# Subprograms

CS 315 – Programming Languages
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# Introduction

- Two fundamental abstraction facilities
  - Process abstraction
    - Emphasized from early days
  - Data abstraction
    - Emphasized in the1980s

# Fundamentals of Subprograms

- Each subprogram has a single entry point
- The calling program is suspended during execution of the called subprogram
  - Therefore, only one subprogram is in execution at a given time.
- Control always returns to the caller when the called subprogram's execution terminates

# Basic definitions

**Subprogram definition**: heading and the actions of the subprogram.

**Subprogram header**: First line of definition
Name, formal parameters, their types.

FORTRAN example:
**SUBROUTINE** *name* (*parameters*)

**Subprogram call**: explicit request for execution.

FORTRAN example:
**CALL** *name* (*parameters*)

# Parameters

- Parameters in the header are called **formal parameters**.
- Parameters in the call are called **actual parameters**.

**Actual/formal parameter correspondence**

<u>Positional</u>

The binding of actual parameters to formal parameters is by position: the first actual parameter is bound to the first formal parameter and so forth

Safe and effective

<u>Keyword</u>

The name of the formal parameter to which an actual parameter is to be bound is specified with the actual parameter

Parameters can appear in any order

# Parameters

Example in Ada,

```
SUMER (LENGTH => 10,
      LIST => ARR,
      SUM => ARR_SUM);
```

Formal parameters: `LENGTH, LIST, SUM.`
Actual parameters: `10, ARR, ARR_SUM.`

The programmer doesn't have to know the order of the formal parameters.
But, must **know the names** of the formal parameters.

# Parameters

- **Ada**, and **FORTRAN 90** allow **positional** parameters **and keyword** parameters to be used **together**.

  SUMER (10, SUM => ARR_SUM, LIST => ARR);

- Once a keyword appears in the call, all remaining parameters must be keyword parameters.

# Parameters

- In **C++** FORTRAN 90 and **Ada**, formal parameters can have **default** values.(if not actual parameter is passed)

In C++, default parameters must appear last because parameters are positionally associated

Ada example:

```
function Comp_Pay (Income: Float;
                   Examptions: Integer := 1;
                   Tax_Rate: Float) return Float;
```

Therefore, the call doesn't have to provide values for all parameters.

A sample call may be

```
Pay := Comp_Pay (2000.0, Tax_Rate => 0.23);
```

# Procedures and functions

- There are two categories of subprograms
- *Procedures*
  - collection of statements that define parameterized computations
- *Functions*
  - structurally resemble procedures but are semantically modeled on mathematical functions
    - They are expected to produce no side effects
    - In practice, program functions have side effects

# Design issues for subprograms

- local variables statically / dynamically allocated
- parameter-passing methods
- type checking between actual / formal parameters
- can pass subprograms as parameters (what is the referencing environment?)
- overloaded subprograms
- generic subprograms (can run on different datatypes)

# Local referencing environments

- Local variables of a subprogram can be statically or dynamically bound to storage

- **Statical binding** [*static local variables*]
  Advantages:
  efficient (no indirection, allocation / deallocation)
  no run time effort
  history sensitive
  Disadvantages:
  inability for recursion

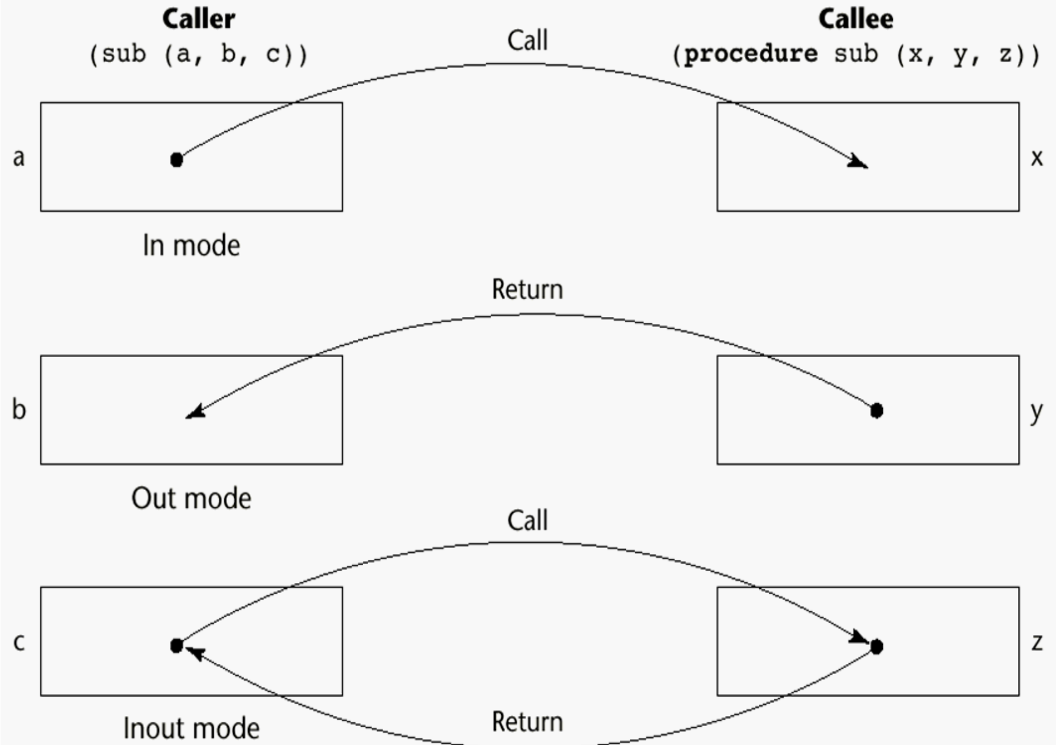
- **Dynamic Binding** [*Stack-dynamic local variables*]
  Advantages:
  allow recursion
  storage can be shared by several subprograms
  Disadvantages:
  Allocation/de-allocation, initialization time
  indirect addressing
  no history sensitivity

# Parameter Passing Methods

- Ways in which parameters are transmitted to and/or from called subprograms
  - Pass-by-value
  - Pass-by-result
  - Pass-by-value-result
  - Pass-by-reference
  - Pass-by-name

# Parameter passing methods

- Semantic Models of Parameter Passing
- **in mode**: formal parameters can **receive** data from corresponding actual parameter
- **out mode**: formal parameters can **transmit** data to corresponding actual parameter
- **inout mode**: can do both.



# Pass by value

- in mode
- value of the actual parameter is used to initialize the value of the formal parameter.
- then the formal parameter behaves as a local variable.
- <u>Advantage</u>: Actual variable is protected.
- <u>Disadvantage</u>: Costly. A new copy has to be made.

# Pass-by-result

- out mode
- no value is transmitted to the subprogram
- corresponding formal parameter acts as a local variable.
- actual parameter must be a variable
- just before termination, the value is passed back to the actual parameter.
- initial value of the actual parameter must not be used by the subprogram.
  - Require extra storage location and copy operation

# Pass-by-result

- **Problem: Actual parameter collision**

definition:
subprogram sub(x, y) { x <- 3 ; y <-5;}
call:
sub(p, p)
*what is the value of p here ? (3 or 5?)*

- The values of x and y will be copied back to p. Which ever is assigned last will determine the value of p.
- The order is important
- The order is implementation dependent ⇒ Portability problems.

# Pass-by-result

- **Problem:** Time to evaluate the address of the actual parameter
  - at the time of the call
  - at the time of the return
- The decision is up to the implementor.

definition:
subprogram sub(x)
i <-5 is changed as a global variable here
x <- ..
call:
i <- 3
sub(A[i])
Is `A[3]` or `A[5]` is changed?
The decision is up to the implementor.

# Pass-by-value-result

- inout mode
- actual values are moved
- also called as **pass-by-copy**
- combination of pass-by-value and pass-by-result
- the value of the actual parameter is used to initialize the corresponding formal parameter
- the formal parameter acts as a local parameter
- At termination, the value of the formal parameter is copied back.

# Pass-by-reference

- inout mode
- access path is transferred
- actual parameter is shared with the called subprogram
- Also called as pass-by-sharing

- Advantage:
  - **Efficient**:
  - No need to duplicate the space
  - No need to copy values

# Pass-by-reference

- <u>Disadvantage</u>: **Slow access**: Extra level of indirection
- **Dangerous**: Actual parameter may be modified unintentionally.
- **Aliasing**:
  definition:
  subprogram sub(x, y)
  call:
  sub(p, p)

Here, x and y in the subprogram are aliases.

- Another way of aliasing:
  definition:
  var x *global variable*
  subprogram sub(y)
  call:
  sub(x)
  Here, x and y in the subprogram are aliases.

# Pass-by-name

- inout mode
- Actual parameter is textually substituted for the corresponding formal parameter in all occurrences in the subprogram.

- **Late binding**: actual binding to a value or an address is delayed until the formal parameter is assigned or referenced.

- If the actual parameter is a **scalar variable**, then it is equivalent to **pass-by-reference**.
- If the actual parameter is a **constant expression**, then it is equivalent to **pass-by-value**.

- <u>Advantage</u>: flexibility
- <u>Disadvantage</u>: slow execution, difficult to implement, confusing.

# Pass-by-name

Example

```
procedure BIG;
integer GLOBAL;
integer array LIST[1:2];
procedure SUB (P: integer);
begin
P := 3;
GLOBAL := GLOBAL + 1;
P := 5;
end;
begin
LIST[1] := 2;
LIST[2] := 2;
GLOBAL := 1;
SUB(LIST[GLOBAL]);
end.
```

LIST[GLOBAL] :=3
GLOBAL := GLOBAL + 1
LIST[GLOBAL] :=5

***Execution:***

LIST[1] :=3
GLOBAL := 1 + 1
LIST[2] :=5

# Parameter passing methods of the major languages

- **FORTRAN 77** and later implementations use **pass-by-value-result** (Earlier implementations used call-by-reference)
- **C** uses **pass-by-value**, **pass-by-reference** is achieved by pointers.
- **Java:** all parameters are passed by value, object parameters are passed by reference
- **C#**
  - Default method: pass-by-value
  - Pass-by-reference is specified by preceding both a formal parameter and its actual parameter with `ref`
- **PHP:** very similar to C#
- **Perl:** all actual parameters are implicitly placed in a predefined array named `@_`
- **Ada** uses **in** (default), **out**, and **inout** parameters.

```
procedure Adder (A: in out Integer;
                 B: in Integer;
                 C: out Float);
```

- Fortran 95 is similar to Ada:

```
Subroutine Adder (A, B, C)
    Integer, Intent(Inout) :: A
    Integer, Intent(In) :: B
    Integer, Intent(Out) :: C
```

# Type-checking parameters

- Types of actual and formal parameters should be checked.
- Otherwise, small typographical errors can lead to errors that are difficult to detect.
- Considered very important for reliability

- FORTRAN 77 and original C: none
- Pascal, FORTRAN 90, Java, and Ada: it is always required
- ANSI C and C++: choice is made by the user
  - Prototypes
- Relatively new languages Perl, JavaScript, and PHP do not require type checking

# Multidimensional arrays as parameters

- In languages C and C++, subprograms can be compiled separately from the calling programs.
- The compiler must be able to build the map function for a multidimensional array, when passed as a parameter.
- These languages store arrays in row major order.
- Since the mapping function for row major order needs the number of columns, it must be provided. For example,

```
void
assign (float matrix [][5], float val, int r,
  int c){
matrix[r][c] = val;
}
address(matrix([r][c])=
  address(matrix[0][0])+(r*n+c)*float_size
main () {
   float m1 [10][5], m2 [15][5];
   assign (m1, 1.2, 3, 4);
   assign (m2, 2.3, 15, 2);
}
```

# Multidimensional arrays as parameters

- Problem: It is not possible to write functions that accept any size of multidimensional arrays. So, it is not flexible.
- Solution is to pass the array as a pointer, and pass the sizes as parameters.

```
Void
assign (float *matrix, int num_cols, float val, int r, int c)
{
   *(matrix +(r * num_cols) + c) = value
}
```

- This is a solution, but the resulting code is not readable. Further, it is not writable, the programmer must write the map function himself.

# Parameters that are subprograms

- It is sometimes convenient to pass subprogram names as parameters
- Issues:
  - The address of the code segment of the called subprogram must be passed.
  - Description of the subprogram's parameters must be sent
  - In C and C++, functions cannot be passed as parameters, but pointers to functions can be passed.
  - In languages that allow nested subprograms, such as JavaScript, there is a problem of referencing environment.

# Parameters that are subprograms

- **Important question** is:
- What is the **referencing environment** for executing the passed subprogram? (For non local variables)
- There are 3 choice:
- **Shallow binding**: the environment of the calling program.
- **Deep binding**: the environment of the subprogram in which the called subprogram is declared.
- **Never been used**: the environment of the subprogram that includes the call statement that passed the subprogram as an actual parameter.

- **Shallow binding**: appropriate for dynamic scope binding.
- **Deep binding**: appropriate for static scope binding.

# Parameters that are subprograms

Example:

```
function sub1() {
  var x;            2:declared in
  function sub2() {
    window.status = x;
  } // sub2
  function sub3(){
    var x;
    x = 3;
    sub4(sub2);     3: passed in
  } // sub3
  function sub4(subx) {
    var x;
    x = 1;
    subx();         1:called by
  } // sub4
  x = 2;
  sub3();
} // sub1
```

```
Passed subprogram S2
Output:
is called by S4
is declared in S1
is passed in S3
```

# Overloaded subprograms

- An overloaded subprogram is a subprogram that has the same name as another subprogram in the same referencing environment
- Each one must have a different number of argumets, or order of arguments or types of arguments to distinguish the one meant.
- The correct meaning (the correct code) to be invoked is determined by the **actual parameter list**. The code whose formal parameter types match the types of the actual parameters is used.
- In case of **functions**, the **return type** may be used to distinguish.
- Ada and C++ allow subprograms to be overloaded.

# Generic subprograms

- A subprogram whose parameters can be of different types.
- The same formal parameter can get values of different types.
- **Ada** and **C++** provide Generic (Polymorphic) Subprograms

# Generic subprograms

Generic Subprograms in Ada

Example:

```
generic
type ELEMENT is private;
type VECTOR is array (INTEGER range <>) of ELEMENT;
procedure GENERIC_SORT(LIST: in out VECTOR);
procedure GENERIC_SORT(LIST: in out VECTOR) is
  TEMP: ELEMENT;
  begin
    ...
  end GENERIC_SORT;
```

This is a template for a procedure.

No code is generated here by the copiler.

It can be instantiated as

```
procedure INT_SORT is new
        GENERIC_SORT (ELEMENT => INTEGER;
                      VECTOR => INT_ARRAY);
```

At this point, the compiler builds a version of `GENERIC_SORT`, and names it `INTEGER_SORT`.

# Generic subprograms

Generic Functions in C++

They are called **template functions**.

Example:

```
template <class Type>
Type max (Type first, Type second) {
  return first > second ? first : second;
}
```

This function can be instantiated for any type for which > is defined.

It can be instantiated implicitly when function is named in a call as

```
int a, b, c;
char d, e, f;
. . .
c = max (a,b);
f = max (d,e);
```

# Design issues for functions

- Functional side effects;
- Return types.

# User defined overloaded operators

- Allowed in Ada and C++
- Example in Ada
- **function** “*” (A, B: **in** MATRIX) **return** MATRIX **is**
- . . .

# Coroutines

- A coroutine is a special kind of subprogram.
- Rather than master-slave relationship, as in subprograms; a caller and called coroutines are on a more equal basis.
- This is called symmetric unit control model.
- SIMULA67 is the first high-level PL that included coroutines.
- SIMULA67 was a PL suitable for Simulation.
- Modula-2 also support coroutines.
- Coroutines have multiple entry points. Entry points are controlled by the coroutine itself.
- Coroutines are history sensitive, thus they have static variables.
- Coroutines are not called, they are resumed. Secondary execution does not necessarily start from the beginning.
- Couroutines are created in an application by a special unit called master unit, which is not a coroutine.
- A coroutine may have an initialization code that is executed only when it is created.
- Only one coroutine executes at a given time.
- There is a single thread of control in a program with coroutines.
- The master unit resumes one of the created coroutines, then coroutines resume each other. Finally one coroutine reaches the end of execution, transfers the control to the master unit.

# Coroutines