G22.2110-003 Programming Languages - Fall 2012

Week 13 - Part 2

Thomas Wies

New York University

Review

Last lecture

- Scala

Outline

Today:

- Exceptions

Sources for today's lecture:

PLP, ch. 8.5

Exceptions

General mechanism for handling abnormal conditions

Category	Examples	How raised
predefined	constraint violations, I/O errors, communication errors, other illegalities	by the runtime system
user-defined	pop from empty stack	explicitly by user code

- exception handlers specify remedial actions or proper shutdown
- exceptions can be stored and re-raised later

Error handling

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How can we do this?

Traditionally, this was done by checking the result of each operation that can go wrong (e.g., popping from a stack, writing to a file, allocating memory).

Unfortunately, this has a couple of serious disadvantages:

1. it is easy to forget to check
2. writing all the checks clutters up the code and obfuscates the common case (the one where no errors occur)

Exceptions let us write clearer code and make it easier to catch errors.

Predefined exceptions in Ada

- Defined in Standard:
  - `Constraint_Error` : value out of range
  - `Program_Error` : illegality not detectable at compile-time: unelaborated package, exception during finalization, etc.
  - `Storage_Error` : allocation cannot be satisfied (heap or stack)
  - `Tasking_Error` : communication failure
- Defined in `Ada.IO_Exceptions`:
  - `Data_Error`, `End_Error`, `Name_Error`, `Use_Error`, `Mode_Error`, `Status_Error`, `Device_Error`

Handling exceptions

Any begin-end block can have an exception handler:

```
procedure Test is
  X: Integer := 25;
  Y: Integer := 0;
begin
  X := X / Y;
exception
  when Constraint_Error =>
      Put_Line("did␣you␣divide␣by␣0?");
  when others           =>
      Put_Line("out␣of␣the␣blue!");
end;
```

A common idiom

```
function Get_Data return Integer is
  X: Integer;
begin
  loop
    begin
      Get(X);
      return X;  -- if got here, input is valid,
                 -- so leave loop
    exception
      when others =>
        Put_Line("input␣must␣be␣integer");
         -- will restart loop to wait for next input
    end;
  end loop;
end;
```

User-defined Exceptions

```
package Stacks is
  Stack_Empty: exception;
  ...
end Stacks;
```

```
package body Stacks is
  procedure Pop (X: out Integer;
                 From: in out Stack) is
  begin
    if Empty(From)
      then raise Stack_Empty;
      else ...
  end Pop;
  ...
end Stacks;
```

The scope of exceptions

- an exception has the same visibility as other declared entities: to handle an exception it must be visible in the handler (e.g., caller must be able to see `Stack_Empty`).
- an `others` clause can handle unnamable exceptions partially

```
when others =>
  Put_Line("disaster somewhere");
  raise;     -- propagate exception,
             --  program will terminate
```

Exception run-time model

What happens when an exception is raised?

1. When an exception is raised, the current sequence of statements is abandoned (e.g., current `Get` and `return` in example)
2. Starting at the current frame, each frame in the current *dynamic* scope is examined (want dynamic as opposed to static scopes because those are values that caused the problem).
3. As each frame is examined, if a handler is found, it is executed, and program execution resumes in that frame. Otherwise, the frame is discarded.
4. If no handler is found, the program terminates.

Note: A discarded frame (including the frame that raised the exception) is never resumed.

Exception information

- an Ada exception is a label, not a type: we cannot declare exception variables and assign to them
- but an exception *occurrence* is a value that can be stored and examined
- an exception occurrence may include additional information: source location of occurrence, contents of stack, etc.
- predefined package `Ada.Exceptions` contains needed machinery

Ada.Exceptions (part of std libraries)

```
package Ada.Exceptions is
  type Exception_Id is private;
  type Exception_Occurrence is limited private;

  function Exception_Identity (X: Exception_Occurrence)
    return Exception_Id;
  function Exception_Name (X: Exception_Occurrence)
    return String;

  procedure Save_Occurrence
    (Target: out Exception_Occurrence;
     Source: Exception_Occurrence);
  procedure Raise_Exception (E: Exception_Id;
                             Message: in String := "")
  ...
end Ada.Exceptions;
```

Using exception information

```
begin
  ...
exception
  when Expected: Constraint_Error =>
     -- Expected has details
    Save_Occurrence(Event_Log, Expected);

  when Trouble: others =>
    Put_Line("unexpected␣" &
             Exception_Name(Trouble) &
             "␣raised");
    Put_Line("shutting␣down");
    raise;
end;
```

Exceptions in C++

- similar *runtime* model,...
- but exceptions are bona-fide types,
- and exception occurrences are first-class values
- handlers appear in `try/catch` blocks

```
try {
  some_complex_calculation();
} catch (const RangeError& e) {
  // RangeError might be raised
  //  in some_complex_calculation
  cerr << "oops\n";
} catch (const ZeroDivide& e) {
  // same for ZeroDivide
  cerr << "why␣is␣denominator␣zero?\n";
}
```

Defining and throwing exceptions

The program throws an object. There is nothing in the declaration of the type to indicate it will be used as an exception.

```
struct ZeroDivide {
  int lineno;
  ZeroDivide (...) { ... }  // constructor
  ...
};


...
if (x == 0)
  throw ZeroDivide(...); // call constructor
                         //  and go
```

Exceptions and inheritance

A handler names a class, and can handle an object of a derived class as well:

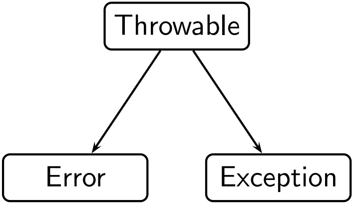
```
class Matherr { }; // a bare object, no info
class Overflow : public Matherr {...};
class Underflow : public Matherr {...};
class ZeroDivide : public Matherr {...};

try {
  weatherPredictionModel(...);
} catch (const Overflow& e) {
  // e.g., change parameters in caller
} catch (const Matherr& e) {
  // Underflow, ZeroDivide handled here
} catch (...) {
  // handle anything else (ellipsis)
}
```

Exceptions in Java

- Model and terminology similar to C++:
  - exceptions are objects that are thrown and caught
  - `try` blocks have handlers, which are examined in succession
  - a handler for an exception can handle any object of a derived class
- Differences:
  - all exceptions are extensions of predefined class `Throwable`
  - checked exceptions are part of method declaration
  - the `finally` clause specifies clean-up actions (in C++, cleanup actions are idiomatically done in destructors)

Exception class hierarchy



- any class extending `Exception` is a *checked* exception
- system errors are extensions of `Error`; these are *unchecked* exceptions

Checked exceptions must be either handled or declared in the method that throws them; this is checked by the compiler.

Exceptions in Java

If a method might throw an exception, callers should know about it.

```
public void replace (String name,
                     Object newVal) throws NoSuch
{
   Attribute attr = find(name);
   if (attr == null) throw new NoSuch(name);
   newVal.update(attr);
}
```

Mandatory cleanup actions

Some cleanups must be performed whether the method terminates normally or throws an exception.

```
public void parse (String file) throws IOException
{
  BufferedReader input =
    new BufferedReader(new FileReader(file));
  try {
    while (true) {
      String s = input.readLine();
      if (s == null) break;
      parseLine(s);  // may fail somewhere
    }
  } finally {
    if (input != null) input.close();
  }  //regardless of how we exit
}
```

Exceptions in Scala

Model, terminology, and syntax similar to Java except that

- exceptions are unchecked by default
- catch blocks can use pattern matching

```
try {
  val f = new FileReader("input.txt")
  // Use and close file
} catch {
  case ex: FileNotFoundException =>
    // Handle missing file
  case ex: IOException => // Handle other I/O error
}
```

- `throw` is an expression that has result type `Nothing`:

```
val half =
  if (n % 2 == 0) n / 2
  else throw new RuntimeException("n␣must␣be␣even")
```

Type checks because `Nothing` is a subtype of `Int`.

Exceptions in ML

- runtime model similar to ADA/C++/JAVA
- `exception` is a single type (like a `datatype` but dynamically extensible)
- declaring new sorts of exceptions:

```
exception StackUnderflow
exception ParseError of { line: int, col: int }
```

- raising an exception:

```
raise StackUnderflow
raise (ParseError { line = 5, col = 12 })
```

Exceptions in ML

- handling an exception:

  ```
  expr_1 handle pattern => expr_2
  ```

  If an exception is raised during evaluation of `expr_1`, and `pattern` matches that exception, `expr_2` is evaluated instead

A closer look

```
exception Div

fun f i j =
  if j <> 0
    then i div j
    else raise Div
```

```
(f 6 2 handle Div => 42) (* evaluates to 3 *)
```

```
(f 4 0 handle Div => 42) (* evaluates to 42 *)
```

Typing issues:

- the type of the body and the handler must be the same
- the type of a `raise` expression can be *any type* (whatever type is appropriate is chosen)

Call-with-current-continuation

Available in Scheme and Sml/NJ; usually abbreviated to `call/cc`.

A *continuation* represents the computation of "rest of the program".

`call/cc` takes a function as an argument. It calls that function with the current continuation (which is packaged up as a function) as an argument.

If this continuation is called with some value as an argument, the effect is as if `call/cc` had itself returned with that argument as its result.

The current continuation is the "rest of the program", starting from the point when `call/cc` returns.

```
(call/cc (lambda (c) (c 5)))        ;; returns 5
(call/cc (lambda (c) 5))            ;; so does this
(call/cc (lambda (c) (+ 1 (c 5)))) ;; ditto
```

The power of continuations

We can implement many control structures with `call/cc`:

- **return**:

```
(lambda (x)
  (call/cc (lambda (ret)
    ...       ;; body of function
    (ret 76) ;; call continuation with result
    ...
  ))
)
```

- **goto**:

```
(begin
  ...
  (call/cc (lambda (k) (set! here k)) ;; set label
  ...
  (here ()) ;; ‘‘goto’’ here
  ...
)
```

Exceptions via call/cc

Exceptions can also be implemented by `call/cc`:

- Need global stack: `handlers`
- For each `try`/`catch`:

```
(call/cc (lambda (k)
           (begin
             (push handlers (lambda ()
                              (begin
                                (pop handlers)
                                (catch-block)
                                (k ()))))
             (try-block)
             (pop handlers))))
```

- For each `raise`:

```
((top handlers))    ; call the top function on
                    ;  the handlers stack
```