"People think that computer science is the art of geniuses but the actual reality is the opposite, just many people doing things that build on each other, like a wall of mini stones."

- Donald Knuth

CSE341
Programming Languages

Lecture 7 – November 24, 2015

Procedures

Slides are taken from C. Li & W. He

Procedures vs. Functions

- Function:
  - no side effect
  - return a value
  - Function call: expression
- Procedure:
  - side effect, executed for it
  - no return value
  - Procedure call: statement
- No clear distinction made in most languages
  - C/C++: void
  - Ada/FORTRAN/Pascal: procedure/function

Syntax

- Terminology:
  - body
  - specification interface
    - name
    - type of return value
    - parameters (names and types)

```
int f(int y);    //declaration
```

```
int f(int y) {
      int x;
      x=y+1;
      return x;
}
```

```
int f(int y){    //definition
      int x;
      x=y+1;
      return x;
}
```

Procedure Call

Caller:

```
…
f(a);
…
```

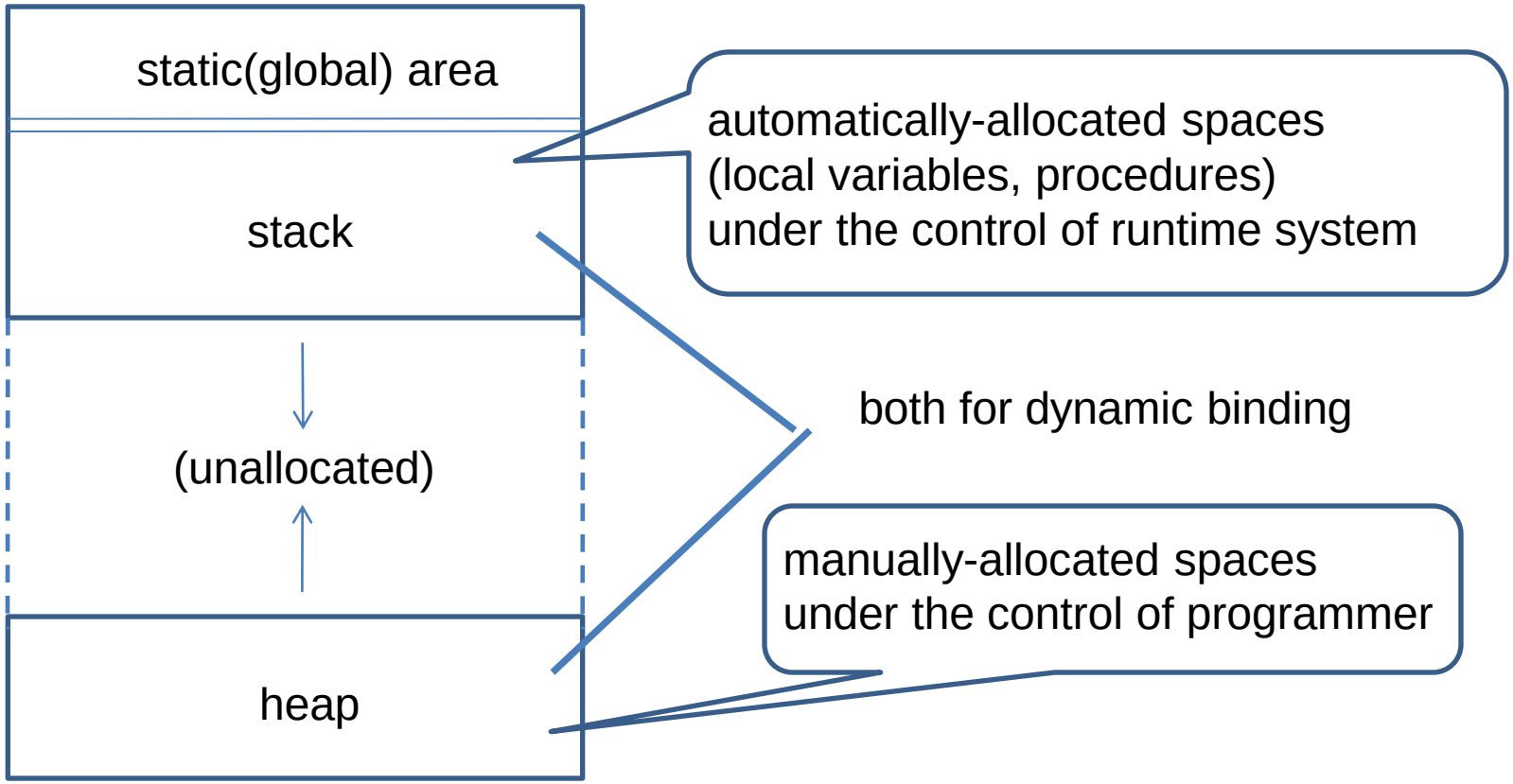
Callee:

```
int f(int y){
   int x;
   if (y==0) return 0;
   x=y+1;
   return x;
}
```

- Control transferred from caller to callee, at procedure call
- Transferred back to caller when execution reaches the end of body
- Can **`return`** early

Environment

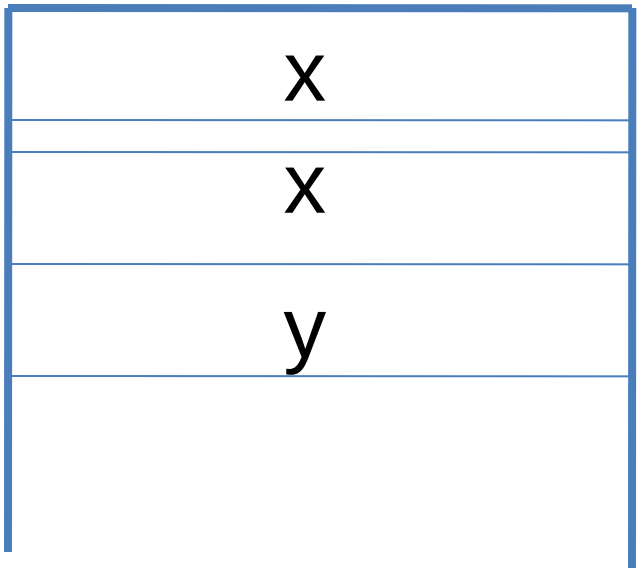
- Environment: binding from names to their attributes



Activation Record for Nested Blocks

- Activation record: memory allocated for the local objects of a block
  - Entering a block: activation record allocated
  - Exit from inner block to surrounding block: activation record released

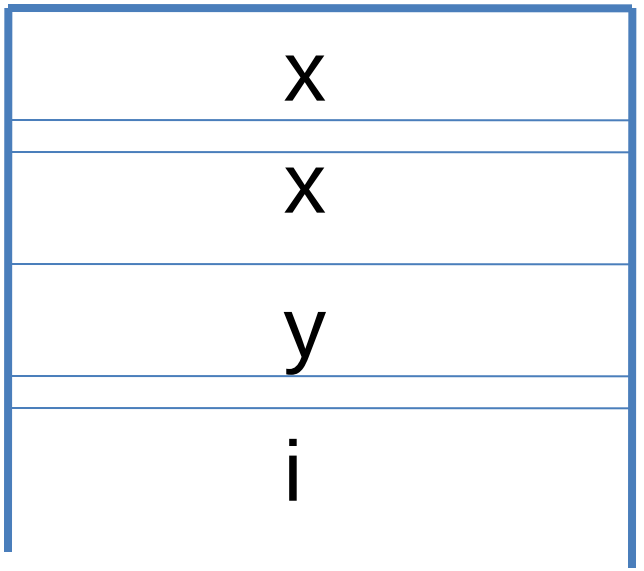
```
int x; //global
{
   int x,y;
   x = y*10;
   {
      int i;
      i = x/2;
   }
}
```



Activation Record for Nested Blocks

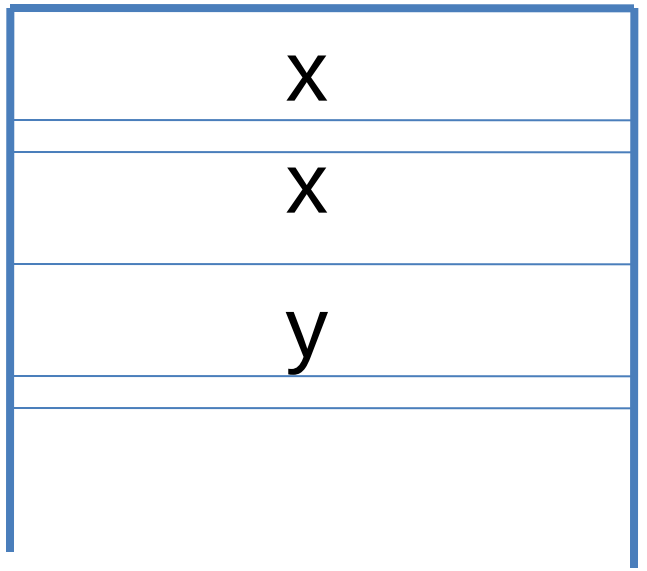
```
int x; //global
{
  int x,y;
  x = y*10;
  {
    int i;
    i = x/2;
  }
}
```

X: Nonlocal variable, in the surrounding activation record



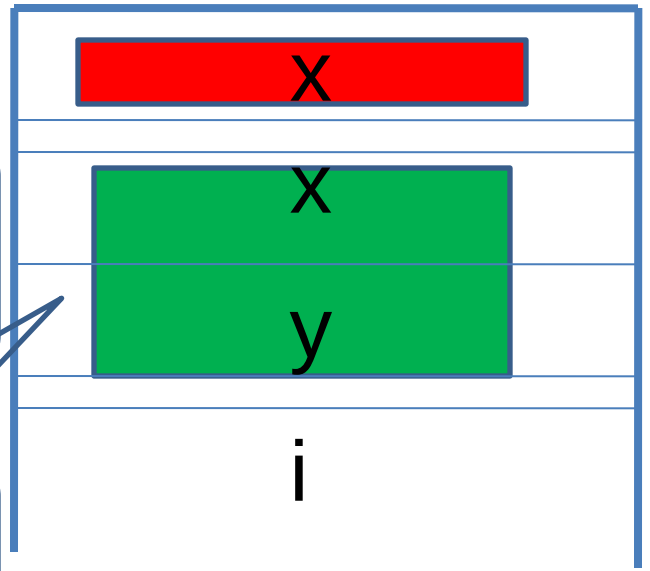
Activation Record for Procedures

```
int x; //global
void B(void) {
  int i;
  i = x/2;
}
void A(void) {
  int x,y;
  x = y*10;
  B();
}
main() {
  A();
  return 0;
}
```



Activation Record for Procedures

```
int x; //global
void B(void) {
  int i;
  i = x/2;
}
void A(void) {
  int x,y;
  x = y*10;
  B();
}
main() {
  A();
  return 0;
}
```



x: global variable in defining environment

Need to retain information in calling environment

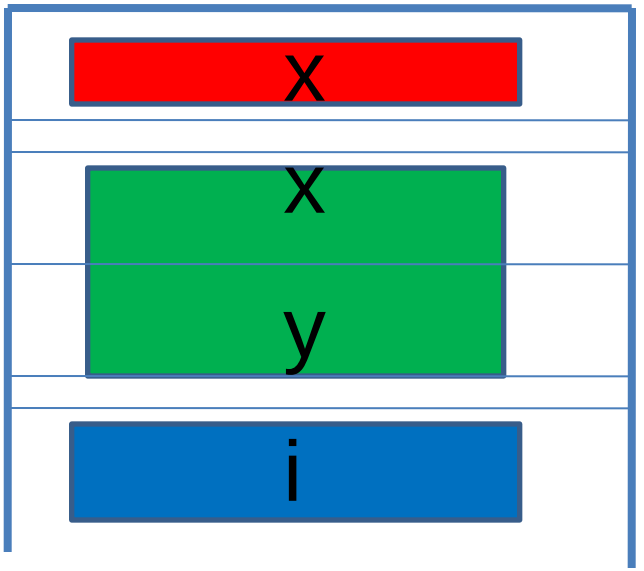
Activation Record for Procedures

```
int x; //global
void B(void) {
  int i;
  i = x/2;
}
void A(void) {
  int x,y;
  x = y*10;
  B();
}
main() {
  A();
  return 0;
}
```

i: local variable in called environment

x: global variable in defining environment

x,y: local variable in calling environment

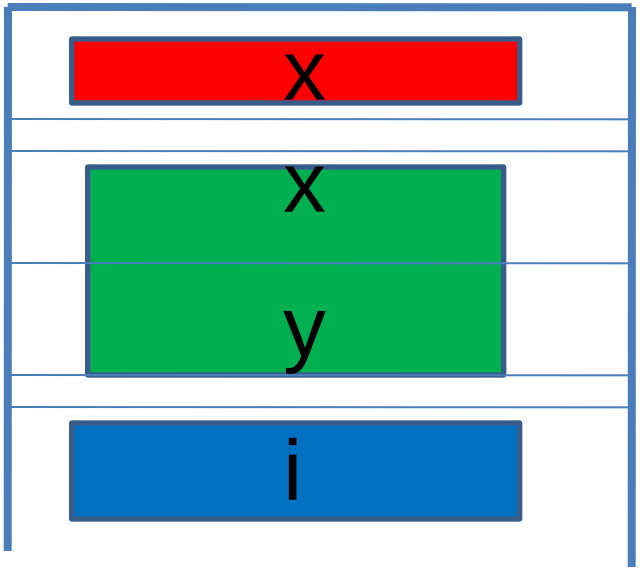


Activation Record for Procedures

```
int x; //global
void B(void) {
  int i;
  i = x/2;
}
void A(void) {
  int x,y;
  x = y*10;
  B();
}
main() {
  A();
  return 0;
}
```

Can only access global variables in defining environment

No direct access to the local variables in the calling environment
(Need to communicate through parameters)



Procedure Call

- Caller:

```
…
f(i);
…
```

actual parameter / argument

Callee:

```
int f(int a){
   ...;
   ...a...;
   ...;
}
```

formal parameter / argument

Parameter Passing Mechanisms:

- When and how to evaluate parameters
- How actual parameter values are passed to formal parameters
- How formal parameter values are passed back to actual parameters

Parameter Passing Mechanisms

- Pass/Call by Value
- Pass/Call by Reference
- Pass/Call by Value-Result
- Pass/Call by Name

Example

- What is the result?

```
void swap(int a, int b) {
    int temp;
    temp = a;
    a = b;
    b = temp;
}
main(){
    int i=1, j=2;
    swap(i,j);
    printf("i=%d, j=%d\n", i, j);
}
```

- It depends…

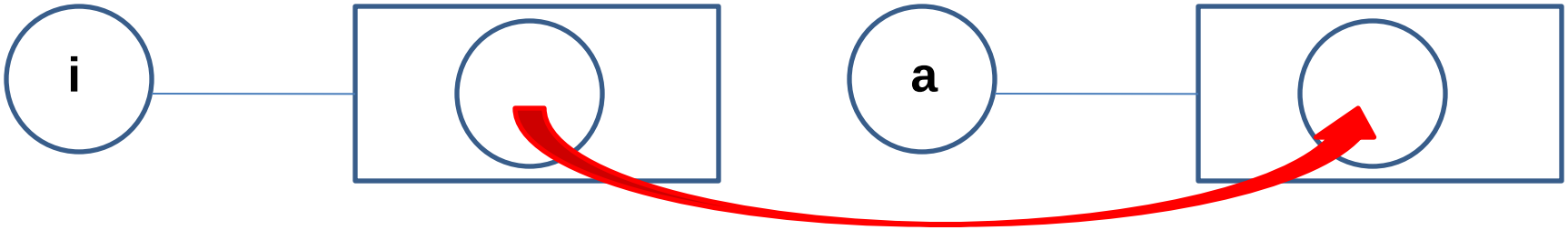
Pass by Value

- Caller:

```
…
f(i);
…
```

Callee:

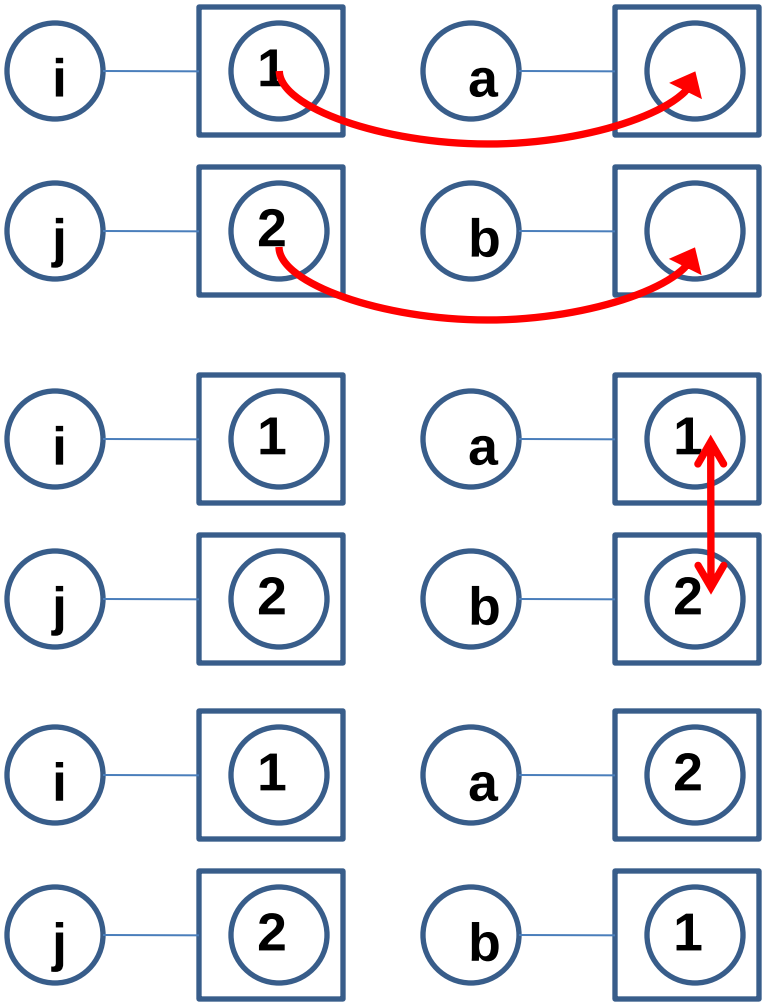
```
int f(int a){
    ...a...;
}
```



- Most common one
- Replace formal parameters by the values of actual parameters
- Actual parameters: No change
- Formal parameters: Local variables (C, C++, Java, Pascal)

Example: Pass By Value

```
void swap(int a, int b) {
   int temp;
   temp = a;
   a = b;
   b = temp;
}
main(){
   int i=1, j=2;
   swap(i,j);
   printf("i=%d, j=%d\n", i, j);
}
```



Are these Pass-by-Value?

- C:

```
void f(int *p) { *p = 0; }

void f(int a[]) { a[0]=0; }
```

- Java:

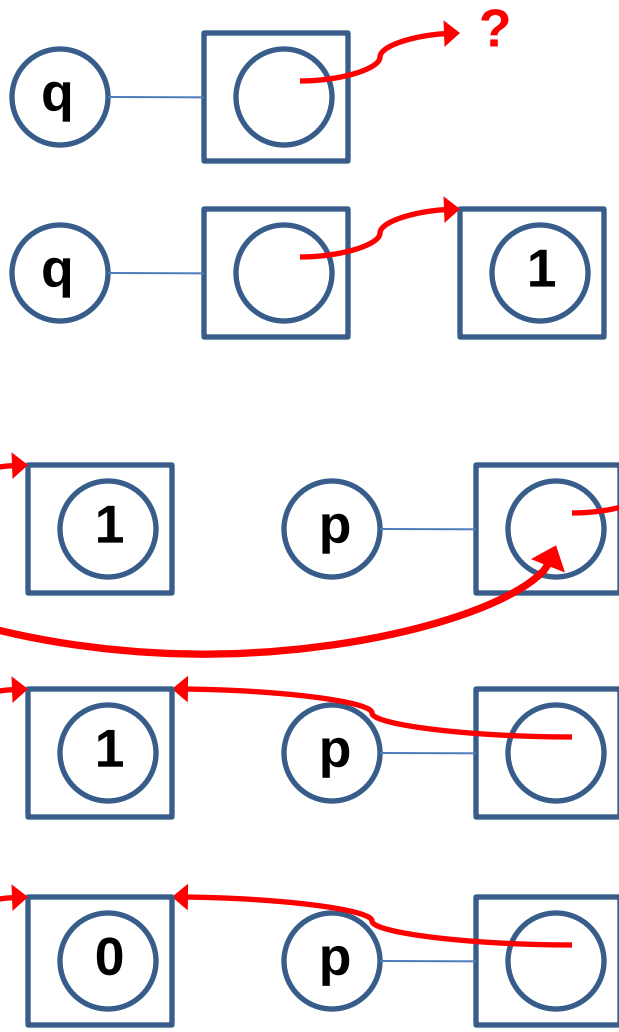
```
void f(Vector v) { v.removeAll(); }
```

Yes!

Pass-by-Value: Pointers

- C:

```
void f(int *p) { *p = 0; }
main() {
   int *q;
   q = (int *) malloc(sizeof(int));
   *q = 1;
   f(q);
   printf("%d\n", q[0]);
}
```



Pass-by-Value: Pointers

- C:

```
void f(int *p) { p = (int *) malloc(sizeof(int)); *p = 0; }
main() {
   int *q;
   q = (int *) malloc(sizeof(int));
   *q = 1;
   f(q);
   printf("%d\n", q[0]);
}
```

- What happens here?

Pass-by-Value: Arrays

- C:

```
void f(int p[]) { p[0] = 0;}
main() {
   int q[10];
   q[0]=1;
   f(q);
   printf("%d\n", q[0]);
}
```

- What happens here?

Pass-by-Value: Arrays

- C:

```
void f(int p[]) { p=(int *) malloc(sizeof(int)); p[0] = 0; }
main() {
   int q[10];
   q[0]=1;
   f(q);
   printf("%d\n", q[0]);
}
```

- What happens here?

Pass-by-Value: Java Objects

- Java:

```
void f(Vector v) { v.removeAll(); }

main() {
   Vector vec;
   vec.addElement(new Integer(1));
   f(vec);
   System.out.println(vec.size());
}
```

- What happens here?

Pass-by-Value: Java Objects

- Java:

```
void f(Vector v) { v = new Vector(); v.removeAll(); }

main() {
   Vector vec;
   vec.addElement(new Integer(1));
   f(vec);
   System.out.println(vec.size());
}
```

- What happens here?

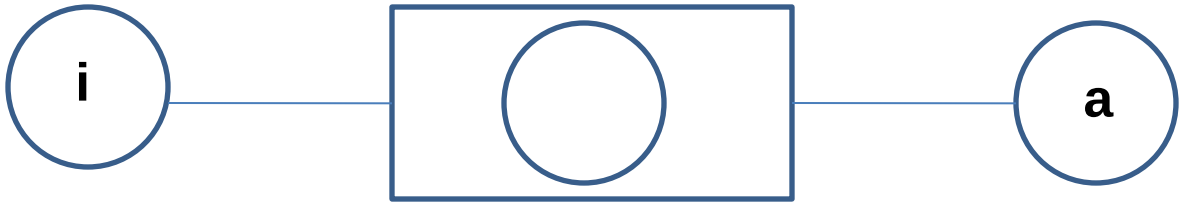
Pass by Reference

- Caller:

```
…
f(i);
…
```

Callee:

```
int f(int a){
    ...a...;
}
```

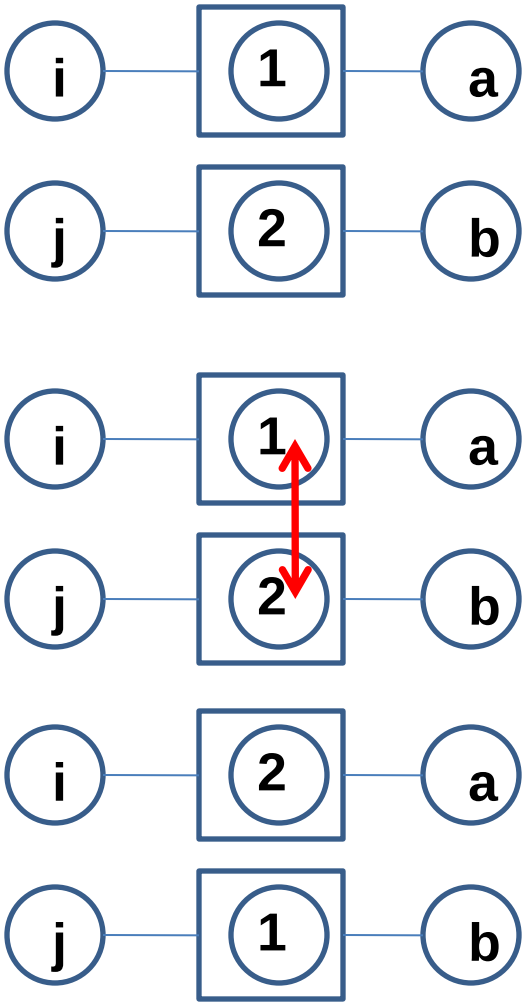


- Formal parameters become **alias** of actual parameters
- Actual parameters: changed by changes to formal parameters
- Examples:
  - Fortran: the only parameter passing mechanism
  - C++ (reference type, `&`) /Pascal (`var`)

Example: Pass By Reference

C++ syntax. Not valid in C

```
void swap(int &a, int &b) {
   int temp;
   temp = a;
   a = b;
   b = temp;
}
main(){
   int i=1, j=2;
   swap(i,j);
   printf("i=%d, j=%d\n", i, j);
}
```



Pass-by-Reference: How to mimic it in C?

C:

```
void f(int *p) { *p = 0; }
main() {
   int q;
   q = 1;
   f(&q);
   printf("%d\n", q);
}
```

- It is really pass-by-value. Why?

It is really pass-by-value

C:

```
void f(int *p) { p = (int *) malloc(sizeof(int)); *p = 0; }
main() {
   int q;
   q = 1;
   f(&q);
   printf("%d\n", q);
}
```

Pass-by-Reference: C++ Constant Reference

C++:

```
void f(const int & p) {
   int a = p;
   p = 0;
}
main(){
    int q;
    q = 1;
    f(q);
    printf("%d\n", q);
}
```

const int &p
Error: expression must be a modifiable lvalue

- What happens here?

Pass-by-Reference: C++ Reference-to-Pointer

C++:

```
void f(int * &p) { *p = 0; }
main(){
    int *q;
    int a[10];
    a[0]=1;
    q=a;
    f(q);
    printf("%d, %d\n", q[0], a[0]);
}
```

0 0

- What happens here?

Pass-by-Reference: C++ Reference-to-Pointer

C++:

```
void f(int * &p) { p = new int; *p = 0; }
main(){
    int *q;
    int a[10];
    a[0]=1;
    q=a;
    f(q);
    printf("%d, %d\n", q[0], a[0]);
}
```

0 1

- What happens here?

Pass-by-Reference: C++ Reference-to-Array

C++:

```
void f(int (&p)[10]) { p[0]=0; }
main(){
    int *q;
    int a[10];
    a[0]=1;
    q = a;
    f(a);
    printf("%d, %d\n", q[0], a[0]);
}
```

0 0

- What happens here?

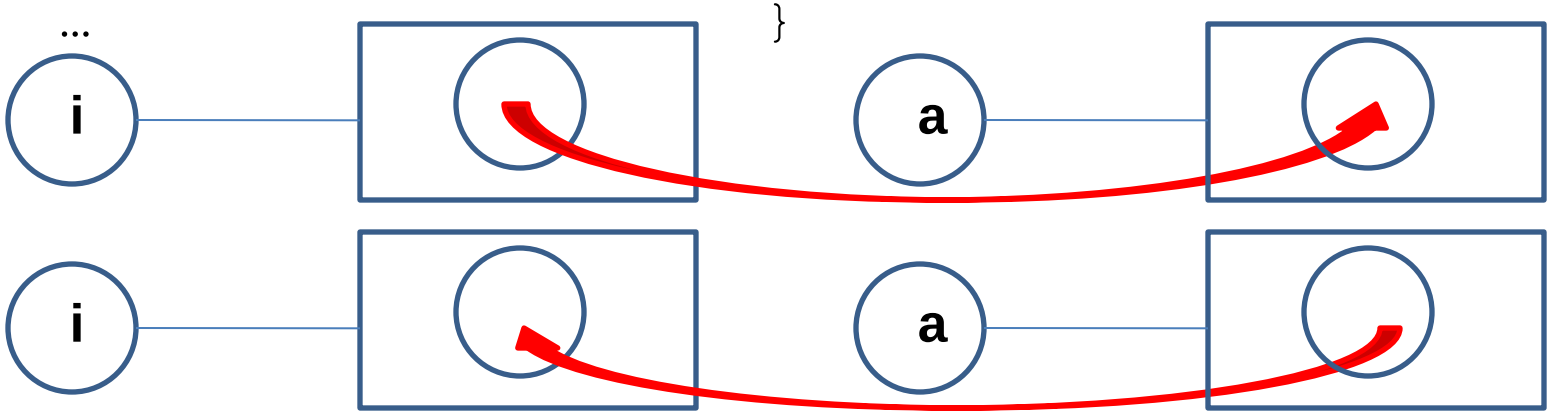
Pass by Value-Result

- Caller:

```
…
f(i);
…
```

Callee:

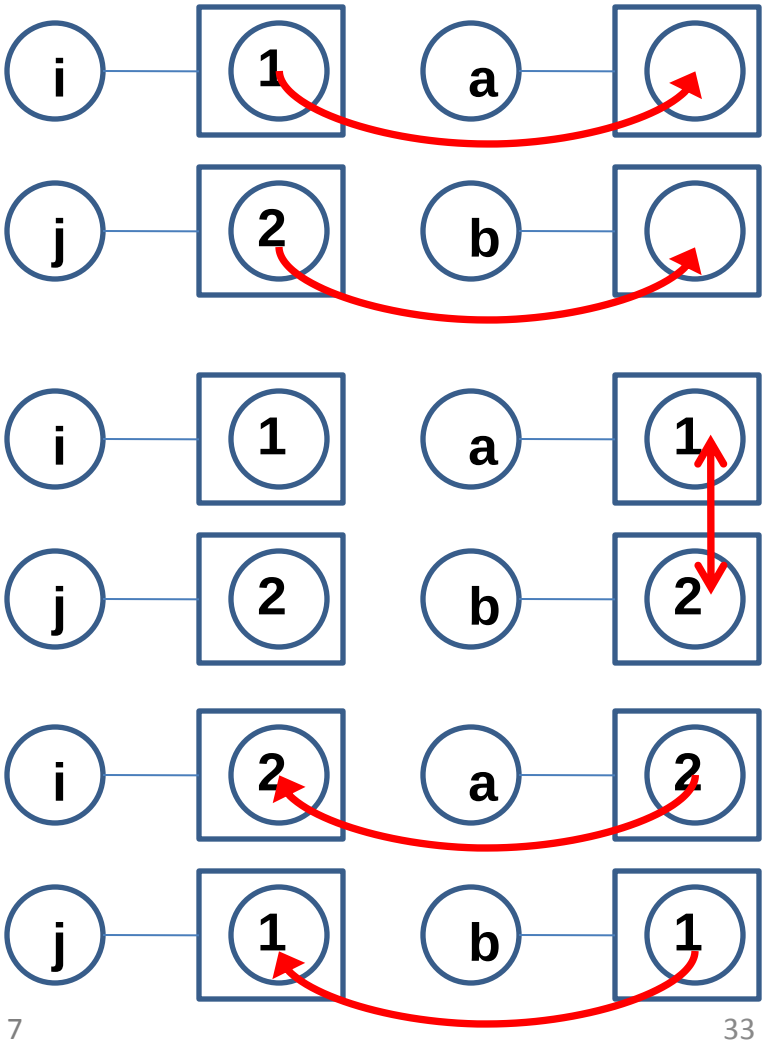
```
int f(int a){
    ...a...;
}
```



- Combination of Pass-by-Value and Pass-by-Reference (Pass-by-Reference without aliasing)
- Replace formal parameters by the values of actual parameters
- Value of formal parameters are copied back to actual parameters

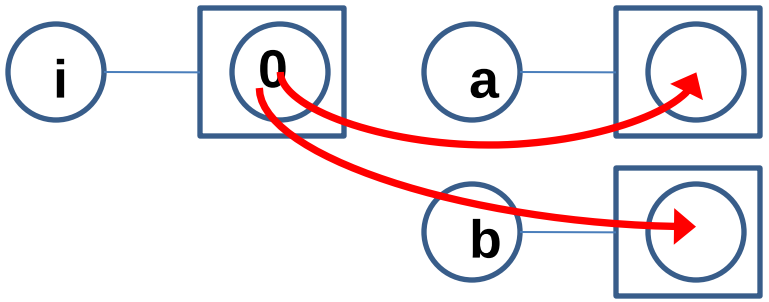
Example: Pass By Value-Result

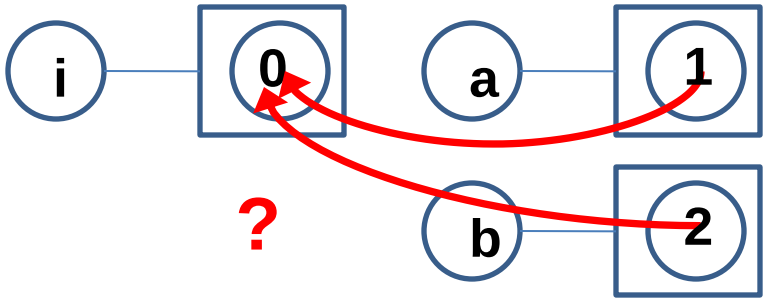
```
void swap(int a, int b) {
   int temp;
   temp = a;
   a = b;
   b = temp;
}
main(){
   int i=1, j=2;
   swap(i,j);
   printf("i=%d, j=%d\n", i, j);
}
```



Unspecified Issues

```
void f(int a, int b) {
   a = 1;
   b = 2;
}
main(){
   int i=0;
   f(i,i);
   printf("i=%d\n", i);
}
```





Pass by Name

- Caller:

```
…
f(i);
…
```

Callee:

```
int f(int a){
    ...a...;
}
```

- Actual parameters only evaluated when they are needed
- The same parameter can be evaluated multiple times
- Evaluated in calling environment
- Callee can change the values of variables used in the argument expression and hence change the expression's value
- Essentially equivalent to normal order evaluation
- Example:
  - Algol 60
  - Not adopted by any major languages due to implementation difficulty

Evaluation Strategy Revisited

- Strict Evaluation
  - the arguments to a function are always evaluated completely before the function is applied
  - eager evaluation
- Non-strict Evaluation
  - the arguments to a function are not evaluated unless they are actually used in the evaluation of the function body
  - short-circuit & lazy evaluation

Strict Evaluation Revisited

- **Applicative order**: the arguments of a function are evaluated from left to right
- **Call by value**: the argument expression is evaluated, and the resulting value is bound to the corresponding variable in the function
- **Call by reference**: a function receives an implicit reference to a variable used as argument
- **Call by sharing** (or object): differing from call-by-reference in that assignments to function arguments within the function are not visible to the caller
- **Call by value-result** (or copy-restore): a special case of call-by-reference where the provided reference is unique to the caller (Fortran & in multiprocessing context)

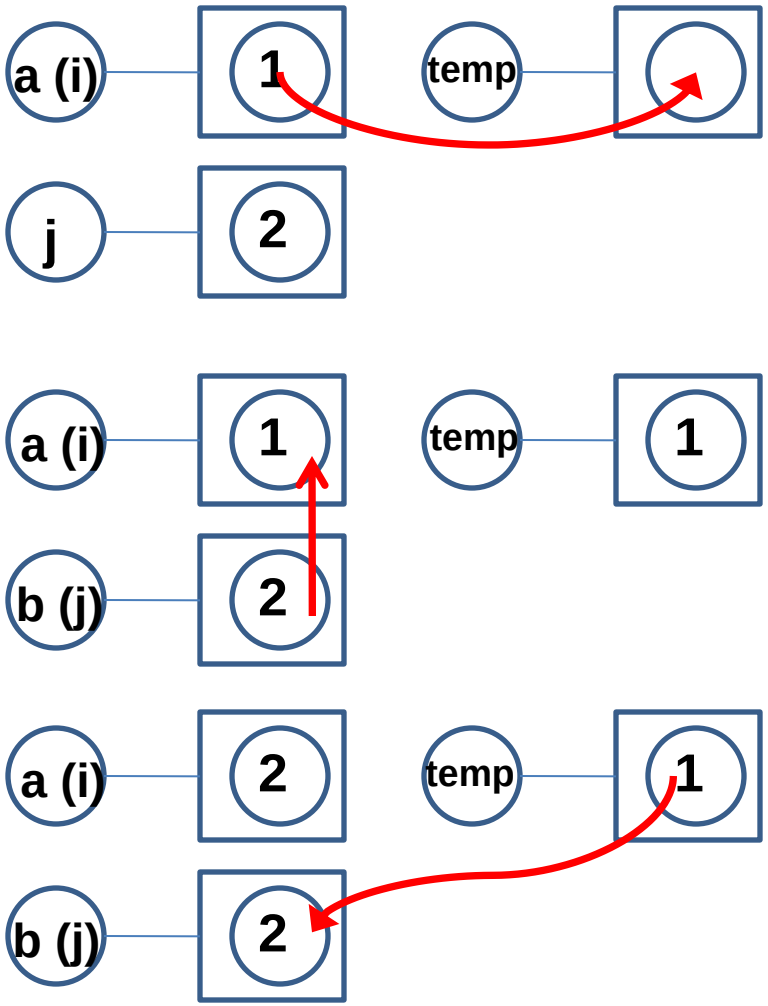
Non-strict Evaluation Revisited

- **Normal order** (or leftmost outermost): the outermost reducible expression is always reduced, applying functions before evaluating function arguments
- **Call by name**: the arguments to a function are not evaluated before the function is called , they are substituted (capture-avoiding) directly into the function body and then left to be evaluated whenever they appear in the function
- **Call by need**: a memoized version of call-by-name where, if the function argument is evaluated, that value is stored for subsequent uses. In pure functional programming, this produces the same results as call-by-name; when the function argument is used two or more times, call-by-need is almost always faster.
- **Call by macro extension**: similar to call-by-name, but uses textual substitution rather than capture-avoiding substitution

Memoization is an optimization technique used to speed up programs by having function calls avoid repeating the calculation of results for previously processed inputs

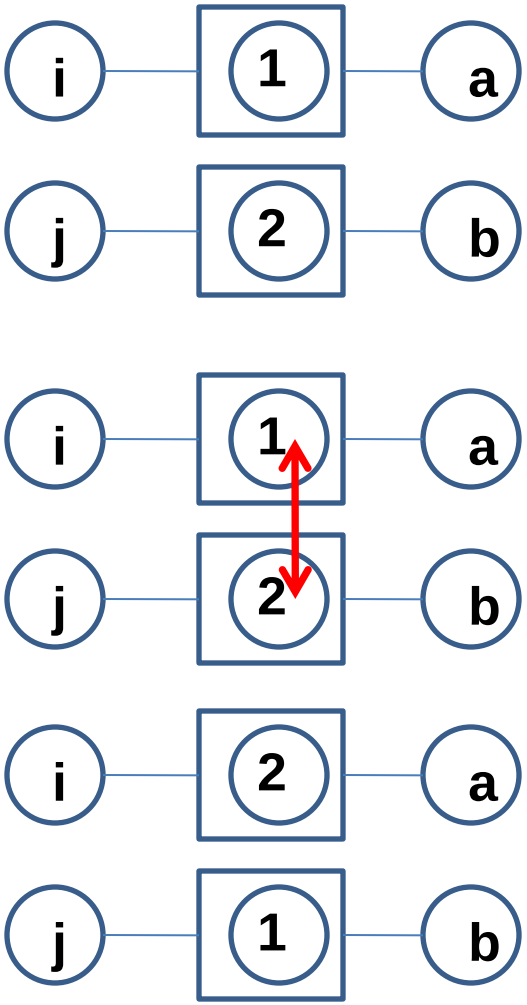
Example: Pass By Name

```
void swap(int a, int b) {
   int temp;
   temp = a;
   a = b;
   b = temp;
}
main(){
   int i=1, j=2;
   swap(i,j);
   printf("i=%d, j=%d\n", i, j);
}
```



Example: Pass By Reference

```
void swap(int &a, int &b) {
   int temp;
   temp = a;
   a = b;
   b = temp;
}
main(){
   int i=1, j=2;
   swap(i,j);
   printf("i=%d, j=%d\n", i, j);
}
```



Pass-by-Name: Side Effects

```
int p[3]={3,2,1};
int i;

void swap(int a, int b) {
   int temp;
   temp = a;
   a = b;
   b = temp;
}
main(){
   i = 1;
   swap(i, p[i]);
   printf("%d, %d\n", i, p[i]);
}
```

```
// call to swap(x,y)
temp = x;
x = y;
y = temp;


// call to swap(i,p[i])
temp = i;
i = p[i];
p[i] = temp;

before call …
i=1 and x[1]=3
after call …
i=3 and x[3]=1
```

- What happens here?

Example: What's the use?

```
double sum(int j, int s, int e, double Ej) {
   double t;
   t = 0;
   for (j=s; j<=e; ) {
        t = t + Ej;
   }
   return t;
}
main(){
   int i=10;
   printf("%f\n", sum(i, 0, 20, x[i]*i);
}
```

Comparisons

- **Call by Value**
  - Efficient. No additional level of indirection.
  - Less flexible and less efficient without pointer.
    - (array, struct, union as parameters)
- **Call by Reference**
  - Require one additional level of indirection (explicit dereferencing)
  - If a parameter is not variable (e.g., constant), a memory space must be allocated for it, in order to get a reference.
  - Easiest to implement.
- **Call by Value-Result**
  - You may not want to change actual parameter values when facing exceptions.
- **Call by Name**
  - Lazy evaluation
  - Difficult to implement