# CMSC330

## Parameter passing and function calls

# This lecture

- Parameter passing
  - Call by name
  - Call by value
  - Call by reference
    - Eager vs. lazy evaluation
- Function calls
- Tail recursion
- Short circuiting

# 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

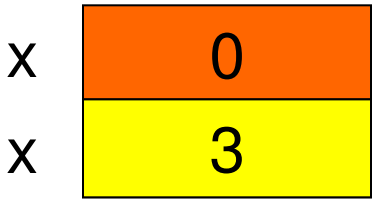
```
void f(int x) {
  x = 3;
}

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

  - Call by value protects function arguments against modifications

# Call-by-Value (cont.)

- Actual parameter is copied to stack location of formal parameter

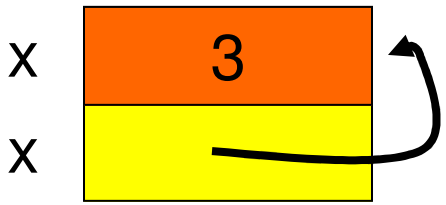
```
void f(int x) {
  x = 3;
}
int main() {
  int x = 0;
  f(x);
  printf("%d\n", x);
}
```



# 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 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 (to be discussed later)
  - Idea: In a function:

```
let add x y = x+y
add (a*b) (c*d)
```

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

Example:

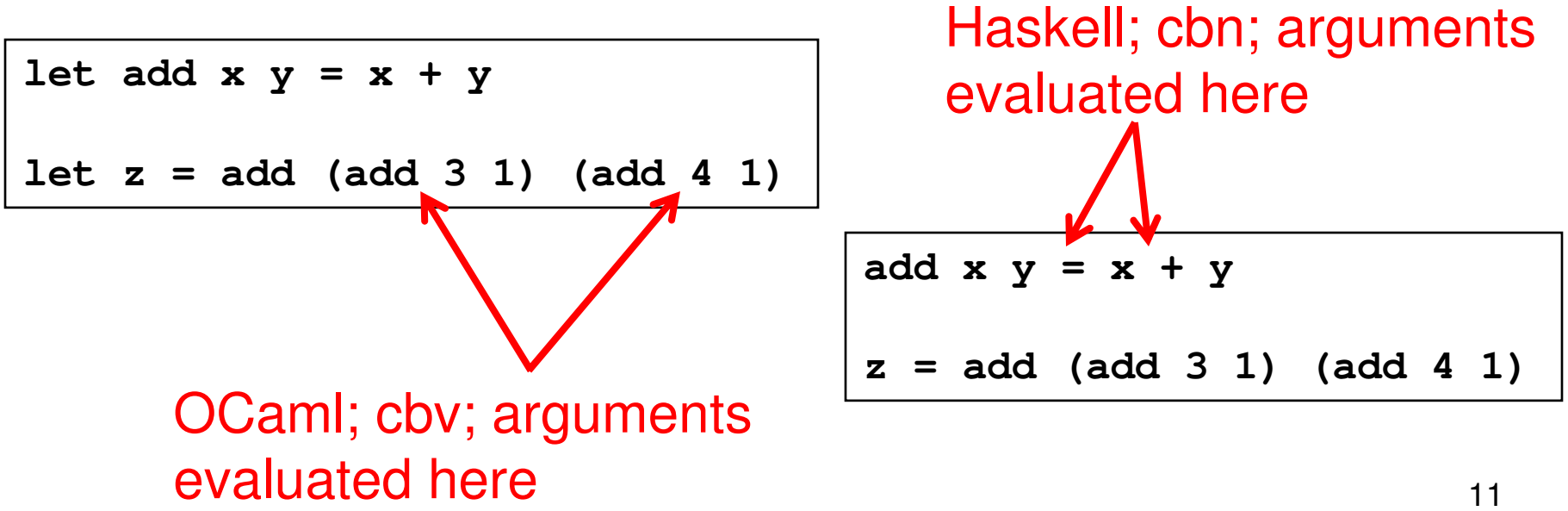
```
add (a*b) (c*d) =
      (a*b) + (c*d)
```

← executed function

  - 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



# 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);
write(Y)
```

  ← becomes Y = Y+Y = 4

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

  What is:

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

becomes **P(A[F(m)])**

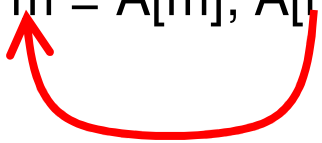
→ A[F(m)] = A[F(m)]+A[F(m)]

→ 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!



# Cool Things to Do with CBN

- CBN is also called lazy evaluation
  - CBV is also known as eager evaluation
  - Implemented using thunks

- Build “infinite” data structures

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

# 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 %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 %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++;          i++;
  f = 5 * i;    a[i] = 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]);
}
```

| 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

# CBV versus CBN

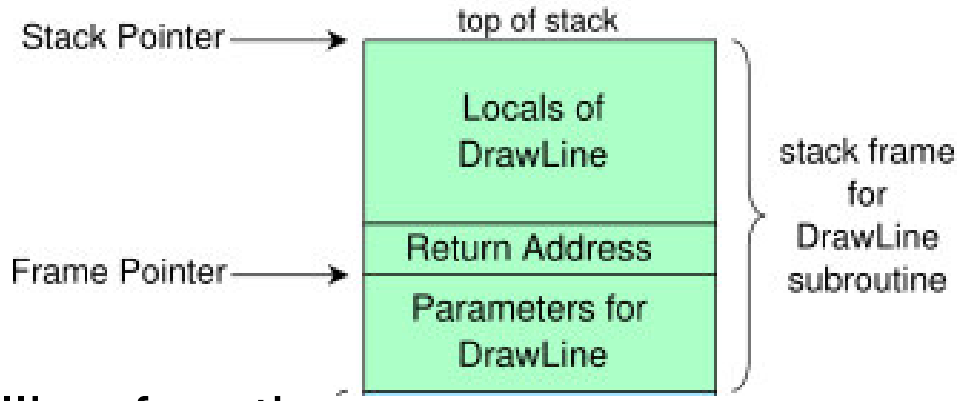
- CBN is flexible- strictly more programs terminate
  - E.g., where we might have an infinite loop with cbv, we might avoid it with cbn by waiting to evaluate
- Order of evaluation is really hard to see in CBN
  - Call-by-name doesn't mix well with side effects (assignments, print statements, etc.)
- Call-by-name is more expensive since
  - Functions have to be passed around
  - If you use a parameter twice in a function body, its thunk (the unevaluated argument) will be called twice
    - Haskell actually uses *call-by-need* (each formal parameter is evaluated only once, where it's first used in a function)

# How Function Calls Really Work

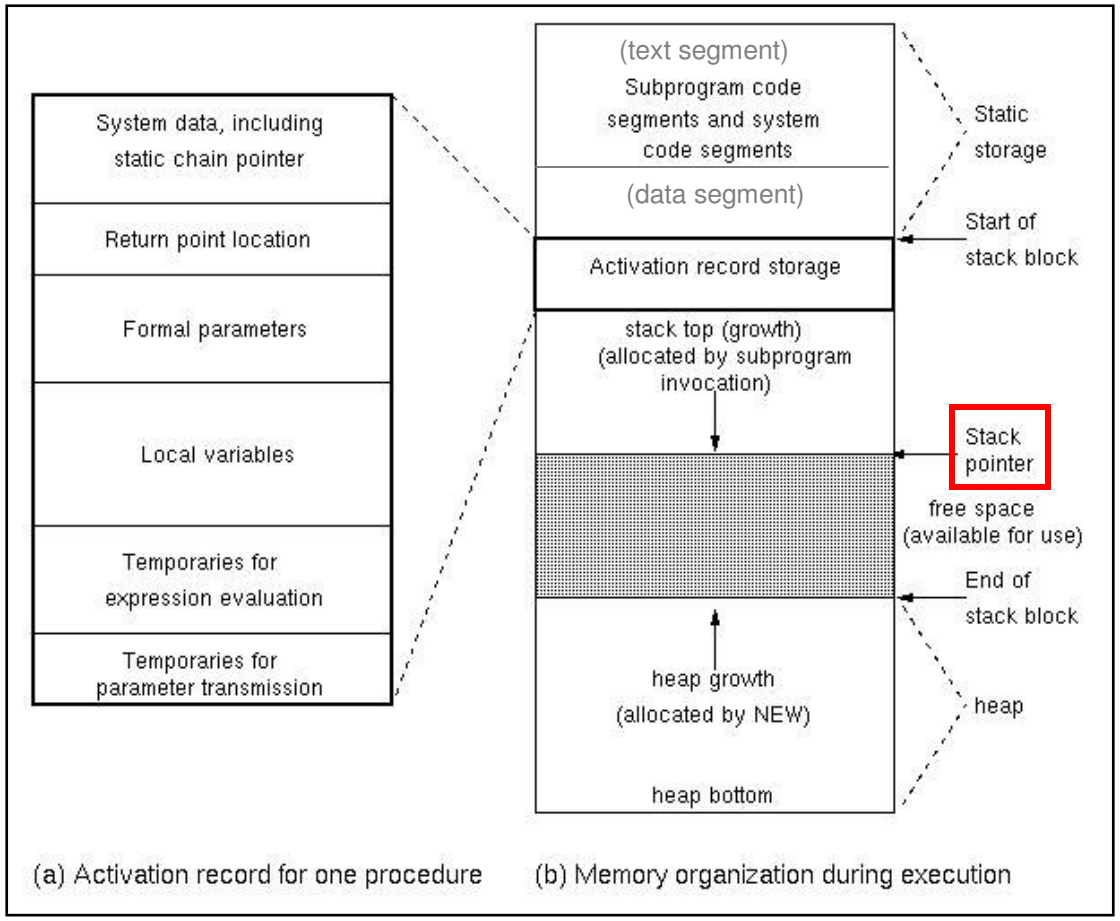
- Function calls are important
  - Usually have direct instruction support in hardware
  - Detail important for assembly language programming
    - See CMSC 212, 311, 412, or 430
- Will just provide quick overview here
- Key point to remember
  - Function calls generally require allocating stack frames

# 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



# Machine Model (Generic UNIX)




- The text segment contains the program's source code
- The data segment contains global variables, static data (data that exists for the entire execution and whose size is known), and the heap
- The stack segment contains the activation records for functions

# Lots More Details

- A whole lot more to say about calling functions
  - Local variables are allocated on stack by the callee as needed
    - This is usually the first thing a called function does
  - Saving registers
    - If the callee needs to save to the stack before you call
  - Passing parameters in registers
    - More efficient than pushing/popping from the stack
  - Etc...
- Details covered in other courses

# 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 *)
```

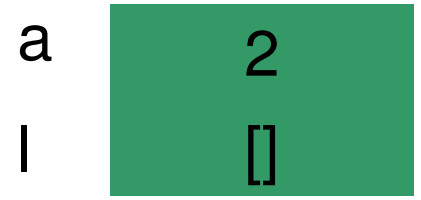
# Tail Recursion

- 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

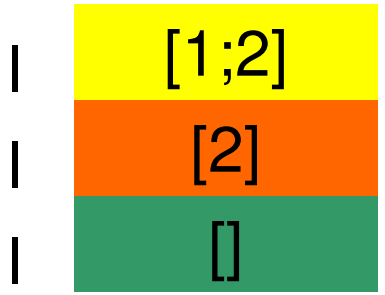
```
let rec len a l = match l with
    [] -> a
  | (_::t) -> (len (a + 1) t)

len 0 [1; 2]
```




Returned value: 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

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

len [1; 2]
```




return: 2

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

# 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');
```