int test, char const * test_image,
    char const * file, int line) {

    if (!test){
        printf("assertion failed: %s , file %s , line %d\n",
            test_image, file, line);
        abort();
    }
}
```

Example: Conditional Termination



Example: Conditional Termination


```
/* Release version */
#define NDEBUG
#include <cassert>
#include <cstdlib>
#include <cstdio>
using namespace std;

int main(){
    int i = 0;
    assert(++i == 0);  // Assert 0 here

    printf(" i is %d \n", i);

    return 0;
}
/* When run yields 'i' is 0  */

void _assert(int test, char const * test_image,
    char const * file, int line) {

    if (!test){
        printf("assertion failed: %s , file %s , line %d\n",
            test_image, file, line);
        abort();
    }
}
```

Non-Local goto

- `setjmp()` and `longjmp()` functions provided in `<setjmp.h>` Header along with collateral type `jmp_buf`
- `setjmp(jmp_buf)`
  - Sets the Jump point filling up the `jmp_buf` object with the current program context
- `longjmp(jmp_buf, int)`
  - Effects a Jump to the context of the `jmp_buf` object
  - Control return to `setjmp` call last called on `jmp_buf`

Example: Non-Local goto: The Dynamics

Caller

```
void f() {
    A a;
    if (setjmp(jbuf) == 0)
    {
        B b;
        g();
        h();
    }
    else {
        cout << ex.what();
    }
    return ;
}
```

Callee

```
jmp_buf jbuf ;

void g(){
    A a;
    UsrExcp ex ("From g()");

    longjmp(jbuf, 1);

    return ;
}
```

Example: Non-Local goto


```
void f() {
        A a;
        if (setjmp(jbuf) == 0)
        {
                B b;
                g();
                h();
        }
        else {
                cout <<
                ex.what();
        }

        return;
}
```

```
jmp_buf jbuf;

void g()
{
    A a;
    UsrExcp ex("From g()");

    longjmp(jbuf, 1);

    return;
}
```

- g() called

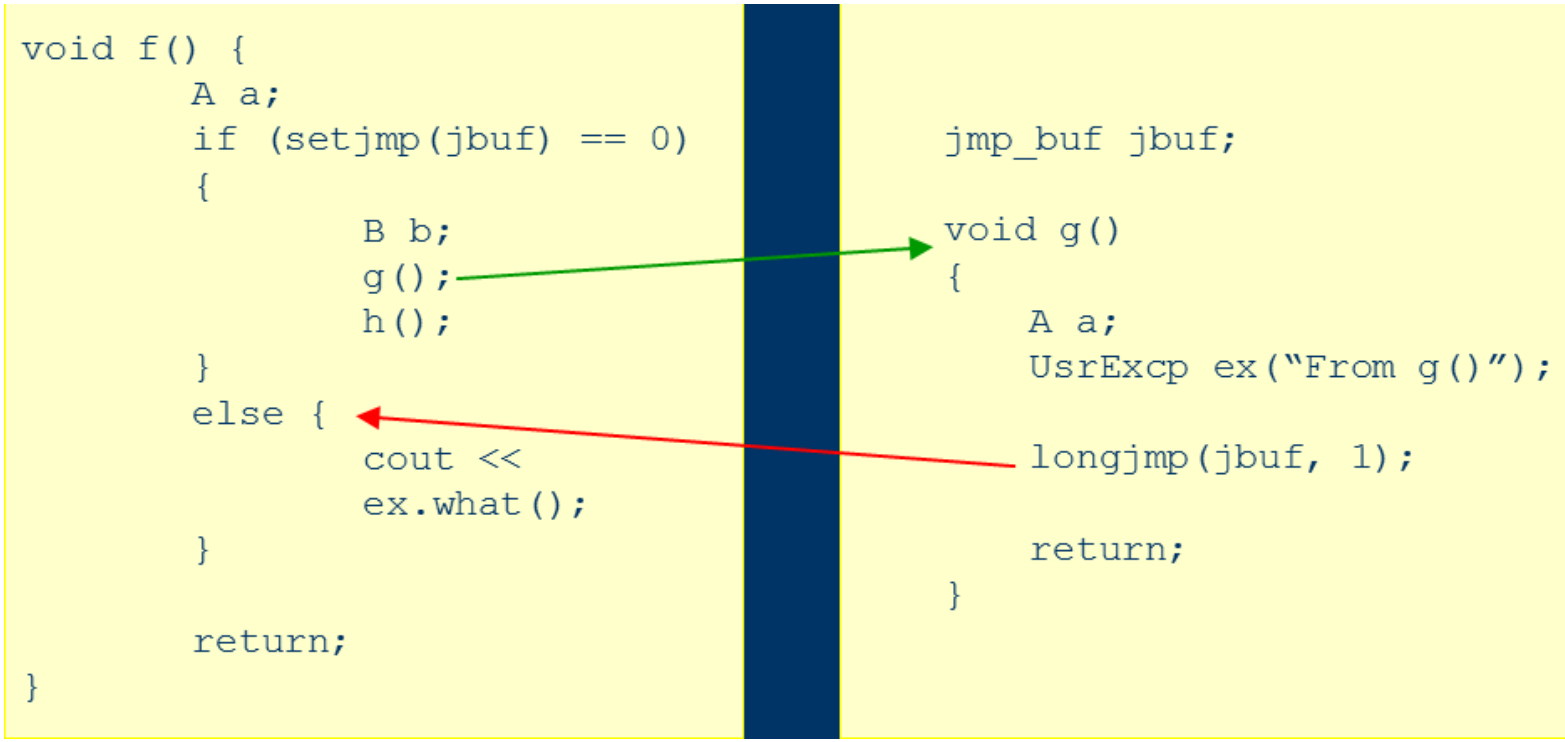
Example: Non-Local goto


```
void f() {
        A a;
        if (setjmp(jbuf) == 0)
        {
                B b;
                g();
                h();
        }
        else {
                cout <<
                ex.what();
        }

        return;
}
```

```
jmp_buf jbuf;

void g()
{
    A a;
    UsrExcp ex("From g()");

    longjmp(jbuf, 1);

    return;
}
```

- g() successfully returns

Example: Non-Local goto



- g() called and longjmp() executed
- setjmp() takes to exception part

Example: Non-Local goto


```
#include<setjmp.h>
#include<stdio.h>
jmp_buf j ;
void raise_exception(){
    printf("Exception raised \n");
    longjmp(j, 1) ; /* Jump to exception handler */
    printf("This line should never appear \n");
}
int main(){
    if (setjmp == 0) {
        printf(" 'setjmp' is intializing  j \n ");
        raise_exception();
        printf("This line should never appear \n");
    }
    else
        printf(" 'setjmp' was just jumped into \n")
        /* This code is the exception handler */
    return 0 ;
}
/* On execution : 'setjmp' is intializing  j ,
   exception raised  and  'setjmp' was just jumped into */
```

Signals

- Header <signal.h>
- raise()
  - Sends a signal to the executing program
- signal()
  - Registers interrupt signal handler
  - Returns the previous handler associated with the given signal
- Converts h/w interrupts to s/w interrupts

Example: Signals


```
// Use signal to attach a signal
// handler to the abort routine
#include <stdio.h>
#include <stdlib.h>
#include <signal.h>
#include <tchar.h>
void SignalHandler(int signal) {
    printf("Application aborting...\n");
}

int main() {
    typedef void (*SignalHandlerPointer)(int);

    SignalHandlerPointer previousHandler;

    previousHandler = signal(SIGABRT, SignalHandler);

    abort();

    return 0;
}
```

Shortcomings

- **Destructor-ignorant**:
  - Cannot release Local Objects i.e. Resources Leak
- **Obtrusive**:
  - Interrogating RV or GV results in Code Clutter
- **Inflexible**:
  - Spoils Normal Function Semantics
- **Non-native**:
  - Require Library Support outside Core Language

Module Summary

- Introduced the concept of exceptions
- Discussed exception (error) handling in C
- Illustrated various language features and library support in C for handling errors
- Demonstrated with examples

Instructor and TAs

Name	Mail	Mobile
Partha Pratim Das, *Instructor*	ppd@cse.iitkgp.ernet.in	9830030880
Tanwi Mallick, *TA*	tanwimallick@gmail.com	9674277774
Srijoni Majumdar, *TA*	majumdarsrijoni@gmail.com	9674474267
Himadri B G S Bhuyan, *TA*	himadribhuyan@gmail.com	9438911655