

CSC 347 - Concepts of Programming Languages

Argument Passing

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Learning Objectives

- ❓ How should arguments to functions be passed in?
 - Interpret call-by-value and call-by-reference function calls



Argument Passing

? What are `x`, `y`, `"hello"`, and `10` below:

```
1 def f (x:String, y:Int) = x * y
2 f ("hello", 10)
```

- `x`, `y` : *formal parameters (or parameters)*
- `"hello"`, `10` : *actual parameters (or arguments)*



Argument Passing

- What does a call to `f` print?

```
1 def g (y:Int) : Int =  
2   y = y + 1  
3 end g  
4  
5 def f () =  
6   var x = 1  
7   g (x)  
8   println (x)  
9 end f
```

Call-By-Value

- Prints `1` in a CBV PL (Scala, Java, C, Python, ...), i.e., `x=1` after call to `g`

Call-By-Reference

- Prints `2` in a CBR PL, i.e., `x=2` after call to `g`



Call-By-Value vs. Call-By-Reference

Call-by-Value

- Most PLs use *call-by-value* (CBV) by default
- To run `g (e)`
 - i. evaluate `e` to a value `v`
 - ii. pass a *copy* of `v` to `g`
 - iii. callee changes to copy of `v` are not visible to caller

Call-by-Reference

- Some PLs use *call-by-reference* (CBR)
- To run `g (e)`
 - i. evaluate `e` to an l-value `r`
 - ii. pass the address `r` to `g`
 - iii. callee changes via `r` are visible to caller



Formal Semantics of Function Calls

- Have: global store ξ for variables and their values
- **?** Where to store and look up functions?
 - Store ϕ maps function names to parameter names and function bodies
- **?** Where to store and look up arguments and local variables?
 - Local store ρ separate from global store ξ
- **?** Function call $\langle f(e_1, \dots, e_n), \xi_0, \phi, \rho_0 \rangle$: what is its meaning?

Call-by-value

$$\begin{array}{c}
 \langle e_1, \xi_0, \phi, \rho_0 \rangle \Downarrow \langle v_1, \xi_1, \phi_1, \rho_1 \rangle \\
 \vdots \\
 \langle e_n, \xi_{n-1}, \phi, \rho_{n-1} \rangle \Downarrow \langle v_n, \xi_n, \phi_n, \rho_n \rangle
 \end{array}
 \left. \vphantom{\begin{array}{c} \langle e_1, \xi_0, \phi, \rho_0 \rangle \Downarrow \langle v_1, \xi_1, \phi_1, \rho_1 \rangle \\ \vdots \\ \langle e_n, \xi_{n-1}, \phi, \rho_{n-1} \rangle \Downarrow \langle v_n, \xi_n, \phi_n, \rho_n \rangle \end{array}} \right\} \text{evaluate arguments } e_n$$

$$\begin{array}{c}
 \phi(f) = (x_1, \dots, x_n, b) \\
 \text{look up function}
 \end{array}$$

$$\frac{\langle b, \xi_n, \phi, \{x_1 \mapsto v_1, \dots, x_n \mapsto v_n\} \rangle \Downarrow \langle v, \xi', \phi', \rho' \rangle \quad \text{evaluate function body } b}{\langle f(e_1, \dots, e_n), \xi_0, \phi, \rho_0 \rangle \Downarrow \langle v, \xi', \phi, \rho_n \rangle} \text{(FunCBV)}$$

Call-by-reference (copy-in, copy-out)

$$\begin{array}{c}
 \langle e_1, \xi_0, \phi, \rho_0 \rangle \Downarrow \langle v_1, \xi_1, \phi_1, \rho_1 \rangle \\
 \vdots \\
 \langle e_n, \xi_{n-1}, \phi, \rho_{n-1} \rangle \Downarrow \langle v_n, \xi_n, \phi_n, \rho_n \rangle
 \end{array}
 \left. \vphantom{\begin{array}{c} \langle e_1, \xi_0, \phi, \rho_0 \rangle \Downarrow \langle v_1, \xi_1, \phi_1, \rho_1 \rangle \\ \vdots \\ \langle e_n, \xi_{n-1}, \phi, \rho_{n-1} \rangle \Downarrow \langle v_n, \xi_n, \phi_n, \rho_n \rangle \end{array}} \right\} \text{evaluate arguments } e_n$$

$$\begin{array}{c}
 \phi(f) = (x_1, \dots, x_n, b) \\
 \text{look up function}
 \end{array}$$

$$\frac{\langle b, \xi_n, \phi, \{x_1 \mapsto v_1, \dots, x_n \mapsto v_n\} \rangle \Downarrow \langle v, \xi', \phi', \rho' \rangle \quad \text{evaluate function body } b}{\langle f(e_1, \dots, e_n), \xi_0, \phi, \rho_0 \rangle \Downarrow \langle v, \xi', \phi, \rho_n \cup \rho'_{\downarrow \{x_1, \dots, x_n\}} \rangle} \text{(FunCBR)}$$



CBR and Temporaries

- ? Can temporary values be passed as l-values?
- `g(x+1)` is not obviously legitimate in CBR
- Some languages reject it, some allow it
- Perl allows it



Call-By-Reference: Perl

- Perl uses CBR

```
1 sub g {  
2     $_[0] = $_[0] + 1;  
3 }  
4  
5 sub f {  
6     my $x = 1;  
7     g ($x);  
8     print ("x = $x\n");  
9 }  
10  
11 f ();
```

```
1 $ perl ./cbr.pl  
2 x = 2
```




Call-By-Reference: Perl

- Perl allows temporaries!

```
1 sub g {  
2     $_[0] = $_[0] + 1;  
3 }  
4  
5 sub f {  
6     my $x = 1;  
7     g ($x + 1);  
8     print ("x = $x\n");  
9 }  
10  
11 f ();
```

```
1 $ perl ./cbr.pl  
2 x = 1
```



Call-By-Reference: Perl

- Simulate CBV by creating copies explicitly

```
1 sub g {  
2     my ($y) = @_;  
3     $y = $y + 1;  
4 }  
5  
6 sub f {  
7     my $x = 1;  
8     g ($x);  
9     print ("x = $x\n");  
10 }  
11  
12 f ();  
13 # x=1
```



Call-By-Value: C

- Simulate CBR in C by explicitly passing, receiving, accessing a pointer

```
1 void g (int *p) {  
2     *p = *p + 1;  
3 }  
4  
5 int main () {  
6     int x = 1;  
7     g (&x);  
8     printf ("x = %d\n", x);  
9     return 0;  
10 }  
11 // x=2
```



Call-By-Reference: C++

- C++ reference type `int&` (unlike `int*`, creates references implicitly)

```
1 void g(int& y) {  
2     y = y + 1;  
3 }  
4  
5 int main() {  
6     int x = 1;  
7     g(x);  
8     // x==2  
9     cout << "x = " << x << endl;  
10    return 0;  
11 }
```

❓ What makes this design error-prone?



Call-By-Reference: C++

! In C++, at caller CBR is indistinguishable from CBV

```
1 void g(int y) { // vs. void g(int& y)
2   y = y + 1;
3 }
4
5 int main() {
6   int x = 1;
7   g(x);
8   // x==1 vs. x==2 when void g(int& y)
9   cout << "x = " << x << endl;
10  return 0;
11 }
```

- Small change in function signature, large effect at caller



Call-By-Reference: C#

- C# has reference parameters `ref int`

```
1 class Test {  
2     static void g (ref int y) {  
3         y = y + 1;  
4     }  
5  
6     static void Main () {  
7         int x = 1;  
8         g (ref x);  
9         // x == 2  
10        Console.WriteLine("{0}", x);  
11    }  
12 }
```

- Unlike `int&` must also be used by caller



Call-By-Reference: C++

- Passing a non-lvalue

```
1 void g(int& y) {  
2     y = y + 1;  
3 }  
4  
5 int main() {  
6     int x = 1;  
7     g(x + 1);  
8     cout << "x = " << x << endl;  
9     return 0;  
10 }
```

```
1 $ g++ -o reference reference.cpp  
2 reference.cpp: In function 'int main()':  
3 reference.cpp:11:8: error: invalid initialization of non-const  
4   reference of type 'int&' from an rvalue of type 'int'  
5     g (x + 1);  
6         ^  
7 reference.cpp:5:6: error: in passing argument 1 of 'void g(int&)'  
8   void g (int& y) {  
9       ^
```



Call-By-Value: Java

- Java has only a restricted form of *pointers*, called *references*
 - must point to heap-allocated objects
 - cannot point to stack-allocated data
 - cannot point to primitive types
- Java references cannot be forged
 - not from integers via casting
 - not from other references via pointer arithmetic
- Objects only accessed via references
 - unlike C++
 - Java has no address-of `&` operator



Call-By-Value: Java

- Simulate CBR In Java: heap-allocated object with field of intended argument type
- Pass a reference to the object instance **by value**

```
1 class IntRef {  
2     public int n;  
3     public IntRef(int n) { this.n = n; }  
4 }  
5  
6 public class Ref {  
7     static void g(IntRef r) { r.n = r.n + 1; }  
8  
9     public static void main(String[] args) {  
10         IntRef s = new IntRef(1);  
11         g(s); // s.n == 2  
12         System.out.println(s.n);  
13     }  
14 }
```



Call-By-Value: Scala

```
1 def f(x: Double) : Double =  
2   val x1 = x  
3   val x2 = x  
4   x1 - x2  
5 end f  
6  
7 println("f= " + f (Math.random())) // prints 0 (difference of same random Double)
```



Call-By-Value: Scala

- Scala allows functions as parameters (no argument: *delayed value = thunk*)

Passing Functions in Scala

```
1 def g(x: () => Double) : Double =  
2   val x1 = x()  
3   val x2 = x()  
4   x1 - x2  
5 end g  
6  
7 // print difference of 2 random doubles  
8 println ("g= " + g (() => Math.random()))
```

Emulate in OOP (Java)

```
1 interface java.util.function.Supplier<T> { T get(); }  
2  
3 class GetRnd implements Supplier<Double> {  
4   public Double get() { return Math.random(); }  
5 }  
6  
7 class Client {  
8   public static double g(Supplier<Double> t) {  
9     double x1 = t.get();  
10    double x2 = t.get();  
11    return x1-x2;  
12  }  
13 }  
14  
15 // print difference of 2 random doubles  
16 System.out.println ("g= " + g (new GetRnd()));  
17 // functional notation without explicit class GetRnd  
18 System.out.println ("g= " + g (() -> Math.random()));
```



Call-By-Name: Scala

- Scala has a special syntax for using thunks as parameters
- *Call-by-name* parameters are non-strict

Thunks in Scala

```
1 def h(x: => Double) : Double =  
2   // discouraged use of thunks  
3   val x1 = x  
4   val x2 = x  
5   x1 - x2  
6 end h  
7  
8 // prints difference of 2 random doubles  
9 println ("h= " + h (Math.random()))
```



Call-By-Name: Scala

- Curried call-by-name functions create new control constructs

```
1 def myWhile (cond: => Boolean) (body: => Unit) : Unit =  
2   if (cond)  
3     body  
4     myWhile (cond) (body)  
5 end myWhile
```

- Use (brackets `{}` or parentheses `()` are required)

```
1 var i = 3  
2 myWhile (i > 0) {  
3   println ("i= " + i)  
4   i = i - 1  
5 }
```



Summary

Call-by-value

- Pass copies of r-values as arguments
- Changes not visible to caller
- Strict evaluation

Call-by-reference

- Pass l-values as arguments
- Changes visible to caller
- Strict evaluation

Call-by-name

- Scala notation to pass parameterless functions as arguments
- Nonstrict evaluation