CSc 520

Principles of Programming Languages
35: Procedures — Closures

Christian Collberg
Department of Computer Science
University of Arizona
collberg@cs.arizona.edu

April 22, 2005

1   Subroutine Closures

- A closure is a structure

$$(\text{procedure\_addr}, \text{environment}).$$

- To pass `C()` to `A` we construct a closure consisting of `C`'s address and the static link that would have been used if `C` would have been called directly:

```
program M;
   procedure A(procedure P)
      P();
   end
   procedure C(); begin end;
begin
   A(C);
end
```

2   Deep Binding

- When a reference to a procedure is created (for example by passing it as a reference to another procedure), when are scope rules applied?

  1. When the reference is first created?
  2. When the routine is first called?

- Early binding of a referencing environment (what Pascal uses) is called *deep binding*.
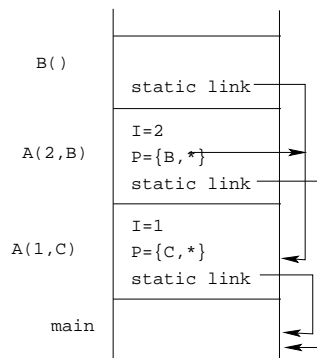
3 Subroutine Closures...

```
procedure A(I:integer; procedure P)
   procedure B(); begin write(I); end;
begin
   if I > 1 then P() else A(2,B);
end

procedure C(); begin end;

begin
   A(1,C);
end
```

- There are two I:s when B is called.

4 Subroutine Closures...

- A closure was created for B when A(2,B) was closed, hence B will print 1.

5 First-Class Subroutines

- A language construct is first-class if it can be passed as a parameter, returned from a subroutine, or assigned to a variable.

- A language construct is second-class if it can be passed as a parameter but not be returned from a subroutine, or assigned to a variable.

- A language construct is third-class if it can't even be passed as a parameter.

- Procedures are second-class in most imperative languages.

6 First-Class Subroutines...

- If a procedure can be returned as the result of a function we could reference an environment that has gone out of scope:

```
procedure A() :  procedure;
   var x :  integer := 5;
   procedure B();
       write(x);
   end
begin
   return B;
end;
begin
   var X : procedure := A();
   X();
end
```

7 First-Class Subroutines. . .

- In functional languages functions are first-class.

- Functional languages specify that local variables have unlimited extent — they exist for as long as someone references them.

- Algol-like languages specify that local variables have limited extent — they exist until the scope in which they are declared is exited.

- Objects with limited extent can be stored on a stack. Objects with unlimited extent must be stored on the heap.

8 First-Class Subroutines. . .

- C and C++ do not have nested scope — no problem.

- Modula-2 — global procedures are first-class (can be stored), local procedures are third-class.

- Modula-3 — global procedures are first-class, local procedures are second-class (can be passed as parameters).

- Ada 83 — procedures are third class.

- Ada 95 — nested procedures can be returned if the scope in which it was declared is at least as wide as that of the declared return type. I.e. a procedure can only be propagated to an area of the program where the referencing environment is active.

9 Call-With-Current-Continuation

- The Scheme built-in function call-with-current-continuation (also called call/cc) takes a function as argument:

```
call-with-current-continuation (foo)
(foo cont)
```

  foo takes a continuation as argument.

- (call/cc foo) calls foo, passing it the current continuation.

- A continuation is a closure that holds the current program counter and environment.

10   Call-With-Current-Continuation...

- `foo` can invoke the continuation and immediately return to the situation as it was when the call was made.

- Any intermediate stack frames are popped off.

- Continuations are first-class: you can store them in variables, return them from functions, etc.

- `call/cc` can be used as a general building-block to construct a variety of control structures, such as iterators and coroutines.

- Continuations can, for example, be used to quickly exit a tree-search procedure once the node we're looking for has been found.

11   Call-With-Current-Continuation...

- The function throws the continuation the value 99 which makes it pop out of the current evaluation and return 99:

```
> (call/cc (lambda (c) (c 99)))
99
```

- The expression `(* [] 76)` is never executed. Rather, the function pops out and returns 99:

```
> (call/cc (lambda (c) (* (c 99) 76)))
99
```

12   Call-With-Current-Continuation...

- Continuations can be stored in variables and invoked later:

```
> (let ((cont #f))
    (call/cc (lambda (k) (set!  cont k)))
    (cont #f))
99
```

- Or, like this:

```
> (define cont #f)
> (+ 5 (call/cc
    (lambda (e) (set!  cont e) (* 4 3))))
17
> (cont 10)
15
```

13   Readings and References

- Read Scott, pp. 141–143

4