deep se
dependable evolvable pervasive software engineering group

Pointers, References and Functions Parameters

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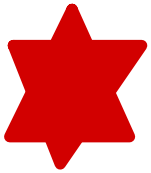
POLITECNICO DI MILANO

Pointers

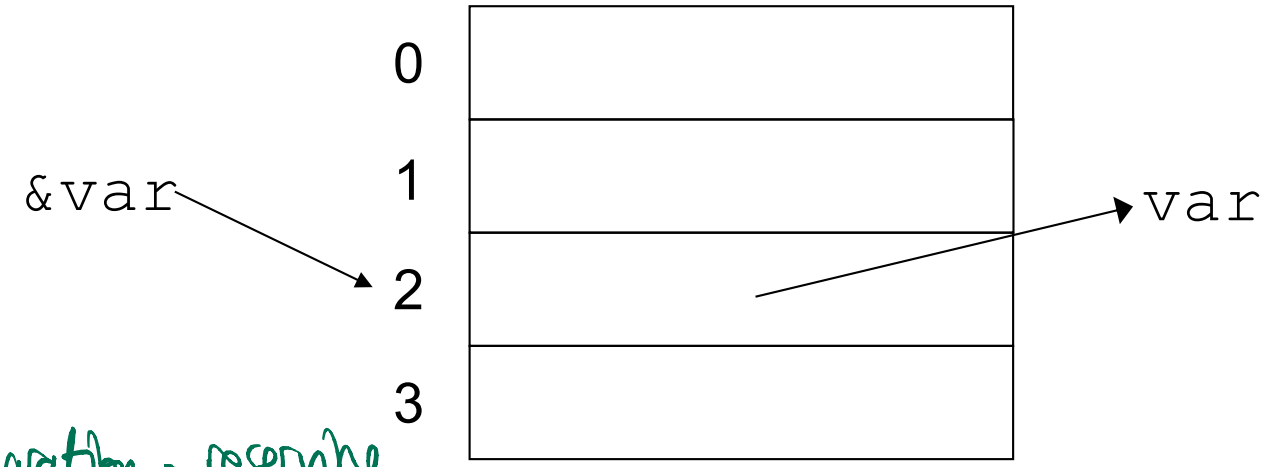
- Declaring a variable means reserving a memory area including several locations
- The number of locations depends on the type of data (e.g., integer 2 bytes, float 4 bytes, ...)
- Each memory location has a physical address and:
  - The name of the variable indicates the contents of the memory location
  - The operator & allows obtaining the memory address of the location associated with the variable to which the operator is applied

of next slide



Variables and Memory

```
int var;
```



declaration = reserving
↑ a memory address.

- Suppose the declaration reserves the memory area at address 2
- `var` indicates the content of the memory location
- `&var` indicates the memory address

↓

"&" = indicating the memory address.

Pointers

- Pointer variables store memory addresses
  - A pointer `p` can hold the address of a memory location
  - Think of them as a kind of integer values

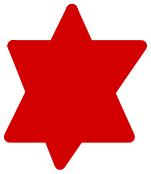
- When declaring a pointer you must also specify what type of object the pointer points to

- Syntax:

```
double *p;
```

"type * name_of_pointer"

- A pointer variable usually requires 2 bytes or 4 bytes depending on the architecture



Dereferencing a pointer

- You can apply the dereferencing * operator to a pointer variable
- *p indicates the content of the location pointed by p
- If p is a pointer to an integer then *p is a simple integer variable

Example

```
int * p;        //declaration of the pointer
 // some code

*p = 5;  // OK. * p is an integer
p = 5;  // error, p is a pointer , whereas 5 is an int
```

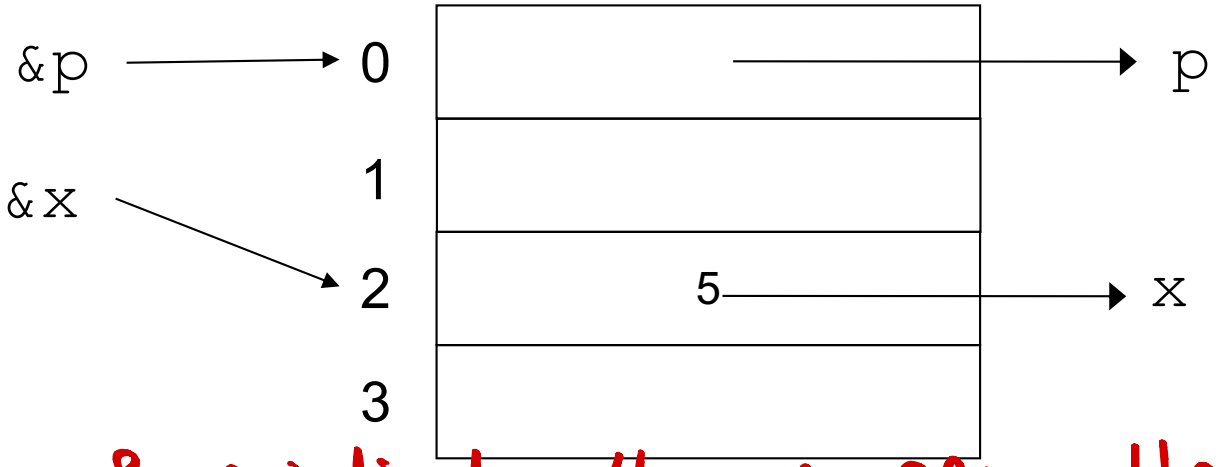
- Warning! The symbol * is used both in the declaration and in the dereferencing

Operations

- We can store in a pointer variable the address of another variable

```
int x;
int *p;

x=5;
p=&x;  // *p is 5
```



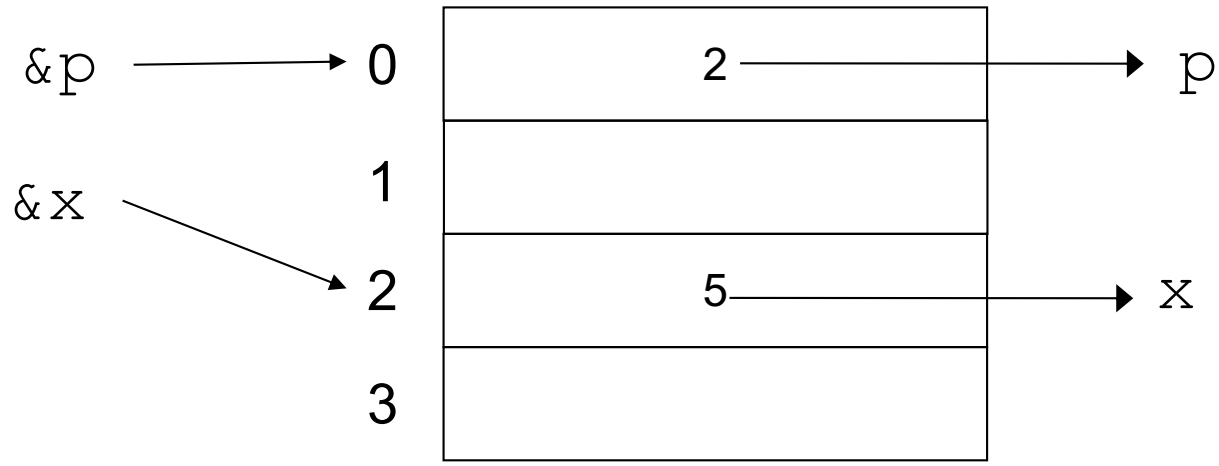
remember: &var indicates the memory address of the variable var.

- `p` will point to the memory area where the value of `x` is stored
- A pointer's type determines how the memory referred to by the pointer's value is used
  - e.g., what an `int*` points to can be added but not, say, concatenated

Operations

- What happens if we perform the assignment?

```
*p=7;
```

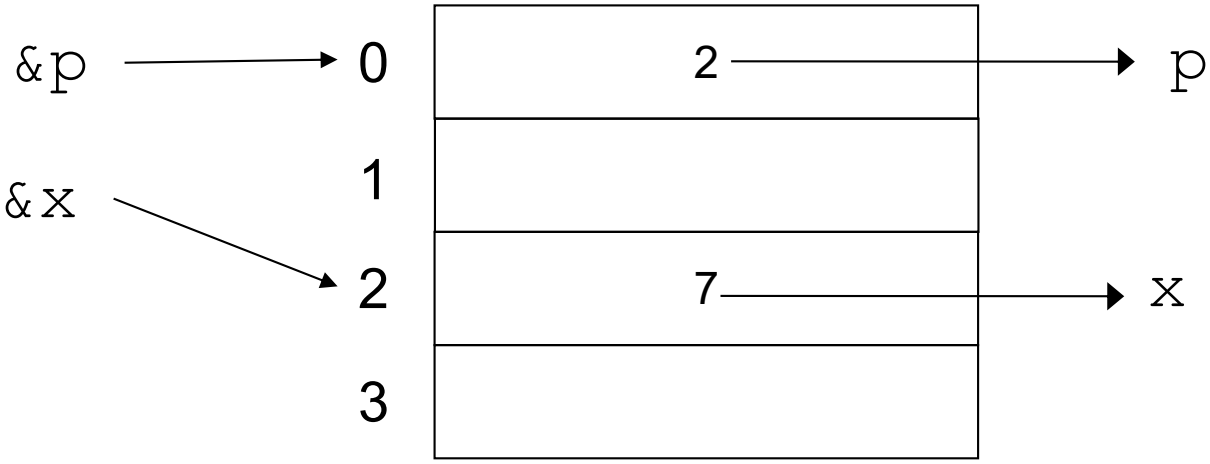


cf last slide, p is a pointer which points @ the memory address &x.

Operations

- What happens if we perform the assignment?

```
*p=7;  // x get 7!
```



given what we just wrote (cf previous slide), x gets 7.

Function Parameters

Recap: Why functions?

- Chop a program into manageable pieces
  - “divide and conquer”
- Match our understanding of the problem domain
  - Name logical operations
  - A function should do one thing well
- Functions make the program easier to read
- A function can be useful in many places in a program
- Ease testing, distribution of labor, and maintenance
- Keep functions small
  - Easier to understand, specify, and debug

Functions

- General form:
  - return_type name (formal arguments); // a declaration
  - return_type name (formal arguments) {body} // a definition
  - For example:

```
double f(int a, double d);
double f(int a, double d) { return a*d; }
```

- Formal arguments are often called parameters

- If you don't want to return a value give void as the return type

```
void increase_power_to(int level);
```

Here, void means "doesn't return a value"

- A body is a block
  - { /* code */ } // a block

Function Parameters

```
double circ(double radius) {
   double res;
   res = radius * 3.14 * 2;
   radius = 7; // No sense instruction, let's see what happens to radius
   return res;
}

// somewhere in the main
double c;
double r=5;

c = circ(r);
```

Function Parameters

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double circ(double radius) {
   double res;
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   return res;
}
```

Formal parameter

```
// somewhere in the main
double c;
double r=5;

c = circ(r);
// r is still 5.0
```

A

- Pass by value:
  - Actual parameter copied within the formal parameter
- Pass by reference
  - Formal and actual parameter are the same object
  - We can return multiple results from functions!

Two ways of passing arguments.

Function Parameters

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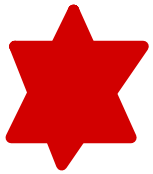
Formal parameter

Actual parameter

YOU HAVE TO DISTINGUISH BETWEEN "actual parameter" & "formal parameter"



Formal and Actual parameters

- In a function definition we use **formal parameters** **representing a symbolic reference** (identifiers) to objects used within the function
  - `radius` is a formal parameter
  - They are used by the function as if they were local variables

the one in the definition of the function.

- The initial value of formal parameters is defined when the function is called using the **actual parameters** specified by the caller
  - `r` in our running example

the one "with the true value", when you call the function.

Parameters Passing

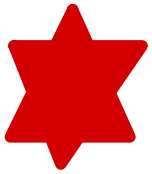
- In a function call, parameters passing consists in associating the actual parameters with the formal parameters
- If the function prototype is:

```
double circ (double radius);
```

- If we write:

```
c = circ (5.0);
```

- `radius` (the formal parameter) will assume the value 5.0 (the actual parameter) for that particular invocation
- The exchange of information with the passing of parameters between caller and callee can take place in two ways:
  - Pass by value
  - Pass by reference



Pass by value

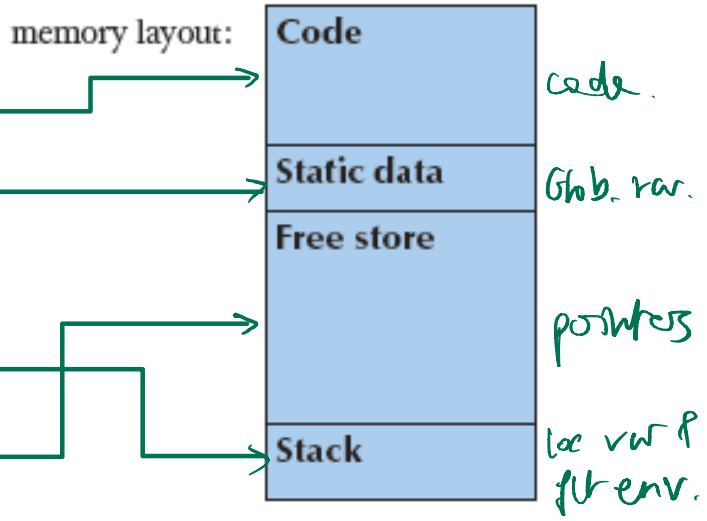
- At the time of the function call, the value of the actual parameter is **copied** into the memory location of the corresponding formal parameter. In other words, the formal parameter and the actual parameter refer to **two different memory locations**

- The function works in its **environment** and therefore on formal parameters

- The actual parameters are not changed

The computer's memory

- As a program sees it
  - The executable code is in "the code section"
  - Global variables are "static data"
  - Local variables and function environments "live on the stack"
  - "Free store" is managed by `new` and `delete` (which work with memory addresses, i.e., are used with pointer variables)



Pass by value example

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double c;
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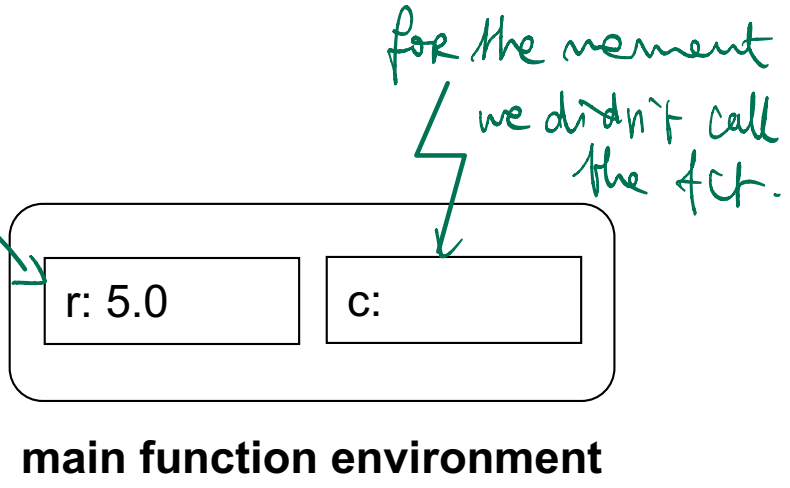

main function environment

- Functions environment are stored in the Stack
- The same mechanism is used to store block variables

Pass by value example

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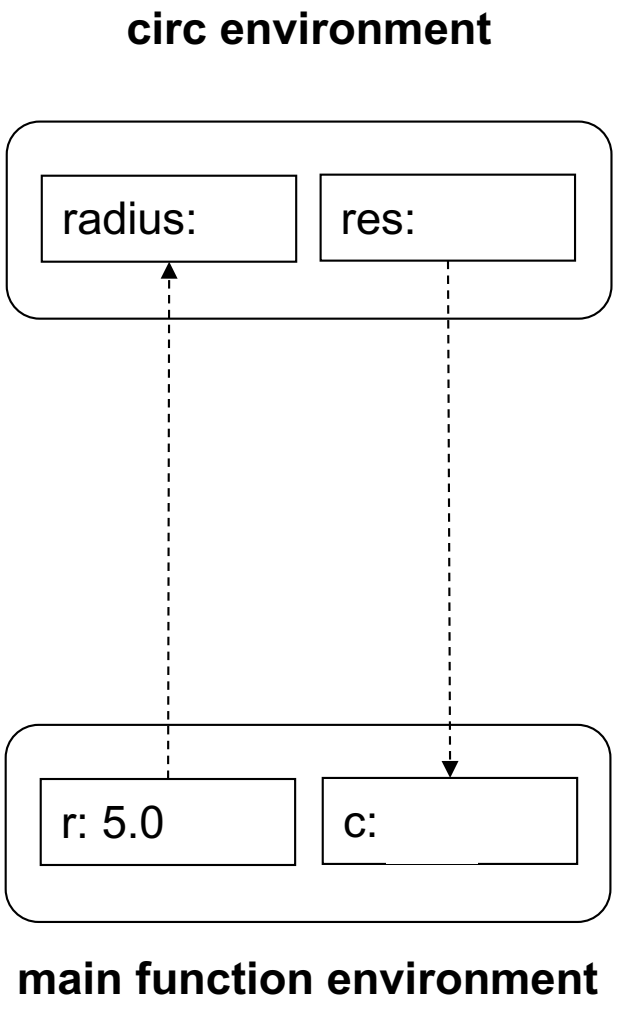

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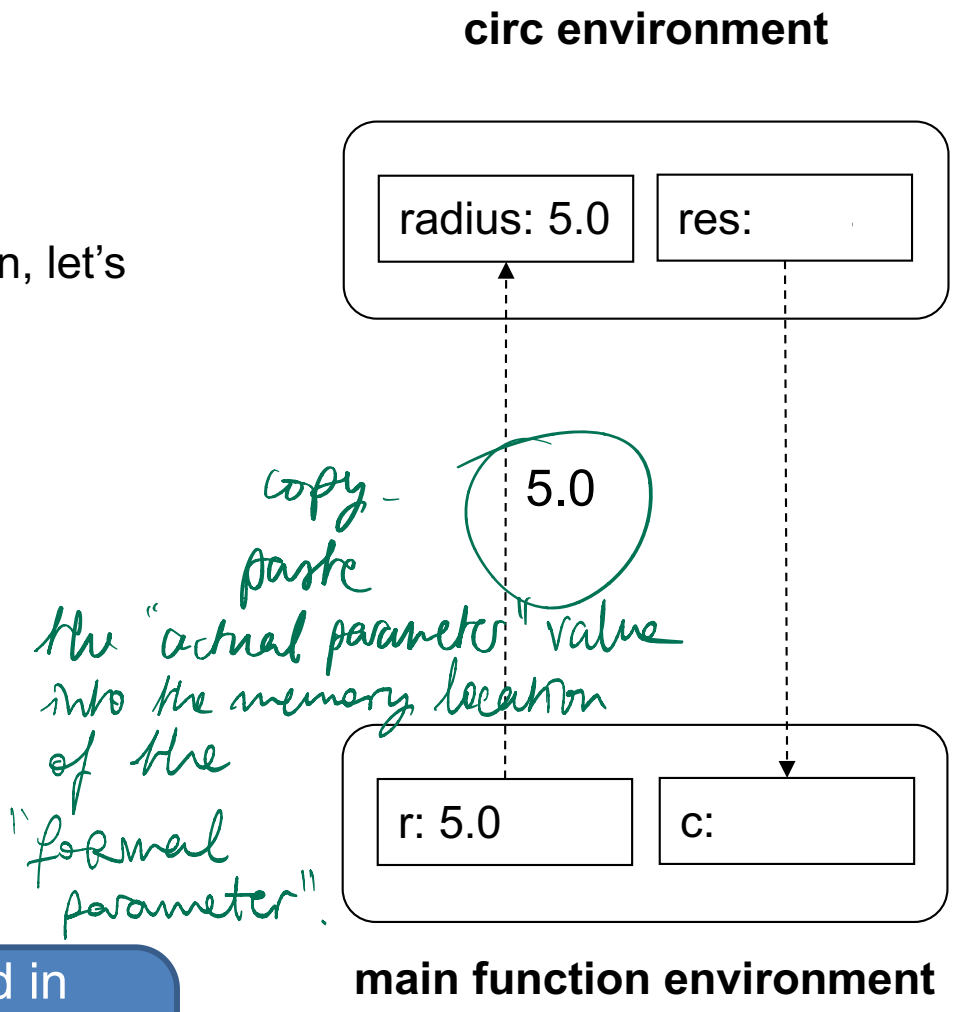

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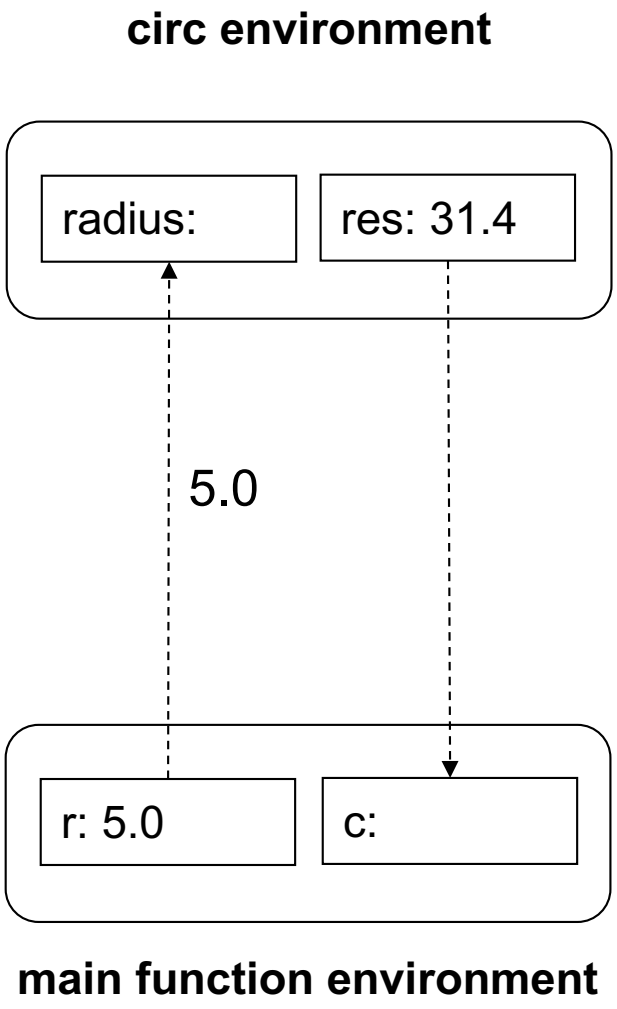

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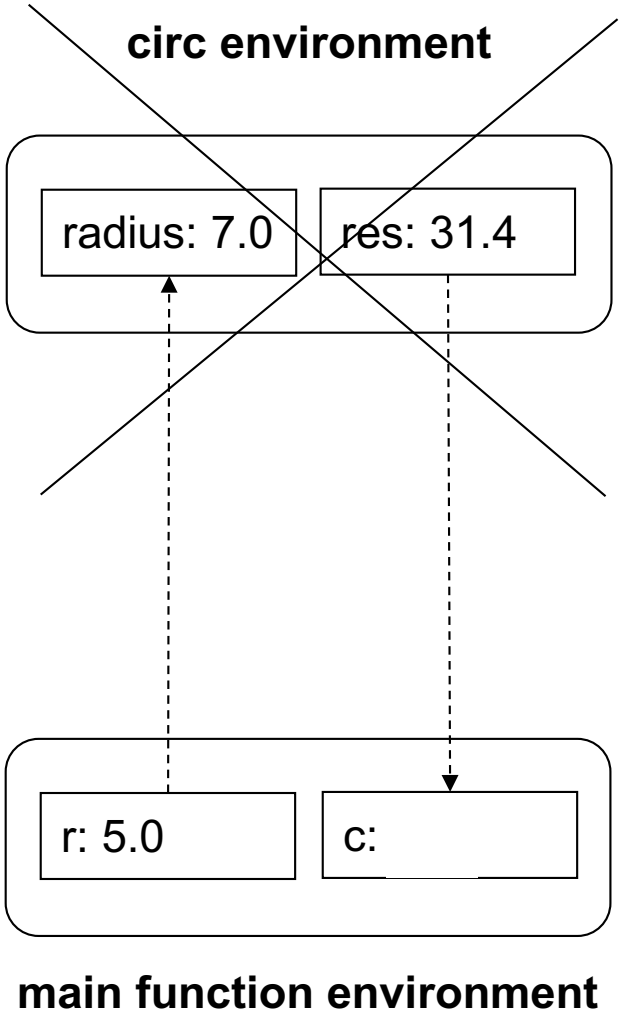
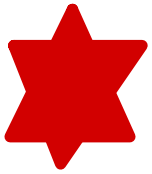
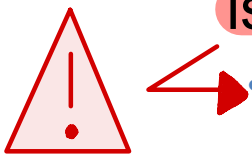




Pass by reference



- At the time of the call the address of an actual parameters is associated with the formal parameters
  - In other words, the actual parameter and the formal parameter **share the same memory location**

) This is where it's ≠ from pass by value.

- The running function works in its environment on the formal parameters (and consequently also on the actual parameters) and **each change** on the **formal parameter** is **reflected** to the corresponding **actual parameter**

) since they have the same memory locat°.

- The function execution effects the caller with modifications to its the caller environment
  - In this way we can return multiple results!

Parameters passing in C

- In C there is no syntax mechanism to distinguish between parameters passing by value and by address
- Parameters passing is always by value:

```
double circ(double radius);
                    /*pass by value*/
```

- To implement pass by reference we need to rely on pointers

```
double circ(double *radius );
                    /*pass by reference*/
```

Pass by reference

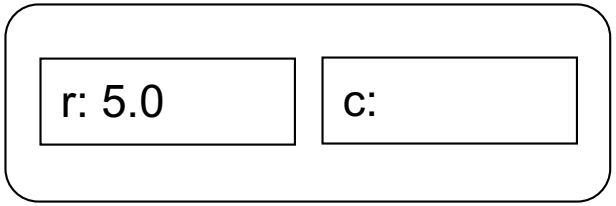
- We need:
  - A pointer for each formal parameter
  - The dereference operator in the function body to access the actual parameter
  - In the function call, the address of the actual parameter is used
- Warning! Arrays are always passed by reference
  - The name of an array variable, is an address, i.e., it is a pointer!
  - Why?
    - Efficiency!

Pass by reference example

```
double circ(double *radius) {
   double res;
   res = *radius * 3.14 *2;
   *radius = 7; /* No sense instruction, let's see
     what happens to radius */
   return res;
}

// somewhere in the main
double c;
double r = 5;

c = circ(&r);
```



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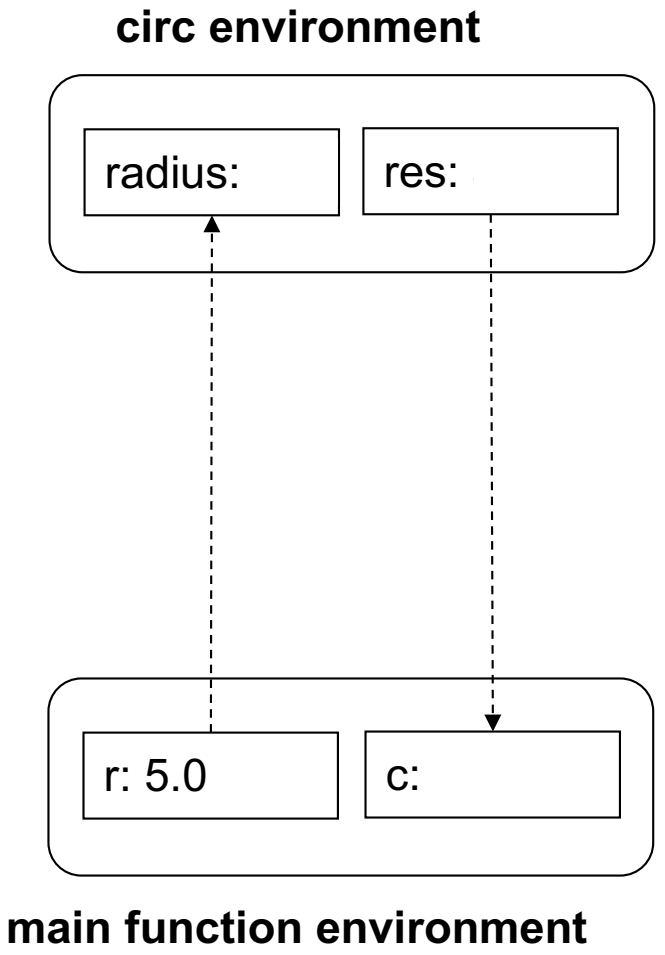

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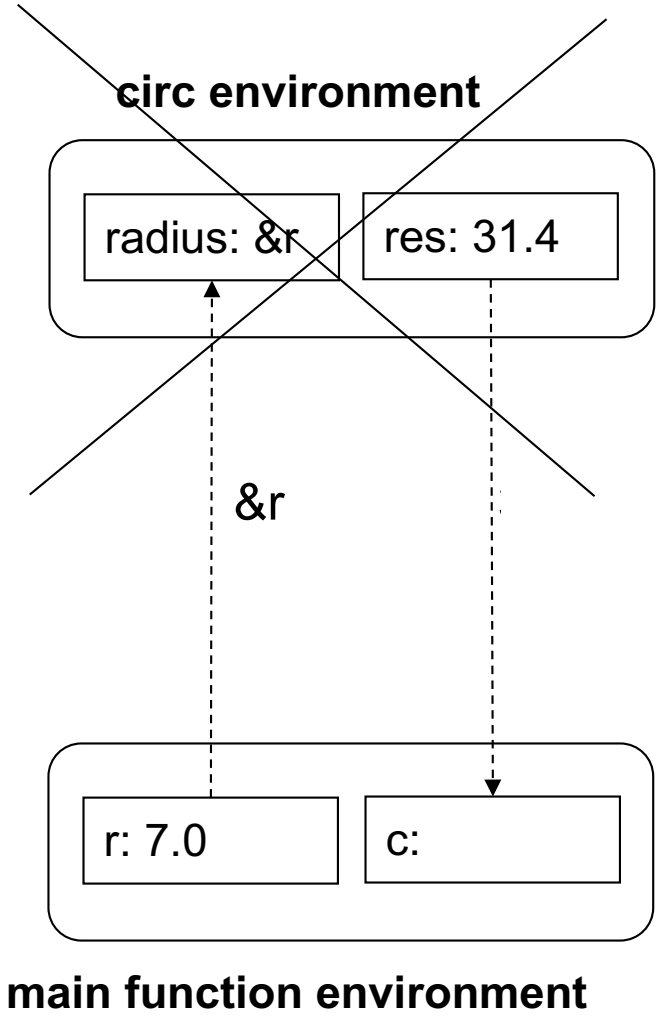
// somewhere in the main
double c;
double r=5;

c=circ(&r);
//Warning! Now r is 7.0
```

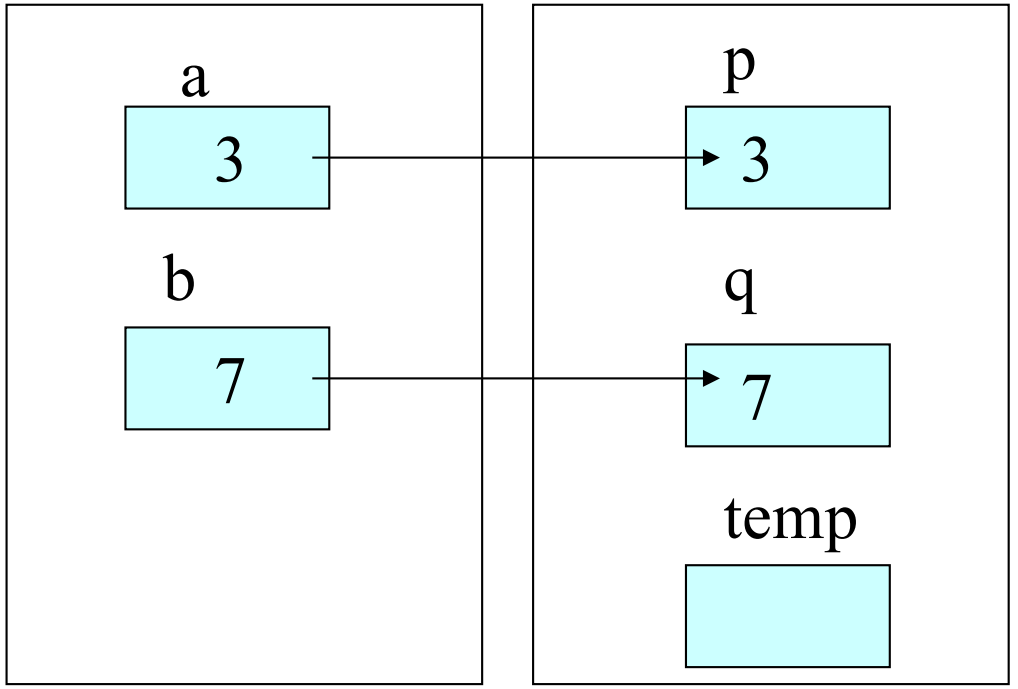
What about circ(22.0);?



Example: swap of 2 ints

```
void swap (int p, int q) {
      int temp;
      temp = p;
      p = q;
      q = temp;
}
```

In main: `swap(a,b)`



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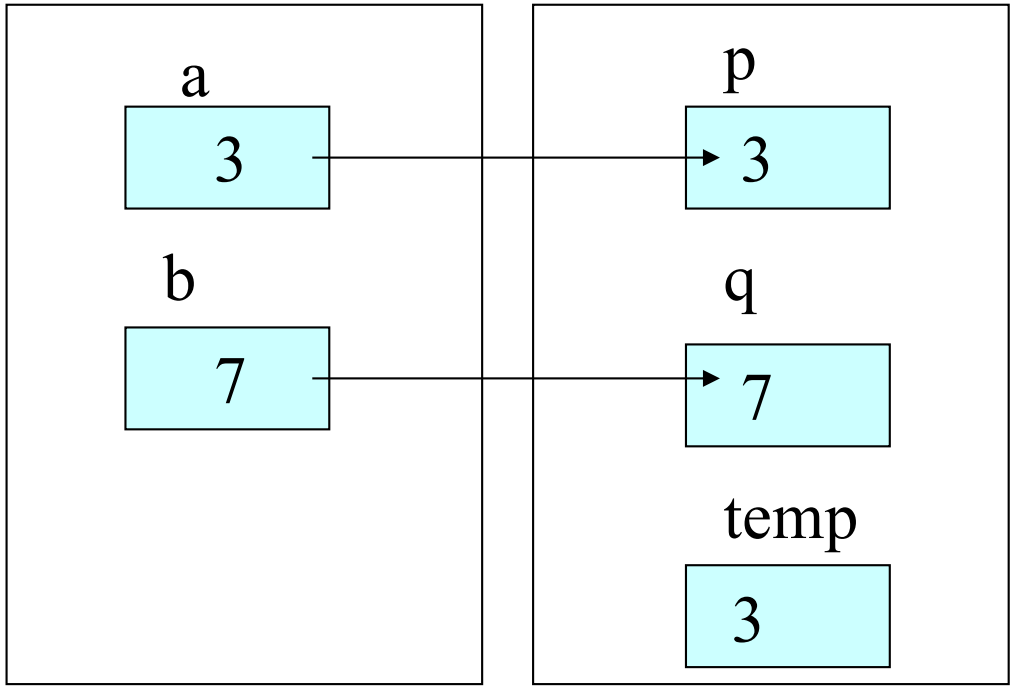

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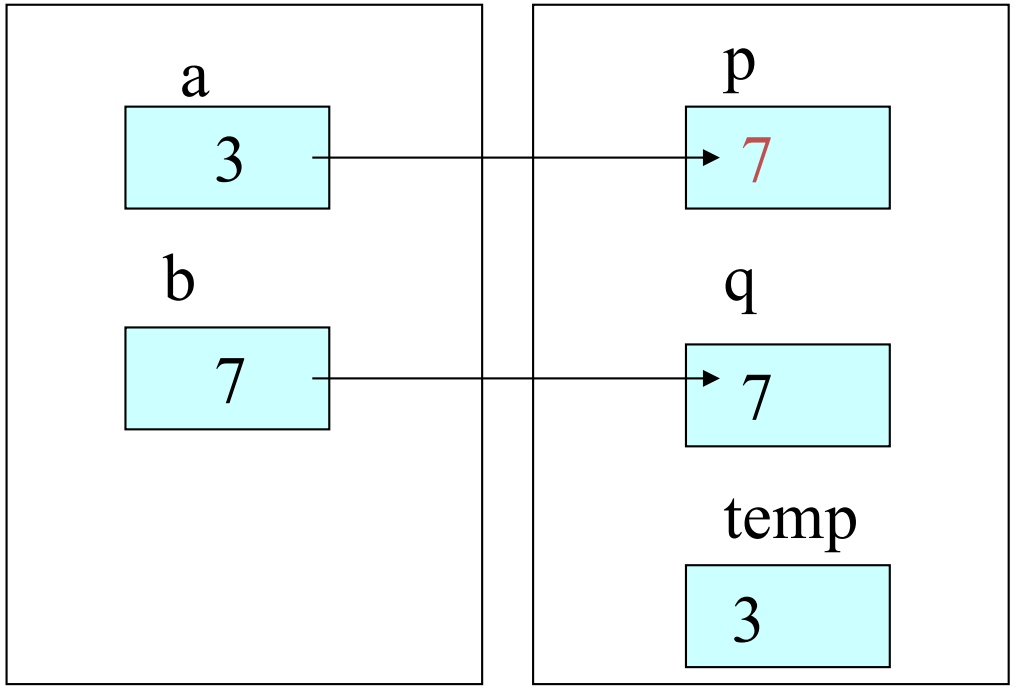

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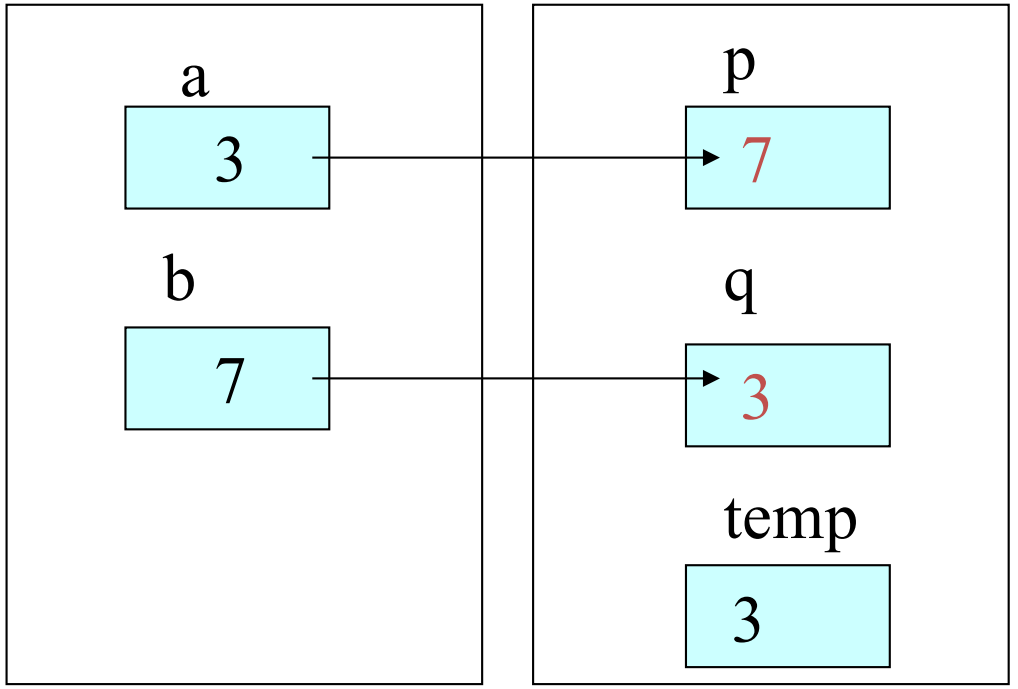

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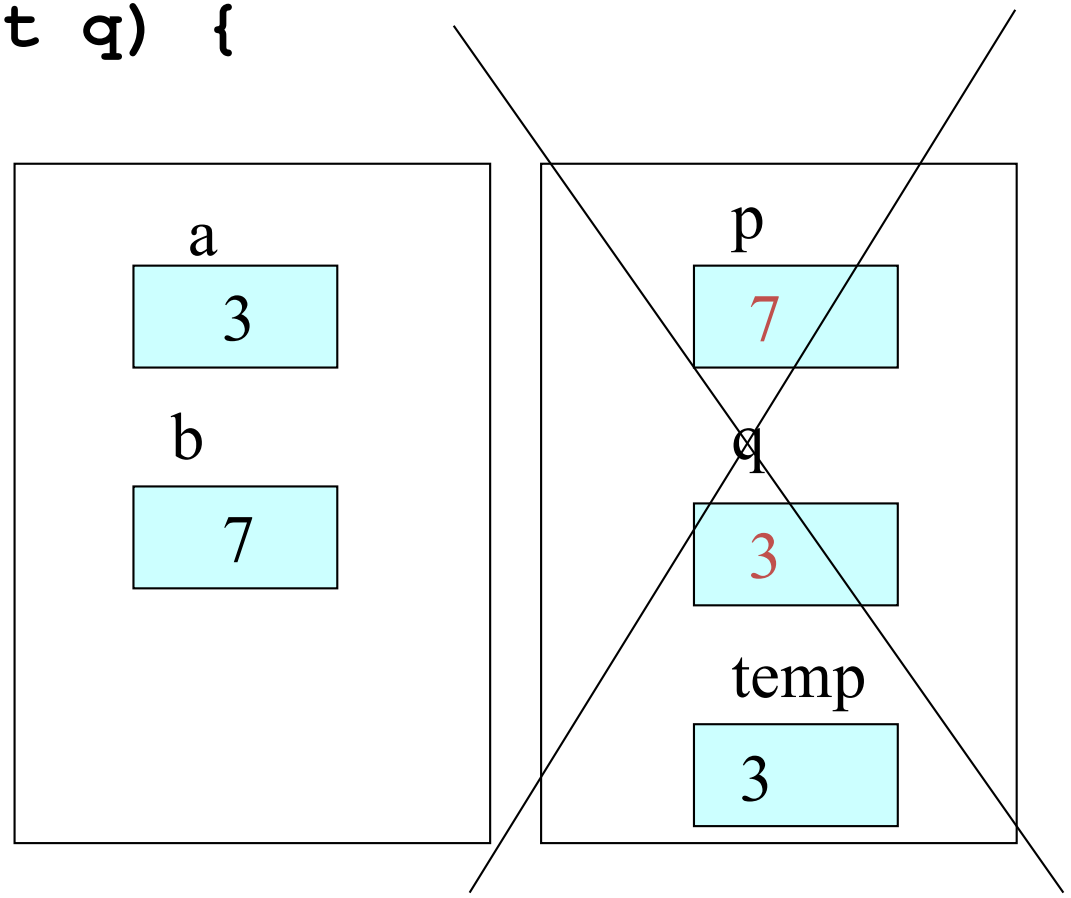

At the end of swap main variables are **unchanged**!

Example: swap of 2 ints

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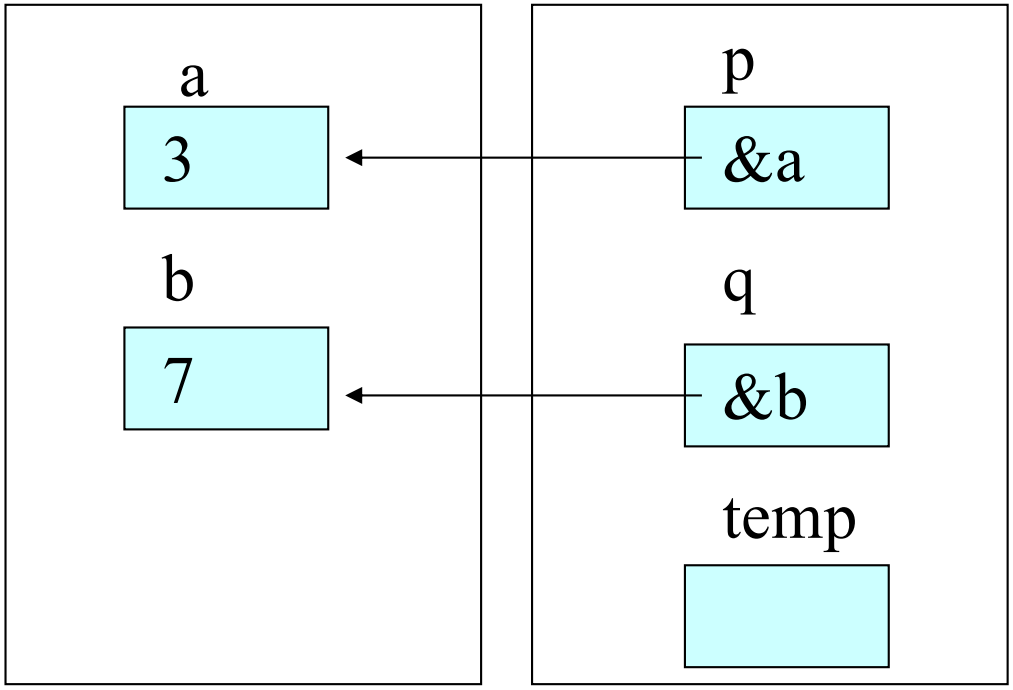
In main: `swap(&a, &b)`



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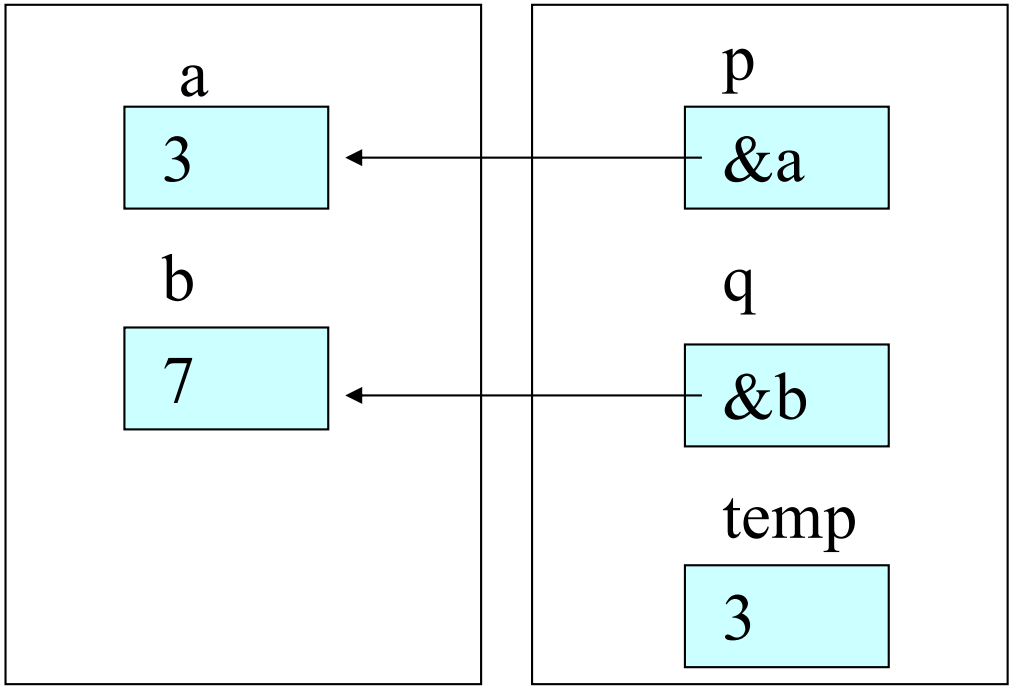

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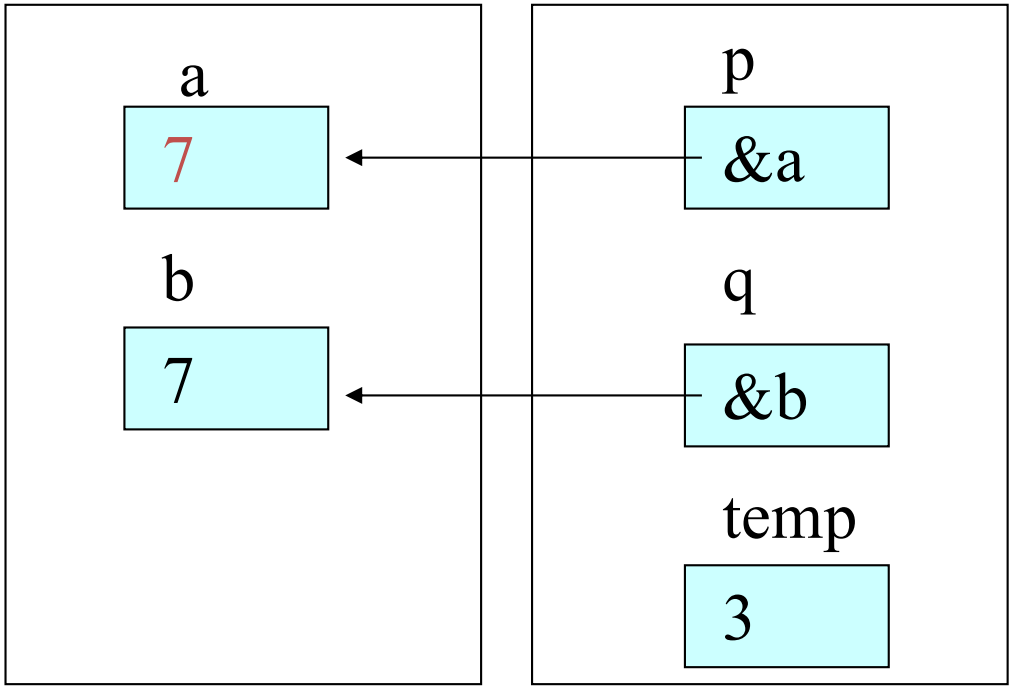

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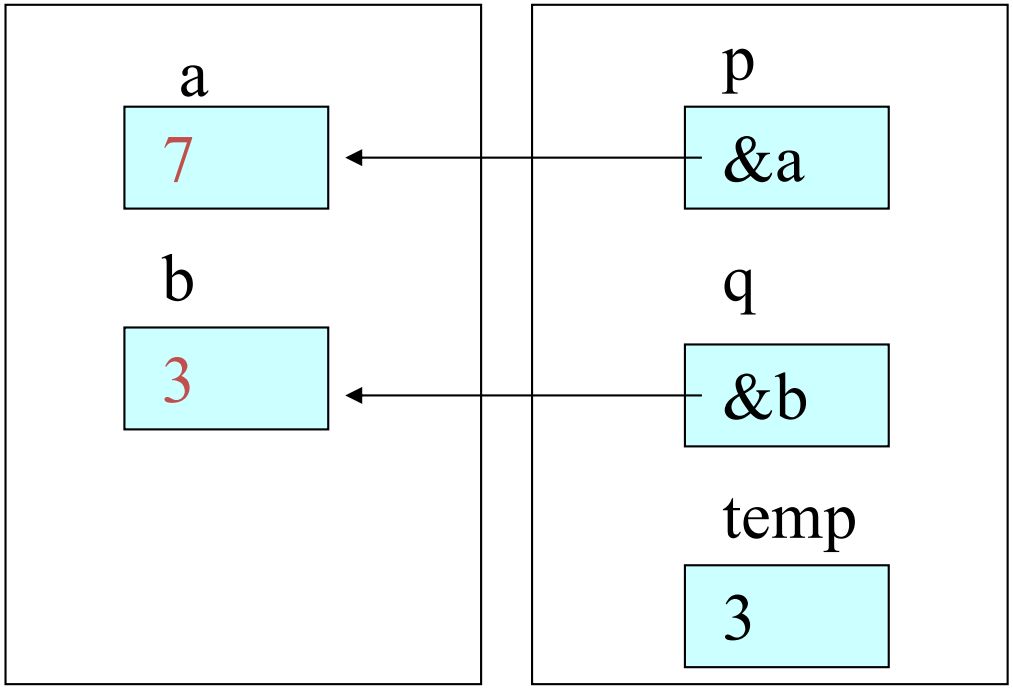

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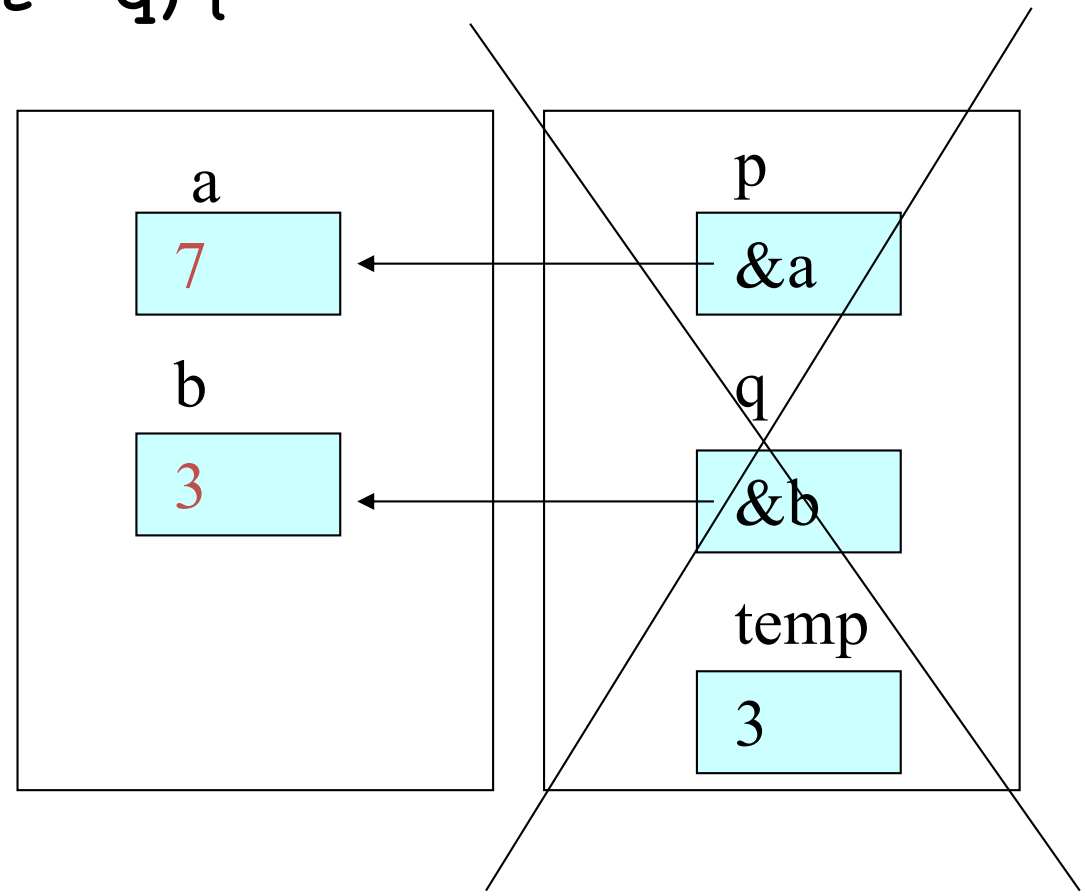
}
```



In main: `swap(&a, &b)`

At the end of swap main variables are **changed**!

```
1
2
3
4
5  #include <iostream>
6
7  void cube( int * nPtr );    /* prototype */
8
9  void main()
10 {
11    int number = 5;
12
13    std::cout << "The original value of number is " << number;
14    cube( &number );
15    printf( "\nThe new value of number is %d\n"
16
17
18 }
19
20 void cube( int *nPtr )
21 {
22    *nPtr = *nPtr * *nPtr * *nPtr;
23 }
```

cube requires a pointer!!

In cube, ***nPtr** is used (***nPtr** is **number!**)

```
The original value of number is 5
The new value of number is 125
```

From functions to procedures

- function:

```
int f(int par1)
{
… (compute integer result") …
return result;
}
```

call:

```
y=f(x);
```

- void function:

```
void f(int par1,int *par2)
{
… (compute integer result) …
*par2=result;
}
```

call:

```
f(x,&y);
```

y gets the proper result value

If we need to return multiple values…

```
void f(int in_par1, …, int in_parn, int *out_par1, int *out_parn,)
{
… (compute integer results) …
*out_par1=result1;
…
*out_parn=resultn;
}
```

Call (one input parameter, two output parameters):

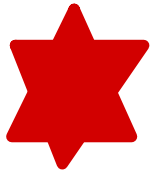
```
f(x,&y,&z);
```

y, z get the proper result values

Pass by value and pass by reference comparison

- Pass by value:
  - Requires a lot of time to perform the copy if the parameter is large
  - Actual parameter and formal parameter are different
  - Cannot return a value to the caller (without a `return` statement!)
- Pass by reference:
  - An address is copied ⇒ fixed size ⇒ fast!
  - Actual parameter and formal parameter are the same
  - Can return a value to the caller

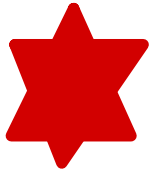
Summary



Pass / Property	by value	by reference
Time and Space	Large	Small
Side effects risk	No	**Yes**
Return value to the caller	No	Yes

References

How to make parameter passing a bit easier

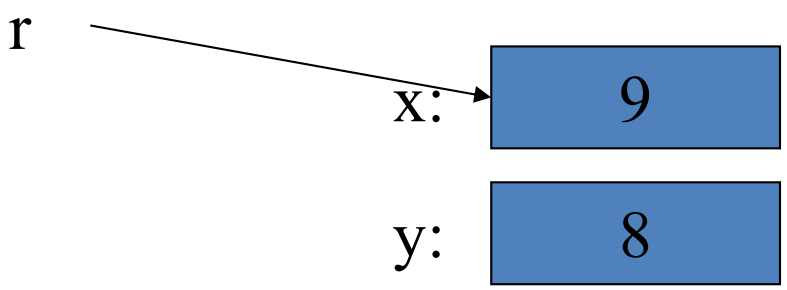


References

- An automatically dereferenced pointer:
  - Or as “an alternative name for an object”
  - A reference is introduced through the & modifier in a variable declaration
  - A reference **must be** initialized
  - The value of a reference **cannot be changed after initialization**
    - I.e., you cannot make a reference refer to another object after initialization

```
int x = 9;
int y = 8;

int &r = x;
```



References

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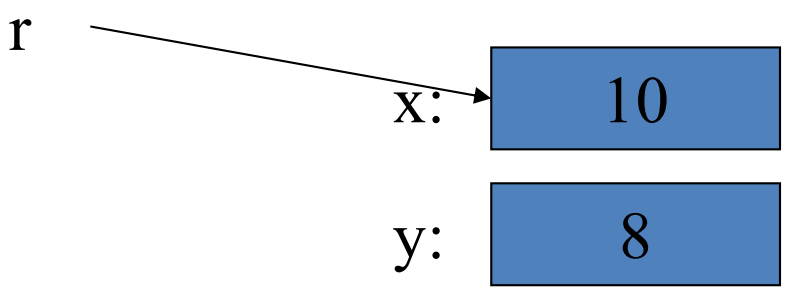
  - A reference **must be** initialized
  - The value of a reference **cannot be changed after initialization**
    - I.e., you cannot make a reference refer to another object after initialization

```
int x = 9;
int y = 8;

int &r = x;
r = 10; // x = 10!
r = &y;     // error (and so is all other attempts to change what r
            // refers to)
```



References

- When we initialize a variable, the value of the initializer is copied into the object we are creating
- When we define a reference, instead of copying the initializer value, we **bind the reference to its initializer**
- Once initialized, a reference remains bound to its initial object
  - **There is no way to rebind a reference to refer to a different object**
  - Because of this, references **must be initialized**
- When we fetch the value of a reference:
  - We are really fetching the value of the object to which the reference is bound
- When we use a reference as an initializer:
  - We are really using the object to which the reference is bound

```
int i = 7;
int& r = i;
int &r3 = r;  // ok: r3 is bound to the same object as r, i.e., to I

// initializes j from the value in the object to which r is bound
int j = r;  // ok: initializes j to the same value as i
```

Pointers and references

- A pointer is a compound type that "points to" another type
- Like references, pointers are used for indirect access to other objects
- Unlike a reference, a **pointer is an object** in its own right
  - **Pointers can be assigned and copied; a single pointer can point to several different objects over its lifetime**
  - **Unlike a reference, a pointer does not need to be initialized at the time it is defined**
- Like other built-in types, pointers have undefined value if they are not initialized. **Be very careful !!!**

Pointers and references

- & and *, are used as both an operator in an expression and as part of a declaration
- The **context** in which a symbol is used **determines** what the symbol **means**

```
int i = 42;
int &r = i;     //& follows a type and is part of a declaration; r is a reference
int *p;         // * follows a type and is part of a declaration; p is a pointer

p = &i;         // & is used in an expression as the address-of operator

*p = i;         // * is used in an expression as the dereference operator

int &r2 = *p; // & is part of the declaration; * is the dereference operator
int *p2 = &i; // * is part of the declaration; & is the address-of operator
```

C++ pass by reference

- C++ relies on references to implement pass by reference parameters passing mechanism

- This simplifies a lot syntax and notation

DEMO

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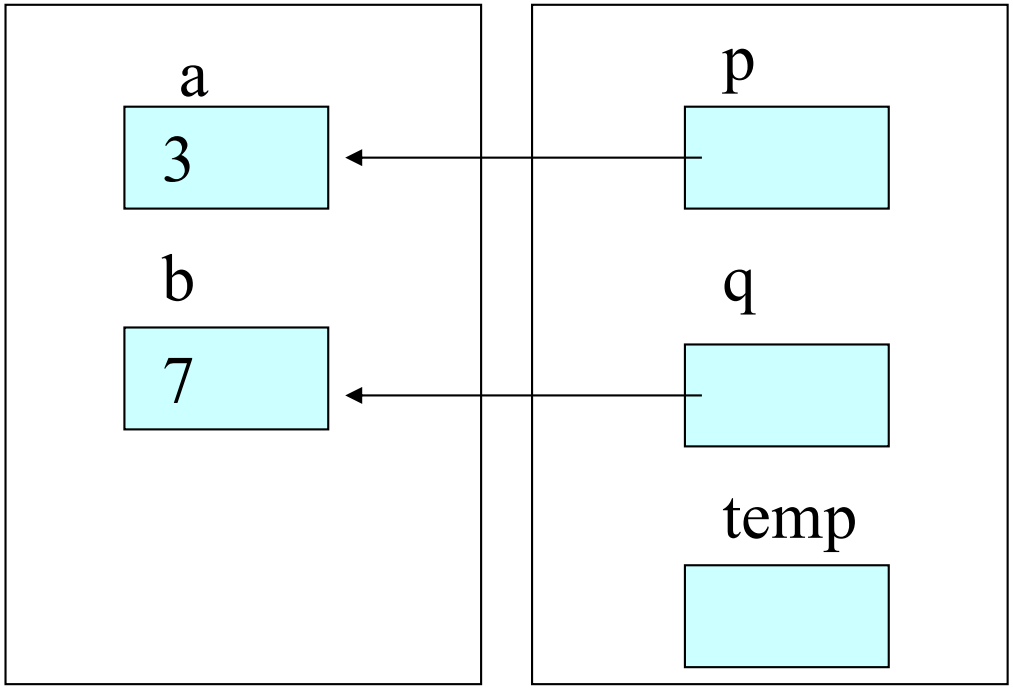
Example: swap of 2 ints

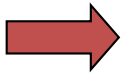
```
void swap (int &p, int &q){
      int temp;
      temp = p;
      p = q;
      q = temp;
}
```

In main: `swap(a, b)`

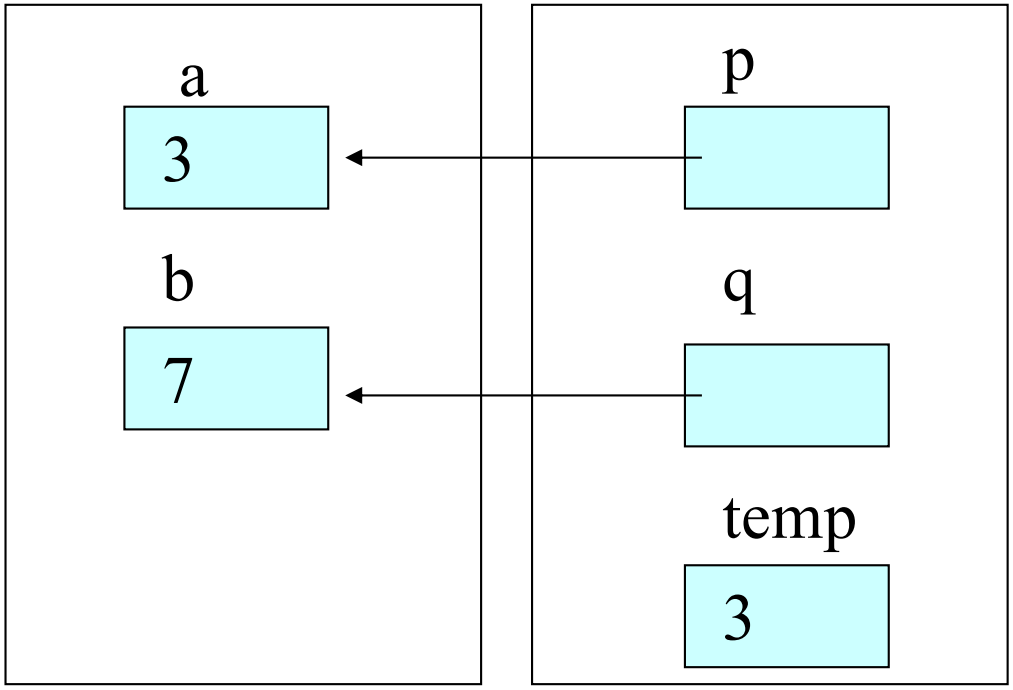


Example: swap of 2 ints

```
void swap (int &p, int &q){
      int temp;
      temp = p;
      p = q;
      q = temp;
}
```



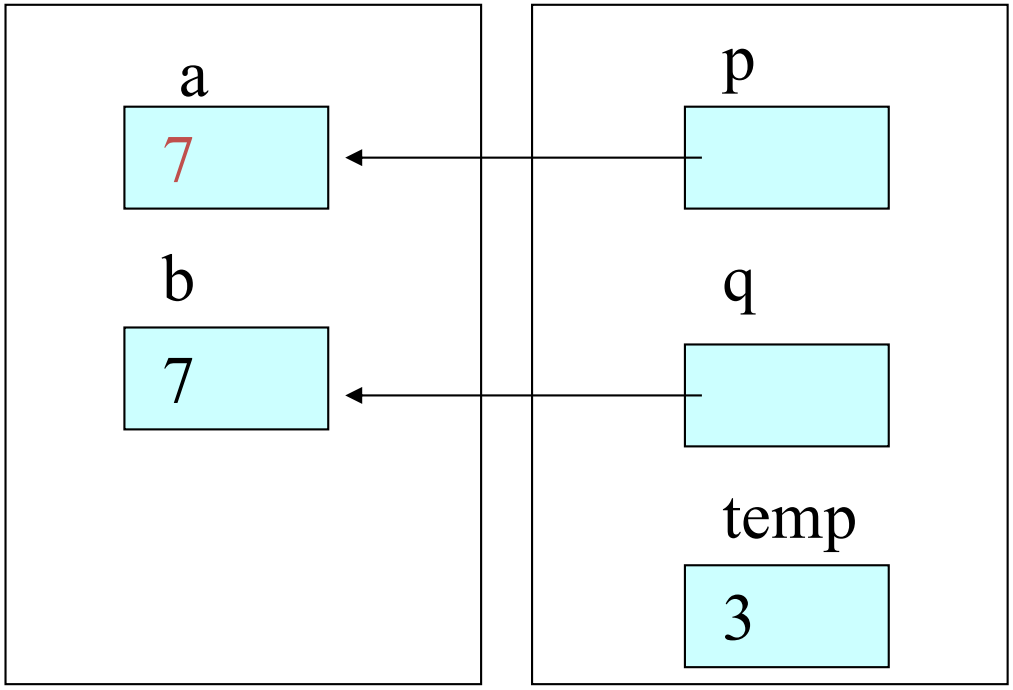
In main: `swap(a, b)`



Example: swap of 2 ints

```
void swap (int &p, int &q){
      int temp;
      temp = p;
      p = q;
      q = temp;
}
```

In main: `swap(a, b)`



Example: swap of 2 ints

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void swap (int &p, int &q){
      int temp;
      temp = p;
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      q = temp;
}
```

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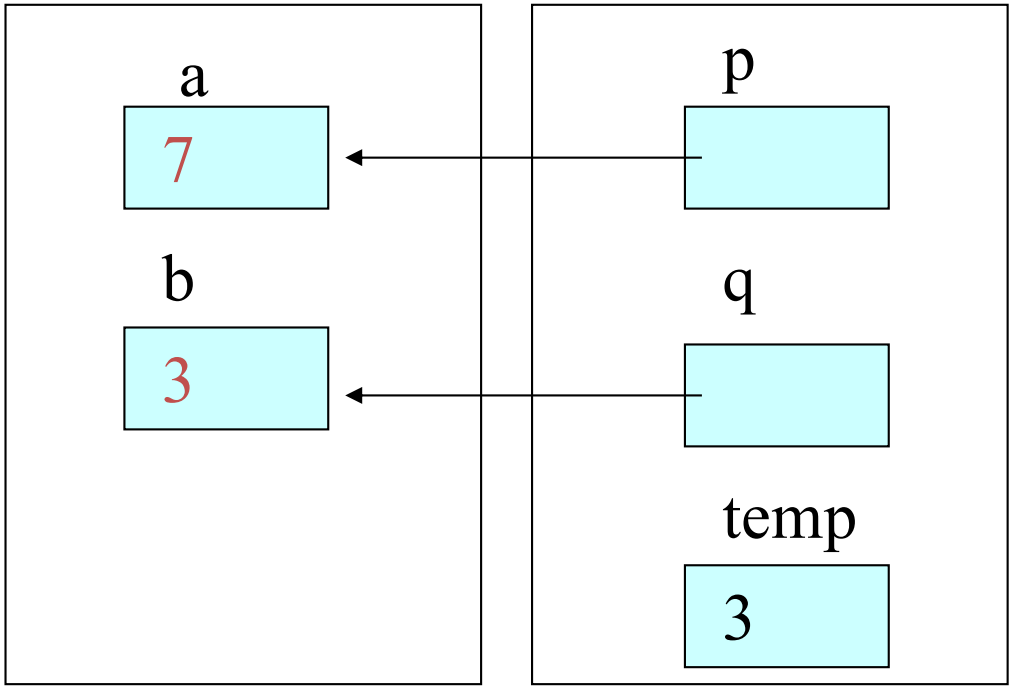
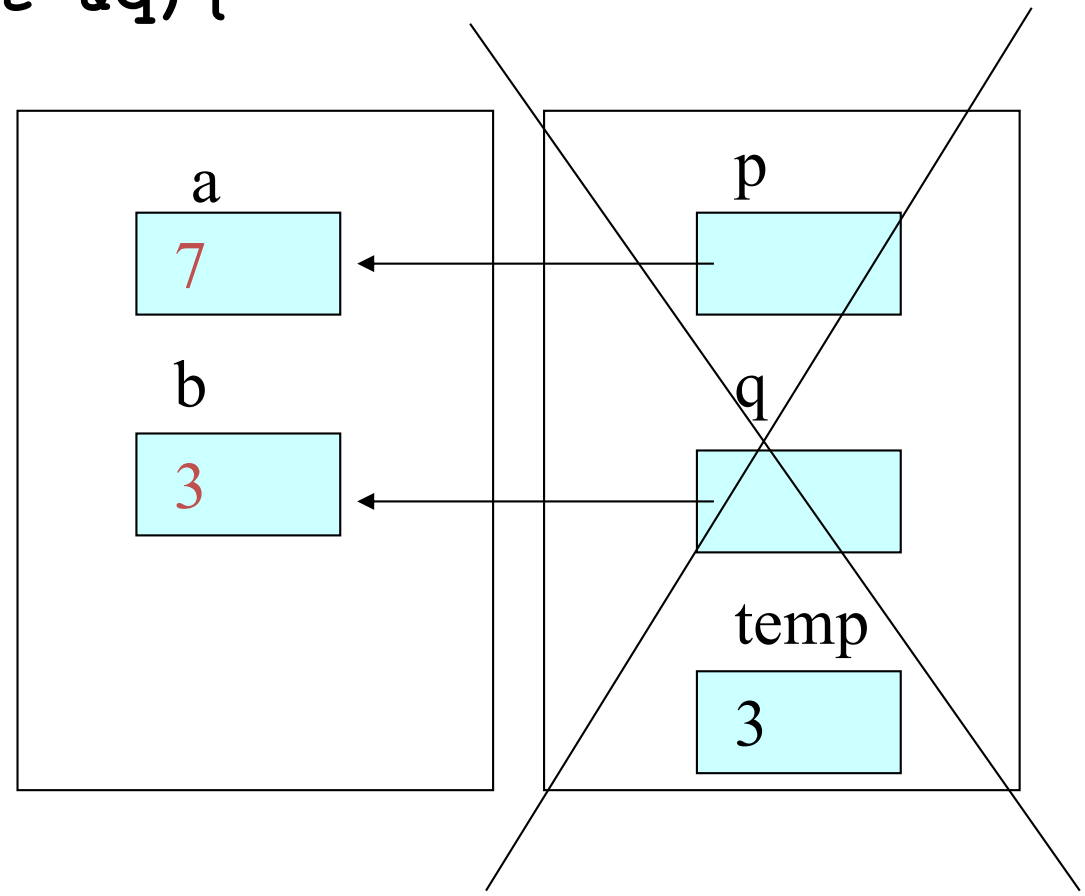


Example: swap of 2 ints

```
void swap (int &p, int &q){
      int temp;
      temp = p;
      p = q;
      q = temp;
}
```



In main: `swap(a, b)`

At the end of swap main variables are **changed**!

`const` Qualifier

`const` Qualifier

- We might want to define a variable whose value we know cannot be changed
  - For example, to refer to the size of a buffer size
- We can make a variable unchangeable by defining the variable's type as **const**:

```
const int bufSize = 512;     // input buffer size
                             //same as constexpr int bufsize=512
bufSize = 512;               // error: attempt to write to const object
```

- **Because we can't change the value of a const object after created, it must be initialized**

```
const int j = 42; // ok: initialized at compile time
const int i = get_size(); // ok: initialized at run time
const int k; // error: k is uninitialized const

j= 47;  // error: we try to change a const variable
```

`const` Qualifier

- By default, const objects are local to a file
- When a const object is initialized from a compile-time constant, our compiler will usually replace uses of the variable with its corresponding value during compilation
  - The compiler will generate code using the value 512 in the places that our code uses bufSize

References to `const`

- We can bind a reference to an object of a const type
- To do so we use a **reference to const**, which is a reference that refers to a const type
- Unlike an ordinary reference, a reference to const cannot be used to change the object to which the reference is bound

```
con
cor

r1

int
```

ng to

Const references can be used to pass **large objects** in **read only** (obtaining the same benefits of C arrays passing **+ read only protection**, i.e., **no side effects**)

Example: pass by (const) reference

```
double circ(double *radius) {
   double res;
   res = *radius * 3.14 *2;
   *radius = 7; /* No sense instruction,
            let's see what happens to radius */
   return res;
}

// somewhere in the main
double c;
double r = 5;

c = circ(&r);
//Warning! Now r is 7.0
```

```
double circ(const double &radius) {
   double res;
   res = radius * 3.14 *2;
   radius = 7; /* No sense instruction,
            let's see what happens to radius */
   return res;
}

// somewhere in the main
double c;
double r = 5;

c = circ(r);
//r is 5.0
```

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}

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double c;
double r = 5;

c = circ(&r);
//Warning! Now r is 7.0
```

```
double circ(const double &radius) {
   double res;
   res = radius * 3.14 *2;
   radius = 7; /* No sense instruction,
            let's see what happens to radius */
   return res;
}

// somewh
double c;
double r=

c = circ(r);
//r is 5.0
```

We get a compiler error here and we need to delete this line of code

Example: pass by (const) reference

```
double circ(double *radius) {
   double res;
   res = *radius * 3.14 *2;
   *radius = 7; /* No sense instruction,
            let's see what happens to radius */
   return res;
}

// somewhere in the main
double c;
double r = 5;

c = circ(&r);
//Warning! Now r is 7.0
```

```
double circ(const double &radius) {
   double res;
   res = radius * 3.14 *2;
   return res;
}

// somewhere in the main
double c;
double r = 5;

c = circ(r);
//r is 5.0
```

What about circ(22.0);?

A **temporary const object** is created, initialized with 22.0 and the function can be executed

Call by Value vs. by Call Reference

Play video

Guidance for passing variables

- Use call-by-value for very small objects (base types!)
- Use call-by-const-reference for large objects
- Use call-by-reference only when you must return a result rather than modify an object through a reference argument

- For example:

```
class Image { /* objects are potentially huge */ };
void f(Image i);… f(my_image);// oops: this could be s-l-o-o-o-w
void f(Image& i);… f(my_image);// no copy, but f() can modify
                                                    // my_image
void f(const Image& i); … f(my_image);// f() won't mess with
                                                    // my_image
```

Variables scope

Scope

- The scope of an identifier is the portion of the program in which the identifier can be referenced
  - Some identifiers can be referenced throughout the program
  - Others can be referenced from only portions of a program

- **Example:**

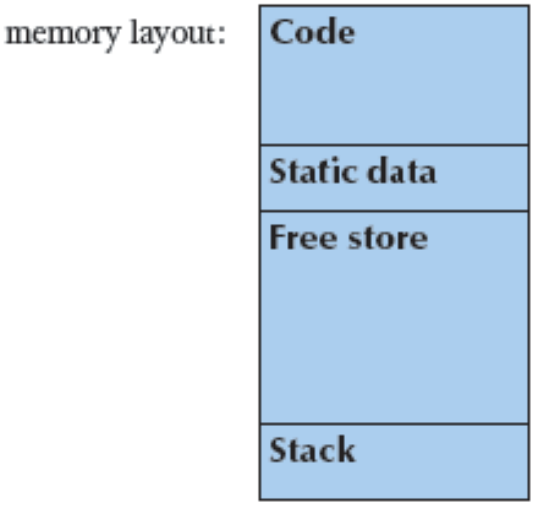
When we declare a local variable in a block (e.g., in a for loop), it can be referenced only in that block or in blocks nested within that block

Methods of variable creation

- Global variable
  - declared very early stage
  - available always and from anywhere
  - created at the start of the program, and lasts until the end, stored in the **static data**
  - difficult to debug

Never use global variables!

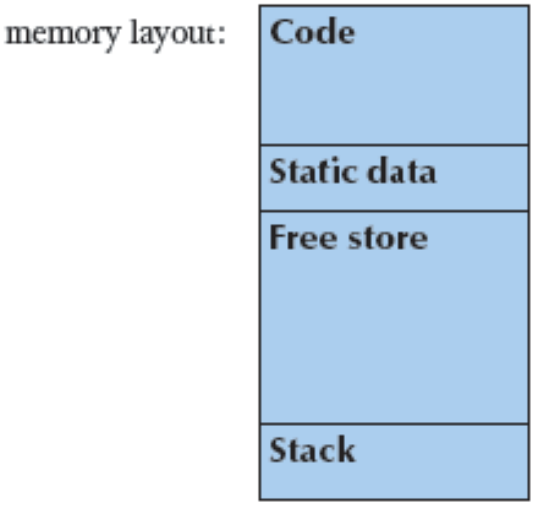
-5 points at exams!



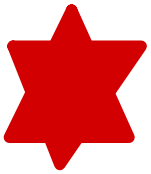
Methods of variable creation

- **Local on the fly** variables
  - simply created when they are needed
  - only available from within the routine/block in which they were created, stored in the **stack**
  - easy to debug

```
for (unsigned j = 0; j < 10; ++j){
    // do something
}
```



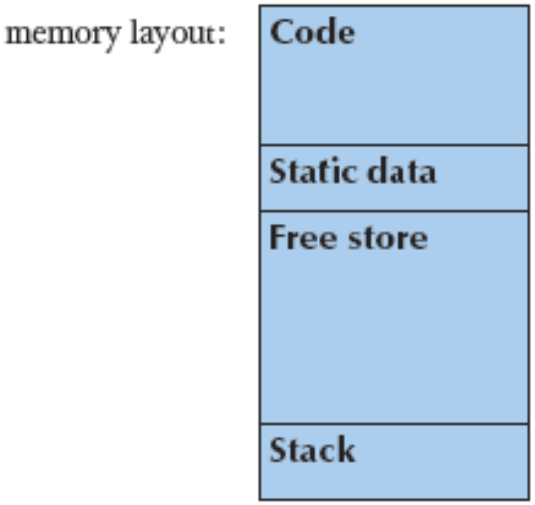
Methods of variable creation



- **Local defined** variable
  - created before they are needed
  - only available in the routine in which they were created
  - easy to debug, stored in the **stack**
  - the most usually favored method

```
void f (int x) {
    // do something
}


int main () {
    int y = 7;
    // etc.
}
```



A program written in C++

```
// This program calculates the number calories in a cheese sandwich
#include <iostream>
const int BREAD = 63;                    // global constant
const int CHEESE = 106;                  // global constant
const int MAYONNAISE = 49;               // global constant
const int PICKLES = 25;                  // global constant
int main()
{
      int totalCalories;                 // local variable
      totalCalories = 2 * BREAD + CHEESE + MAYONNAISE + PICKLES;
      cout << "There were " << totalCalories;
      cout << " calories in my lunch yesterday."<< endl;
      return 0;
}
```

Global constant are ok!

Function definition and function prototype

```
#include <iostream>

int square (int);    // Function prototype

int main()
{
    for (int x = 0; x < 10; x++) // local on the fly variable
          cout << square(x) << ' ';
    cout << endl;
    return 0;
}
int square (int y)   // Function definition
{
    return y * y;
}
```

Local variable

Global and Local declarations

Be careful with variables scope (and name hiding)

```
#include <iostream>
void func( float );
const int a = 17;       // global constant
int b;                  // global variable
int c;                  // global variable
int main()
{
        b = 4;          // assignment to global b
        c = 6;          // assignment to global c
        func(42.8);
        return 0;
}
void func( float c)     // prevents access to global c
{
        float b;        // prevent access to global b
        b = 2.3;        // assignment to local b
        cout << " a = " << a;
        cout << " b = " << b;
        cout << " c = " << c;
}
```

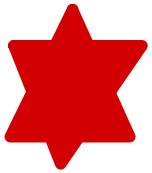
Values:
a = 17 b = 4 c = 6

Output:
a = 17 b = 2.3 c = 42.8

Explanation

- In this example, *func* accesses global constant *a*
- However, *func* declares its own local variable *b* and parameter *c*
- Local variable *b* takes precedence over global variable *b*, effectively hiding global variable *b* from the statements in function *func*
- Function parameter acts like local variable

Lifetime of a variable



- Local defined variables: variables declared inside a function or variables declared as function parameter
- When you will call the function, memory will be allocated for all local variables defined inside the function
- Finally, memory will be deallocated when the function exits
- The period of time a variable will be “alive” while the function is executing is called “lifetime” of this variable

Another example - Scopes nest

```
int x;  // global variable – avoid those where you can
int y;  // another global variable

void f();

int main(){
        x =8; y = 3;
        f();
        cout << x << ' ' << y << '\n'; // what will cout print?
}

void f()
{
  int x;                // local variable (Note – now there are two x's)
  x = 6;                // local x, not the global x
  {
        int x = y;      // another local x, initialized by the global y
                        // (Now there are three x's)
        ++x;            // increment the local x in this scope
  }
  // what is the value of x here?
  y++;
}
```

// avoid such complicated nesting and hiding: keep it simple!

DEMO

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