Parameter Passing

Handout #38
CS251 Lecture 30
April 12, 2002

Call-by-Value

In call-by-value, pass to a function the values resulting from evaluating the argument expressions.

Example (HOFL substitution model):

\[
\begin{align*}
\text{((abs (x y) (* x x)) (+ 1 2) (* 3 4))} \\
\rightarrow \text{((abs (x y) (* x x)) 3 12)} ; \text{First evaluate args} \\
\rightarrow \text{(* 3 3)} ; \text{Then substitute values} \\
\rightarrow \text{9} ; \text{Then continue evaluation}
\end{align*}
\]

Each argument expression is evaluated exactly once regardless of whether or not it is used in the body of the function.

Alternative characterization: environments map names to values (or cells containing values in an imperative language).
Call-by-Value: HOFL/HOILEC Implementation (without bindrec)

evalExp : Exp -> Val Ident.Env -> Val

evalExp (VarRef(name)) env =
  (case Env.lookup(name,env) of
    NONE => raise EvalError ("Unbound variable")
    | SOME(v) => v)

evalExp (FunApp(rator,rands)) env =
  let val fcn = evalExp rator env
      val args = evalExps rands env
    in funapply fcn args
  end

funapply (ClosureVal(fmls,body,env)) argVals =
  evalExp body
    (Env.extend(fmls,map ref argVals,env))
funapply _ env = raise EvalError "applying non-closure"

Call-by-Value: HOILIC Implementation

evalExp : Exp -> Val ref Ident.Env -> Val

evalExp (VarRef(name)) env =
  (case Env.lookup(name,env) of
    NONE => raise EvalError ("Unbound variable")
    | SOME(ref v) => v) (* Dereference value from cell *)

evalExp (FunApp(rator,rands)) env =
  let val fcn = evalExp rator env
      val args = evalExps rands env
    in funapply fcn args
  end

funapply (ClosureVal(fmls,body,env)) argVals =
  evalExp body
    (Env.extend(fmls,map ref argVals,(* Implicit cells *)
               env))
funapply _ env = raise EvalError "applying non-closure"
Call-by-Value Languages

Most modern languages are call-by-value (e.g. C, Java, Scheme, ML, Pascal’s value parameters).

- ML is like the HOILEC implementation: variables are bound directly to values, not cells holding values.
- C, Pascal, Java, Scheme are like the HOILIC implementation: each variable is bound to an implicit cell automatically dereferenced at each variable reference.

Parameter Passing Test

Assume that `iprint` displays an integer followed by a newline and returns the integer. Assume `sprint` works similarly for strings.

E.g. assuming left-to-right evaluation, `(+ (iprint 1) (iprint 2))` prints a 1 and 2 on the console and returns 3 (the result of the addition).

Consider the following `test` function in HOILIC:

```scheme
(abs (a b c)
  (seq (sprint "enter")
    (bind result (+ c (* b b))
      (seq (sprint "exit")
        result))))
```

What does the following print under various parameter passing mechanisms?

```scheme
(test (iprint (+ 1 2)) (iprint (+ 3 4)) (iprint (+ 5 6)))
```
Call-by-Name

In call-by-name, pass to a function the unevaluated argument expressions. The argument is re-evaluated every time it is used in the body. (It is never evaluated if it is never used.)

Example (HOFL substitution model):

\[
((\text{abs } (x \ y) \ (* \ x \ x)) \ (+ \ 1 \ 2) \ (* \ 3 \ 4))
\]

\[
\rightarrow (* (+ 1 2) (+ 1 2)) \quad \text{Substitute unevaluated argument expressions}
\]

\[
\rightarrow (* 3 3) \quad \text{Continue evaluation}
\]

\[
\rightarrow 9
\]

Each argument expression is evaluated the number of times it is used in the function body. Better than call-by-value for arguments never used, but worse for arguments used more than once.

Alternative characterization: environments map names to (cells of) non-memoizing promises.

ALGOL-60 was a call-by-name language.

Call-by-Name: HOFL/HOILEC Implementation (without bindrec)

```
datatype Promise = Delay of Exp * Promise Ident.Env

evalExp : Exp -> Promise Ident.Env -> Val

evalExp (VarRef(name)) env =
    \text{case Env.lookup(name,env) of}
    \quad \text{NONE => raise EvalError ("Unbound variable")}
    \quad SOME(Delay(exp,env)) = evalExp exp env

evalExp (FunApp(rator,rands)) env =
    let val fcn = evalExp rator env
        val argPromises = map (fn r => Delay(r,env)) rands
    in funapply fcn argPromises
end

funapply (ClosureVal(fmls,body,env)) argPromises =
    evalExp body
    (Env.extend(fmls, argPromises ,env))
```
Simulating Call-by-Name in Call-by-Value

Can simulate call-by-name in a call-by-value language by wrapping a thunk around every argument and dethunking every variable reference.

For example, here is the call-by-name parameter test expressed in Scheme:

```scheme
(define test
  (lambda (a b c)
    (begin (print "enter")
      (let ((result (lambda () (+ (c) (* (b) b)))))
        (begin (display "exit")
          (result))))))))
(test (lambda () (print (+ 1 2)))
  (lambda () (print (+ 3 4)))
  (lambda () (print (+ 5 6))))
```

Call-by-Need (Lazy Evaluation)

In call-by-need, pass to a function the unevaluated argument expressions. The argument is evaluated only the first time it is used in the body, and that value is used thereafter. (It is never evaluated if it is never used.)

Example (HOFL)

```
((abs (x y) (* x x)) (+ 1 2) (* 3 4))
; Substitute (but share) unevaluated argument expressions
-> (* . .)  -> (* . .)  -> 9
  \ /    \ /    \ /    \ /
(+ 1 2)  3
```

Each argument expression is evaluated once if it is used in the function body, but zero times if it is never used. This is the best case scenario!

Alternative characterization: envs map names to (cells of) memoized promises. The Haskell language uses call-by-need.
Call-by-Need: HOFL/HOILEC Implementation (without bindrec)

datatype Promise = Delay of Exp * Promise Ident.Env * Val option ref

evalExp : Exp -> Promise Ident.Env -> Val

evalExp (VarRef(name)) env =
  case Env.lookup(name,env) of
    NONE => raise EvalError ("Unbound variable")
  | SOME(Delay(exp,env,memo)) =
    case !memo of
      NONE => let val v = evalExp exp env
        in (memo := SOME(v); v) end
    | SOME(v) => v

evalExp (FunApp(rator,rands)) env =
  let val fcn = evalExp rator env
    val delayedArgs = map (fn r => Delay(r,env,ref NONE)) rands
  in funapply fcn delayedArgs
  end

Simulating Call-by-Need in Call-by-Value

Can simulate call-by-need in a call-by-value language by wrapping a promise around every argument and forcing every variable reference.

For example, here is the call-by-need parameter test expressed in Scheme:

(define test
  (lambda (a b c)
    (begin (print "enter")
      (let ((result (delay (+ (force c)
                                (* (force b)
                                   (force b)))))))
        (begin (display "exit")
               (force result)))))))

(test (delay (print (+ 1 2)))
      (delay (print (+ 3 4)))
      (delay (print (+ 5 6))))
Relationship between by-value, by-name, by-need

In a purely functional language, evaluating expression $E$ under call-by-name and call-by-need always gives the same result.

In a purely functional language, if $E$ evaluates to values $V_1$, $V_2$, and $V_3$ under call-by-value, call-by-name, and call-by-need (respectively), then $V_1$, $V_2$, and $V_3$ must be the same value.

However, call-by-name/need will sometimes return values in cases where call-by-value fails to do so (because of errors or infinite loops). E.g.:

$$
((\lambda (x \ y) \ (* \ x \ x)) \ (+ \ 1 \ 2) \ (/ \ 3 \ 0)) \\
((\lambda (x \ y) \ (* \ x \ x)) \ (+ \ 1 \ 2) \ (\text{loop})) \\
; \text{Suppose } (\text{loop}) \text{ loops infinitely}
$$

In an imperative language, all bets are off. That is, for some expressions, each mechanism can return a completely different value.

Call-by-Reference

In call-by-reference, pass to a function the reference cell of any parameter that is a variable (create a new reference cell for parameters that are not variables).

;; HOILIC example
;; In HOILIC, "<-" updates the implicit cell of a variable
;; (like set! in Scheme)
(bindseq ((a 0)
    (inc (abs (x) (seq (<- x (+ x 1)) a))))
  (prepend a) ; In both CBV and CBR, returns 0
  (prepend (inc a)) ; CBV returns 0; CBR, returns 1
  (prepend (inc a)) ; CBV returns 0; CBR, returns 2
  (empty))))
Call-by-Reference in Pascal

Pascal supports both call-by-value and call-by-reference. Call-by-reference parameters are distinguished with a var keyword in parameter declarations.

```pascal
program testRef;

procedure p(x : int, var y : int);
begin
  x := x * 2;
  y := y + x
end;

begin
  var a : int := 3;
  var b : int := 4;
  p(a, b);
  {a is still 3, but b is now 10}
end.
end.
```

Call-by-Reference: swap

You can use call-by-reference to write a swap function. E.g., in Pascal:

```pascal
program testSwap;

procedure swap(var x : int, var y : int);
begin
  var temp : int := x;
  x := y;
  y := temp
end;

begin
  var a := 3;
  var b := 4;
  swap(a, b);
  {Could also call swap on array slots. E.g.
  swap(c[i], d[j])}
end.
end.
```
Simulating call-by-reference in C

Although C is a call-by-value language, it has “features” that allows simulating call-by-reference.

- The address-of operator (&) returns the location of (i.e. pointer to) a variable.
- The dereference operator (*) returns the contents of a pointed-at variable.

```c
void swap (int* x, int* y) {
    int temp = x*;
    x* = y*;
    y* = temp;
}
int a = 3;
int b = 4;
swap(&a, &b);
/* Can also use on arrays. E.g.: swap(&c[i], &d[j]) */
```

Call-by-reference in C++

C++ is an object-oriented extension to C that supports a call-by-reference parameter passing mode.

```cpp
void swap (int &x, int &y) {
    int temp = x;
    x = y;
    y = temp;
}
int a = 3;
int b = 4;
swap(a, b);
/* Can also use on arrays. E.g.: swap(c[i], d[j]) */
```
Simulating call-by-reference in ML, Scheme, and Java

In ML, the effect of call-by-reference can be achieved by passing explicit cells (references)

```ml
fun swap (x, y) = 
  let val temp = (^ x) 
      val _ = x := (^ y) 
      val _ = y := temp 
  in () 
  end
val a = ref 3 
val b = ref 4 
val _ = swap(a, b)
```

The same trick can be pulled in Scheme and Java. Note that there is no way to access the implicit cells that variables are bound to in Scheme and Java, so it is impossible to write a swap function on the implicit cells. E.g., if a and b are Scheme variables, there is no `swap` function such that `(swap a b)` swaps the values of a and b.

Compound Data

Parameter passing issues are more complex in the context of compound data structures, which can be allocated either on the stack (Execution Land) or in the heap (Object Land).

In ML, Scheme, and Java:
- all compound values are allocated in the heap.
- All compound values are “small” pointers to heap-allocated objects that are automatically dereferenced.
- Inaccessible objects are automatically reclaimed by garbage collection.

In C and Pascal:
- Can choose between allocating compound data on stack (the default) vs. heap (C’s `malloc`, Pascal’s `new`).
- Stack-allocated compound values are “big” values in structured variables.
- All pointers must be dereferenced explicitly (using C’s `*`, Pascal’s `↑`).
- Programmer must manually reclaim inaccessible objects (C’s `free`, Pascal’s `dispose`.)
Points in C

typedef struct P {int x; int y;} point;

point scaledCopy (int s, point p)
{ point q; q.x = s * p.x; q.y = s * p.y; return q; }

void scale1 (int s, point p)
{ p.x = s * p.x; p.y = s * p.y; }

void scale2 (int s, point* p)
{ (*p).x = s * (*p).x; (*p).y = s * (*p).y; }

void printPoint (point p)
{ printf("x=%d;y=%d\n", p.x, p.y); }

int main ()
{ point a,b; a.x = 1; a.y = 2;
  b = scaledCopy(3,a); printPoint(a); printPoint(b);
  scale1(4,a); scale2(5,&b); printPoint(a); printPoint(b); }

Integer Lists in C

typedef struct IL {int head; struct IL *tail;} intlist;

int sumlist (intlist* lst)
{ if (lst == NULL) return 0;
  else return (*lst).head + sumlist((*lst).tail); }

intlist* fromTo (int lo, int hi)
{ intlist* result;
  if (lo > hi) return NULL;
  else {result = (intlist*) malloc(sizeof(intlist));
    (*result).head = lo;
    (*result).tail = fromTo(lo + 1, hi);
    return result;}}

int main ()
{ printf("sumlist(fromTo(1,10))=%d\n",
  sumlist(fromTo(1,10));}