CMSC 330: Organization of Programming Languages

Parameter Passing

Programming Language Features (cont.)

- Names & binding
  - Namespaces
  - Static (lexical) scopes
  - Dynamic scopes
- Polymorphism
  - Parametric
  - Subtype
  - Ad-hoc
- Parameter passing
  - Call by value
  - Call by reference
  - Call by name
    - Eager vs. lazy evaluation
- Parallelism
  - Multithreading
  - Message passing

Parameter Passing in OCaml

- What value is bound to z?

```
let add x y = x + y

let z = add 3 4
```

7

```
let add x y = x + y

let z = add (add 3 1) (add 4 1)
```

9

```
let r = ref 0
let add x y = (!r) + x + y
let set_r () = r := 3; 1

let z = add (set_r ()) 2
```

6

Actuals evaluated before call

Call-by-Value

- In call-by-value (*cbv*), arguments to functions are fully evaluated before the function is invoked
  - Also in OCaml, in let x = e1 in e2, the expression e1 is fully evaluated before e2 is evaluated
- C, C++, and Java also use call-by-value

```
int r = 0;

int add(int x, int y) { return r + x + y; }

int set_r(void) {
  r = 3;
  return 1;
}

add(set_r(), 2);
```

Call-by-Value in Imperative Languages

- In C, C++, and Java, call-by-value has another feature
  - What does this program print? 0

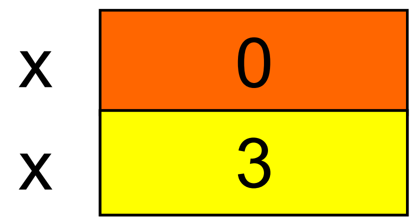
```
void f(int x) {
  x = 3;
}

int main() {
  int x = 0;
  f(x);
  printf("%d\n", x);
}
```

  - Cbv protects function arguments against modifications

Call-by-Value (cont.)

- Actual parameter is copied to stack location of formal parameter

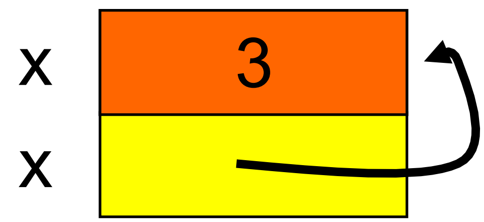
```
void f(int x) {
  x = 3;
}
int main() {
  int x = 0;
  f(x);
  printf("%d\n", x);
}
```



Call-by-Reference

- Alternative idea
  - Implicitly pass a pointer or reference to actual parameter
  - If the function writes to it the actual parameter is modified

```
void f(int & x) {
  x = 3;
}
int main() {
  int x = 0;
  f(x);
  printf("%d\n", x);
}
```



Call-by-Reference (cont.)

- Advantages
  - Allows multiple return values
  - Avoid copying entire argument to called function
    - More efficient when passing large (multi-word) arguments
    - Can do this without explicit pointer manipulation
- Disadvantages
  - More work to pass non-variable arguments
    - Examples: constant, function result
  - May be hard to tell if function modifies arguments
  - Introduces aliasing

Aliasing

- We say that two names are aliased if they refer to the same object in memory
  - C examples (this is what makes optimizing C hard)

```
int x;
int *p, *q; /*Note that C uses pointers to
               simulate call by reference */
p = &x;   /* *p and x are aliased */
q = p;    /* *q, *p, and x are aliased */
```

```
struct list { int x; struct list *next; }
struct list *p, *q;
...
q = p;    /* *q and *p are aliased */
          /* so are p->x and q->x */
          /* and p->next->x and q->next->x... */
```

Call-by-Reference (cont.)

- Call-by-reference is still around (e.g., C++)

```
int x = 0;                        // C++
void f(int& y) { y = 1; }         // y = reference var
f(x); printf("%d\n", x);          // prints 1
f(2);                             // error
```

- Seems to be less popular in newer languages
  - Older languages still use it
    - Examples: Fortran, Ada, C with pointers
  - Possible efficiency gains not worth the confusion
  - The "hardware" is basically call-by-value
    - Although call by reference is not hard to implement and there may be some support for it

Call-by-Value Discussion

- Cbv is standard for languages with side effects
  - When we have side effects, we need to know the order in which things are evaluated
    - Otherwise programs have unpredictable behavior
  - Call-by-value specifies the order at function calls
  - Call-by-reference can sometimes give different results
- Differences blurred for languages like Java
  - Language is call by value
  - But most parameters are object references anyway
    - Still have aliasing, parameter modifications at object level

Call-by-Name

- Call-by-name (cbn)
  - First described in description of Algol (1960)
  - Generalization of Lambda expressions
  - Idea: In a function:

    Let add x y = x+y

    add (a*b) (c*d)

    Example:
    add (a*b) (c*d) =
    (a*b) + (c*d) ← executed function

    Then each use of x and y in the function definition is just a literal substitution of the actual arguments, (a*b) and (c*d), respectively
  - Implementation: Highly complex, inefficient, and provides little improvement over other mechanisms

Call-by-Name (cont.)

- In call-by-name (*cbn*), arguments to functions are evaluated at the last possible moment, just before they're needed

```
let add x y = x + y

let z = add (add 3 1)  (add 4 1)
```

OCaml; cbv; arguments evaluated here

Haskell; cbn; arguments evaluated here

```
add x y = x + y

z = add (add 3 1) (add 4 1)
```

Call-by-Name (cont.)

- What would be an example where this difference matters?

```
let cond p x y = if p then x else y
let rec loop n = loop n
let z = cond true 42 (loop 0)
```

OCaml; cbv; infinite recursion at call

```
cond p x y = if p then x else y
loop n = loop n
z = cond True 42 (loop 0)
```

Haskell; cbn; never evaluated because parameter is never used

Call by Name Examples

- P(x) {x = x + x;}

  What is:

  ```
  Y = 2;
  P(Y);      ← becomes Y = Y+Y = 4
  write(Y)
  ```

- F(m) {m = m + 1; return m;}

  What is:

  ```
  int A[10];
  m = 1;
  P(A[F(m)])
  ```

becomes P(A[F(m)])

→ A[F(m)] = A[F(m)]+A[F(m)]

→ A[m++] = A[m++]+A[m++]

→ A[2] = A[3]+A[4]

Call by Name Anomalies

- Write a function to exchange values of X and Y
- Usual way - swap(x,y) { t=x; x=y; y=t; }
  - Cannot do it with call by name!
- Reason
  - Cannot handle both of following
    - swap(A[m], m)
    - swap(m, A[m])
  - One of these must fail
    - swap(A[m], m) → t = A[m] ; A[m] = m; m = t;
    - swap(m, A[m]) → t = m ; m = A[m]; A[m] = t;   // fails!

Two Cool Things to Do with CBN

- CBN is also called lazy evaluation
  - CBV is also known as eager evaluation

- Build control structures with functions

```
let cond p x y = if p then x else y
```

- Build “infinite” data structures

```
integers n = n::(integers (n+1))
take 10 (integers 0)  (* infinite loop in cbv *)
```

Simulating CBN with CBV

- Thunk
  - A function with no arguments
- Algorithm
  1. Replace arguments $a_1 \ldots a_k$ by thunks $t_1 \ldots t_k$
     - When called, t_i evaluates and returns a_i
  2. Within body of the function
     - Replace formal argument with thunk invocations

```
let add1 x = x + 1 in add1 (2+3)
```

↓

```
let add1 x = x() + 1 in add1 (fun () -> (2+3))
```

Simulating CBN with CBV (cont.)

```
let cond p x y = if p then x else y
let rec loop n = loop n
let z = cond true 42 (loop 0)
```

- becomes...

Get 1st arg — Return 2nd arg — Never invoked

```
let cond p x y = if (p ()) then (x ()) else (y ())
let rec loop n = loop n  (* didn't transform... *)
let z = cond (fun () -> true)
             (fun () -> 42)
             (fun () -> loop 0)
```

Parameters are now thunks

Three-Way Comparison

- Consider the following program under the three calling conventions
  - For each, determine i's value and which a[i] (if any) is modified

```
int i = 1;

void p(int f, int g) {
  g++;
  f = 5 * i;
}

int main() {
  int a[] = {0, 1, 2};
  p(a[i], i);
  printf("%d %d %d %d\n",
    i, a[0], a[1], a[2]);
}
```

Example: Call-by-Value

```
int i = 1;

void p(int f, int g) {
  g++;
  f = 5 * i;
}

int main() {
  int a[] = {0, 1, 2};
  p(a[i], i);
  printf("%d %d %d\n",
    i, a[0], a[1], a[2]);
}
```

i	a[0]	a[1]	a[2]	f	g
1	0	1	2		
				1	1
				5	2

Example: Call-by-Reference

```
int i = 1;

void p(int f, int g) {
  g++;
  f = 5 * i;
}

int main() {
  int a[] = {0, 1, 2};
  p(a[i], i);
  printf("%d %d %d\n",
    i, a[0], a[1], a[2]);
}
```

i/g	a[0]	a[1]/f	a[2]
1	0	1	2
2		10	
2		10	

Example: Call-by-Name

```
int i = 1;

void p(int f, int g) {
  g++;
  f = 5 * i;
}

int main() {
  int a[] = {0, 1, 2};
  p(a[i], i);
  printf("%d %d %d\n",
    i, a[0], a[1], a[2]);
}
```

```
i++;
a[i] = 5*i;
```

i	a[0]	a[1]	a[2]
1	0	1	2
2			10
2			10

The expression a[i] isn't evaluated until needed, in this case after i has changed.

Other Calling Mechanisms

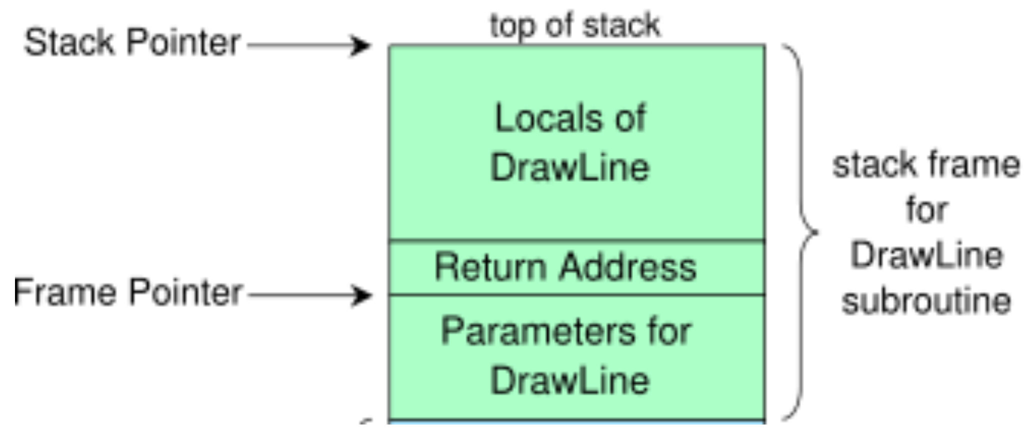
- Call-by-result
  - Actual argument passed by reference, but not initialized
  - Written to in function body (and since passed by reference, affects actual argument)
- Call-by-value-result
  - Actual argument copied in on call (like cbv)
  - Mutated within function, but does not affect actual yet
  - At end of function body, copied back out to actual
- These calling mechanisms didn't really catch on
  - They can be confusing in cases
  - Recent languages don't use them

How Function Calls Really Work

- Function calls are important
  - Usually have direct instruction support in hardware
  - Detail important for assembly language programming
    - See CMSC 216, 411, 412, or 430
- Will just provide quick overview here
- Key point to remember
  - Function calls generally require allocating stack frames

Stack Frame / Activation Record

- Machine-dependent data structure containing state information for each function invocation
  - Allocated on stack at function invocation
  - Freed upon function return (by popping stack)
- Contents may include
  - Local variables
  - Return address
  - Actual parameters
  - Return value
  - Address of frame of calling function
  - Address of frame of lexically enclosing function



Tail Calls

- A tail call is a function call that is the last thing a function does before it returns
  - Not just function call in last line of code in function

```
let add x y = x + y
let f z = add z z           (* tail call *)
```

```
let rec len = function
  [] -> 0
| (_::t) -> 1 + (len t)    (* not tail call, performs +1 *)
```

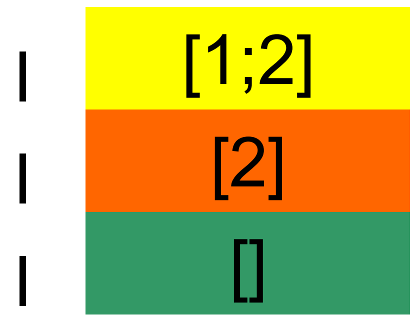
```
let rec len a = function
  [] -> a
| (_::t) -> len (a + 1) t (* tail call *)
```

Tail Recursion

- Recall that in OCaml, all looping is via recursion
  - Seems very inefficient
  - Needs one stack frame for each recursive call
- A function is tail recursive
  - If it is recursive
  - And recursive call is a tail call
- If function is tail recursive
  - Can reuse stack frame for each recursive call

Tail Recursion (cont.)

```
let rec len l = match l with
      [] -> 0
   | (_::t) -> 1 + (len t)

len [1; 2]
```



eax: 2

- Function is not tail recursive
  - Use stack frame store return value
  - Add 1 to return value, use as new return value

Tail Recursion (cont.)

```
let rec len a l = match l with
    [] -> a
  | (_::t) -> (len (a + 1) t)

len 0 [1; 2]
```

a	2
l	[]

eax: 2

- Function is tail recursive
  - Same stack frame can be reused for the next call
  - Since we'd just pop it off and return anyway

Short Circuiting

- Will OCaml raise a Division_by_zero exception?

```
let x = 0

if x != 0 && (y / x) > 100 then
  print_string "OCaml sure is fun"

if x == 0 || (y / x) > 100 then
  print_string "OCaml sure is fun"
```

- No: && and || are short circuiting in OCaml
  - e1 && e2 evaluates e1. If false, it returns false. Otherwise, it returns the result of evaluating e2
  - e1 || e2 evaluates e1. If true, it returns true. Otherwise, it returns the result of evaluating e2

Short Circuiting (cont.)

- C, C++, Java, and Ruby all short-circuit &&, ||
- But some languages don't, like Pascal (although Turbo Pascal has an option for this):

```
x := 0;
...
if (x <> 0) and (y / x > 100) then
  writeln('Sure OCaml is fun');
```

  - So this would need to be written as

```
x := 0;
...
if x <> 0 then
  if y / x > 100 then
    writeln('Sure OCaml is fun');
```