CS 412
Introduction to Compilers

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Lecture 37: Exceptions
2 May 01

Administration

- Design reports due Friday
- Project demos May 10–11
  - 1:30, 2:15, 3:00, 3:45

Exceptions

- Many languages allow *exceptions:* alternate return paths from a function
  - null pointer, overflow, emptyStack,...
- Function either terminates *normally* or with an exception
  - *total* functions ⇒ robust software
  - no encoding error conditions in result
- Several different exception models: effect on implementation efficiency

Generating exceptions

- Java, C++: statement `throw` *E* is statement that terminates exceptionally with exception *E*
- Exception propagates *lexically* within current function to nearest enclosing `try..catch` statement containing it
- If not caught within function, propagates *dynamically* upward in call chain.
- Tricky to implement dynamic exceptions efficiently

Implicit vs. explicit re-throw

- Implicitly vs. explicitly re-thrown : does an exception automatically propagate out of a function?
- Tradeoff: convenience vs. "no surprises"
- Java, C++, ML: **yes**; CLU: **no** (converts to special implicitly-thrown `failure` exception)

```
f() throws Exc =(...throw Exc...)

g() throws Exc = (
  f()
)

g() throws Exc (
  try
    f()
  catch (Exc) throw Exc;
)
```


Declaration of exceptions

- Must a function declare all exceptions it can throw?
- Implementer convenience: annoying to declare all exceptions (overflow, null pointers,...)
- vs. Client robustness: want to know all exceptions that can be generated
- Java: must declare "non-error" exceptions
- CLU: must declare all but `failure` (but uncaught exceptions automatically converted to `failure`)
- ML: cannot declare exceptions at all (good for quick hacking, bad for reliable software)
- C++: declaration is optional (useless to user, compiler)

Naming exceptions

- Java, C++: exceptions are objects
  - name of exception is name of object's class
  - exceptional return distinguished from normal return even *w/* same type

```
Exception m() throws Exception {
   throw new Exception(); }
```

- ML, CLU: exceptions are special names with associated data—disjoint

```
exception badness(int);
void m() throws badness {
   throw badness(4);
}
```


Desired Properties

- Exceptions are for unusual situations and should not slow down common case:
  - *No* performance cost when function returns normally
  - Little cost for executing a try..catch block—when exception is not thrown.
  - Cost of throwing and catching an exception may be somewhat more expensive than normal termination
- Not easy to find such an implementation!

Lexical exception throws

- Some exceptions can be turned into goto statements; can identify lexically

```
try {
  if (b) throw new Foo();
  else x = y;
} catch (Foo f) { … }
```

```
⟹   if (b) { f = new Foo(); goto l1; }
     x = y; goto l2;
     l1: { … }
     l2:
```


Dynamic exception throws

- Need to find closest enclosing try..catch dynamically that catches the particular exception being thrown
- No generally accepted technique! (*See* Appel, Muchnick, Dragon Book for absence of discussion)

Impl. #1: extra return value

- Return an extra (hidden) boolean from every function indicating whether function returned normally or not

```
throw e       ⇒ return (true, e)
return e      ⇒ return (false, e)
a = f(b, c)   ⇒ (exc, t1) = f(b,c);
                if (exc) goto handle_exc_34;
                a = t1;
```

- Every function call requires extra parameter, extra check
- No cost for try..catch unless exception thrown. Handler label determined statically. Dynamic throw: handler does return (true, *e*)
- Can express as source-to-source translation

#2: setjmp/longjmp (orig. Java)

- setjmp(buf) saves all registers into a buffer buf (incl. sp, pc!), returns 0
- longjmp(*e*) restores all registers from buffer e; places 1 into return register. Makes setjmp "return again"
- Implementation: thread-specific jmpbuf current_catch

```
throw(e)         ⇒ exc = e;
                   longjmp(current_catch);

try S catch C    ⇒ push_catch();
                   if (setjmp(current_catch) == 0) S
                   else C;
                   pop_catch();
```

setjmp/longjmp summary

- Advantages:
  - no cost as long as `try/catch`, `throw` unused
  - works even without declared exceptions: no static information needed
- Disadvantages:
  - `try/catch`, `try/catch/finally` are slow even if no exception is thrown
  - May need to walk up through several `longjmp`s until right `try..catch` is found.
  - `current_catch` must be thread-specific

Continuations

- When we return from a function (either normally or exceptionally) want to jump to the right *continuation*—"rest of program"
- Abstractly: a continuation is a function that does not return (return type **none**)
  - takes its argument in the return register (eax)
- Recall: representation of function value is closure (*code address, activation record*)
- Returning from a function means restoring pc, fp to previous values: calling continuation defined by closure (return address, fp) !
- `setjmp` creates continuation, `longjmp` calls it

Exceptions as continuations

- Goal of exception handling mechanism is to map an exception to its continuation
- Extra boolean: pass only one continuation
  - Returned boolean & exception value resolved to continuation in caller's code
- `setjmp`/`longjmp`: two continuations passed: normal and exceptional
  - Thread-specific global variable is optimization of extra argument; resolving of exceptional continuations done the slow way.

#3: Tables of continuations

- Extra boolean: walk up stack frame by frame
- setjmp/longjmp: walk up one try/catch at a time
- Would like to be able to jump up the stack to the right place *immediately*
- *Problem*: need precise continuation info to do this; try..catch must update a *continuation table* CT: (exception→ (pc, fp))

throw e1 ⇒ call-continuation(CT[e1])

try S catch(e_1) S_1...catch(e_n) S_n ⇒

  CTsave = CT; CT = CT[e_1↦(L_1, fp),...,e_n↦(L_n,fp)]; S; goto L;

  L_1 : CT=CTsave; S_1; goto L

  ...

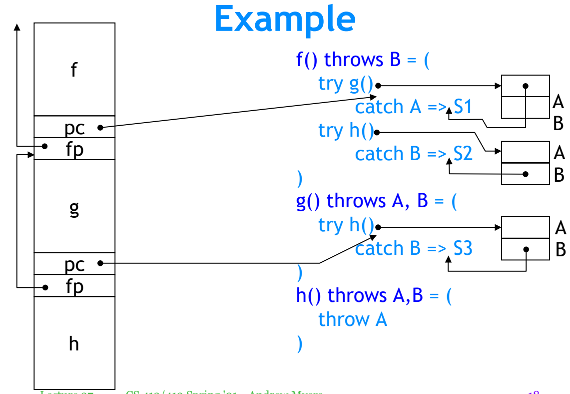
L:

Expensive!

#4: Static Exception Tables

- Invented for CLU by Bob Scheifler
- *Observation*: exceptions that are caught usually go up only one or two stack frames; more important to find right exception handler (pc) than stack frame (fp)
- Throw code:
  - walk up stack one frame at a time (fp known)
  - in each frame, use return address to select table
  - table maps exception to right pc
- Table is static → no cost for try/catch!

Example



Static Exception Tables

- Advantages:
  - no cost for try/catch: tables created by compiler
  - no extra cost for function call
  - throw → catch is reasonably fast (one table lookup per stack frame, can be cached)
- Disadvantages:
  - table lookup more complex if using Java/C++ exception model (need dynamic type discrimination mechanism)
  - can't implement as source-to-source translation
  - must restore callee-save registers during walk up stack (can use symbol table info to find them)

Summary

- Several different exception implementations commonly used
- Extra return value, `setjmp`/`longjmp` impose overheads but can be implemented in C (hence used by C++, Java)
- Static exception tables have no overhead except on throw, but require back end compiler support