# BLG 102E
# Introduction to Scientific Computing and Engineering

## SPRING 2025

## WEEK 9

ISTANBUL TECHNICAL UNIVERSITY


TWO
EXTRA
SPINS
NEXT
PLAYER
SPINS
NO COUNT
NEXT
PLAYER
SPINS

# Pointers

# Pointers

**A variable *contains* a value,**

**but a *pointer* specifies *where* a value is located.**

A pointer denotes the
*memory location* of a variable

# Pointers

- In C, pointers are important for several reasons.
  - ***Pointers allow sharing of values stored in variables in a uniform way***
  - ***Pointers can refer to values that are allocated on demand (dynamic memory allocation)***
  - ***Pointers are necessary for implementing polymorphism, an important concept in object-oriented programming (later for C++)***

# A Banking Problem

Consider a person.

(Harry)

Harry has more than one bank account.

# Harry Needs a Banking Program

Harry wants a program for making bank deposits and withdrawals.

```
… balance += depositAmount …
… balance -= withdrawalAmount …
```

# Harry Needs a Multi-Bank Banking Program

But not all deposits and withdrawals should be from the *same* bank.

```
… balance += depositAmount …
… balance -= withdrawalAmount …
```

# Good Design

But withdrawing is withdrawing

– no matter which bank it is.

Same with depositing.

Same problem – same code, right?

# Pointers to the Rescue

By using a *pointer*,

it is possible to *switch* to a different account

*without* modifying the code for

deposits and withdrawals.

# Pointers to the Rescue

Harry starts with a variable for storing an account balance. It should be initialized to 0 since there is no money yet.

```
double harrys_account = 0;
```

# Pointers to the Rescue

If Harry anticipates that he may someday use other accounts, he can use a pointer to access any accounts.

So Harry also declares a pointer variable named **`account_pointer`** :

```
double* account_pointer
```

The type of this variable is "*pointer to double*".

# Addresses and Pointers

A *pointer to double* type can hold the address of a **`double`**.

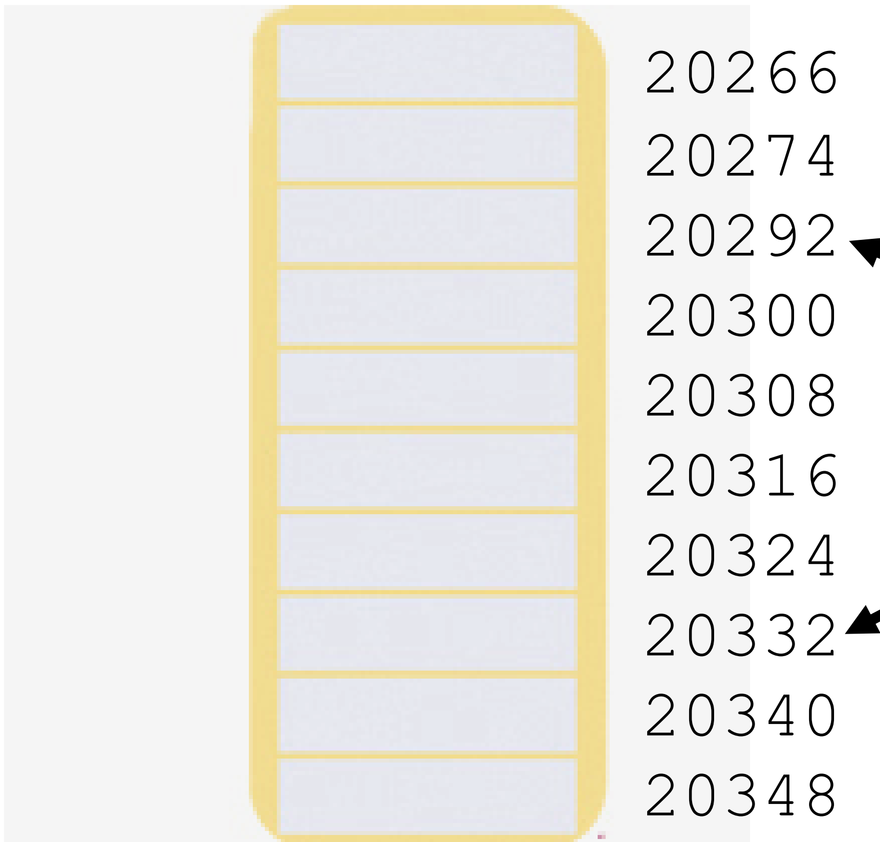
So what’s an address?

# Addresses and Pointers

Here’s a picture of RAM.

Every byte in RAM has an *address*.

(shown in groups of eight bytes)




an address

another address

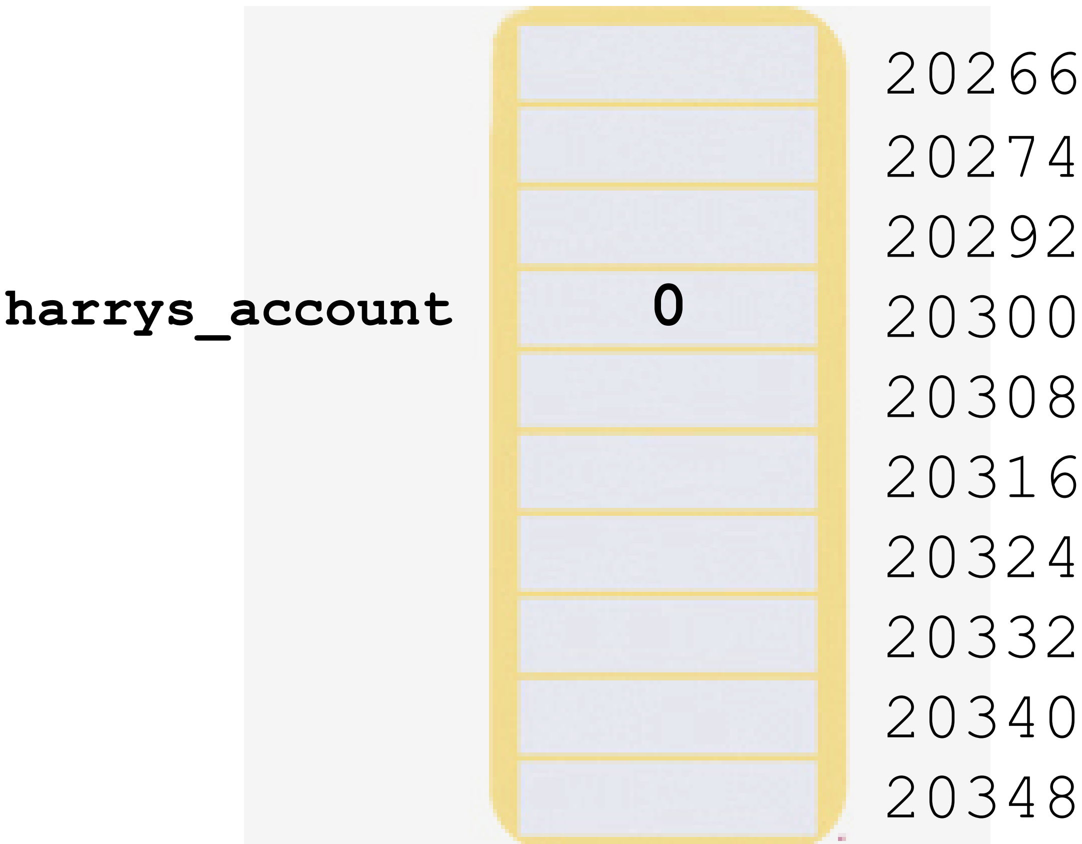
# Addresses and Pointers

Here’s how we have pictured a variable in the past:

`harrys_account` 

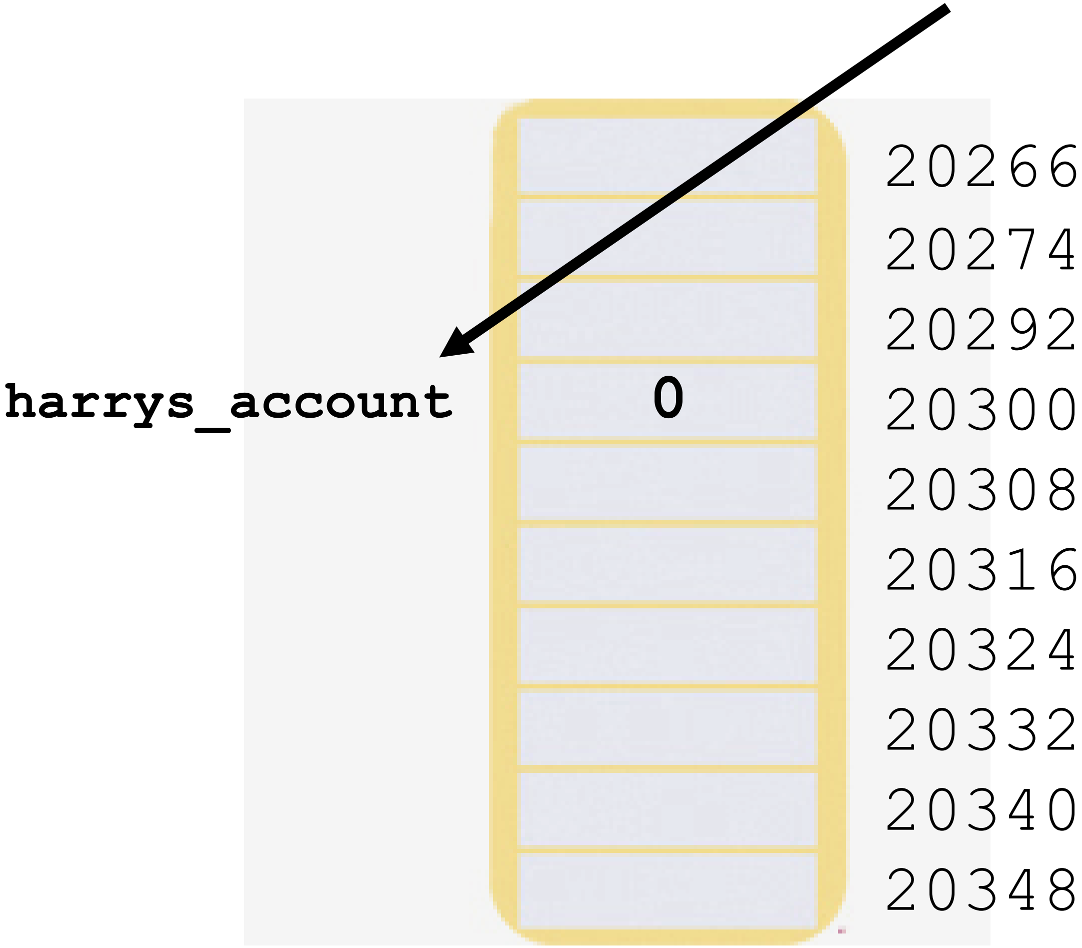
# Addresses and Pointers

But really it's been like this all along:



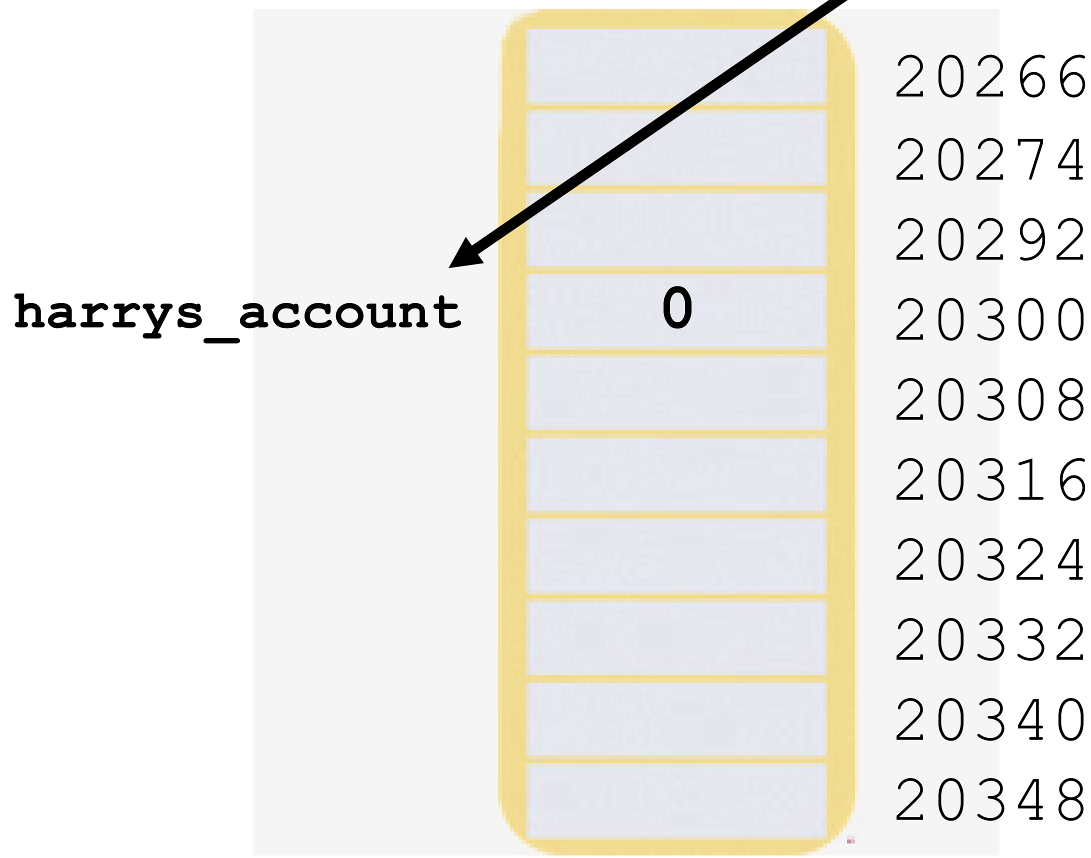
# Addresses and Pointers

The address of the variable named **`harrys_account`**



# Addresses and Pointers

The address of the variable named **harrys_account** is **20300**



# Pointers to the Rescue

So when Harry declares a pointer variable,
he also initializes it to point to **`harrys_account`**:

```
double harrys_account = 0;
double* account_pointer = &harrys_account;
```

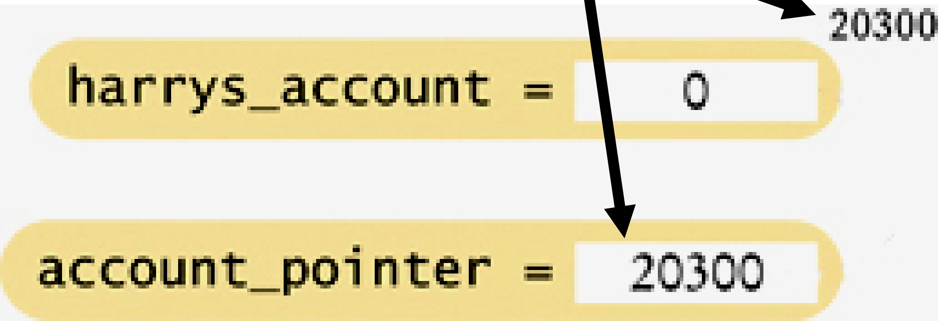
The **&** operator yields the location (or address) of a variable.

Taking the address of a **`double`** variable yields a value of type **`double*`** so everything fits together nicely.

# Pointers to the Rescue

**account_pointer** now *contains* the *address* of **harrys_account**

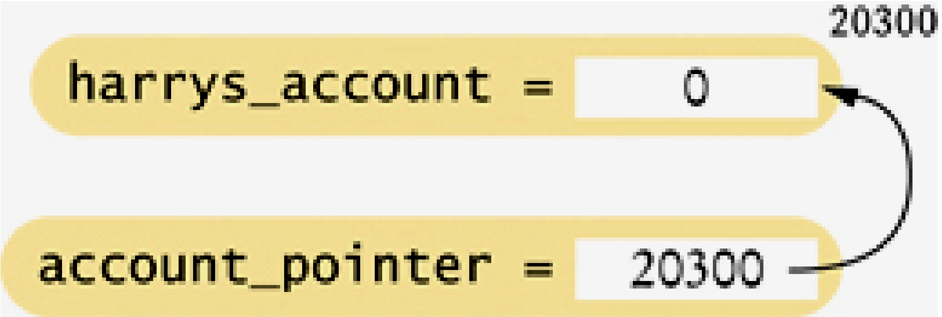
```
double harrys_account = 0;
double* account_pointer = &harrys_account;
```



# Pointers to the Rescue

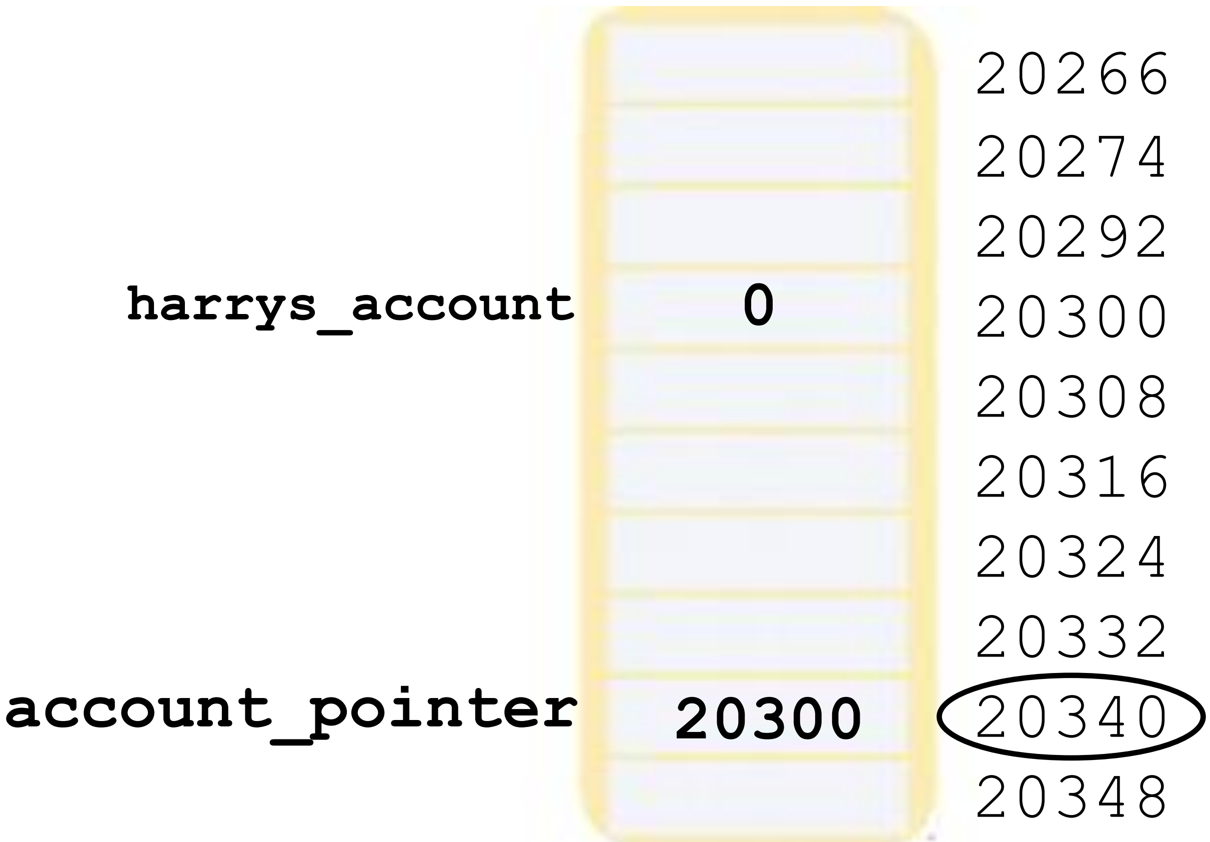
**`account_pointer`** now "points to" **`harrys_account`**

```
double harrys_account = 0;
double* account_pointer = &harrys_account;
```



# Addresses and Pointers

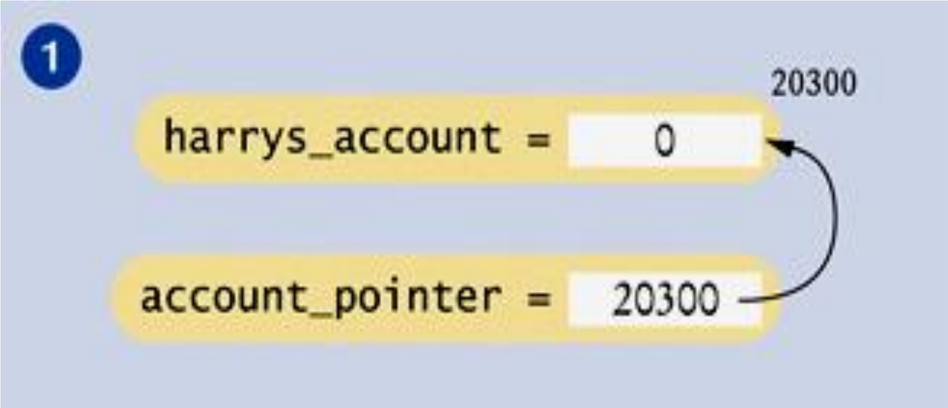
And, of course, **`account_pointer`** is *somewhere* in RAM:



# Addresses and Pointers

To access a different account, you would change the pointer value stored in **`account_pointer`**:

```
double harrys_account = 0;
account_pointer = &harrys_account;
```

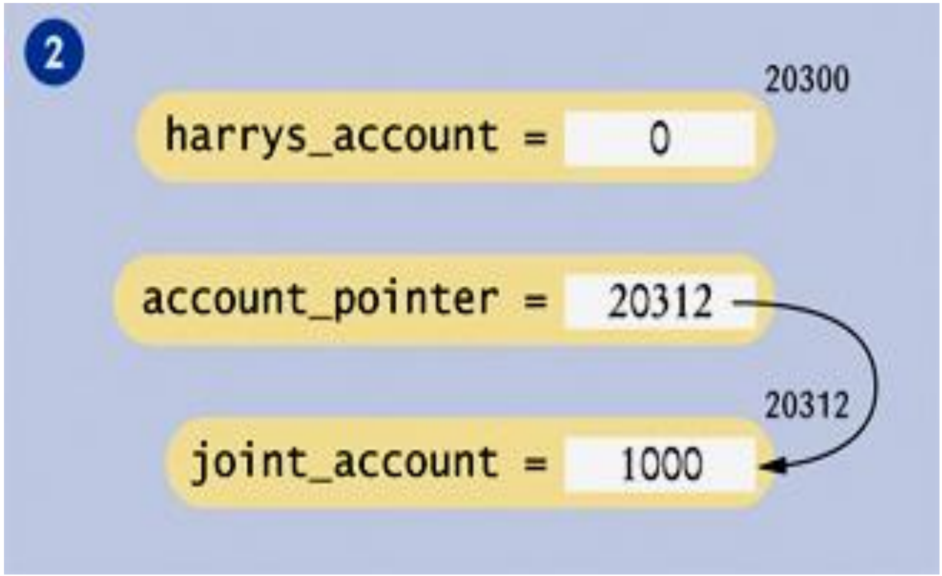



use **`account_pointer`** to access **`harrys_account`**

# Addresses and Pointers

To access a different account, like **`joint_account`**, change the pointer value stored in **`account_pointer`** and similarly use **`account_pointer`**.

```
double harrys_account = 0;
account_pointer = &harrys_account;
double joint_account = 1000;
account_pointer = &joint_account;
```



# Addresses and Pointers – and ARROWS

Do note that the computer stores numbers,

not arrows.

# Accessing the Memory Pointed to by A Pointer Variable

When you have a pointer to a variable,
you will want to access the value to which it points.

```
... *account_pointer ...
```

In C, the * operator is used to indicate
the memory location associated with a pointer.

# Accessing the Memory Pointed to by A Pointer Variable

An expression such as **`*account_pointer`** can be used wherever a variable name of the same type can be used:

```
// display the current balance
printf("%f\n", *account_pointer);
```

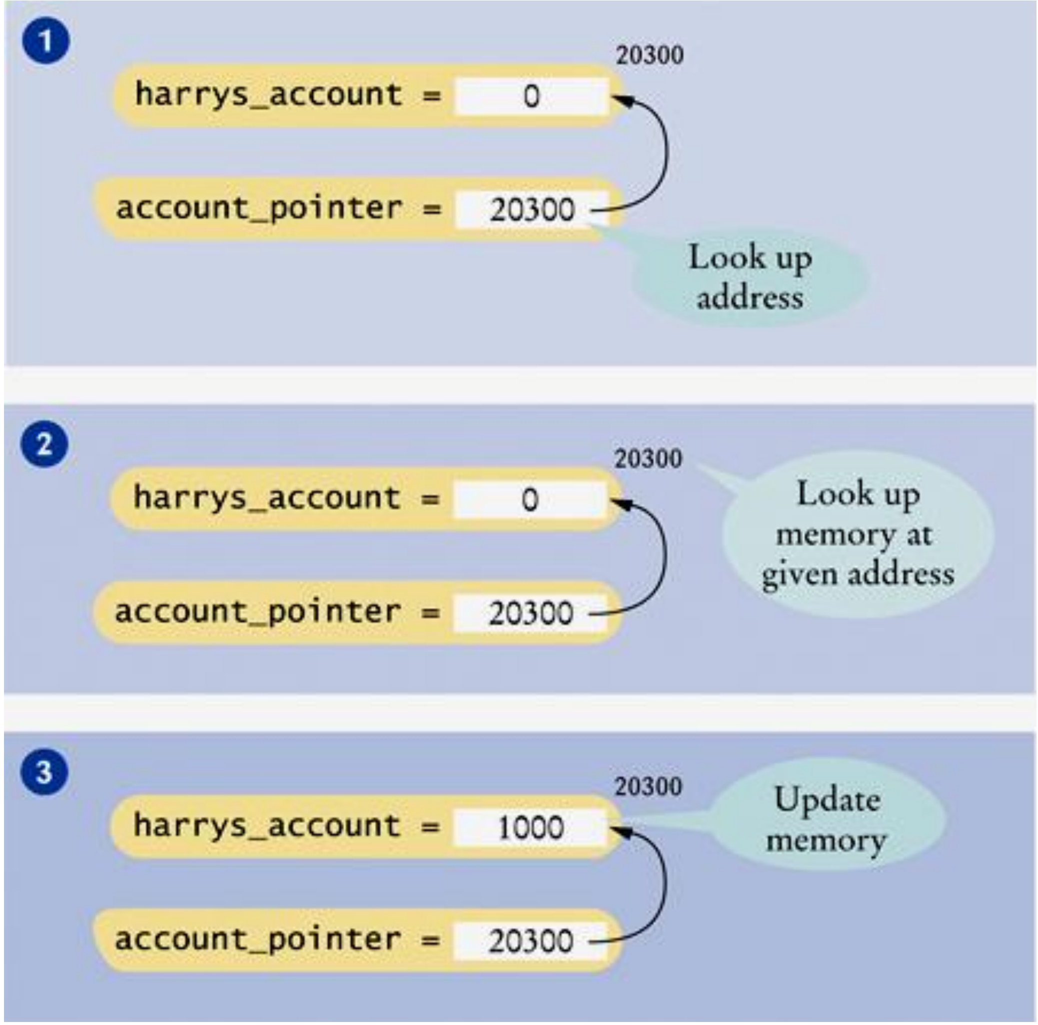
It can be used on the left or the right of an assignment:

```
// withdraw $100
*account_pointer = *account_pointer - 100;
```

(or both)

# Harry Makes the Deposit

```
// deposit $1000
  *account_pointer = *account_pointer + 1000;
```



# Accessing the Memory Pointed to by A Pointer Variable

Of course, this only works
if **`account_pointer`** is pointing
to **`harrys_account`*!***

# Errors Using Pointers – Uninitialized Pointer Variables

When a pointer variable is first defined,
it contains a random address.

Using that random address is an error.

# Errors Using Pointers – Uninitialized Pointer Variables

In practice, your program will likely crash or mysteriously misbehave if you use an uninitialized pointer:

```
double* account_pointer; // No initialization

*account_pointer = 1000;
```

**NO!**

**`account_pointer` contains an *unpredictable* value!**

**`Where is the 1000 going?`**

# NULL

There is a special value
that you can use
to indicate a pointer
that doesn't point anywhere:

**`NULL`**

# NULL

If you define a pointer variable
and are not ready to initialize it quite yet,
it is a good idea to set it to **`NULL`**.

You can later test whether the pointer is **`NULL`**.

If it is, don't use it:

```
double* account_pointer = NULL; // Will set later
if (account_pointer != NULL) {  // OK to use
   printf("%f\n", *account_pointer);
}
```

## NULL

Trying to access data through a NULL pointer is still illegal,
and
it will cause your program to crash.

```
double* account_pointer = NULL;

printf("%f\n", *account_pointer);
```

**CRASH!!!**

# Syntax of Pointers

## Syntax 7.1 Pointer Syntax

```
double account = 0;
double* ptr = &account;
```

You should always initialize a pointer variable, either with a memory address or NULL.

The type of ptr is "pointer to double".

The & operator yields a memory address.

```
*ptr = 1000
printf("%lf\n",*account_pointer);
```

The * operator accesses the location to which ptr points.

This statement changes account to 1000.

This statement reads from the location to which ptr points.

# Pointer Syntax Examples

**Table 1** Pointer Syntax Examples

Assume the following declarations:

```
int m = 10; // Assumed to be at address 20300
int n = 20; // Assumed to be at address 20304
int* p = &m;
```

| Expression | Value | Comment |
|---|---|---|
| `p` | 20300 | The address of `m`. |
| `*p` | 10 | The value stored at that address. |
| `&n` | 20304 | The address of `n`. |
| `p = &n;` | | Set `p` to the address of `n`. |
| `*p` | 20 | The value stored at the changed address. |
| `m = *p;` | | Stores 20 into `m`. |
| `m = p;` | **Error** | `m` is an `int` value; `p` is an `int*` pointer. The types are not compatible. |
| `&10` | **Error** | You can only take the address of a variable. |
| `&p` | The address of `p`, perhaps 20308 | This is the location of a pointer variable, not the location of an integer. |
| `double x = 0;` `p = &x;` | **Error** | `p` has type `int*`, `&x` has type `double*`. These types are incompatible. |

## Harry’s Banking Program

Here is the complete banking program.

It demonstrates the use of a pointer variable to allow *uniform access* to variables.

```
#include <stdio.h>

int main()
{
   double harrys_account = 0;
   double joint_account = 2000;
   double* account_pointer = &harrys_account;
   *account_pointer = 1000; // Initial deposit
```

# Harry’s Banking Program

```
// Withdraw $100
*account_pointer = *account_pointer - 100;

// Print balance
printf("Balance: %lf\n", *account_pointer);


// Change the pointer value so that the same
// statements now affect a different account
account_pointer = &joint_account;

// Withdraw $100
*account_pointer = *account_pointer - 100;

// Print balance
printf("Balance: %lf\n", *account_pointer);

return 0;
}
```

## Common Error: Confusing Data And Pointers

A pointer is a memory address

– a number that tells where a value is located in memory.

It is a common error to confuse the pointer with the variable to which it points.

# Common Error: Where's the *?

```
double* account_pointer = &joint_account;
account_pointer = 1000;
```

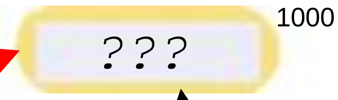
The assignment statement does *not* set the joint account balance to 1000.

It sets the pointer variable, **`account_pointer`**, to point to memory address 1000.

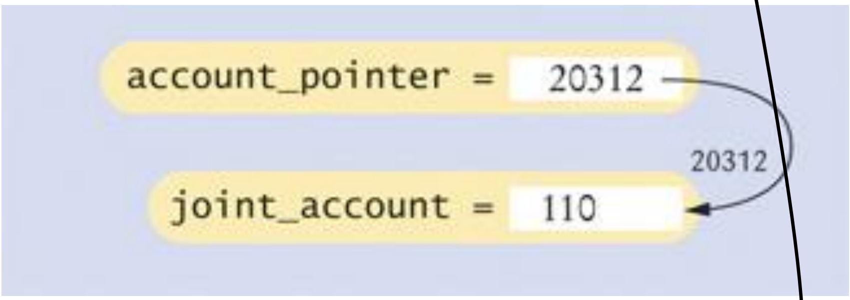
ERROR

# Common Error: Where's the *?

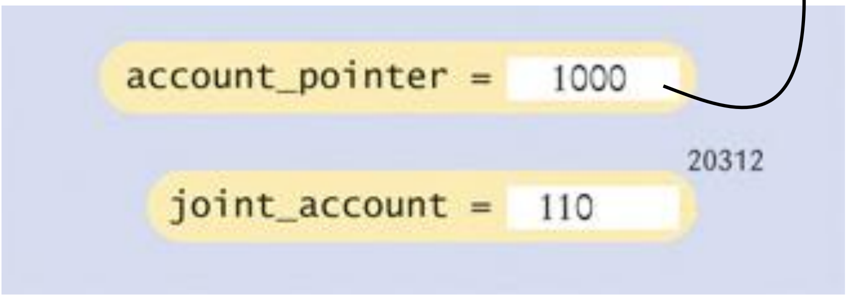
**`joint_account`** is almost certainly *not* located at address 1000!




```
double* account_pointer = &joint_account;
```




```
account_pointer = 1000;
```



# Common Error: Where's the *?

Most compilers will report an error for this kind of error.

# Confusing Definitions

It is legal in C to define multiple variables together, like this:

```
int i = 0, j = 1;
```

This style is confusing when used with pointers:

```
double* p, q;
```

The **`*`** associates only with the first variable.
That is, **`p`** is a **`double*`** pointer, and **`q`** is a **`double`** value.

To avoid any confusion, it is best to define each pointer variable separately:

```
double* p;
double* q;
```

# Pointers and References

Changing value of parameter:

```
void withdraw(double* balance, double amount)
{
    if (*balance >= amount)
    {
        *balance = *balance - amount;
    }
}
```

but the call will have to be:

```
withdraw(&harrys_checking, 1000);
```

# Arrays and Pointers

In C, there is a deep relationship between pointers and arrays.

This relationship explains a number of special properties and limitations of arrays.

# Arrays and Pointers

Pointers are particularly useful for understanding the peculiarities of arrays.

The *name* of the array denotes

a pointer to the starting element.

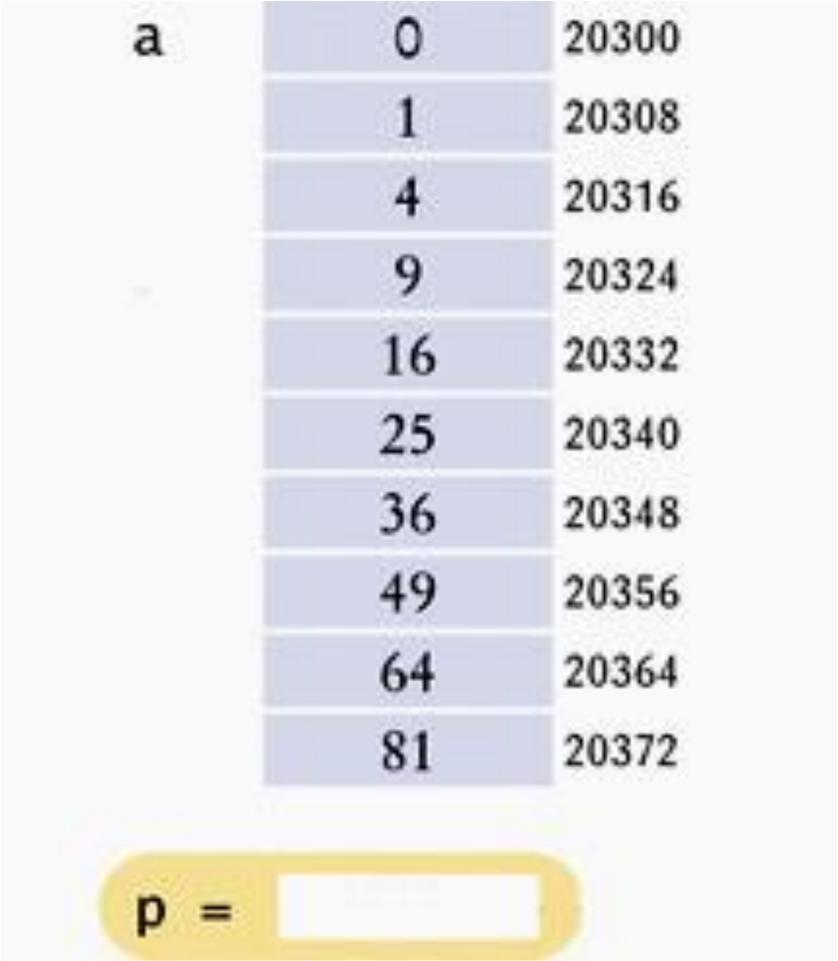
# Arrays and Pointers

Consider this declaration:

`int a[10];`

(Assume we have filled it as shown.)

You can capture the pointer to the first element in the array in a variable:



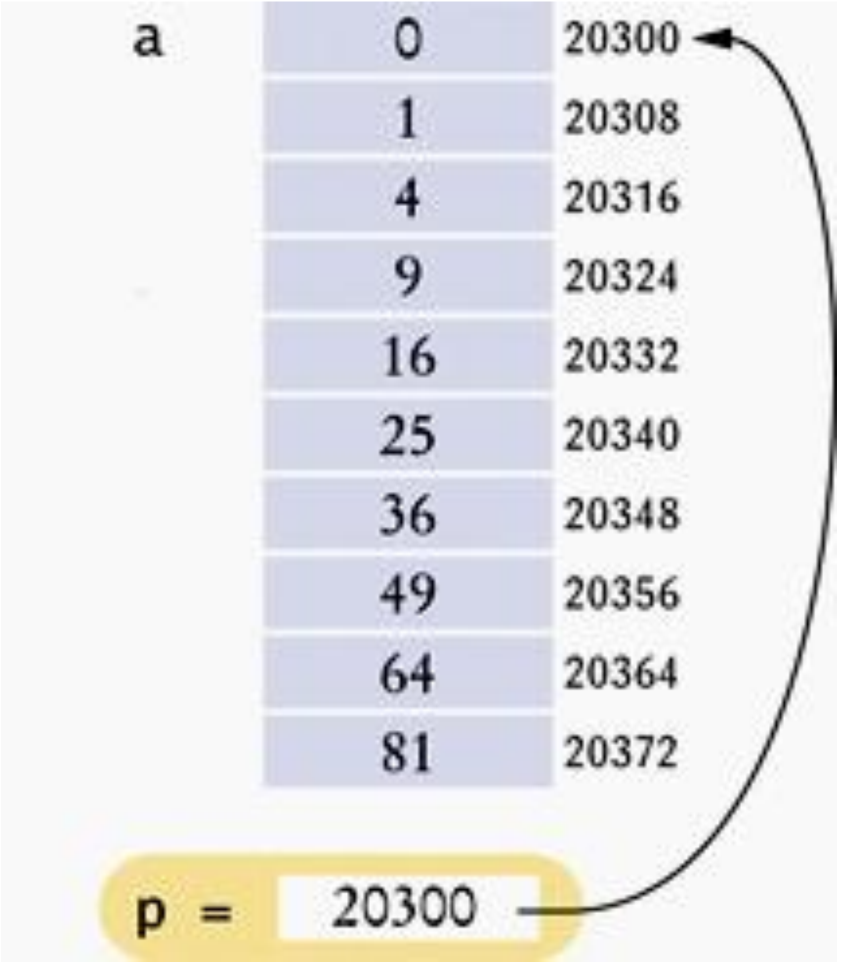
# Arrays and Pointers

Consider this declaration:

```
int a[10];
```

(Assume we have filled it as shown.)

You can capture the pointer to the first element in the array in a variable:




```
int* p = a; // Now p points to a[0]
```

# Arrays and Pointers – Same Use

You can use the array name **`a`** as you would a pointer:

These output statements are equivalent:

```
printf("%d", *a);
printf("%d", a[0]);
```

# Pointer Arithmetic

*Pointer arithmetic* allows you to
add an integer to an array name.

```
int* p = a;
```

`p + 3` is a pointer to the array element with index **3**

The expression: `*(p + 3)`

.

# The Array/Pointer Duality Law

The *array/pointer duality law* states:

**`a[n]`** is identical to **`*(a + n)`**,

where **`a`** is a pointer into an array
and **`n`** is an integer offset.

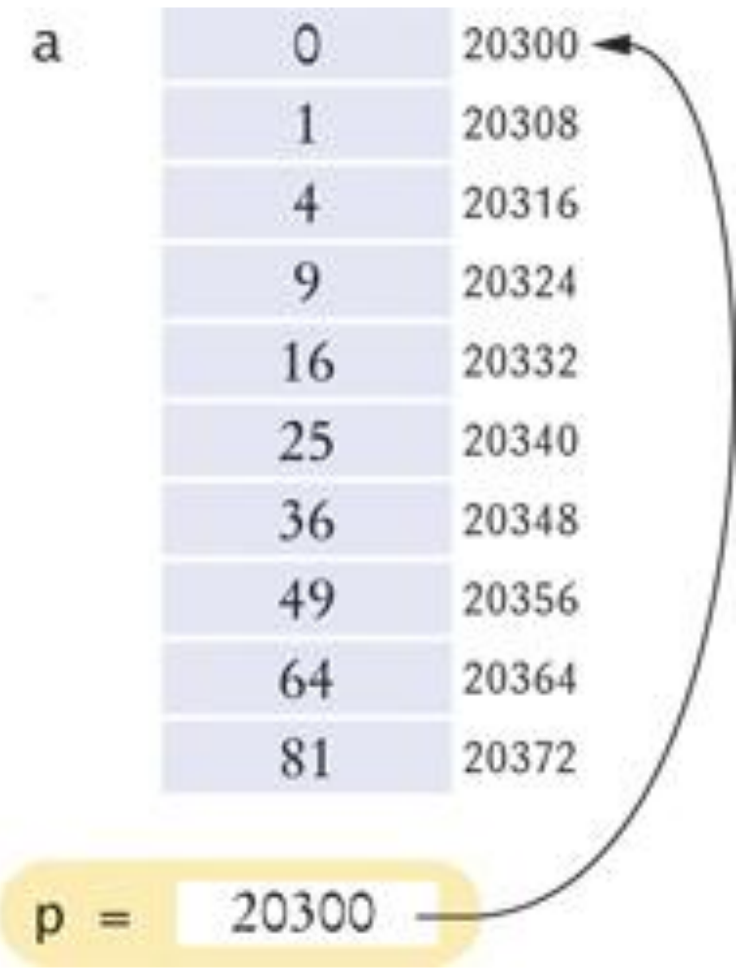
# The Array/Pointer Duality Law

This law explains why all C arrays start with an index of zero.

The pointer **`a`** (or **`a + 0`**) points to the starting element of the array.

That element must therefore be **`a[0]`**.

You are adding 0 to the start of the array, thus *correctly going nowhere!*



# The Array/Pointer Duality Law

Now it should be clear why array parameters are different from other parameter types.

(if not, we'll show you)

# The Array/Pointer Duality Law

Consider this function that computes the sum of all values in an array:

***`Look at this`***

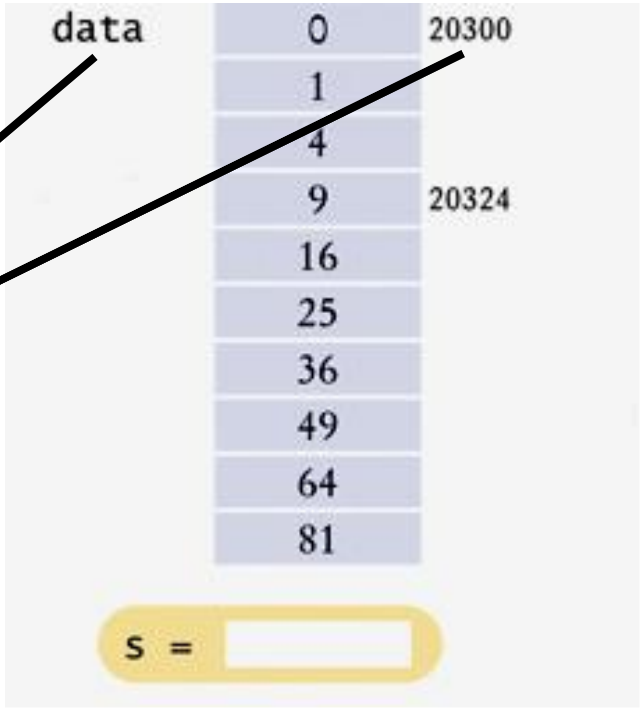
```
double sum(double a[], int size)
{
    double total = 0;
    for (int i = 0; i < size; i++) {
        total = total + a[i];
    }
    return total;
}
```

# The Array/Pointer Duality Law

Here is a call to the function.

```
double data[10];
... // Initialize data

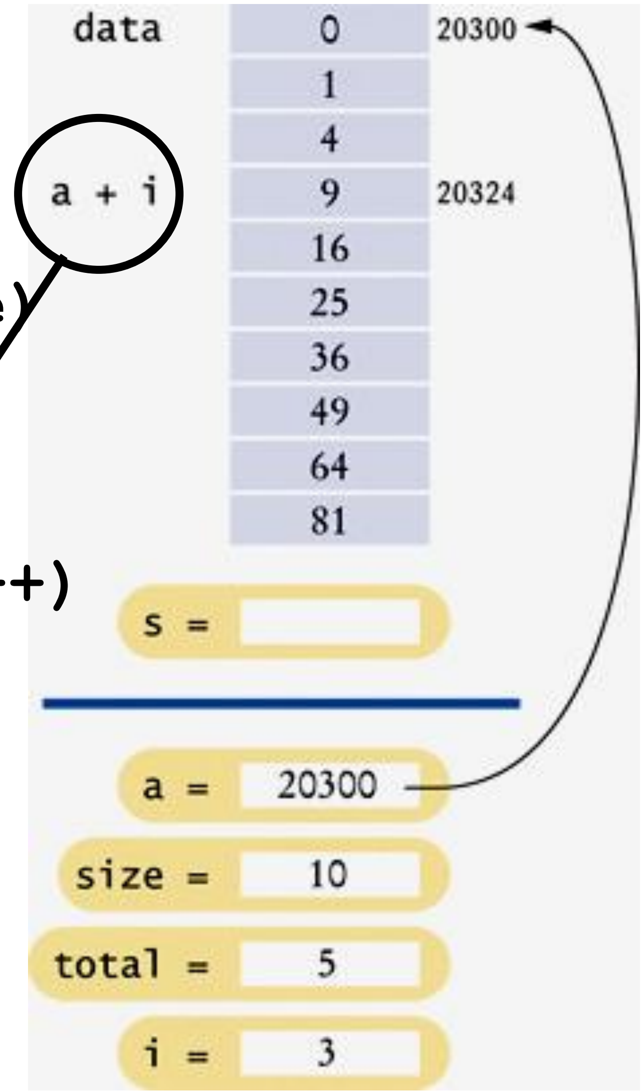
double s = sum(data, 10);
```



# The Array/Pointer Duality Law

After the loop has run
to the point when **`i`** is 3:

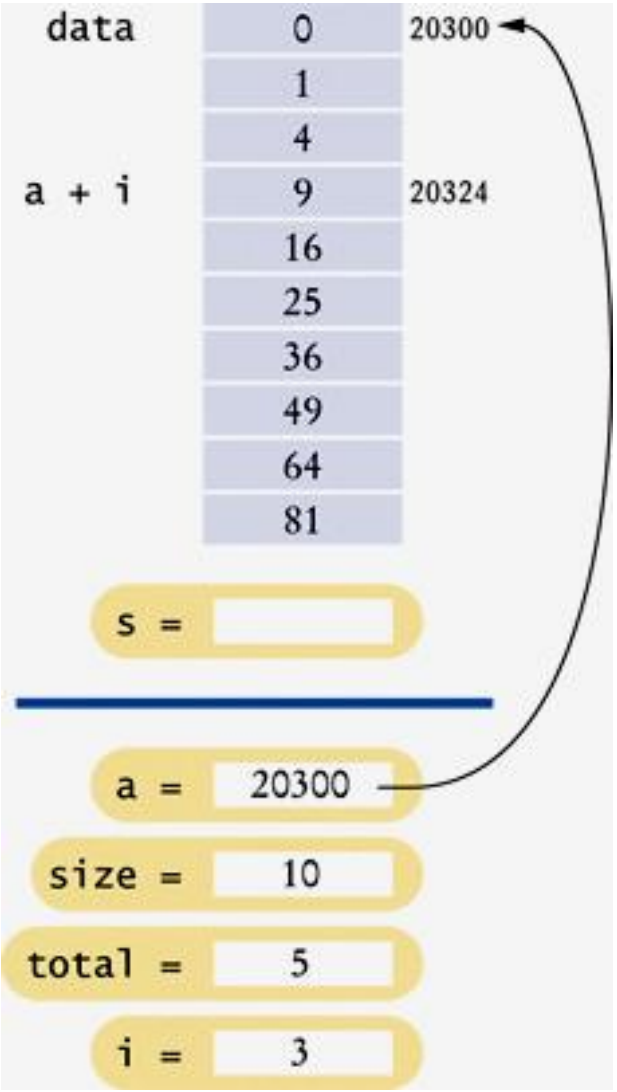
```
double sum(double a[], int size)
{
    double total = 0;
    for (int i = 0; i < size; i++)
    {
        total = total + a[i];
    }
    return total;
}
```



# The Array/Pointer Duality Law

The C compiler considers
**`a`** to be a pointer, not an array.

The expression **`a[i]`**
is *syntactic sugar*
for **`*(a + i)`**.



# Syntactic Sugar

Computer scientists use the term

"*syntactic sugar*"

to describe a notation that is easy to read for humans and that masks a complex implementation detail.

## Syntactic Sugar

That masked complex implementation detail:

```
double sum(double* a, int size)
```

is how we *should* define the first parameter

but

```
double sum(double a[], int size)
```

looks a lot more like we are passing an array.

# Arrays and Pointers

**Table 2 Arrays and Pointers**

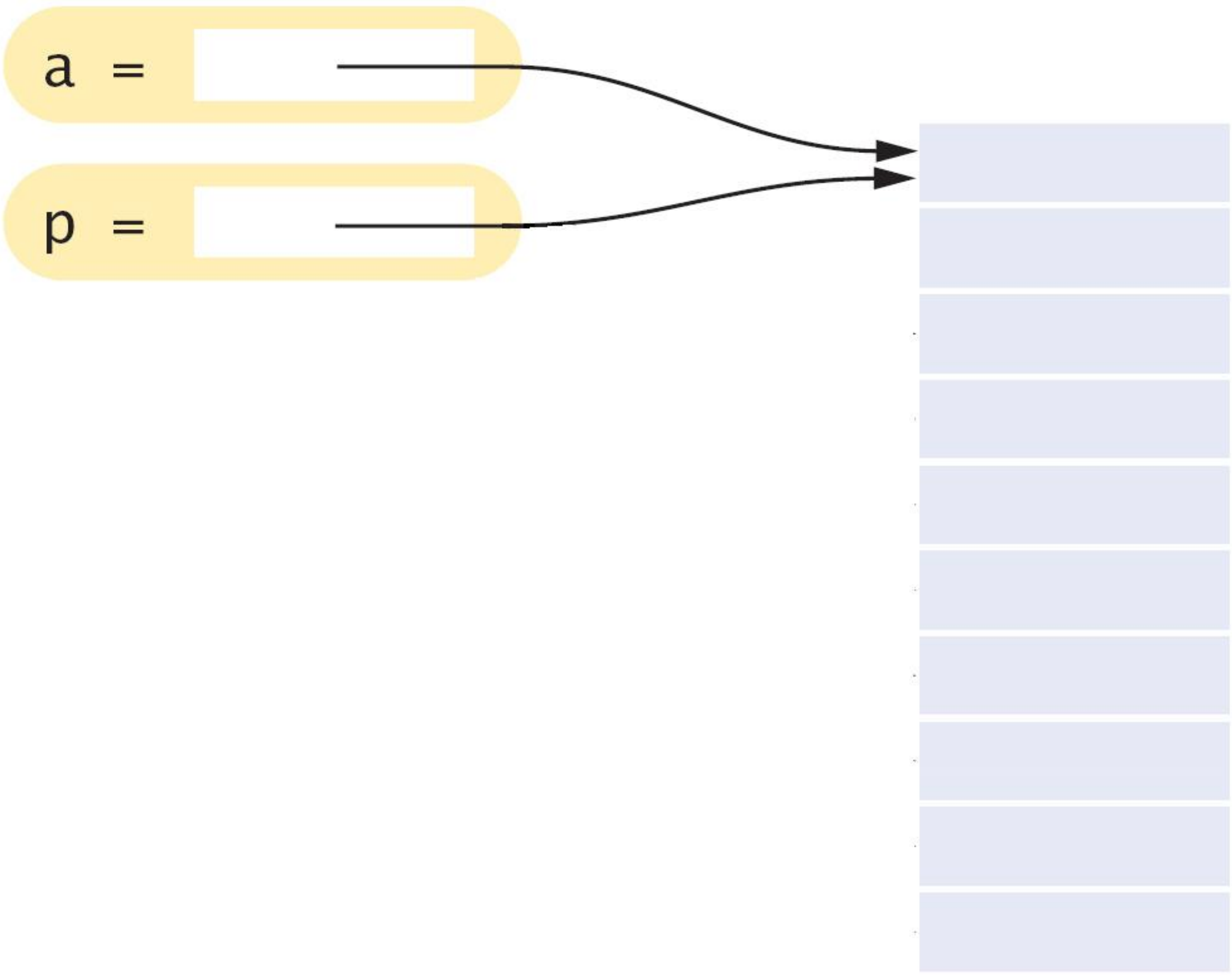
| Expression | Value | Comment |
|---|---|---|
| `a` | 20300 | The starting address of the array, here assumed to be 20300. |
| `*a` | 0 | The value stored at that address. (The array contains values 0, 1, 4, 9, ....) |
| `a + 1` | 20308 | The address of the next `double` value in the array. A `double` occupies 8 bytes. |
| `a + 3` | 20324 | The address of the element with index 3, obtained by skipping past $3 \times 8$ bytes. |
| `*(a + 3)` | 9 | The value stored at address 20324. |
| `a[3]` | 9 | The same as `*(a + 3)` by array/pointer duality. |
| `*a + 3` | 3 | The sum of `*a` and 3. Since there are no parentheses, the `*` refers only to `a`. |
| `&a[3]` | 20324 | The address of the element with index 3, the same as `a + 3`. |

## Using a Pointer to Step Through an Array

Watch variable p as this code is executed.

```
double sum(double* a, int size)
{
    double total = 0;
    double* p = a;
    // p starts at the beginning of the array
    for (int i = 0; i < size; i++) {
        total = total + *p;
        // Add the value to which p points
        p++;
        // Advance p to the next array element
    }
    return total;
}
```

# Using a Pointer to Step Through an Array



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double sum(double* a, int size)
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    double total = 0;
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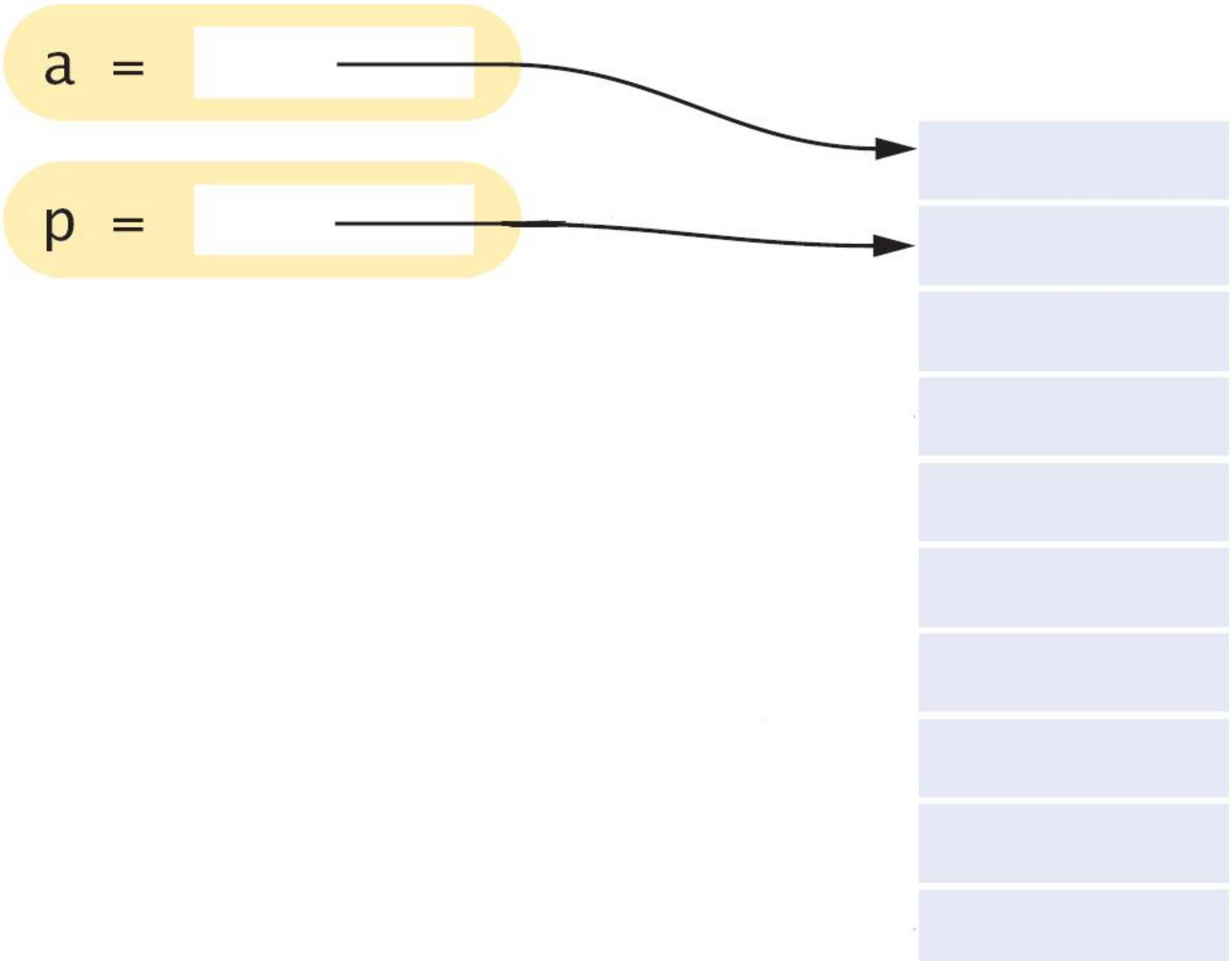
    // p starts at the beginning of the array
    for (int i = 0; i < size; i++)
    {
        total = total + *p;
        // Add the value to which p points
        p++;
        // Advance p to the next array element
    }
    return total;
}
```

# Using a Pointer to Step Through an Array



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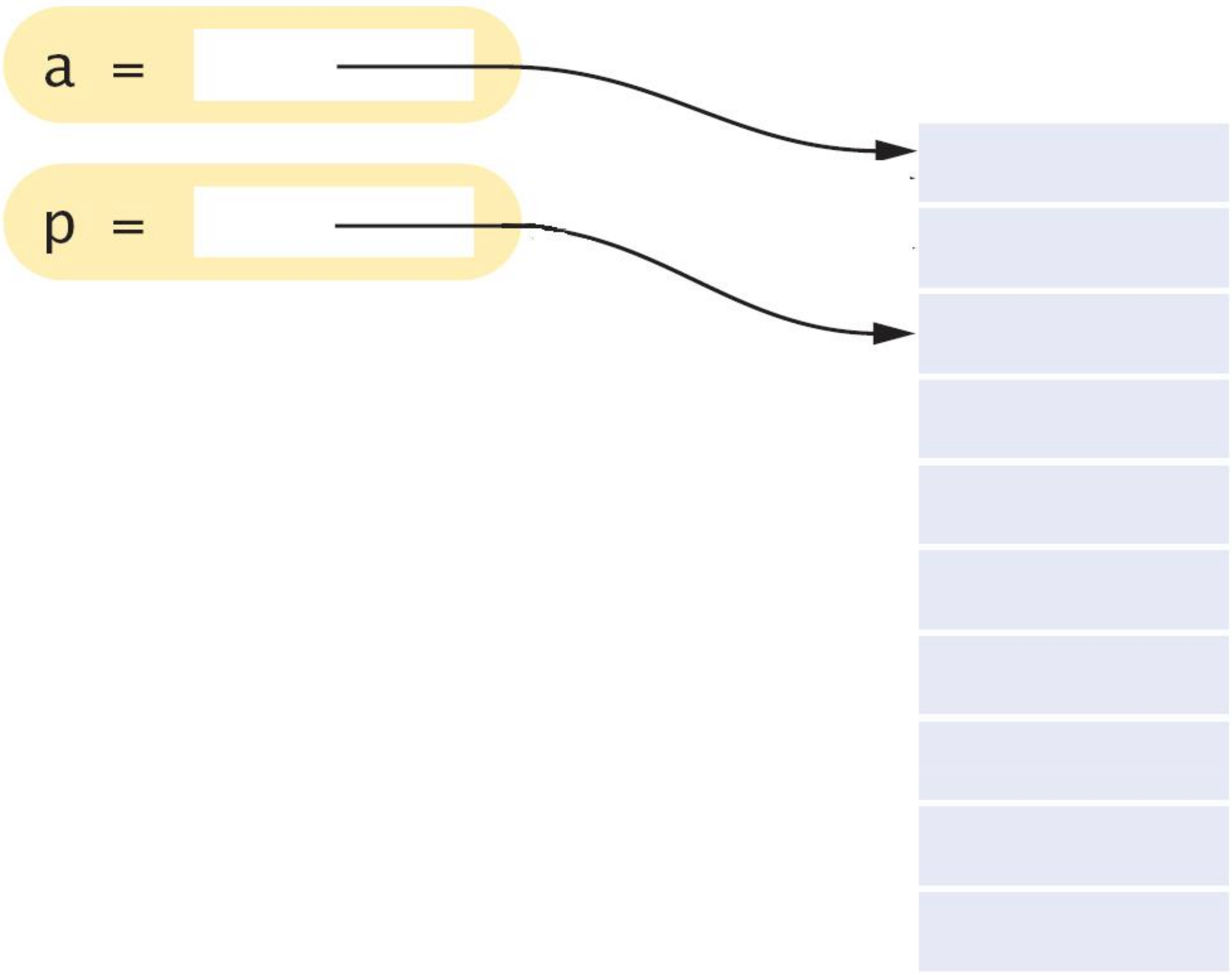
```
double sum(double* a, int size)
{
    double total = 0;
    double* p = a;
    // p starts at the beginning of the array
    for (int i = 0; i < size; i++)
    {
        total = total + *p;
        // Add the value to which p points
        p++;
        // Advance p to the next array element
    }
    return total;
}
```

# Using a Pointer to Step Through an Array

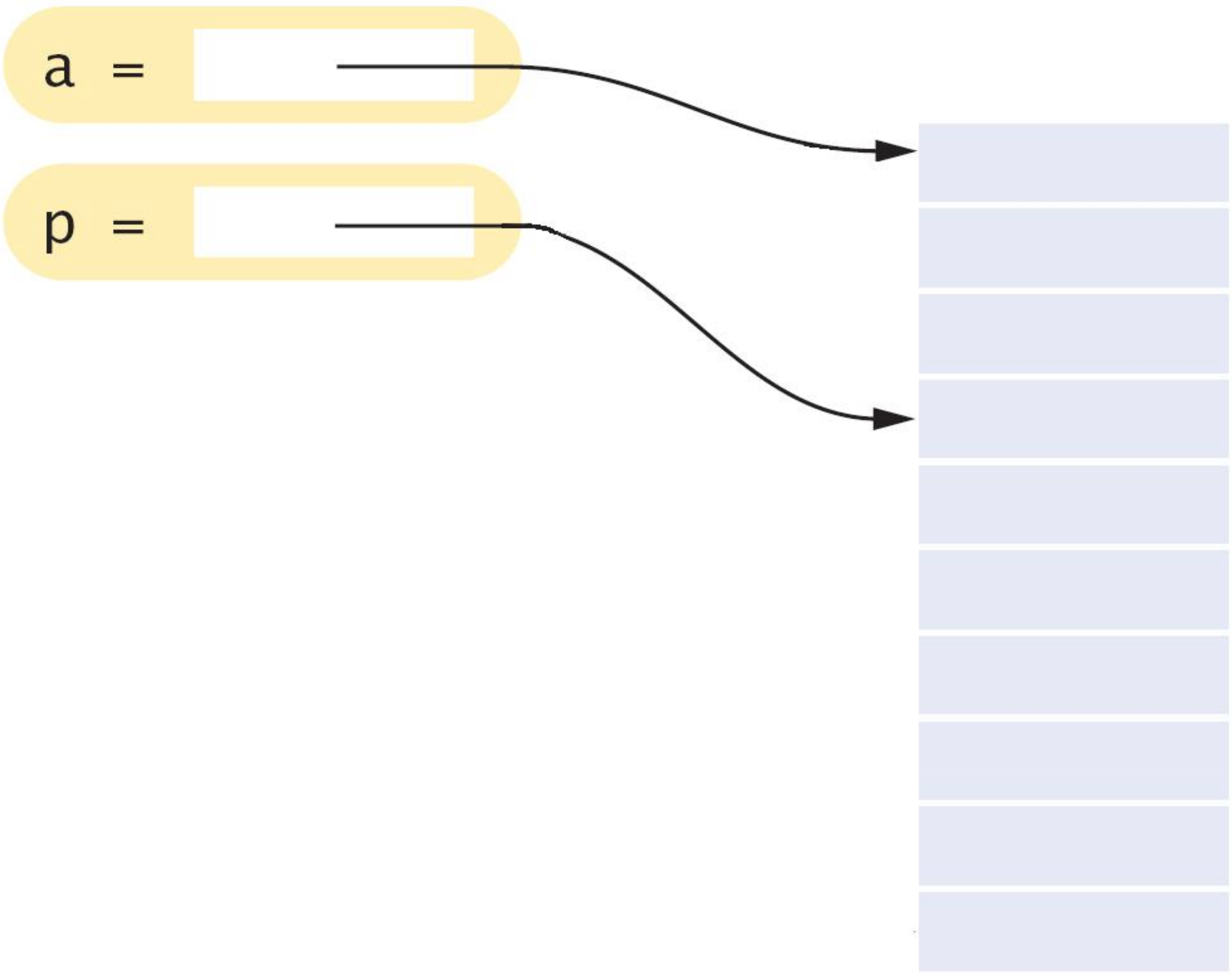


# Using a Pointer to Step Through an Array

Add, then move **`p`** to the next position by incrementing.

```
double sum(double* a, int size)
{
   double total = 0;
   double* p = a;
   // p starts at the beginning of the array
   for (int i = 0; i < size; i++)
   {
      total = total + *p;
      // Add the value to which p points
      p++;
      // Advance p to the next array element
   }
   return total;
}
```

# Using a Pointer to Step Through an Array

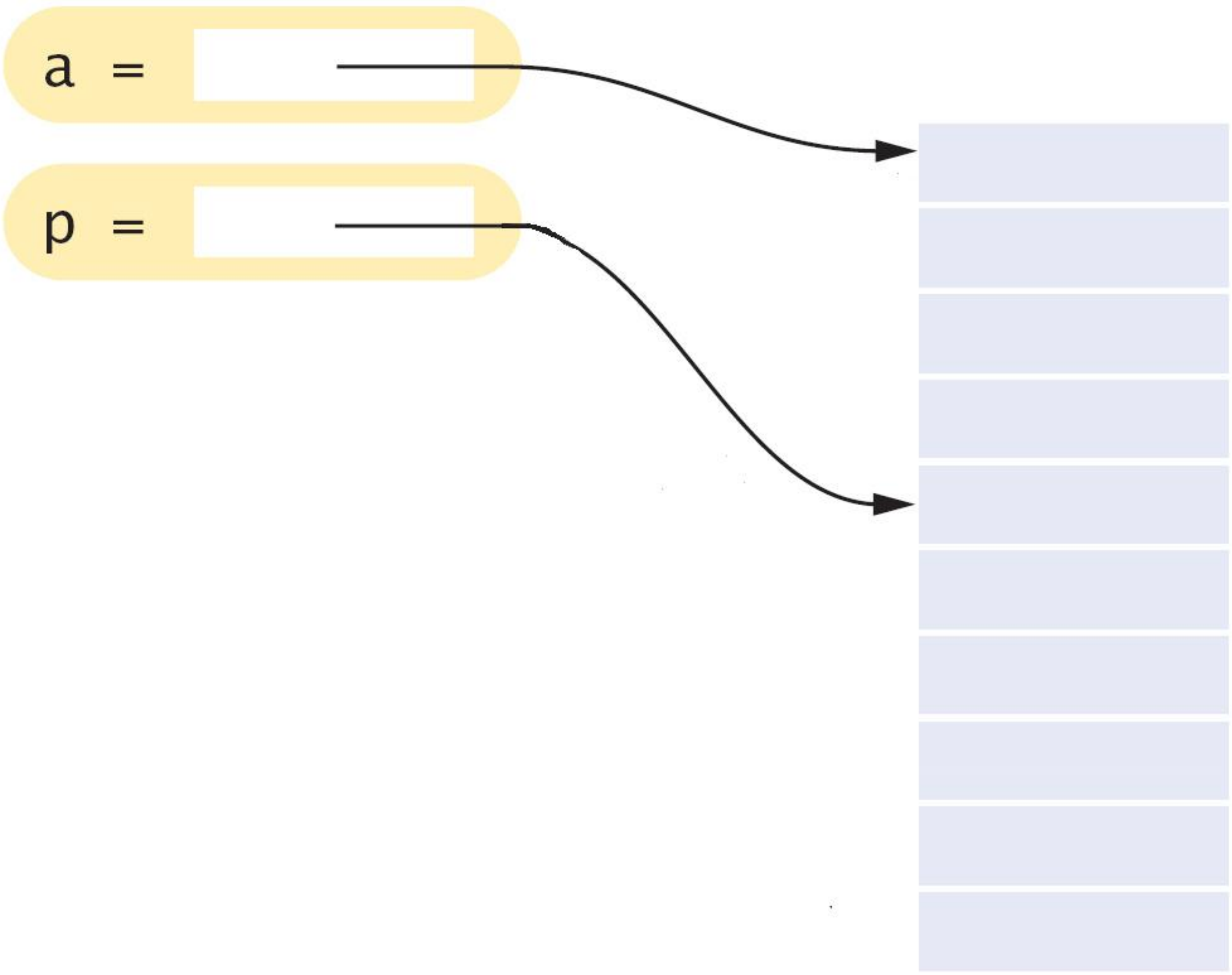


# Using a Pointer to Step Through an Array

Add, then again move **p** to the next position by incrementing.

```
double sum(double* a, int size)
{
    double total = 0;
    double* p = a;
    // p starts at the beginning of the array
    for (int i = 0; i < size; i++)
    {
        total = total + *p;
        // Add the value to which p points
        p++;
        // Advance p to the next array element
    }
    return total;
}
```

# Using a Pointer to Step Through an Array

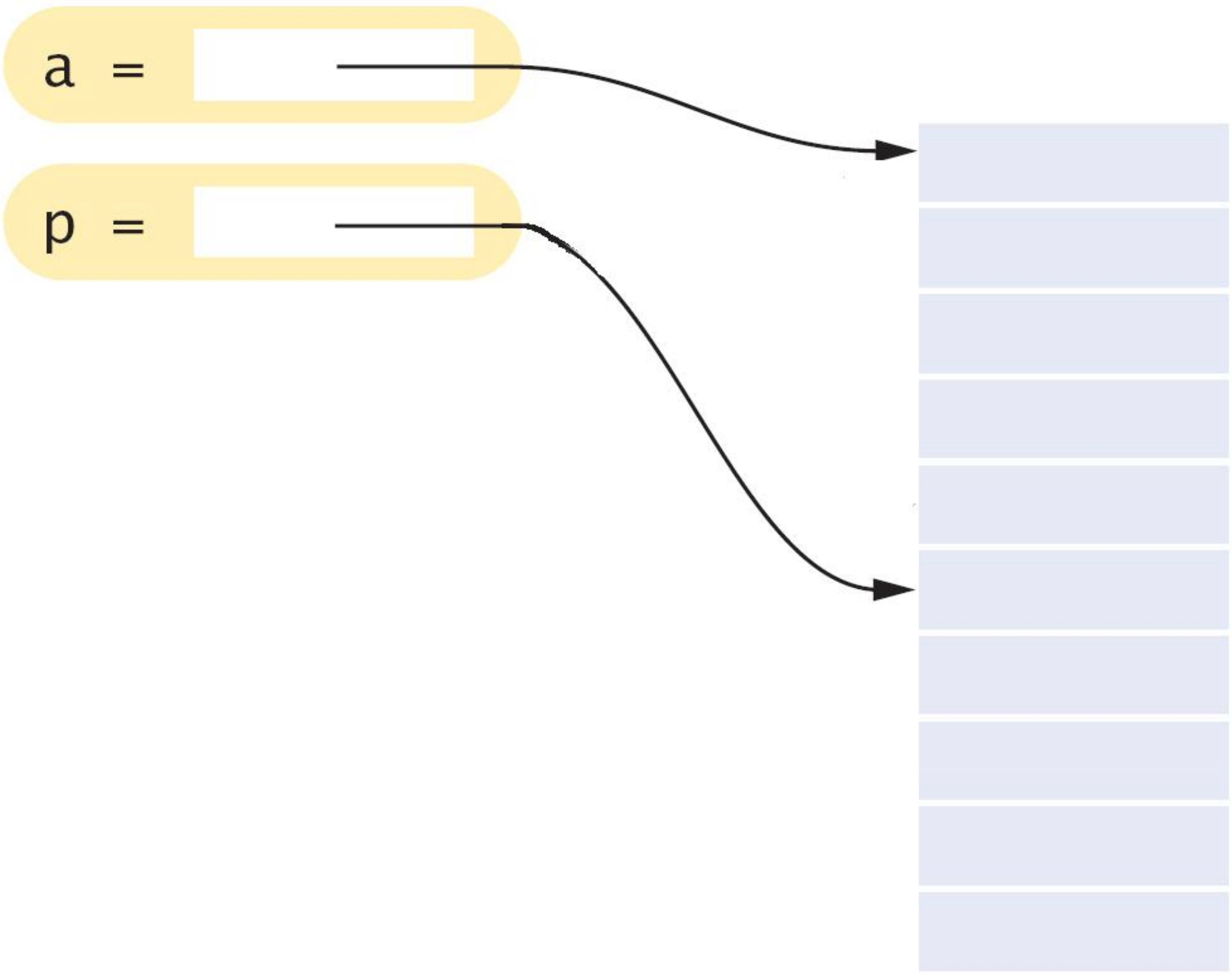


# Using a Pointer to Step Through an Array

Add, then move **p**.

```
double sum(double* a, int size)
{
    double total = 0;
    double* p = a;
    // p starts at the beginning of the array
    for (int i = 0; i < size; i++)
    {
        total = total + *p;
        // Add the value to which p points
        p++;
        // Advance p to the next array element
    }
    return total;
}
```

# Using a Pointer to Step Through an Array

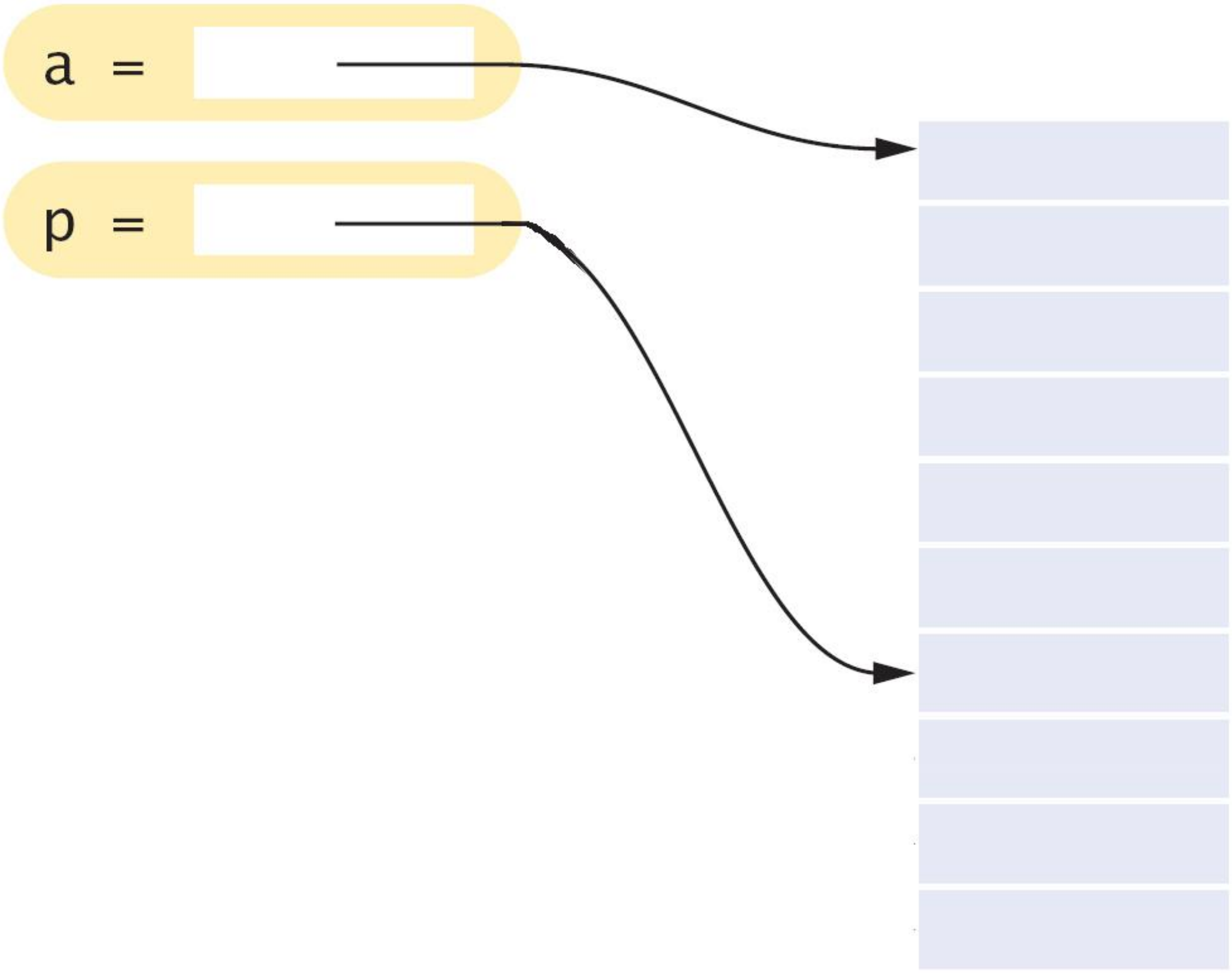


# Using a Pointer to Step Through an Array

Again...

```
double sum(double* a, int size)
{
   double total = 0;
   double* p = a;
   // p starts at the beginning of the array
   for (int i = 0; i < size; i++)
   {
      total = total + *p;
      // Add the value to which p points
      p++;
      // Advance p to the next array element
   }
   return total;
}
```

# Using a Pointer to Step Through an Array

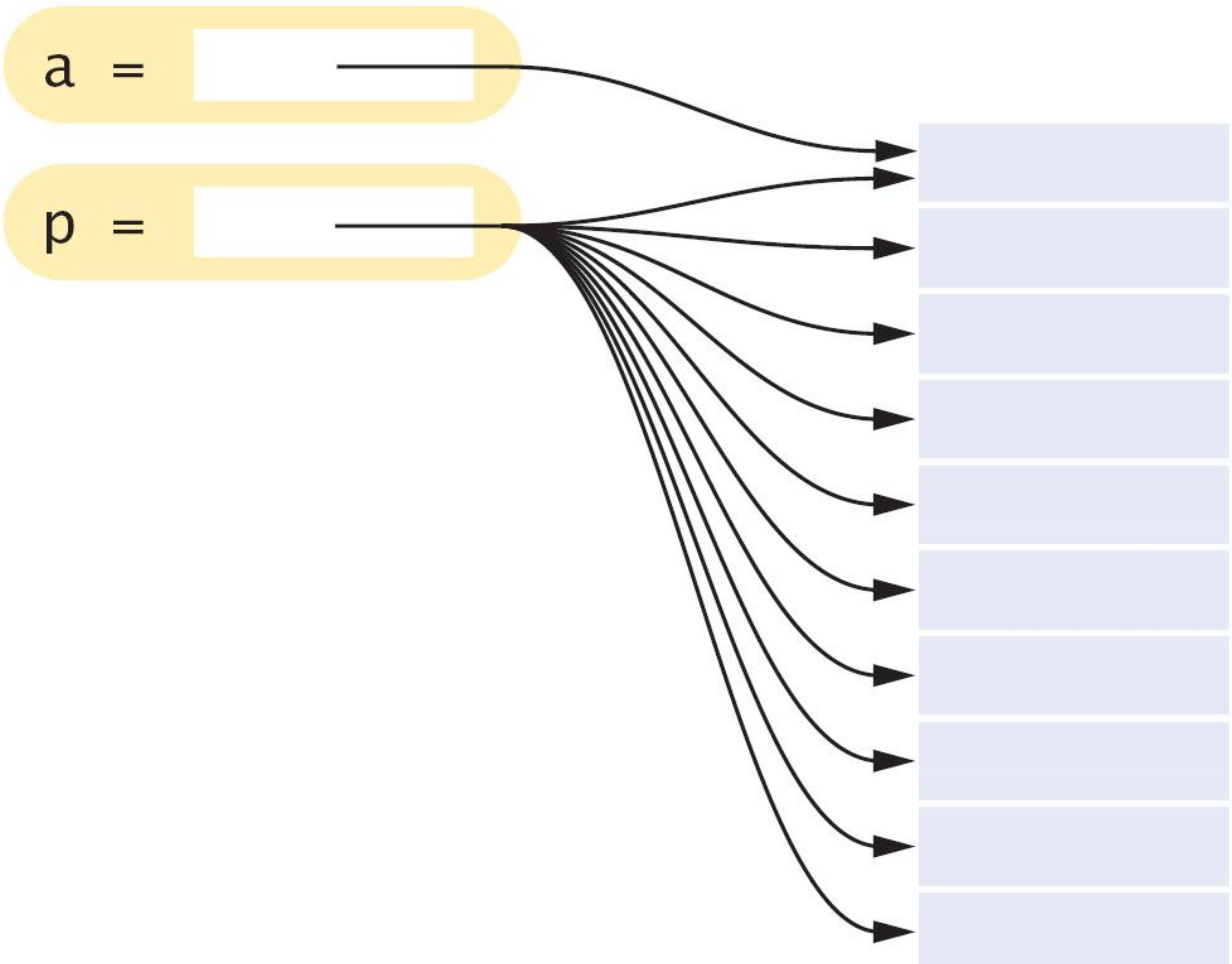


## Using a Pointer to Step Through an Array

And so on until every single position in the array has been added.

```
double sum(double* a, int size)
{
    double total = 0;
    double* p = a;
    // p starts at the beginning of the array
    for (int i = 0; i < size; i++)
    {
        total = total + *p;
        // Add the value to which p points
        p++;
        // Advance p to the next array element
    }
    return total;
}
```

# Using a Pointer to Step Through an Array



# Using a Pointer to Step Through an Array

It is a tiny bit more efficient to use and increment a pointer than to access an array element.

# Program Clearly, Not Cleverly

Some programmers take great pride
in minimizing the number of instructions,
even if the resulting code is hard to understand.

```
while (size > 0) // Loop size times
{
    total = total + *p;
    p++;
    size--;
}
```

could be written as:

```
total = total + *p++;
```

Ah, so much better?

# Program Clearly, Not Cleverly

```
while (size > 0)
{
    total = total + *p;
    p++;
    size--;
}
```

could be written as:

```
while (size-- > 0)
    total = total + *p++;
```

Ah, so much better?

# Program Clearly, Not Cleverly

Please do not use this programming style.

Your job as a programmer is not to dazzle other programmers with your cleverness,
but to write code that is easy
to understand and maintain.

# Common Error: Returning a Pointer to a Local Variable

What would it mean to
"return an array"
?

## Common Error: Returning a Pointer to a Local Variable

Consider this function that tries to return
a pointer to an array containing two elements,
the first and last values of an array:

```
double* firstlast(double a[], int size)
{
    double result[2];
    result[0] = a[0];
    result[1] = a[size - 1];
    return result;
}
```

***Local** memory is invalid after the function call has ended!*

*What would the value the caller gets be pointing to?*

# Common Error: Returning a Pointer to a Local Variable

A solution would be to pass
in an array to hold the answer:

```
void firstlast(double a[], int size,
                    double result[])
{
    result[0] = a[0];
    result[1] = a[size - 1];
}
```

# Example : Methods for Array Element Accessing

```
#include <stdio.h>
int main()
{   int b[5] = {10, 20, 30, 40, 50};
    int * bPtr;      // Pointer to int
    bPtr = b;        // Pointer gets address of b array
    int i;           // Loop counter
//-------------------------------------------------------------
     for (i=0; i < 5; i++)
          printf("%d  ", b [ i ] );
     printf("\n\n"); // Newlines
//-------------------------------------------------------------
    for (i=0; i < 5; i++)
          printf("%d  ", bPtr [ i ] );
     printf("\n\n");
//-------------------------------------------------------------
     for (i=0; i < 5; i++)
          printf("%d  ",   * ( bPtr + i ) );
     printf("\n\n");
//-------------------------------------------------------------
     for (i=0; i < 5; i++)
          printf("%d  ",   * ( b + i ) );
     printf("\n\n");
}
```

Screen Output :

```
10  20  30  40  50

10  20  30  40  50

10  20  30  40  50

10  20  30  40  50
```

# Example: Pointer to another Pointer

```c
#include <stdio.h>

int main()
{
int a = 20;
int *x;     //Pointer
int **q;    //Pointer to another pointer

x = &a; // Get address of a
q = &x; // Get address of x

printf(" a = %d    &a = %p \n", a,  &a);
printf("*x = %d   **q = %d \n", *x, **q);
printf(" x = %p    *q = %p \n", x, *q);
printf("&x = %p     q = %p \n", &x, q);
printf("&q = %p \n", &q);

} // end main
```

Program Output

```
a    = 20
&a = 0022FF74

 *x = 20
**q = 20

 x = 0022FF74
*q = 0022FF74

&x = 0022FF70
  q = 0022FF70

&q = 0022FF6C
```