Exception Handling I

What should a program do if it tries to pop an element off an empty stack, or divides by 0, or indexes outside an array, or produces an arithmetic error, such as overflow?

In C, many procedures will return a status code. In most cases programmers will “forget” to check this status flag.

Modern languages have built-in exception handling mechanisms. When an exception is raised (or thrown) it must be handled or the program will terminate.

Exceptions can be raised implicitly by the run-time system (overflow, array bounds errors, etc), or explicitly by the programmer.

Exception Handling II

When an exception is raised, the run-time system has to look for the corresponding handler, the piece of code that should be executed for the particular exception.

The right handler cannot be determined statically (at compile-time). Rather, we have to do a dynamic (run-time) lookup when the exception is raised.

In most languages, you start looking in the current block (or procedure). If it contains no appropriate handler, you return from the current routine and re-raise the exception in the caller. This continues until a handler is found or until we get to the main program (in which case the program terminates with an error).

Exception Handling III

What happens after an exception handler has been found and executed?

resumption modelGo back to where the exception was raised and re-execute the statement (PL/I).

termination modelReturn from the procedure (or unit) containing the handler (Ada).
Exceptions in Modula-3 I

Exceptions are declared like this:

```
INTERFACE M;
  EXCEPTION Error(TEXT);
  PROCEDURE P () RAISES {Error};
END M;
```

Exceptions can take parameters. In this case, the parameter to Error is a string. Presumably, the programmer will return the kind of error in this string.

The declaration of P states that it can only raise one exception, Error.

If there is no RAISES clause, the procedure is expected to raise no exceptions.

Exceptions in Modula-3 II

```
S_1 and S_2 can raise exceptions implicitly, or the programmer can raise an exception explicitly using RAISE.

When the Error-exception is raised, the EXCEPT-block is searched and the code for the Error exception is executed.

PROCEDURE P () RAISES {Error};
BEGIN
  TRY
    S_1; RAISE Error("Help!"); S_2;
  EXCEPT
    Error (V) => Write(V); |
    Problem (V) => Write("No Probs!"); |
    ELSE Write("Unhandled Exception!");
  END;
END P;
```

Exceptions in Modula-3 III

An unhandled exception is re-raised in the next dynamically enclosing TRY-block. If no matching handler is found the program is terminated.

```
MODULE M;
BEGIN
  TRY
    TRY S_1; EXCEPT
      Problem (V)=Write(V);
    END;
    EXCEPT
      Error (V) => Write(V); |
      ELSE Write("Unhandled Exception!");
    END;
  END M;
```

Exceptions in Modula-3 IV

An unhandled exception is re-raised in the calling procedure.

```
MODULE M;
PROCEDURE P ();
BEGIN
  TRY
    S_1; EXCEPT
      Problem (V)=RAISE Error("OK")
    END;
  EXCEPT
    Error (V) => Write(V); |
    Problem (V) => Write(V);
  ELSE Write("Unhandled Exception!");
  END;
END M;
```

```
We want 0-overhead exception handling. This means that — unless an exception is raised — there should be no cost associated with the exception handling mechanism.

We allow raising and handling an exception to be quite slow.

When an exception is raised we need to be able to
1 in the current procedure find the exception handler (if any) that encloses the statement that raised the exception, and
2 rewind the stack (pop activation records) until a procedure with an exception handler is found.

We build a RangeTable at compile-time. It has one entry for each procedure and for each TRY-block. Each entry holds four addresses: pc_high, pc_low, handler and cleanup. [pc_low···pc_high] is the range of addresses for which handler is the exception handler.

Unwinding the Stack I

Let procedure S raise exception E at code address V. We search the range table to find an entry which covers V, i.e. for which pc_low<=V<=pc_high.

Entry (6) covers all of procedure S (for S to S_end), and hence V. There’s no exception handler for this range. We just execute S’s cleanup code, S_C.

S_C will restore saved registers, etc, and deallocate the activation record.

The Range Table

We build a RangeTable at compile-time. It has one entry for each procedure and for each TRY-block. Each entry holds four addresses: pc_high, pc_low, handler and cleanup. [pc_low···pc_high] is the range of addresses for which handler is the exception handler.
Unwinding the Stack II

Since S didn't have a handler, we must unwind the stack until one is found.
S’s return address is K, which is covered by entry (5) in the range table. Entry (5) has a handler defined (at address H1). Run it!

The Exception Handler

The exception handler itself can be translated as a sequential search.
If the TRY-EXCEPT-block has no ELSE part, the default action will be to re-raise the exception.

```
TRY
  S1;
  RAISE e;
  S2;
  RAISE e;
  IF e = E1 THEN
    H1
  ELSIF e = E2 THEN
    H2
  ELSE
    RAISE e
  ENDIF;
```

Example I (a)

Explanation of the source code:
Consider the example on the next slide.
The main program calls procedure P(). There is a <default handler> defined for the program at address H3.
Procedure P() calls Q(). Exception X1 is caught by the handler at address H2.
Q() calls R().
R() calls S(). Exception X2 is caught by the handler at address H1.
S() throws exception X1 at address A1.
Example I (b)

Explanation of run-time actions:

- A1 \(\in [S, S_{\text{end}}]\), in Range Table entry (6). (6) has no handler, so we execute its cleanup routine \((S_C)\) and update \(PC\) to the return address, \(A2\).
- Since \(A2 \in [E3, E4]\) in Range Table entry (5), and \((5).\text{handler}\neq H1\neq \text{NIL}\), we GOTO \(H1\). This handler doesn't handle exception \(X1\), so it will simply re-raise \(X1\).
- \(Q()\) has no handler, so we execute its cleanup routine \((Q_C)\) and propagate the exception to \(P()\). I.e. We update \(PC\) to the return address stored in \(Q\)'s frame, \(A4\).
- Since \(A4 \in [E1, E2]\) in Range Table entry (2), and \((2).\text{handler}=H2\), we GOTO \(H2\). This handler catches \(X1\). \(\Rightarrow\) Done.

Summary

- The algorithm we've shown has no overhead (not even one instruction), unless an exception is thrown.
- The major problem that we need to solve is finding the procedure descriptor for a particular stack frame.
- An alternative implementation would be to store a pointer in each frame to the appropriate descriptor. The extra space is negligible, but it would cost 1-2 extra instructions per procedure call.

Further reading: