An Example: pass-by-value-result vs. pass-by-reference

```
program foo;
var x: int;
    procedure p(y: int);
    begin
        y := y + 1;
        y := y * x;
     end
begin
    x := 2;
    p(x);
    print(x);
end
```

	pass-by-value-result		pass-by-reference	
	x	**y**	**x**	**y**
(entry to p)	2	2	2	2
(after y:= y + 1)	2	3	3	3
(at p's return)	6	6	9	9

Aliases can be created due to pass-by-reference

- Given void fun(int &first, int &second),
  - Actual parameter collisions
    - E.g., fun(total, total) makes first and second to be aliases
  - Array element collisions
    - E.g., fun(list[i], list[j]) can cause first and second to be aliases if i == j
  - Collisions between formals and globals
    - E.g., int* global;
      void main() { … sub(global); … }
      void sub(int* param) { … }
    - Inside sub, param and global are aliases

Pass-by-Name

- Implement an inout-mode parameter transition method
- The body of a function is interpreted at call time after textually substituting the actual parameters into the function body
- The evaluation method is similar to C preprocessor macros

An Example in Algol

```
procedure double(x);
   real x;
begin
   x := x * 2;
end;
```

Therefore, double(C[j]) is interpreted as C[j] = C[j] * 2

Another Example

- Assume k is a global variable,

```
procedure sub2(x: int; y: int; z: int);
begin
    k := 1;
    y := x;
    k := 5;
    z := x;
end;
```

- How is the function call sub2(k+1, j, i) interpreted?

Disadvantages of Pass-by-Name

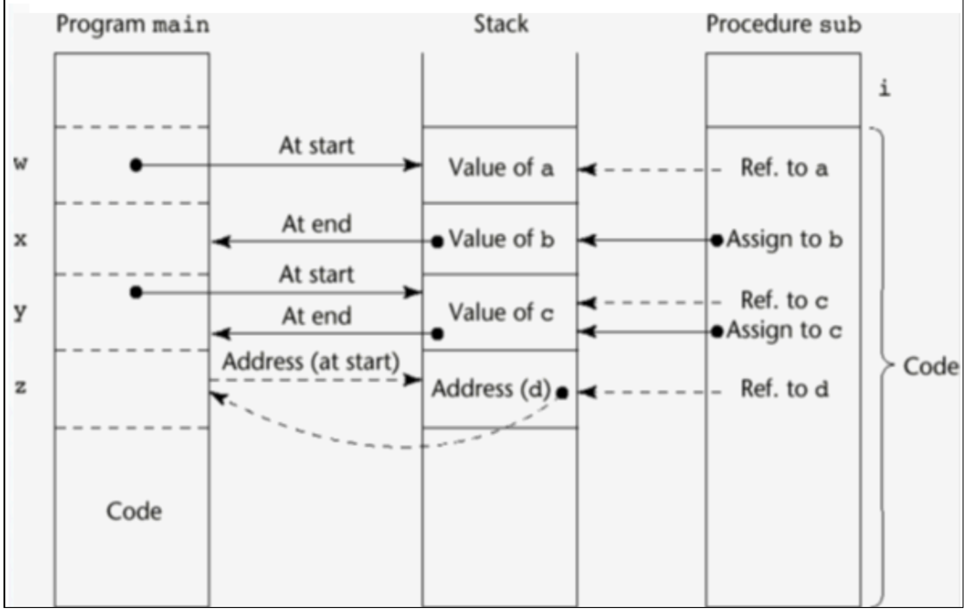
- Very inefficient references
- Too tricky; hard to read and understand

Implementing Parameter-Passing Methods

- Most languages use the runtime stack to pass parameters
  - Pass-by-value
    - Values are copied into stack locations
  - Pass-by-result
    - Values assigned to the actual parameters are placed in the stack
  - Pass-by-value-result
    - A combination of pass-by-value and pass-by-result
  - Pass-by-reference
    - Parameter addresses are put in the stack

An Example

- Function header: void sub (int a, int b, int c, int d)
  - a: pass by value
  - b: pass by result
  - c: pass by value-result
  - d: pass by reference
- Function call: main() calls sub(w, x, y, z)



Design Considerations for Parameter Passing

- Efficiency
- Whether one-way or two-way data transfer is needed

One Software Engineering Principle

- Access by subroutine code to data outside the subroutine should be minimized
  - In-mode parameters are used whenever no data is returned to the caller
  - Out-mode parameters are used when no data is transferred to the callee but the subroutine must transmit data back to the caller
  - Inout-mode parameters are used only when data must move in both directions between the caller and callee

A practical consideration in conflict with the principle

- Pass-by-reference is the fastest way to pass structures of significant size

Parameters that are subroutines

- In some situations, subroutine names can be sent as parameters to other subroutines
- Only the transmission of computation is necessary, which could be done by passing a functional pointer

Two complications with subroutine parameters

- Are parameters type checked?
  - Early Pascal and FORTRAN 77 do not type check
  - Later versions of Pascal, Modula-2, and FORTRAN 90 do
  - C and C++ do

Two complications with subroutine parameters

- What referencing environment should be used for executing the passed subroutine?
  - The environment of the call statement that *enacts* the passed subroutine(**shallow binding**)
  - The environment of the *definition* of the subroutine(**deep binding**)
  - The environment of the call statement that *passed* it as an actual parameter(**ad hoc binding**)

An Example

```
function sub1() {
    var x;
    function sub2() {
        alert (x);
    };
    function sub3() {
        var x;
        x = 3;
        sub4(sub2);
  };
    function sub4(subx) {
        var x;
        x = 4;
        subx();
    };
    x = 1;
    sub3();
};
```

- For shallow binding, the referencing environment of sub2 is sub4
- For deep binding, the referencing environment of sub2 is sub1
- For ad hoc binding, the referencing environment of sub2 is sub3

What is the output of alert(x)?

- Shallow binding?
- Deep binding?
- Ad hoc binding?

Referencing Environment for Subroutine Parameters

- Deep binding and ad hoc binding can be the same when a subroutine is declared and passed by the same subroutine
- In reality, ad hoc binding has never been used
- Static-scoped languages usually use deep binding
- Dynamic-scoped languages usually use shallow binding

An Example

```
function Sent() {
    print(x);
};
function Receiver(func) {
    var x;
    x = 2;
};
function Sender() {
    var x;
    x = 1;
    Receiver(Sent)
};
```

- In static-scoped languages, Receiver is not always visible to Sent, so deep binding is natural
- In dynamic-scoped languages, it is natural for Sent to have access to variables in Receiver, so shallow binding is appropriate

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Design Issues for Functions

- Are side effects allowed?
  - Ada requires in-mode parameters, and does not allow any side effect
  - Most languages support two-way parameters, and thus allow functions to cause side effects

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Design Issues for Functions

- What types of values can be returned?
  - FORTRAN, Pascal, and Modula-2: only simple types
  - C: any type except functions and arrays
  - Ada: any type (but subroutines are not types)
  - JavaScript: functions can be returned
  - Python, Ruby and functional languages: methods are objects that can be treated as any other object

Overloaded Subroutine

- A subroutine that has the same name as another subroutine in the same referencing environment, but its number, order, or types of parameters must be different
  - E.g., void fun(float);
    void fun();
- C++ and Ada have overloaded subroutines built-in, and users can write their own overloaded subroutines

Generic Subroutine

- A generic or polymorphic subroutine takes parameters of different types on different activations
- An example in C++

```
template<class Type>
Type max(Type first, Type second) {
   return first > second ? first: second;
}
int a, b, c;
char d, e, f;
…
c = max(a, b);
f = max(d, e);
```


Generic Subroutine

- Overloaded subroutines provide a particular kind of polymorphism called **ad hoc polymorphism**
  - Overloaded subroutines need not behave similarly
- **Parametric polymorphism** is provided by a subroutine that takes generic parameters to describe the types of parameters
- Parametric polymorphic subroutines are often called generic subroutines

Coroutine

- A special kind of subroutine. Rather than the master-slave relationship, the caller and callee coroutines are on a more equal basis
- A **coroutine** is a subroutine that has multiple entry points, which are controlled by coroutines themselves

Coroutine

- The first execution of a coroutine begins at its beginning, but all subsequent executions often begin at points other than the beginning
- Therefore, the invocation of a coroutine is named a **resume**
- Typically, coroutines repeatedly resume each other, possibly forever
- Their executions interleave, but do not overlap

An Example

```
sub co1() {
    ...
    resume(co2);
    ...
    resume(co3);
}
```

- The first time co1 is resumed, its execution begins at the first statement, and executes down to resume(co2) (with the statement included)
- The next time co1 is resumed, its execution begins at the first statement after resume(co2)
- The third time co1 is resumed, its execution begins at the first statement after resume(co3)

Coroutine

- The interleaved execution sequence is related to the way multiprogramming operating systems work
  - Although there may be one processor, all of the executing programs in such a system appear to run concurrently while sharing the processor
  - This is called **quasi-concurrency**
- Coroutines provide quasi-concurrent execution of program units

Reference

[1] Robert W. Sebesta, Concepts of Programming Languages, 8th edition, pg. 383-434