λ

Abstraction of control

Programmazione Funzionale
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Tutors

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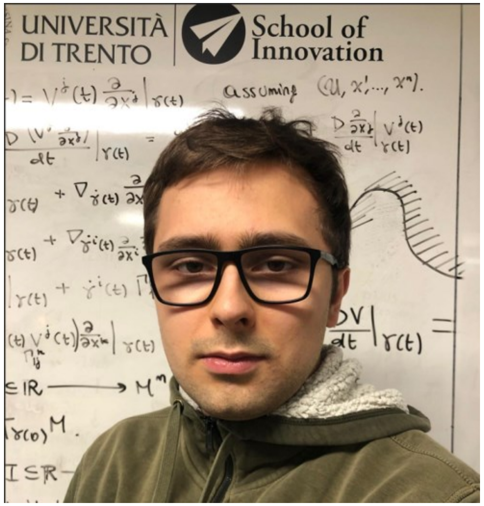

Mattia Maramotti

Tutoring slot

- Four options:
  - Monday early afternoon (14:30 - 15:30)
  - Monday late afternoon (16:30 – 17:30)
  - Wednesday afternoon (15:30 – 16:30) – this overlaps with English classes
  - Friday morning (11:30 – 12:30)

Tutoring slot

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Event code
OKLORL

Today

- Type inference in ML
- Environment
- Scoping rules
- Abstraction of control and methods for parameter passing

Type inference in ML

Type inference in ML

- Types of operands and results of arithmetic expressions must agree, e.g., `(a+b)*2.0`
  - The right operand is a `real`
  - Therefore `a+b` must be a `real`
  - Therefore, so are `a` and `b`
- In a comparison (e.g., `a<=10`), both arguments have the same type, so `a` is an integer
- In a conditional, the types of the `then`, the `else` and the expression itself must all be the same

Type inference in ML

- If an expression used as an argument of a function is of a known type, the parameter must be of that type
- If the expression defining the result of a function is of a known type, the function returns that type
- If there is no way to determine the types of the arguments of an overloaded function (such as +), the type is the default (usually `integer`)
- If there is no way to determine the types of the arguments and operators are not used (so we do not have any type constraint), we can use the generic type ‘a
- If there is no way to determine the type of two arguments and there is no relation among them, we can use the generic types ‘a and ‘b

What can be inferred about the types of the arguments in the following function?

```
fun foo (a,b,c,d) =
    if a=b then c+1 else
        if a>b then c
        else b+d;
```

- In the second line we have the expression `c+1`
- Since 1 is an integer, `c` must also be an integer
- In the third line, the expressions following the `then` and `else` must be of the same type
- Since one of these is `c`, so the type of both is integer
- So `b+d` is of integer type
- Therefore, `b` and `d` must also be integers
- Since `a` and `b` are compared on lines 2 and 3, they must be of the same type
- Therefore, `a` is also an integer
- The function type is hence `val foo = fn: int * int * int * int -> int`

What's the inferred type … without trying it ☺

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Few more questions

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Environments

Environment

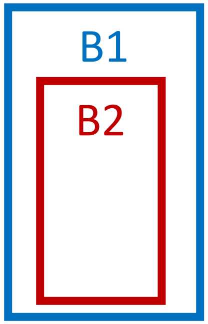
- Environment: the collection of associations between names and denotable objects that exist at runtime at a specific point in a program and at a specific moment in the execution
- Declaration: a mechanism (implicit or explicit) that creates an association in an environment.

Blocks

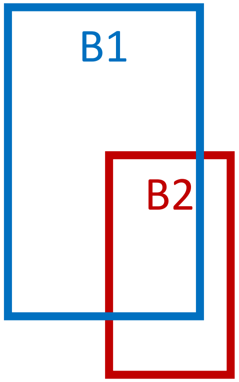
- In modern programming languages, a block is a key concept for the environment organization
- Block: a section of the program identified by opening and closing signs that contains declarations local to that region
  - C, Java: { … }
  - LISP: (…)
  - ML: let … in … end
- We distinguish between
  - Block associated with a procedure: body of the procedure with local declarations
  - In-line (anonymous) block: it can appear in any position in which a command appears

Nesting

- Blocks can (for some languages) be nested




```
int x;
int f(){
    return 0;
}
type T = int;
```




```
open block A;
    open block B;
close block A;
    close block B;
```

- Procedure nesting is not allowed by C but allowed by Pascal, Ada and ML

Environment

- The environment in a block can be subdivided in:
  - Local environment: associated with the entry into a block
    - Local variables
    - Formal parameters
  - Non-local environment: associations inherited from other blocks external to the current one
  - Global environment: part of the non-local environment that contains associations common to all blocks
    - Explicit declarations of global variables

What defines the environment?

- Visibility rules (based on the block structure)
- Scope rules
- Rules for the parameter passing
- Binding policy

Visibility of rule declarations among blocks

- Rules of visibility (preliminary)
  - A local declaration in a block is visible in this block, and in all nested blocks, as long as these do not contain another declaration of the same name, that hides or masks the previous declaration.

- Associations declared in an outer block are visible internally but deactivated if redeclared in the internal block
- Associations introduced within a block are not visible outside
- Associations introduced within a block are not visible by sibling or other blocks not containing this block

What defines the environment?

- Visibility rules (based on the block structure)
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Scope rules

How can we interpret the rules of visibility?

- A local declaration in a block is visible in that block and in all nested blocks, as long as no intervening block contains a new declaration of the same name (that hides the previous one)

Actually this definition is not that clear!

Which value will be printed?

```
A:{int x = 0;
   void fie(){
       x = 1;
   }
   B:{int x;
       fie();
   }
   write(x);
}
```

static

1
since `fie()` is defined in `Block A`

dynamic

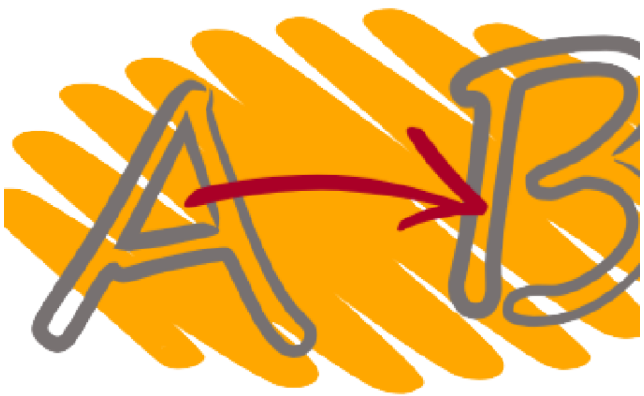
0
since `fie()` is called in `Block B`

It depends on the scope rule used

Scope rule

A non-local reference in a block can be resolved by

- Static scoping: in the block that syntactically includes the block
- Dynamic scoping: in the block that is executed immediately before the block

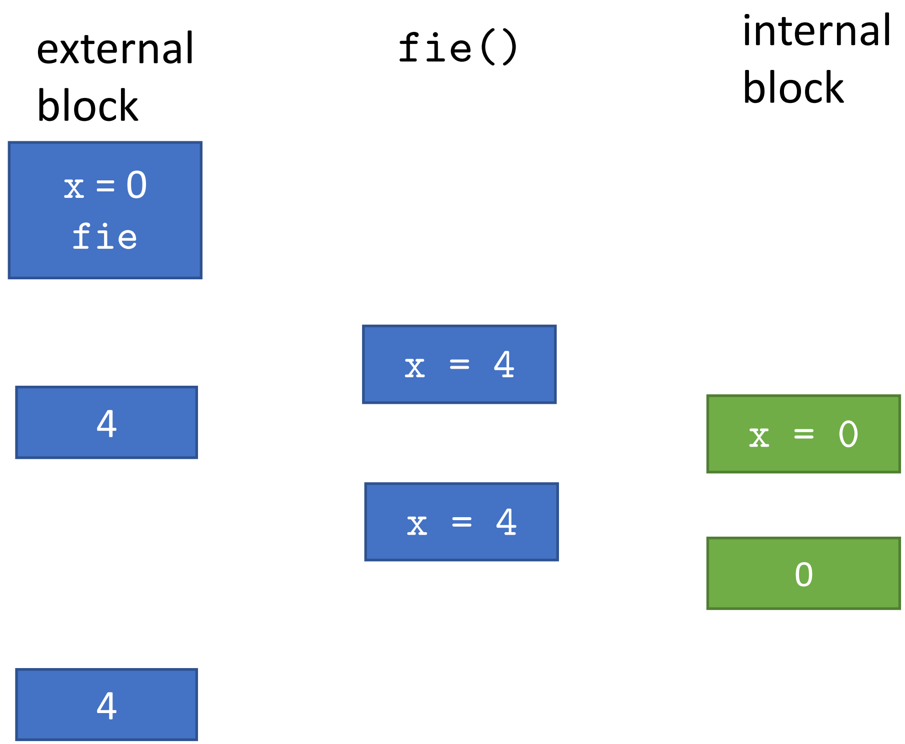


Static (lexical) scoping

Static scoping

- In static scoping a non-local name is resolved in the block that textually includes it

```
{int x=0;
 void fie (int n){
     x = n+1;
 }
 fie(3);
 write (x);
     {int x =0;
      fie(3);
      write (x);
      }
  write (x);
}
```



Static scoping: independent of local names

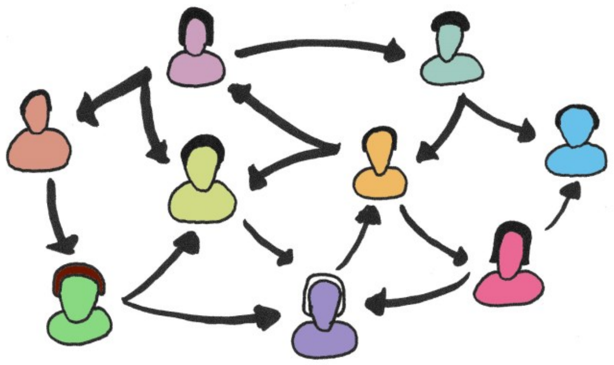
- Changing the local declaration from `x` to `y` in `fie`, has no effect with the static scoping (independent of local names).

```
{int x=10;
 void foo(){
    x++;
 }
 void fie() {
    int y = 0;
    foo();
 }
 fie();
}
```

`x=10+1`
since `x` refers to the variable declared in the block containing `foo`

Advantages of static scoping

- The programmer has a better understanding of the program
- The compiler can connect the name occurrences with its correct declaration, thus enabling several correctness tests and code optimisations
- The compiler has some important information about the storage of the variables making more efficient the execution (w.r.t. the dynamic scoping)
- ALGOL, Pascal, C, C++, Ada, Scheme, ML and Java use some form of static scoping.

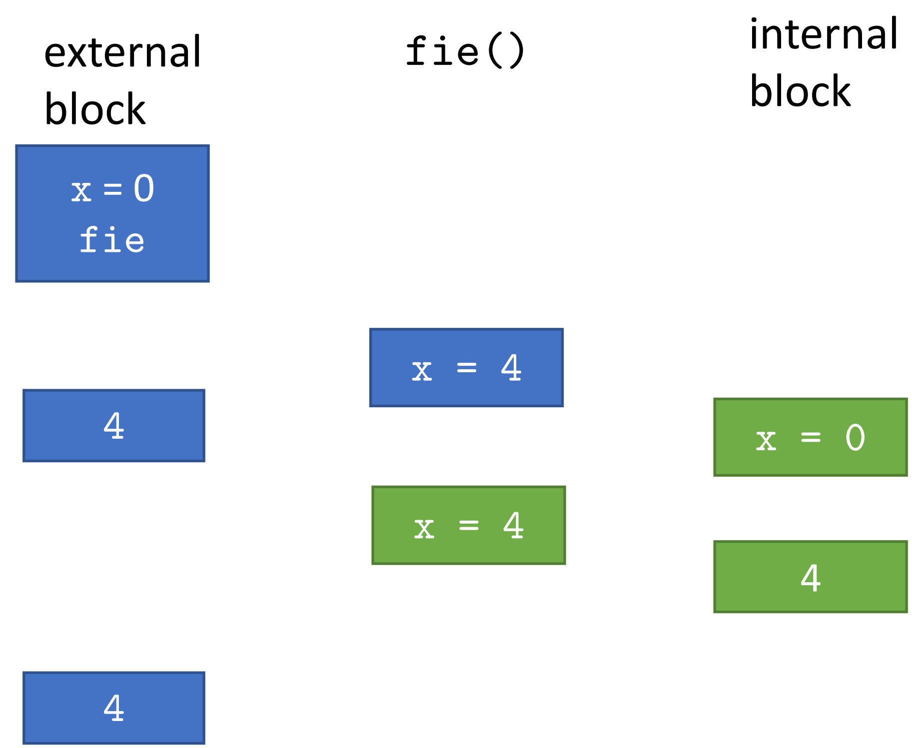


Dynamic scoping

Dynamic scoping

- In dynamic scoping a non-local name is resolved in the block that has been most recently activated and has not yet been deactivated

```
{int x=0;
 void fie (int n){
     x = n+1;
 }
 fie(3);
 write (x);
     {int x=0;
      fie(3);
      write (x);
      }
  write (x);
}
```



Dynamic scoping: specializing a function

- Dynamic scope allows the modification of the behaviour of procedures or subprograms without using explicit parameters but only by redefining some of the non-local variables used
- `visualize` is a function that displays a text in a certain colour

```
{var colour = red;
  visualize (text);
}
```

Pros and cons of dynamic scoping

- Through the redefinition of non-local variables it is possible to change the behaviour of the program
- However, it often makes programs more difficult to read
- It is less efficient

Static versus dynamic scoping

- Difference between static and dynamic scope only for not local and not global
- Static scoping (also lexical scoping)
  - All information is included in the program text
  - Associations can be derived at compile-time
  - Principle of independence
  - Easier to implement and more efficient
  - Used in Algol, Pascal, C, Java, ML
- Dynamic scoping
  - Information derived during execution
  - It allows for changing the behaviour of the program
  - Often results in programs hard to read
  - Harder to implement and less efficient
  - Some versions of Lisp, Perl

Environments in ML

Referencing external variables

- What is the result of this code?

```
> val x=3;
> fun addx(a) = a+x;
> val x=10;
> addx(2);
```

x	10
addx	Definition of addx
x	3

previous environment

- The value of x is the value when the function is defined

```
> addx(2);
val it = 5: int
```

What do the following pieces of code produce?

- After the following definitions

```
val a=2;
fun f(b)=a*b;
val b=3;
fun g(a) = a+b;
val a=4;
```

- What does the following produce?

```
> f(4);
val it = 8: int

> f(4)+b;
val it = 11: int

> f(4)+a;
val it = 12: int
```

What do the following pieces of code produce?

- After the following definitions

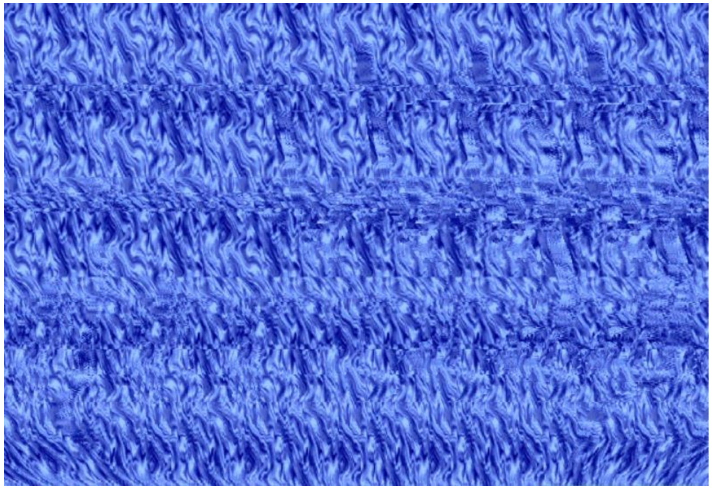
```
val a=2;
fun f(b)=a*b;
val b=3;
fun g(a) = a+b;
val a = 4;
```

- What do the following produce?

```
> g(5);
val it = 8: int

> g(5)+a;
val it = 12: int

> f(g(6));
val it = 18: int

> g(f(7));
val it = 17: int
```

What defines the environment?

- Visibility rules (based on the block structure)
- Scope rules
- Rules for the parameter passing
- Binding policy



Abstraction of control

Abstraction of control

- Main mechanism: subprogram/procedure/function
- Subprogram: piece of code identified by its name, with a local environment and exchanging information with the rest of the code using parameters
- Two main constructs

definition

```
int foo (int n, int a) {
     int tmp=a;
     if (tmp==0) return n;
     else return n+1;
}
...
int x;
x = foo(3,0);
x = foo(x+1,1);
```

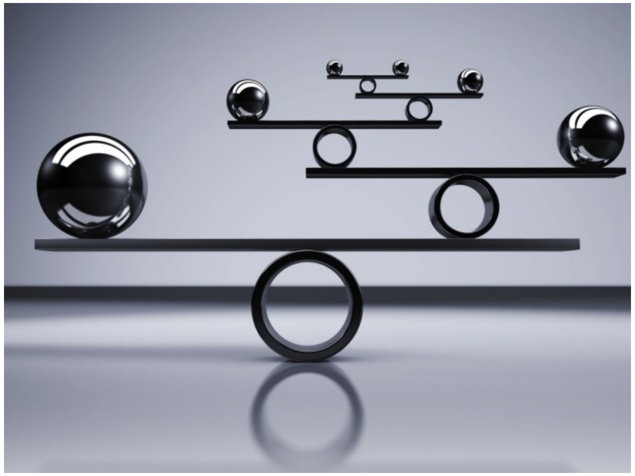
use

Mechanisms for exchanging information with external code

- Parameters
- Return value
- Nonlocal environment

Methods for passing parameters

- Three classes of parameters:
  - Input parameters
  - Output parameters
  - Input/output parameters



Call by value

Call by value

- The value is the actual one (r-value) assigned to the formal parameter, that is treated like a local variable
- Transmission from `main` to `proc` ⇨
- Modifications to the formal parameter do not affect the actual one
- On procedure termination, the formal parameter is destroyed (together with the local environment)
- No way to be used to transfer information from the callee to the caller!

An example

```
int y = 1;
void foo (int x) {
    x = x+1;
}
...
y = 1;
foo(y+1);
```

x assumes the initial value 2

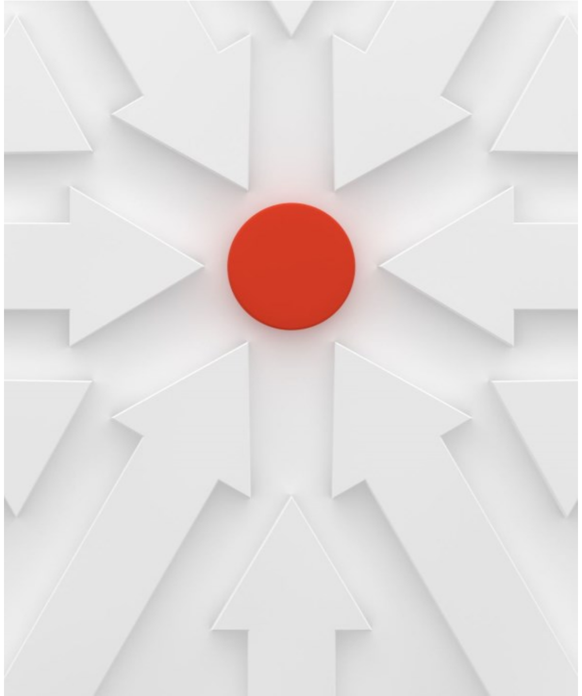
x is incremented to 3

x is destroyed

y+1 is evaluated, and its value assigned to x

y is still 1

- The formal parameter `x` is a local variable
- There is no link between `x` in the body of `foo` and `y` (`y` never changes its value)
- On exit from `foo`, `x` is destroyed
- It is not possible to transmit data from `foo` via the parameter

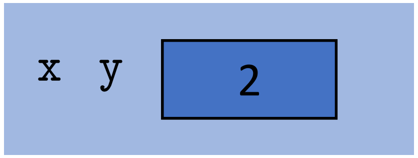


Call by reference

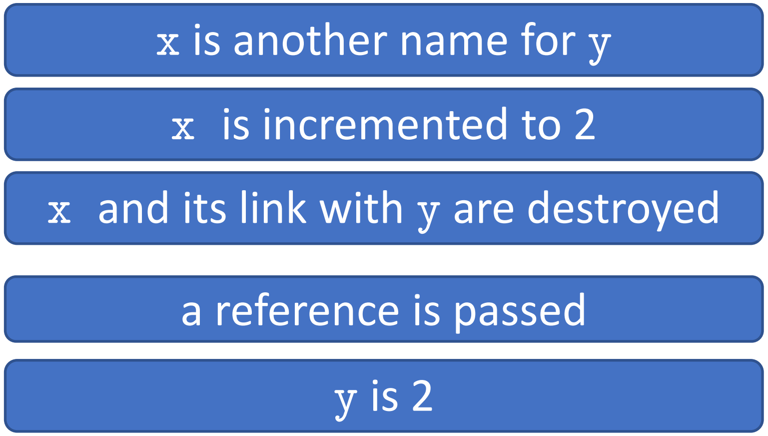
Call by reference (or variable)

- A reference (address) to the actual parameter (an expression with l-value) is passed to the function
- **The actual parameter must be an expression with l-value**
- References to the formal parameter are references to the actual one (aliasing)
- Transmission from and to `main` and `proc` ⇔
- Modifications to the formal parameter are transferred to the actual one
- On procedure termination the link between formal and actual is destroyed

An example




```
int y = 1;
void foo (reference int x) {
    x = x+1;
}
...
y = 1;
foo(y);
```



- A reference (address, pointer) is passed
- `x` is an alias of `y`
- The actual value is an l-value
- On exit from `foo`, the link between `x` and the address of `y` is destroyed
- Transmission: Two-way between `foo` and the caller

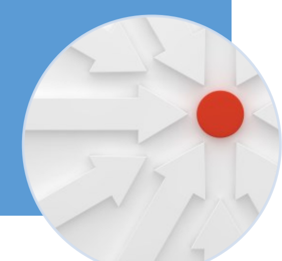
Call by value vs call by reference

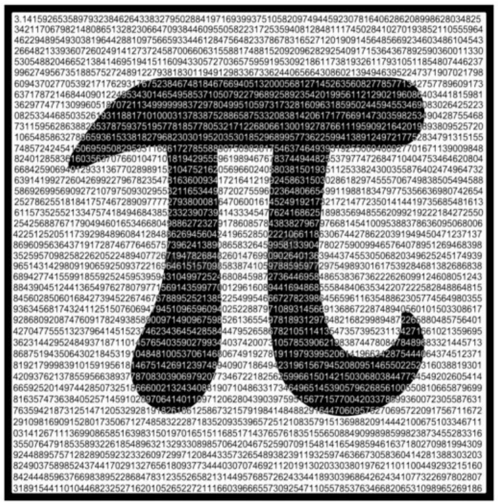
- Simple semantics
- Call could be expensive due to copy operations
- Need for other mechanisms to communicate with the called procedure

Call by value

- Complicated semantics: aliasing
- Call is efficient
- Reference to formal parameter slightly more expensive

Call by reference





Call by constant

Call by constant/read -only

- Read-only parameter method: ⇨
- Procedures are not allowed to change the value of the formal parameter (could be statically controlled by the compiler)
- Implementation could be at the discretion of the compiler (“large” parameters passed by reference, “small" by value)
- In Java: `final`

```
void foo (final int x){ //x cannot be modified
```

- In C/C++: `const`

Call by result

Call by result

- The actual parameter is an expression that evaluates to an l-value
- No link between the formal and the actual parameter in the body
- The local environment is extended with an association between the formal parameter and a new variable
- When the procedure terminates, the value of the formal parameter is assigned to the location corresponding to l-value of the actual parameter
- Output-only communication: no way to communicate from `main` to `proc` ⇦

An example

```
void foo (result int x) {
    x = 8;
}
...
y = 1;
foo(y);
```

x is a local variable

x is 8

the value of x is assigned to the current l-value of y

x is destroyed

y is 8

- Dual of the call by value
- No link between `x` and `y` in the body of `foo`
- When `foo` ends, the value of `x` is assigned to the location obtained with the l-value of `y`
- It is important when the l-value of `y` is determined (when the function is called or when it terminates)

Call by value result

Call by value-result

- Bidirectional communication using the formal parameter as a local variable ⇔
- The actual parameter must be an expression that can yield an l-value
- At the call, the actual parameter is evaluated and the r-value assigned to the formal parameter.
- At the end of the procedure, the value of the formal parameter is assigned to the location corresponding to the actual parameter

An example

```
void foo (value-result int x) {
    x = x+1;
}
...
y = 8;
foo(y);
```

- `x` is a local variable
- the value of `y` assigned to `x`
- `x` = 9
- the value of `x` assigned to `y`
- `x` is destroyed

- `y` is 9

- No link between `x` and `y` in the body of `foo`
- When `foo` ends, the value of `x` is assigned to the location obtained with the l-value of `y`

Call by name

Call by name

- Aim: give a precise semantics to parameter passing
- Copy-rule mechanism of the actual parameter to the formal one
- A call to P is the same as executing the body of P after substituting the actual parameters for the formal one
- “Macro expansion", implemented in a semantically correct way: every time the formal parameter appears we re-evaluate the actual one
- Input and output parameters ⇔
- Appears to be simple but … it is not that simple: it has to deal with variables with the same name
- No longer used by any imperative language

An example

```
int x=0;
int foo (name int y){
     int x = 2;
     return x + y;
}
...
int a = foo(x+1);
```

- Blindly applying the copy rule would lead us to a result of x+x+1=5
- Incorrect result as it would depend on the name of the local variable
- With a body `{int z = 2; return z + y;}` the result would have been z+x+1=3

- When the body contains the same name of the actual parameter, we say that it is captured by the local declaration
- In order to avoid substitutions in which the actual parameter is captured by the local declaration, we impose that the formal parameter – even after the substitution – is evaluated in the environment of the caller and not of the callee
- Substitute the actual parameter together with its evaluation environment – fixed at the time of the call

Actual parameter evaluation

```
int y;
void fie (int x){
     int y;
     x = x + 1; y = 0;
}
...
y = 1;
fie(y);
```

x is y (external)

x is 2

y (local) is 0

y is 2

- A pair <exp,env> is passed (closure), where
  - exp is the actual parameter, not evaluated
  - env is the evaluation environment
- Every time the formula is used, exp is evaluated in env

Call by name vs call by value-result

```
void fiefoo (valueresult int x,
valueresult int y) {
      x = x+1;
      y = 1;
}
...
int i = 1;
int[] A = new int[5];
A[1]=4;
fiefoo(i,A[i]);
```

x is 1, y is A[1]

x is 2

y is 1

i is 2, A[1] is 1

call- by value-result

```
void fiefoo (name int x,
name int y) {
      x = x+1;
      y = 1;
}
...
int i = 1;
int[] A = new int[5];
A[1]=4;
fiefoo(i,A[i]);
```

x is i, y is A[i]

x is 2

y is 1

i is 2, A[1] is 4, A[2]=1

call- by name

Summing up

Call type	Direction	Link between formal and actual parameters			Actual parameter l-value?	Implementation
		Before	During	After		
Value	⇨	*			NO	Copy
Reference	⬄	*	*	*	YES	Reference
Constant	⇨	*			NO	Copy and/or reference
Result	⇦			*	YES	Copy
Value-result	⬄	*		*	YES	Copy
Name	⬄		Every time it appears		Can be	Closure

Exercise 4.1

- Say what will be printed by the following code fragment written in a pseudo-language which uses dynamic scope; the parameters are passed by reference.

```
{int x = 2;
 int fie(reference int
y){
    x = x + y;
 }
 {int x = 5;
 fie(x);
 write(x);
 }
 write(x);
}
```

Exercise 4.2

- State what will be printed by the following fragment of code written in a pseudo-language which uses static scope and call by name.

```
{int x = 2;
 void fie(name int y){
    x = x + y;
 }
 {int x = 5;
    {int x = 7}
    fie(x++);
    write(x);
 }
 write(x);
}
```

Exercise 4.3

- State what will be printed by the following code fragment written in a pseudo-language which allows value-result parameters.

```
int X = 2;
void foo (value-result int Y){
    Y++;
    write(X);
    Y++;
 }
foo(X);
write(X);
```

Summary

- Type inference in ML
- Environments
- Scoping mechanisms
- Methods for parameter passing

Readings

- Chapter 4 of the reference book
  - Maurizio Gabbrielli and Simone Martini "Linguaggi di Programmazione - Principi e Paradigmi", McGraw-Hill

Next time

- Recursion in ML