Ve 280

Programming and Introductory Data Structures

Exception; Abstract Data Types

Announcement

- A make-up lecture this Friday, 12:10 pm – 1:50 pm
  - In the same classroom

Outline

- Exception: the Concepts
- Exception Handling in C++

- Introduction to Abstract Data Types

Review: Motivation of Exception

- Need to do **runtime checking** to handle unusual conditions

- For this, need to determine **legitimate output** for **illegitimate input**:

Exceptions

Determining legitimate output for illegitimate input

- There are three general strategies for determining **legitimate output** for **illegitimate input**:

1. "It's my problem!"
   - Try to "fix" things and continue execution by "coercing" legitimate inputs from illegitimate ones by
     - either modifying the inputs
     - or returning default outputs that make sense in the context
   - For example, `list_rest()` could return an empty list if input is an empty list.
   - Such behavior must be explained in the specification!

Exceptions

Determining legitimate output for illegitimate input

- There are three general strategies for determining **legitimate output** for **illegitimate input**:

1. "It's my problem!"

    - However, this strategy fails whenever there is no "default" behavior for the function with the given illegal inputs.
    - For example, what is division over 0?
        - Division over 0 is simply undefined, and trying to define it changes the rules of math.

Exceptions

Determining legitimate output for illegitimate input

- There are three general strategies for determining **legitimate output** for **illegitimate input**:

2. "I Give up!"

   - Use something like `assert()`.
   - `assert(condition)` terminates the program if condition is not true.

```
list_rest (list_t l)
// REQUIRES: list is not empty
{
    assert(!list_isEmpty(l));
}
```

Exceptions

Determining legitimate output for illegitimate input

- There are three general strategies for determining **legitimate output** for **illegitimate input**:

2. "I Give up!"

  - However, it is Not Nice to terminate a program this way.
  - There are some situations where this type of "hard exit" is ok, but there is usually some more things to do before terminating.
    - For example, free the allocated memory.
  - Usually, exiting from a function deep in the call stack is not the way to do it.

Exceptions

Determining legitimate output for illegitimate input

- There are three general strategies for determining **legitimate output** for **illegitimate input**:

3. "It's your problem!"

The caller of the function

- Encode "failure" in the **return values**.
- Unfortunately, you often can't encode "failure" elegantly in the return values.
- For example, `list_first()` can return **any** integer, so no special value is available to encode "the list is empty!".
- Compared to the other two, this is usually the strategy that you use.

Exceptions

It's your problem!

- To fully implement this strategy for runtime checking,

  - Every writer of **every function** must:

  1. Be diligent in checking for illegitimate inputs.
  2. Make sure to pass back the proper encoded "failure" return values.

  - Every writer of **every call** to one of these functions must:

  1. Be diligent in examining these returned values.
  2. Be diligent in acting on these returned values.

Exceptions

It's your problem!

- In practice, this strategy is unworkable for several reasons:

1. You get lazy.

    - You say to yourself, "This kind of error cannot **possibly** occur here, so I'll just omit this check for it."
    - Others may get lazy and not want to check for your return values.

Exceptions

It's your problem!

- In practice, this strategy is unworkable for several reasons:

2. You **forget** to check.

  - For example, if `foo` calls `bar`, `bar` calls `baz`, and `baz` returns an error; `bar` will probably notice, but `bar` has to remember to pass this to `foo`!

Exceptions

It's your problem!

- In practice, this strategy is unworkable for several reasons:

3. It gets unwieldy.

  - If you are ruthlessly diligent about it, your code becomes unmanageable.
  - You have to write too much error handling code, and it becomes hopelessly intertwined with the "normal-case" code.
  - In other words, this doesn't scale well.

- So, we need some mechanism to help deal with these runtime errors…

Exceptions

Dealing with runtime errors

- Fortunately, such a mechanism for dealing with runtime errors has been around for a long time.

- It is called an **exception handling mechanism**.

- **Exception**: something bad that happens in a block of code, such as a bad parameter that prevents the block from continuing to execute.

Exceptions

Exception Handling

- When an exception occurs, the block of the normal-case code is exited, and control is passed to another block of code (the **error handling** code).
- This error handling code then tries to correct the problem.
- In pictures:

Exceptions

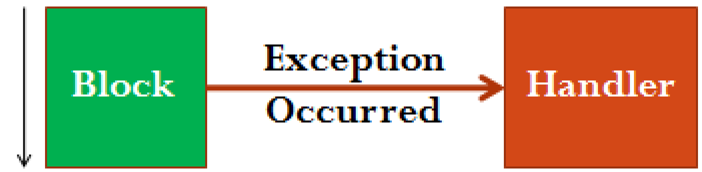
Exception Handling

- Exception handling lets us separate the normal code from the error handling code, with a conceptual "goto" between the two.

- Conceptually, normal part and error handling part are separate, but in C++, error handling part could appear in the same function as normal part.

Exceptions

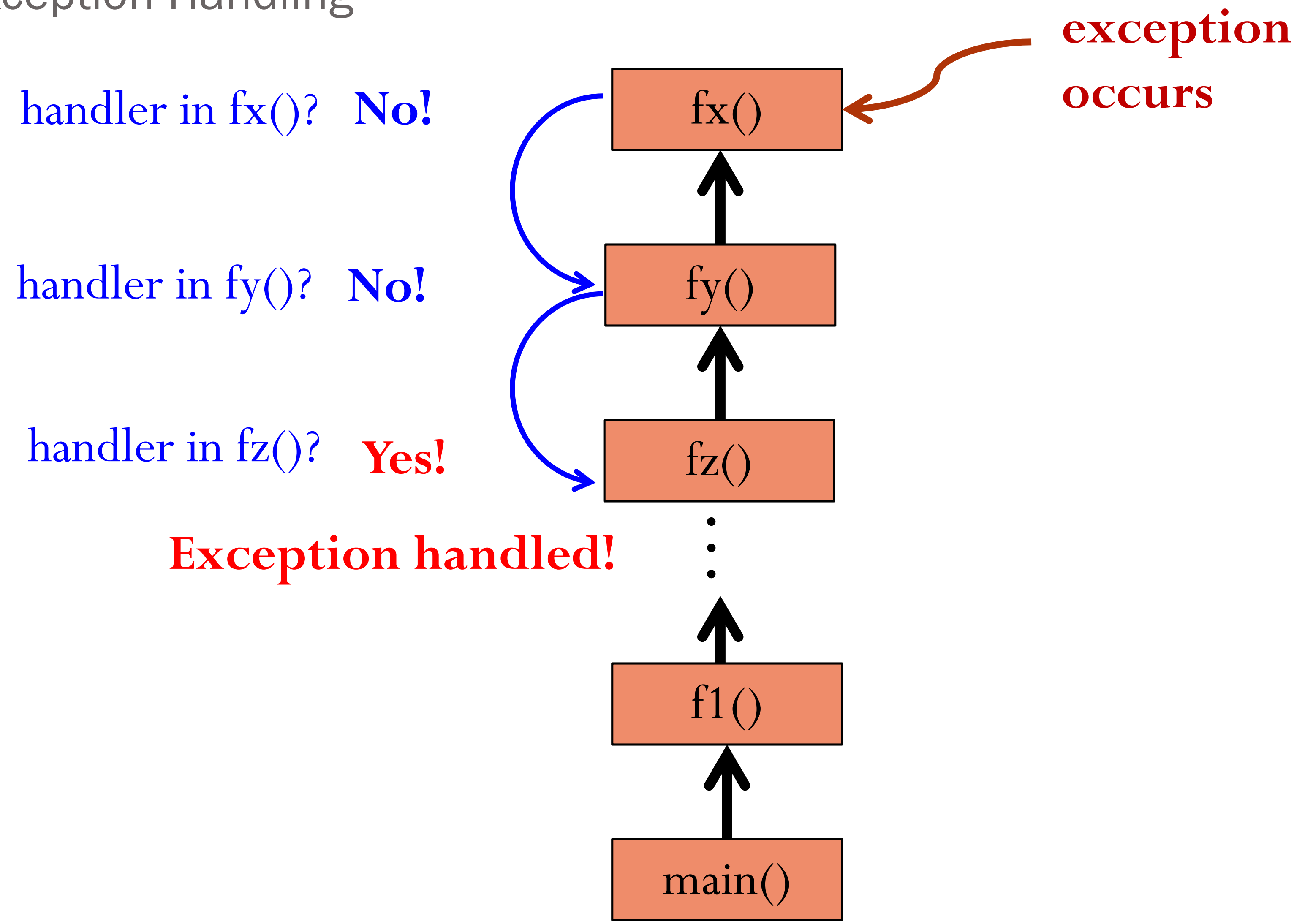
Exception Handling



- An important mechanism for exception handling is the **exception propagation**, which specifies where to find the handler.
  - First, the remaining part of the function where exception happens is searched for the handler. If found, exception is resolved.
  - If not, the function g() that calls the one issuing the exception is searched for the handler. If found, done!
  - If still not, the function that calls g() is searched … So on and so forth.
  - In the worst case, the exception propagates up the call chain all the way to **the caller of main()**, at which point your program exits.

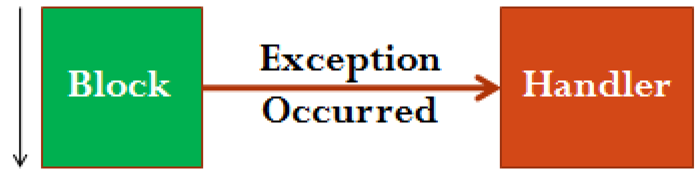
Exceptions

Exception Handling



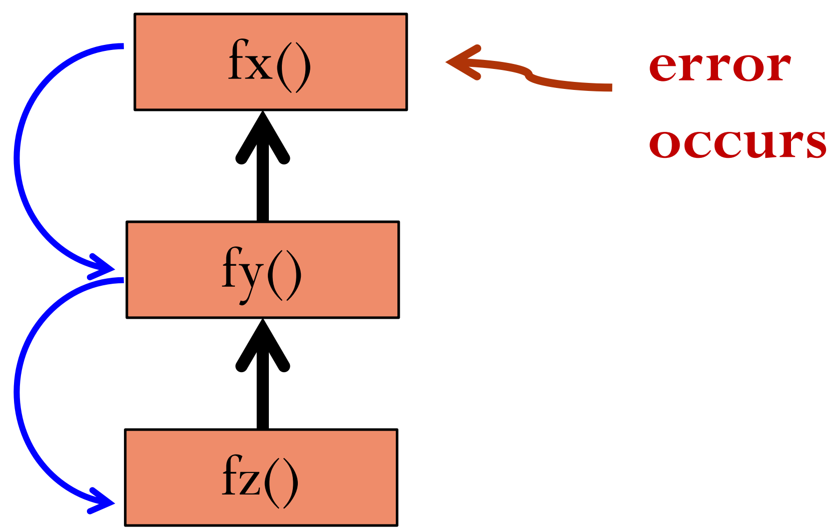
Exceptions

Exception Handling



- An exception handling mechanism is merely a neat way to **automatically** pass an exceptional condition up the call chain, until it is handled somewhere.
- This mechanism doesn't require you to propagate the error **yourself**!
  - It prevents you from having to encode things in return values.

In old method, you have to pass return value from f(x) to f(y), then from f(y) to f(z). This needs **extra coding** and requires you to **remember**!



Outline

- Exception: the Concepts
- Exception Handling in C++
- Introduction to Abstract Data Types

Exception Handling

C++ Terminology

- **Throwing an exception:** the act of making the program aware that an exception just occurred.
- **Catching an exception:** the act of responding to the exception that occurred.
- **Exceptions occur** in a block of code called a **try block**.
- **Exceptions are handled** in a separate but related block of code called a **catch block**.
- Alternative names:
  - throwing exceptions → raising exceptions
  - catch block → exception handlers

Exception Handling

C++ Terminology

- In pictures:

```
void foo() {
    try { Block }
    catch (Type var) { Handler }
}
```

Exception Handling

Usage in C++

- Exceptions have **types** and **objects** (just like variables).
- We first need to **declare** an exception type, which can either be a basic type or a user-defined type, such as a **struct** or a **class**.
- When we throw an exception, we specify an **object** of the exception type in a **throw statement**.

```
int n = -1;
if(n < 0) throw n;
// The exception type is int
// We throw an object n of int type
```

- You can think of this object as being a kind of parameter of the exception, allowing some information describing the exception to be passed to the handler.

Exception Handling

Usage in C++

- We can define an exception type ourselves, using **struct** or **class**.

- Example: `struct NegInt_t { int val; };`

- Throw an exception of `NegInt_t` type

```
if(n < 0) {
   NegInt_t error;
   error.val = n;
   throw error;
}
```

Exception Handling

Usage in C++

- For the factorial function, we'll add a check for a negative parameter, and a throw statement if it is encountered.

```
int factorial(int n)
// EFFECTS: returns n! if n>=0
//          throws n otherwise
{
  int result;
  if (n < 0) throw n;
  for(result = 1; n != 0; n--){
    result *= n;
  }
  return result;
}
```

Exception Handling

Usage in C++

- Now we can call `factorial()` inside a try block, with a catch block to handle the error:

```
int foo(int i) {
  try {
    cout << factorial(i) << endl;
  }
  catch (int v) {
    cout << "Error: negative input: ";
    cout << v << endl;
  }
}
```

The catch block will catch an object of exception type `int`, and store this object in `v`.

Exception Handling

Usage in C++

```
int foo(int i) {
      try { … }
      catch (int v) { … }
}
```

- You can think of the catch block as "protecting" the try block to which it is attached.
- You cannot write a catch block unless you have a try block to attach it to.
- On the other hand, you can throw an exception **from** anywhere, instead of just within a try or catch block.

Exception Handling

Usage in C++

- Exception will be **propagated** along the calling function stack. Only the **first** catch block with the **same type** as the thrown exception object will handle the exception
  - If the current function f() does not have a matching catch block, it will propagate to the caller of f()
  - If no matching catch blocks, propagate to the caller of main, and program exits

```
int foo(int i) {
  try { //throw an int }
  catch (double v) {
    // will not catch the
    // exception with int type
  }
}
```

Exception Handling

Using in C++

- If the exception is successfully handled in the catch block, execution continues normally with the first statement following the catch block.

```
int foo(int i) {
      try { … }
      catch (int v) { … }
      ... // Do something next
}
```

Next to do

Exception Handling

Usage in C++

- Now suppose `foo`'s catch block can't handle the exception. It can propagate the exception by throwing it again:

```
int foo(int i) {
  try {
    cout << factorial(i) << endl;
  }
  catch (int v) {
    cout << "Error: negative input: ";
    cout << v << endl;
    throw v;
  }
}
```

Exception Handling

Usage in C++

```
int foo(int i) {
  try {
    cout << factorial(i) << endl;
  }
  catch (int v) {
    cout << "Error: negative input: ";
    cout << v << endl;
    throw v;
  }
}
```

Here the handler explicitly propagates the exception to `foo`'s caller after printing a message to standard output.

Exception Handling

Usage in C++

- In general, a try block can have associated a catch with more than one type of exception:

```
try {
   if (foo) throw 2.0;
   // some statements
   if (bar) throw 4;
   // more statements
   if (baz) throw 'a';
}
catch (int n) { }
catch (double d) { }
catch (char c) { }
catch (...) { }
```

Exception Handling

Usage in C++

```
try {
   if (foo) throw 2.0;
   // some statements go here
   if (bar) throw 4;
   // more statements go here
   if (baz) throw 'a';
}
catch (int n) { }
catch (double d) { }
catch (char c) { }
catch (...) { }
```

The type of the thrown exception is matched to the list of catch blocks in order. The first matching catch block is executed.

Exception Handling

Usage in C++

```
try {
   if (foo) throw 2.0;
   // some statements go here
   if (bar) throw 4;
   // more statements go here
   if (baz) throw 'a';
}
catch (int n) { }
catch (double d) { }
catch (char c) { }
catch (...) { }
```

The last handler is a **default handler**, which matches any exception type. It can be used as a "catch-all" in case no other catch block matches.

Exception Handling

Usage in C++

- Finally, we need some way of telling the caller that a function can throw an exception, so that the caller can be prepared to handle it.
- We do this via the specification comment.
- The EFFECTS clause must state it:

```
int factorial(int n);
// EFFECTS: returns n! if n>=0
//          throws int n if n<0.
```

Outline

- Exception: the Concepts
- Exception Handling in C++

- Introduction to Abstract Data Types

Types

- The role of a type:
  - The set of values that can be represented by items of the type
  - The set of operations that can be performed on items of the type.

- Example
  - C++ string values:

    operations:

Struct Types

- Struct types have the following feature:
  - **Every detail** of the type is known to all users of that type.
  - This is sometimes called the **concrete implementation**.

- Example: the `struct Grades` talked before.

```
struct Grades {
  char name[9];
  int  midterm;
  int  final;
};
```

Struct Types

```
struct Grades {
   char name[9];
   int  midterm;
   int  final;
};
```

- Every function knows the details of exactly how `Grades` are represented.
- A change to the `Grades` definition (for example, change C-string for `name` to a C++-String) requires that we **make changes throughout the program** and recompile everything using this struct.

Abstract Data Types

Introduction

- Contrast the property of struct types with that of the functions
  - A function written by others shows **what** the function does, but not **how** it does it

- For function, if we find a faster way to implement, we can just replace the old implementation with the new one
  - No other components of the program calling the function need to change

Abstract Data Types

Introduction

- To solve the problem for struct type, we'll define **abstract data types**, or **ADTs**.
- An ADT provides an **abstract description** of **values** and **operations**.
- The definition of an ADT must combine **both** some notion of **what** values that type represents, and **what** operations on values it supports.
  - However, we can leave off the details of **how**.
- Example: mobile phone
  - Type: a portable telephone that can make and receive calls
  - Operations: turn on/off, make/receive call, text message

We don't know details!

Abstract Data Types

Introduction

- Abstract data types provide the following two advantages:

1. Information hiding: we don't need to know the details of how the **object** is **represented**, nor do we need to know how the **operations on those objects** are **implemented**.
2. Encapsulation: the objects and their operations are defined in the same place; the ADT combines both data and operation in one entity.

Abstract Data Types

Example

- `list_t`:
  - Information Hiding: In the `list_t` data type, you never knew the precise implementation of the `list_t` structure (except by looking in `recursive.cpp`).
  - Encapsulation: The definitions of the operations on lists (`list_print`, `list_make`, etc.) were found in the same header file as the type definition of `list_t`.

Abstract Data Types

Benefits

- Abstract data types have several benefits like we had with functional abstraction:
  - ADTs are **local**: the implementation of other components of the program does not depend on the **implementation** of ADT.
    - To realize other components, you only need to focus **locally**.
  - ADTs are **substitutable**: you can change the implementation and no users of that type can tell.

Abstract Data Types

Introduction

- Someone still needs to know the details of how the type is implemented.
  - I.e., how the values are represented and how the operations are implemented
- This is referred to as the "**concrete representation**" or just the "**representation**".

- Question: Who can access the representation?
- Answer: **only** the operations defined for that type should have access to the representation.
  - Everyone else may access/modify this state only **through** operations.

Abstract Data Types

On to Classes

- C++ “class” provides a mechanism to give **true** encapsulation.

- The basic idea behind a class is to provide **a single entity** that both defines:
  - The **nature** of an object.
  - The **operations** available on that object. These operations are sometimes also called **member functions** or **methods**.

References

- **Problem Solving with C++ (8th Edition)**, by *Walter Savitch*, Addison Wesley Publishing (2011)
  - Chapter 16 Exception Handling

- **Problem Solving with C++ (8th Edition)**, by *Walter Savitch*, Addison Wesley Publishing (2011)
  - Chapter 10.3 Abstract Data Types
  - Chapter 10.2 Classes