CSc 520

Principles of Programming Languages

35: Procedures — Closures

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Subroutine Closures

- A closure is a structure

  (procedure_addr,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
```


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.

Subroutine Closures...

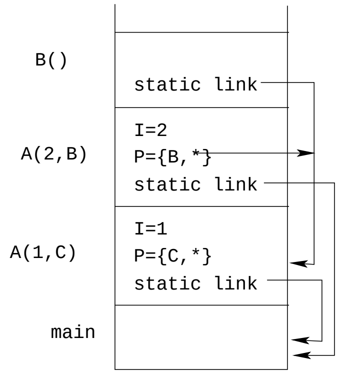
```
procedure A(I:integer; procedure P)
   procedure B(); begin write(I); end;
begin
   if I > 1 then P() else A(2,B);
end

procedure C(); begin end;

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

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

Subroutine Closures...



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

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.

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
```


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.

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.

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.

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.

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
  ```

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
```


Readings and References

- Read Scott, pp. 141–143