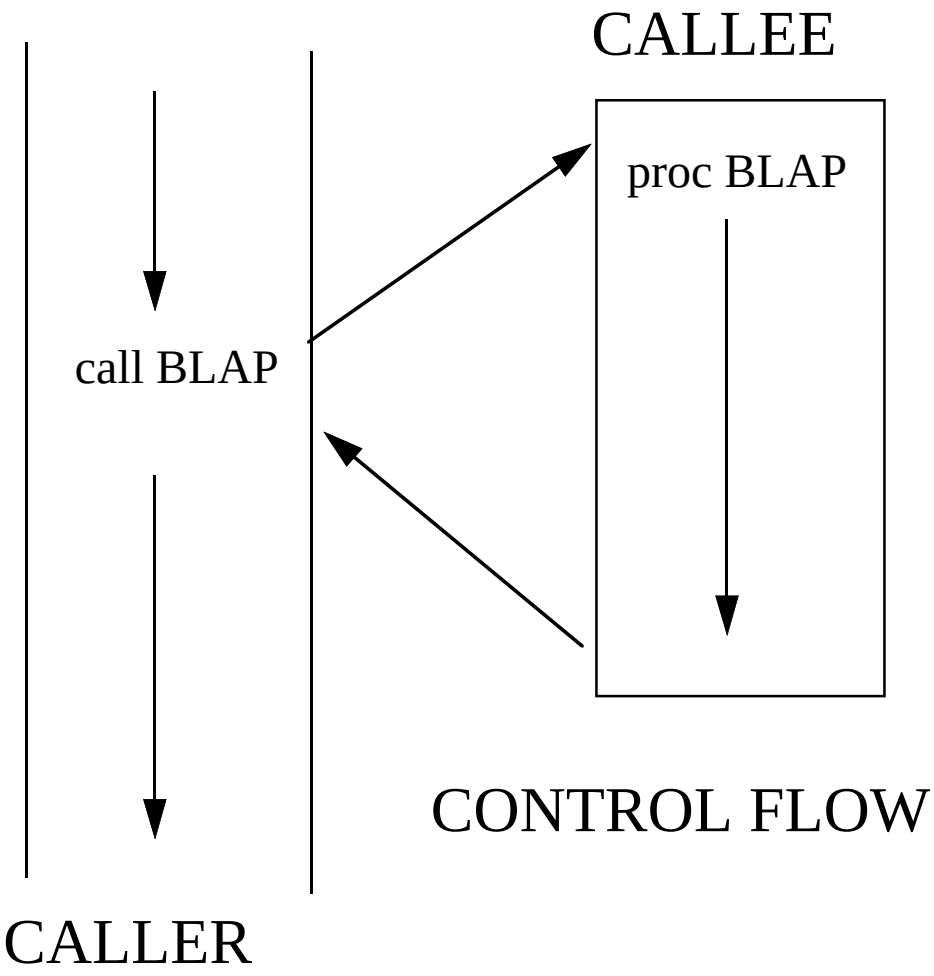
Subprograms

- **Characteristics:**
  - → **single entry point**
  - → **calling unit suspends**
  - → **control returns to caller**



Subprograms

Terminology Problem

in Calling Unit	in Called Unit
actual parameter	dummy parameter
actual parameter	formal parameter
argument	parameter

- **arguments & parameters**
  - → **p(5.1, a + b) proc p(x: real, y: int)**
  - → **Correspondence-- matching method**
  - → **positional**
  - → **keyword p(y => a + b, x => 5.1)**
- **Default values**
  - → **proc p(x: real := 1.0, y: int)**
  - → **p(y => a + b)**

Parameter Passing

- **Issues**
  - → **Data flow between arguments and parameters:**

    argument -> parameter "in mode" (calling -> called)

    parameter -> argument "out mode" (called -> calling)

    both "inout mode"
  - → **Transfer by copy (r-value) or by access path (pointer or l-value)?**
  - → **When are arguments evaluated?**

Methods

- **Pass-by-value**
  - → **mode: *in***
  - → **transfer: by copy**

    => no access to outer environment
  - → **evaluation: argument evaluated at time of call**

    e.g., f(2 + 3) ≡ f(5) y := 5

    F(y) ≡ F(5)
  - → **Note: protects arguments, *may be inefficient (copy)***

- **Pass-by-result**
  - → **mode: *out***
  - → **transfer: by copy**
  - → **evaluation: address to copy back to evaluated at time of call**
  - → **What happens here? What is final value of x on return?**

    p(x,x) Collision: **procedure** P (a, b);

    a := 5; b := 7;

Methods (continued)

- **Pass by value/result**
  - → **mode: *inout***
  - → **transfer: by copy (in and out)**
  - → **evaluation: at time of call**
    - value
    - return address
- **Pass by reference**
  - → **mode: *inout***
  - → **transfer: by shared access path**
    - addr ( )
  - → **evaluation: address of arguments evaluated at time of call**
  - → **Note: pass-by-value/result ≠ pass-by-reference**

Example -- value/result vs. 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.
```

Here, y is an alias for x

	value/result		***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)*

* Actually NOT available after the return

Another Method

- **Pass-by-name**
  - → **Symbolic* substitution of actual for each occurrence of formal**
  - → **mode: *inout***
  - → **transfer: ?**
  - → **evaluation: when formal is *demanded* in *body* of procedure - *not at time of call!***

    => eval 0 or more times

- **Advantage: Delays evaluation of arguments**

```
function f(p: bool, c: real, a: real):real
begin
    if p then c else a
end

f(x = 0, 1.0, 1.0/x)
```

* NOT Textual; textual substitution is the method in MACROs

Pass-by-Name (continued)

- **Disadvantages**

  → **inefficient**

  re-evaluation of actuals

  need *thunk* = (code,env)

  special implementation issue

```
procedure p1;
var x:int;
begin
    x := 2;
    p2(x+1);
end;

procedure p2(y:int);
var x:int;
begin
    x := 5;
    glob := x + y     ===>    x + (x + 1)  =>  p2.x + (p1.x + 1)
end;
```

Now: glob = 11 or 8?

Pass-by-Name (continued)

- **May be hard to understand**

```
procedure swap(x,y);
var temp:int;
begin
    temp := x;
    x := y;
    y := temp;
end.
```

Pass-by-value will **not** work here

Pass-by-reference **will** work

Pass-by-name works only **sometimes**

swap (a[i],a[j])

```
-- temp := a[i]
-- a[i] := a[j];
-- a[j] := temp;
```

YES

swap(i,a[i])

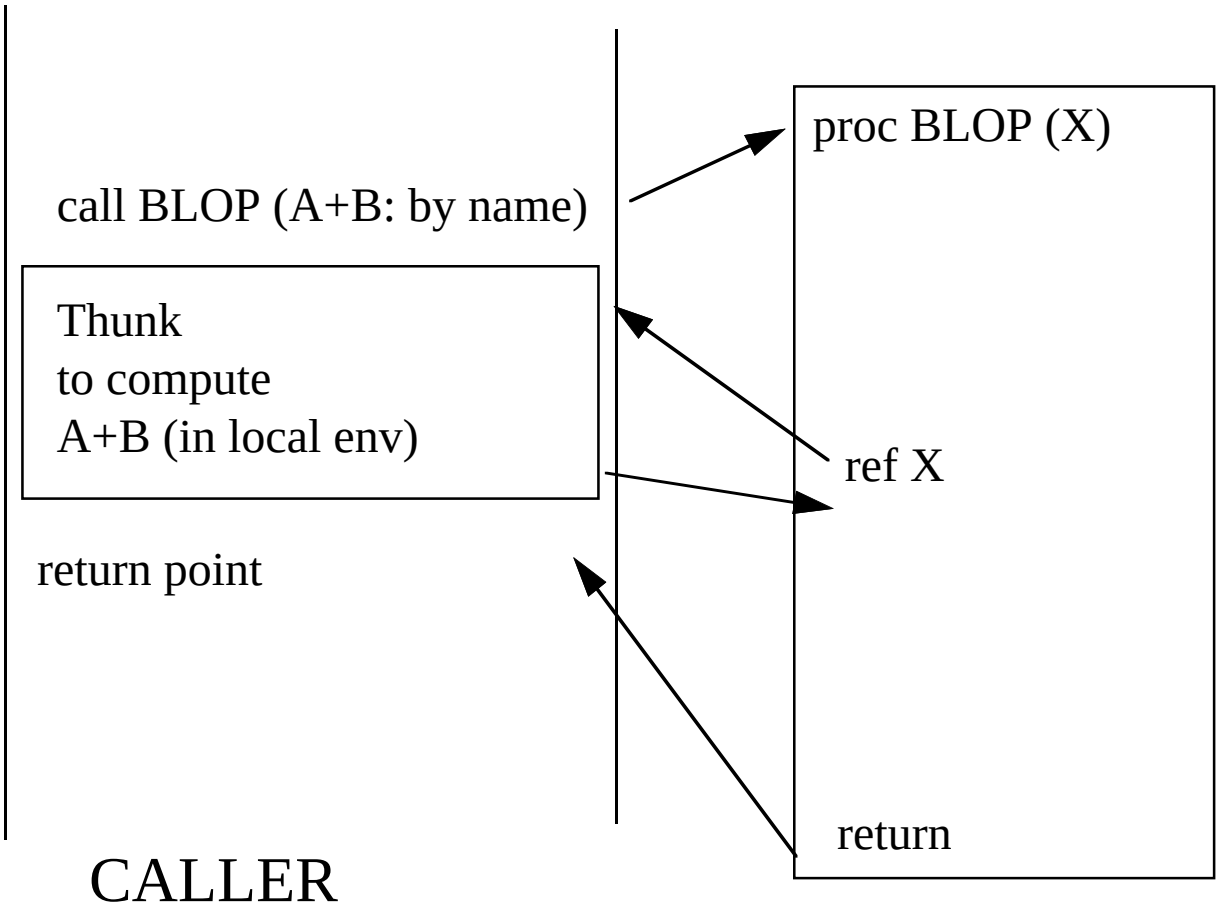
```
-- temp := i;
-- i := a[i];
-- a[i] := temp;
```

NO

THUNKS (aka Jensen's Device)

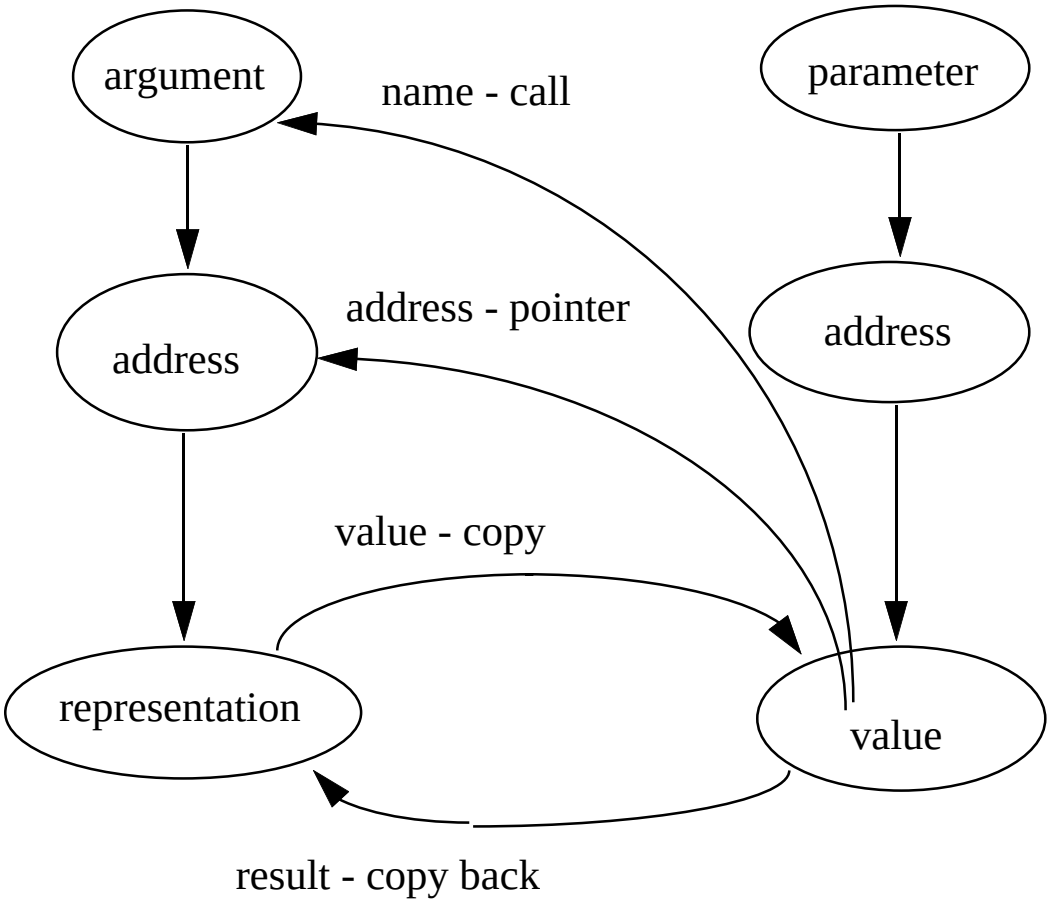
- **A Thunk is a parameterless* function, that exists in the calling program that evaluates the argument**

- **A parameter reference in the called program compiles as a call to the corresponding Thunk**



* A single parameter may be needed to distinguish between whether the return value is to be an l-value or an r-value if the callee cannot distinguish

ARGUMENT/PARAMETER RELATIONSHIPS



ARGUMENT NAME-VALUE

PARAMETER NAME-VALUE

(SLIGHTLY ABBREVIATED NAME-VALUE GRAPHS)

Internal Parameter Reference Method

Passing Method	Reference Method
Value	Local, direct reference
Result	Local, direct reference
Value/Result	Local, direct reference
Address (Reference)	As Pointer
Name (Expression)	Procedure Call to Thunk

SWAP: Call-by-reference

```
procedure swap(x,y);
var temp:int;
begin
        temp := x;
        x := y;
        y := temp;
end
```

- -

Call: swap (i , a[i]) where i = 2 and a[2] = 5

=====> swap (^i , ^a[2] , ^swap-code)

temp := ^i	temp <- 2
^i := ^a[2]	i <- 5
^a[2] := temp	a[2] <- 2

VALUES APPROPRIATELY SWAPPED

SWAP: Call-by-name

```
procedure swap(x,y);
var temp:int;
begin
        temp := x;
        x := y;
        y := temp;
end
```

- -

Call: swap (i , a[i]) where i = 2 and a[2] = 5

=====> swap (^i , ^a[2] , ^env , ^swap-code)

temp := eval (i , env)	temp <- 2
addr (i , env) := eval (a[i] , env)	i <- 5
addr (a[i] , env) := temp	a[5] <- 2

NOTE: VALUE OF a[2] IS **NOT** CHANGED!

Procedure and Function Arguments

```
program p123();
procedure p1(p);          -- p is a procedure parameter
var x: int;
begin {p1}
    x := 1;
    p();                  -- the passed procedure is invoked
end; {p1}

procedure p2();
var x : int;
    procedure p3();       Note: p3 is not normally visible to p1
    begin {p3}
        print (x)         -- must be the x in p2, not the x in p1!
    end; {p3}
begin {p2}
    x := 2;
    p1(p3)
end {p2}

begin {main}     p2();     end. {main}
```

- **Note: This requires *thunks* for static scoping ("deep binding").**

DEEP OR SHALLOW BINDING

- **Deep binding refers to static (lexical, textual, compile time) binding of non-local identifiers**

- **Shallow binding refers to dynamic (calling sequence, calling chain, run time) binding**

- **NOTE TO REMEMBER FOR LATER**

  → **when we get to Activation Record Stacks, shallow binding will be seen as binding that is "most recent" in the stack (i.e. following the dynamic link)**

  → **deep binding follows the static links that generally point to deeper activation records in the stack**