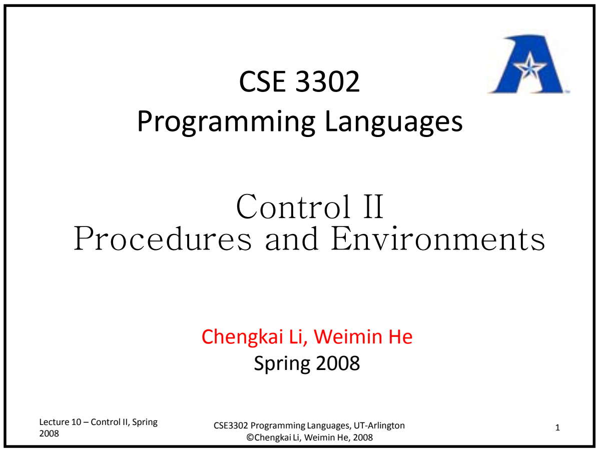

CSE 3302
Programming Languages

Control II
Procedures and Environments

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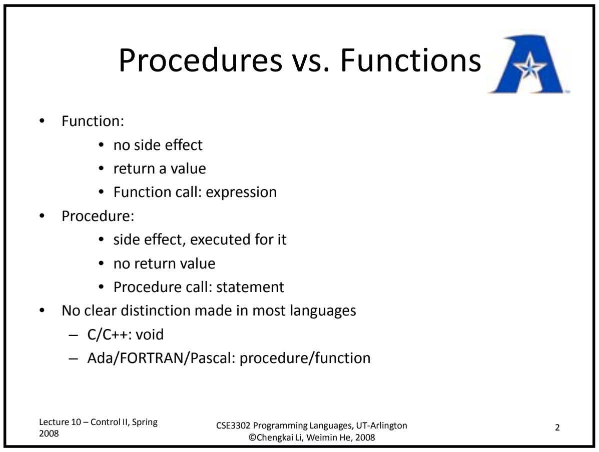
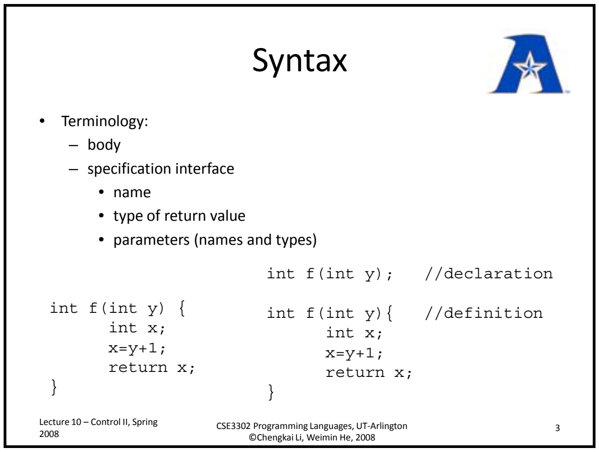
Spring 2008



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



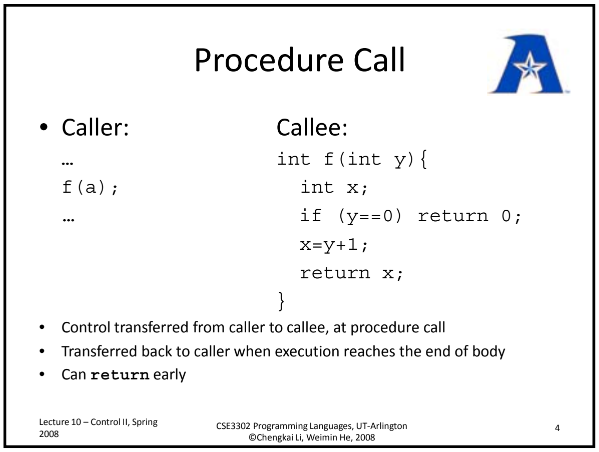
Syntax

- 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

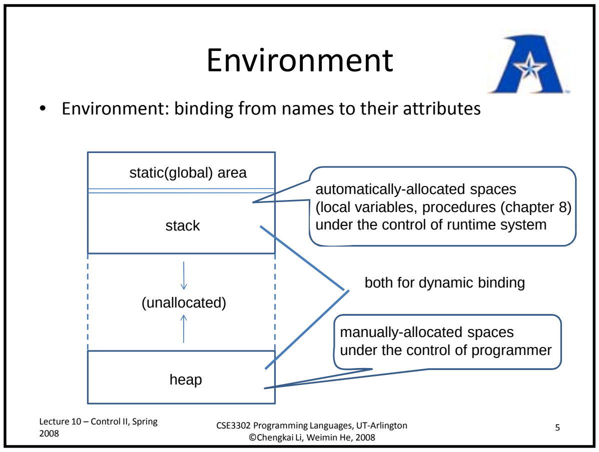
- Caller:

```
…
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

static(global) area

stack

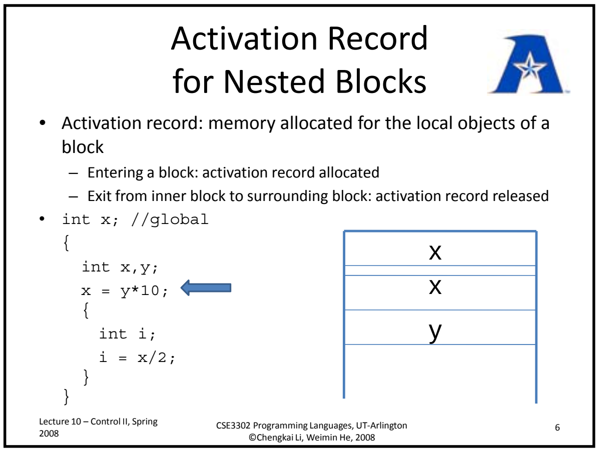
(unallocated)

heap

automatically-allocated spaces (local variables, procedures (chapter 8) under the control of runtime system

both for dynamic binding

manually-allocated spaces under the control of programmer



Activation Record for Nested Blocks

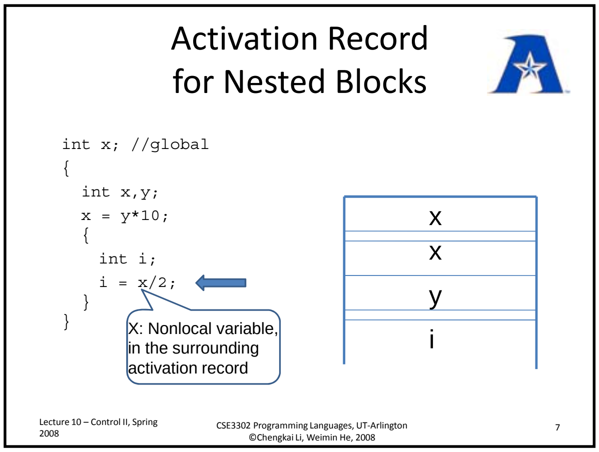
- Activation record: memory allocated for the local objects of a block
  - Entering a block: activation record allocated
  - Exit from inner block to surrounding block: activation record released

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

x

x

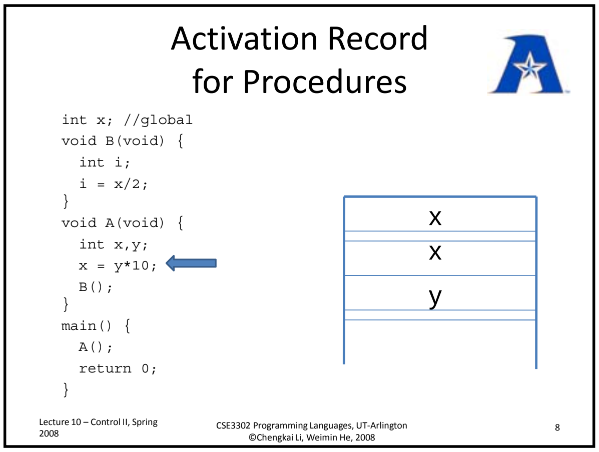
y



Activation Record for Nested Blocks

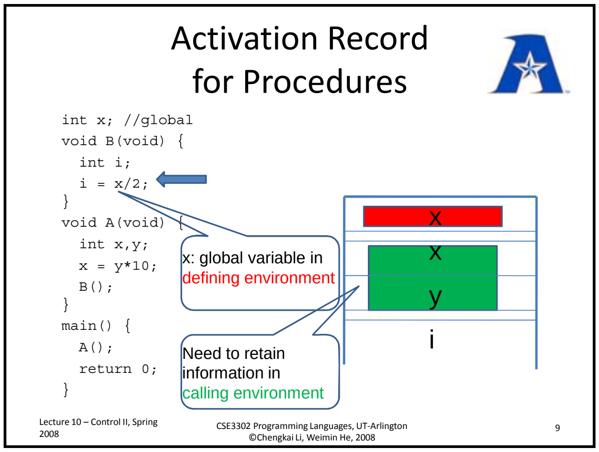
```
int x; //global
{
  int x,y;
  x = y*10;
  {
    int i;
    i = x/2;
  }
}
```

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;
}
```

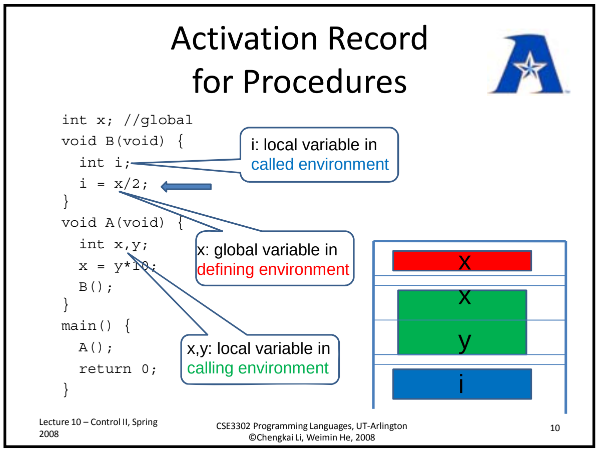


Activation Record for Procedures

```
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



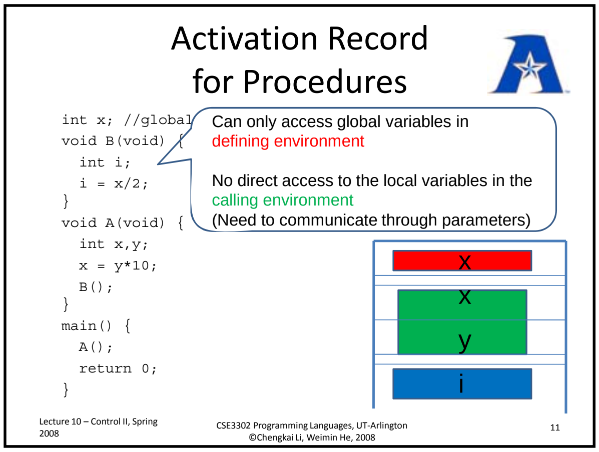
Activation Record for Procedures

```
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

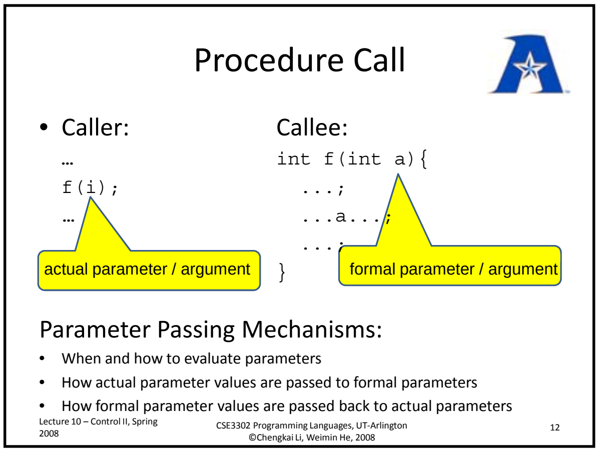


Activation Record for Procedures

```
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…

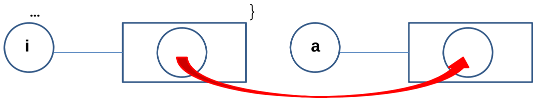
Pass by Value

- Caller:

```
…
f(i);
…
```

Callee:

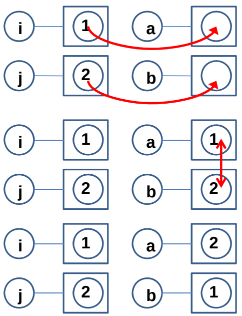
```
int f(int a){
    ...a...;
}
```



- 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:

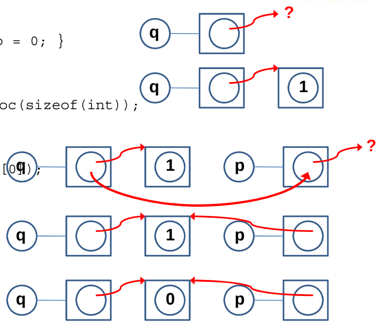
```
void f(Vector v) { v.removeAll(); }
```

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?

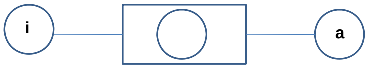
Pass by Reference

- Caller:

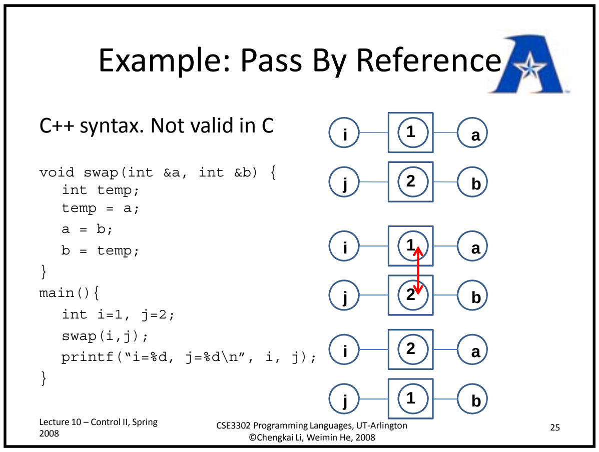
```
…
f(i);
…
```

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`)

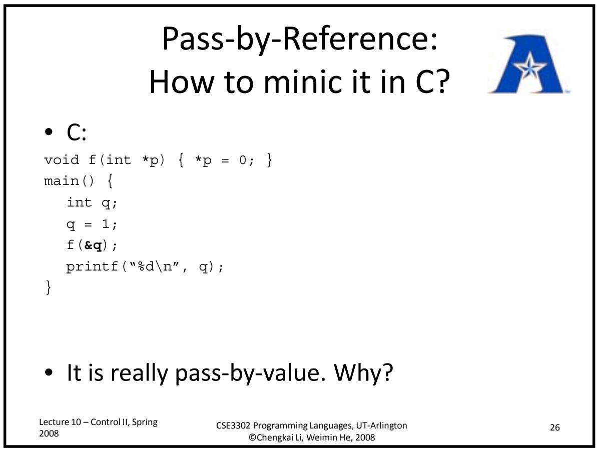


Example: Pass By Reference

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);
}
```

i
1
a
j
2
b
i
1
a
j
2
b
i
2
a
j
1
b

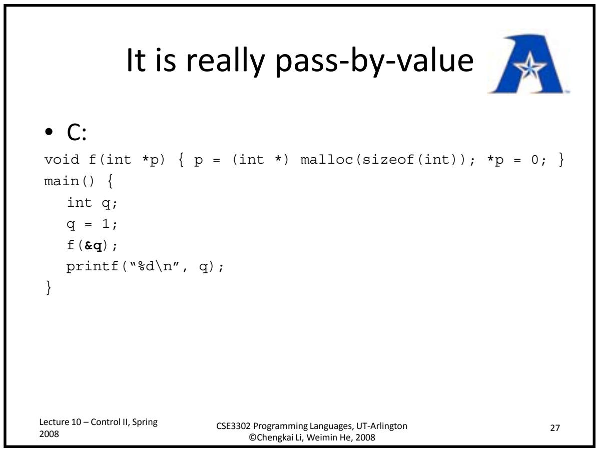


Pass-by-Reference: How to minic it in C?

- C:

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

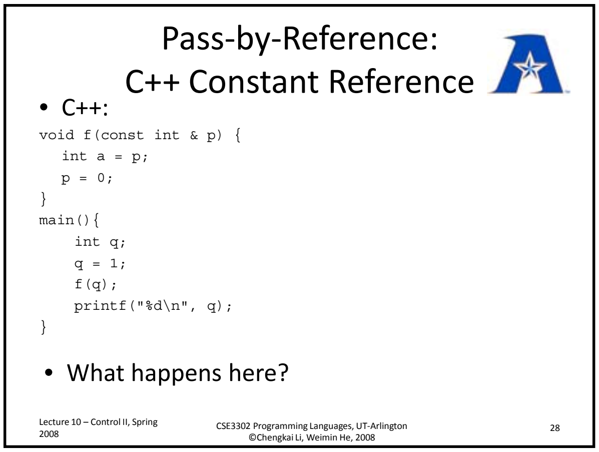
- It is really pass-by-value. Why?



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);
}
```

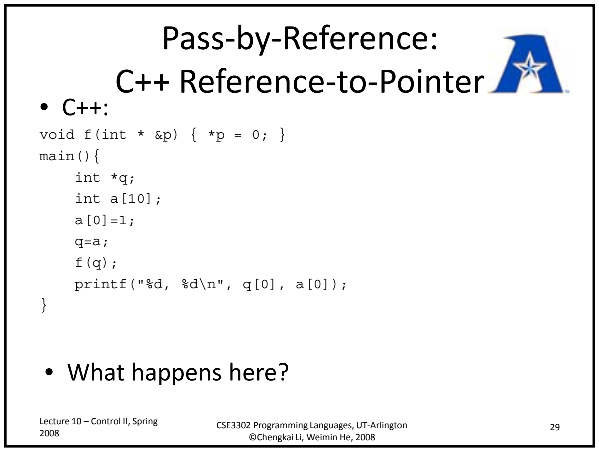


Pass-by-Reference: C++ Constant Reference

- C++:

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

- What happens here?

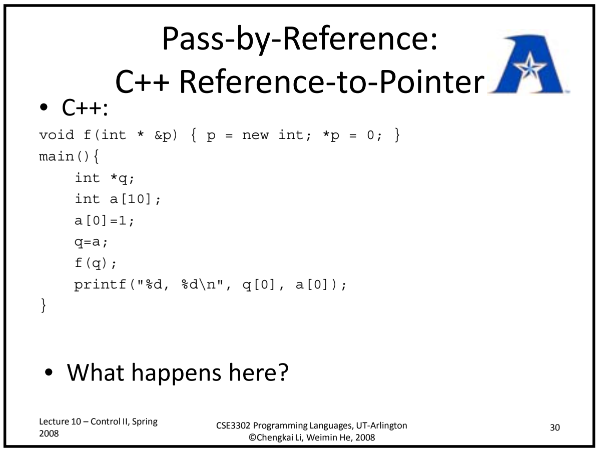


Pass-by-Reference: C++ Reference-to-Pointer

- 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]);
}
```

- What happens here?

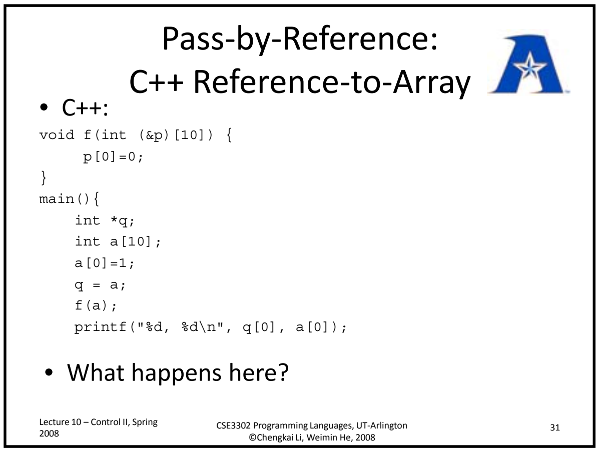


Pass-by-Reference: C++ Reference-to-Pointer

- 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]);
}
```

- What happens here?

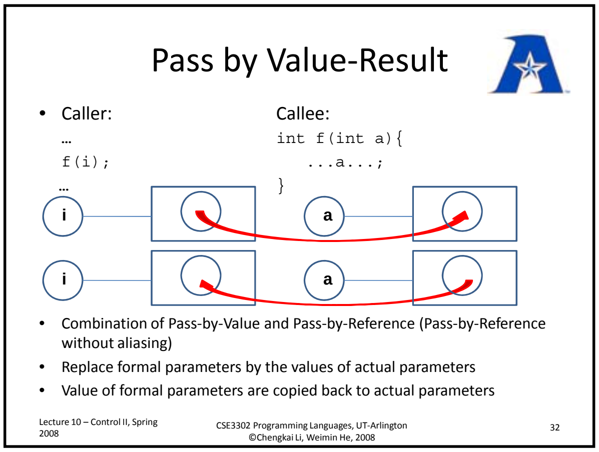


Pass-by-Reference: C++ Reference-to-Array

- 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]);
```

- What happens here?



Pass by Value-Result

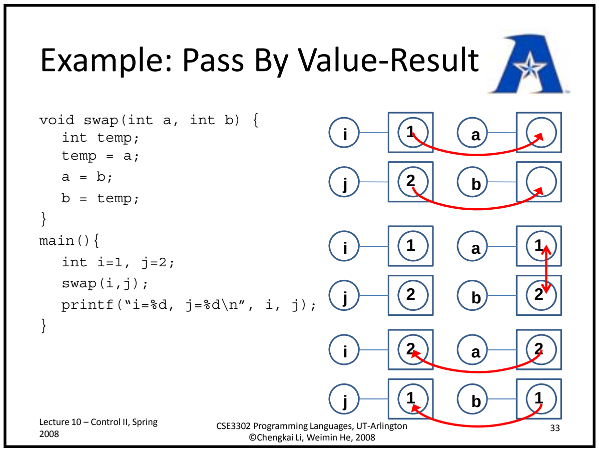
- Caller:

```
…
f(i);
…
```

Callee:

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

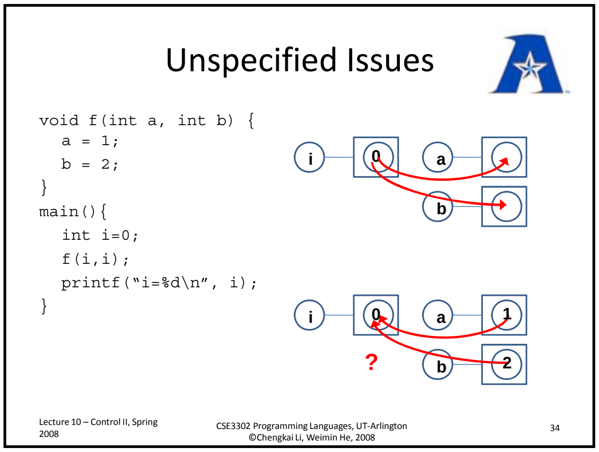
- Combination of Pass-by-Value and Pass-by-Reference (Pass-by-Reference without aliasing)
- Replace formal parameters by the values of actual parameters
- Value of formal parameters are copied back to actual parameters



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);
}
```

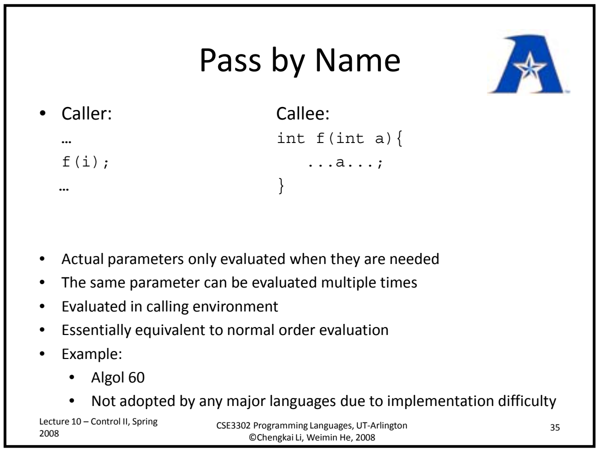
i
1
a
j
2
b
i
1
a
1
j
2
b
2
i
2
a
2
j
1
b
1



Unspecified Issues

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

i
0
a
b
i
0
a
1
?
b
2



Pass by Name

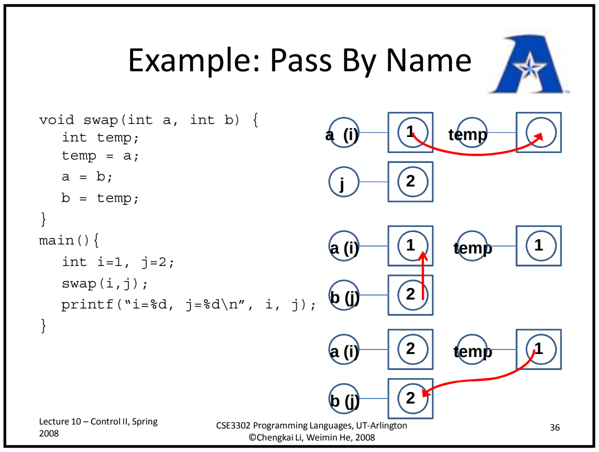
- Caller:

```
…
f(i);
…
```

Callee:

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

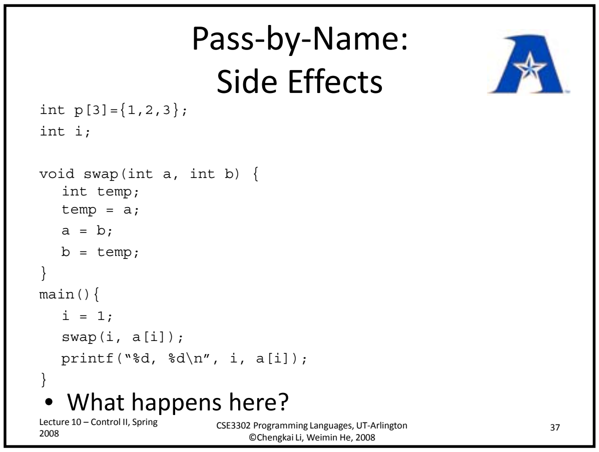
- Actual parameters only evaluated when they are needed
- The same parameter can be evaluated multiple times
- Evaluated in calling environment
- Essentially equivalent to normal order evaluation
- Example:
    - Algol 60
    - Not adopted by any major languages due to implementation difficulty



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);
}
```

a (i)
1
temp
j
2
a (i)
1
temp
1
b (j)
2
a (i)
2
temp
1
b (j)
2

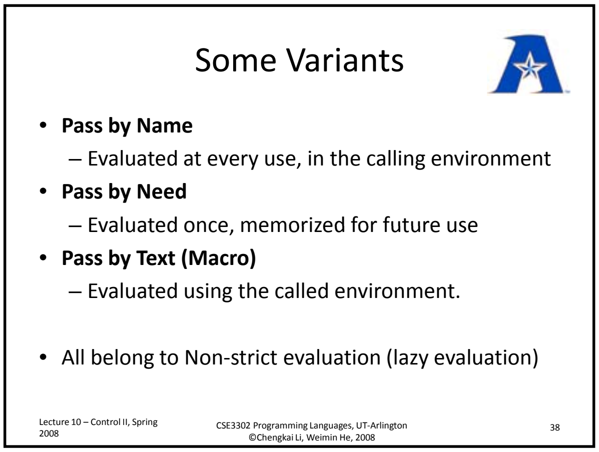


Pass-by-Name: Side Effects

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

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

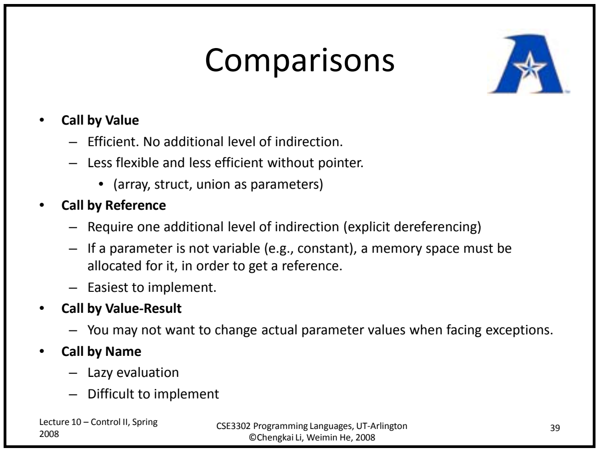
- What happens here?



Some Variants

- **Pass by Name**
  – Evaluated at every use, in the calling environment
- **Pass by Need**
  – Evaluated once, memorized for future use
- **Pass by Text (Macro)**
  – Evaluated using the called environment.

- All belong to Non-strict evaluation (lazy evaluation)



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