Review

Last lecture

- Scala
Outline

Today:

- Exceptions

Sources for today’s lecture:

*PLP, ch. 8.5*
## Exceptions

General mechanism for handling abnormal conditions

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

One way to improve robustness of programs is to write code to explicitly handle errors.

*How can we do this?*
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).
One way to improve robustness of programs is to write code to explicitly handle errors.

*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`
Any begin-end block can have an exception handler:

```plaintext
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 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 appears 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
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

```c
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.

```c++
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:

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

```java
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.

```java
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

```scala
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`:

```scala
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

```plaintext
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.

\[
\begin{align*}
\text{(call/cc (lambda (c) (c 5)))} & \quad ;; \text{returns 5} \\
\text{(call/cc (lambda (c) 5))} & \quad ;; \text{so does this} \\
\text{(call/cc (lambda (c) (+ 1 (c 5))))} & \quad ;; \text{ditto}
\end{align*}
\]
The power of continuations

We can implement many control structures with call/cc:

- **return:**

  \[
  \lambda (x) \\
  \;\;\; (\text{call/cc}\; (\lambda \; (\text{ret}) \\
  \;\;\; \;\; \;\; ... \;\; \;\; \;\; ; \;\; \text{body of function} \\
  \;\;\; \;\; \;\; (\text{ret} \; 76) \;\; ;\; \text{call continuation with result} \\
  \;\;\; \;\; \;\; ... \\
  \;\;\; \;\; \;\; )) \\
  \)

- **goto:**

  \[
  \begin{aligned}
  & (\text{begin} \\
  & \;\;\; ... \\
  & \;\;\; (\text{call/cc}\; (\lambda \; (k)\; (\text{set!}\; \text{here} \; k))) \;\; ;\; \text{set label} \\
  & \;\;\; ... \\
  & \;\;\; (\text{here} () ) \;\; ;\; \text{‘‘goto’’ here} \\
  & \;\;\; ... \\
  & ) \\
  \end{aligned}
  \]
Exceptions via call/cc

Exceptions can also be implemented by call/cc:

- Need global stack: `handlers`
- For each `try/catch`:
  
  ```scheme
  (call/cc (lambda (k)
  (begin
      (push handlers (lambda ()
      (begin
        (pop handlers)
        (catch-block)
        (k ())))))
  (try-block)
  (pop handlers))))
  ``

- For each `raise`:
  
  ```scheme
  ((top handlers)) ; call the top function on
  ; the handlers stack
  ```