Programming with Indexed Variables

Variable with One Index: 1-Dimensional Array

```
... what(...) {
 int a[10] ;
   ...........
}
```

What does the declaration mean?

Meaning

- It is an 1-dimensional array of ten locations, each of type `int`.
- Compiler generates machine code so that every time the function `what()` is invoked (called), there will be an allocation of 10 consecutive locations of type `int`. The locations are destroyed when the control returns from the function.

Meaning

- The total space allocated is $10 \times$ `sizeof(int)`. If the size of an `int` location is 4-bytes, the total allocated space is 40-bytes.
- The locations are indexed by 0 to 9.

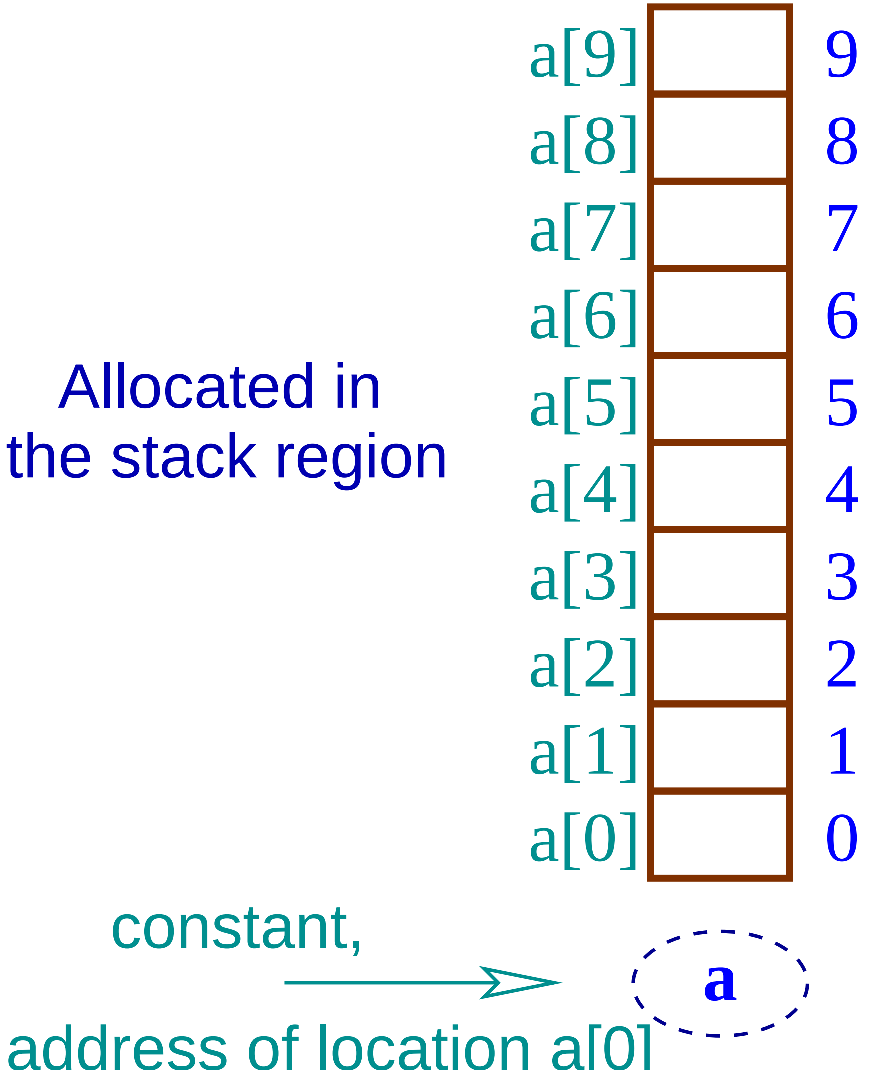
Meaning

- The name `a` of the array is a constant expression, whose value is the address of the 0^{th} location.
- The i^{th} location may be treated as an indexed variable `a[i]`, $0 \leq i < 10$[a].

[a] The C compiler does not stop you going beyond the index 9, but there may be serious run-time error.

Meaning

The array `a[]` is local to the function `what()` and its space is allocated in the stack frame (activation record) of the function.


a[9]
a[8]
a[7]
a[6]
a[5]
a[4]
a[3]
a[2]
a[1]
a[0]
9
8
7
6
5
4
3
2
1
0
Allocated in
the stack region
constant,
address of location a[0]
a

Indexed Variable

Let e be an integer expression whose value v is within the range 0 to 9, `a[e]` refers to the v^{th} location of the array. `a[e]` is treated as a variable with its content (r-value) and address (l-value).

```
a[2] = a[1] = 1 ;
a[3] = 6 - 2*a[1] ;
a[a[3]] = a[2+a[1]] + 10 ;
```

Indexed Variable

If v is not within the range $[0 \cdots 9]$, an access to `a[e]` may give a run-time error. But normally a C compiler, unlike Pascal or Ada, does not check for array index bound.

Array Name

The array name a is an expression but it is not bound to a location so, no value can be assigned to it.

```
int a[10] ;
  .........
a = ....  // Illegal
```

Array Name

```
#include <stdio.h>
int main() // arrayName.c
{
    int a[10] ;
    a = (int *)100 ;
    return 0;
}
```

```
$ cc -Wall arrayName.c
arrayName.c:  In function ‘main’: arrayName.c:9:
error:  incompatible types in assignment
```

Array Name

It was mentioned earlier, that the value of `a` is the address of the 0^{th} location i.e.

`a` is equivalent to `&a[0]` and

`*a` is equivalent to `a[0]`.

Array and Pointer

The expression `a+e` is the address of the location `a[e]` i.e. `&a[e]` $\equiv$ `(a+e)`, and `*(a+e)` is same as `a[e]`.

Address	Pointer
`a = a+0` $\equiv$ `&a[0]`	`*a` $\equiv$ `a[0]`
`a+1` $\equiv$ `&a[1]`	`*(a+1)` $\equiv$ `a[1]`
`a+2` $\equiv$ `&a[2]`	`*(a+2)` $\equiv$ `a[2]`
...	...

Array and Pointer

The i^{th} location of a 1-D array `a[]` of type `int` starts from the address `(unsigned)a` $+$ i*`sizeof(int)`[a].

[a]The `(unsigned)a` makes the address an unsigned integer. We shall not use it explicitly to make the expression look clean.

Array and Pointer

Location	Starting Address
0^{th}	`a`
1^{st}	`a` + `sizeof(int)`
2^{nd}	`a` + 2∗`sizeof(int)`
...	...
i^{th}	`a` + i∗`sizeof(int)`

Pointer Arithmetic

As the value of sizeof() depends on data type, so the meaning of `a + i` also changes depending on the type of `a[]`.

Pointer Arithmetic

```
#include <stdio.h>
int main() // ptrArith1.c
{
    char c[5], *cP;
    int  i[5], *iP;
    double d[5], *dP ;

    printf("char pointer\t\tint pointer\t\tdouble pointer\n
    printf("-----------\t\t----------\t\t-------------\n

    printf("c: %p,\t\ti: %p,\t\td: %p\n", c, i, d) ;
    printf("c+1: %p,\ti+1: %p,\td+1: %p\n", c+1, i+1, d+1)
```

```
printf("c+2: %p,\ti+2: %p,\td+2: %p\n", c+2, i+2, d+2)
printf("c+10: %p,\ti+10: %p,\td+10: %p\n", c+10, i+10,

cP = c, iP = i, dP = d;
printf("\ncP: %p,\t\tiP: %p,\t\tdP: %p\n", cP, iP, dP)
printf("cP+1: %p,\tiP+1: %p,\tdP+1: %p\n", cP+1, iP+1,
printf("cP+2: %p,\tiP+2: %p,\tdP+2: %p\n", cP+2, iP+2,
printf("cP+10: %p,\tiP+10: %p,\tdP+10: %p\n", cP+10, iP

cP = (char *)0, iP = (int *)0, dP = (double *)0;
printf("\ncP: %p,\tiP: %p,\tdP: %p\n", cP, iP, dP) ;
printf("cP+1: %p,\tiP+1: %p,\tdP+1: %p\n", cP+1, iP+1,
printf("cP+2: %p,\tiP+2: %p,\tdP+2: %p\n", cP+2, iP+2,
printf("cP+10: %p,\tiP+10: %p,\tdP+10: %p\n", cP+10, iP
```

```
    return 0;
}
```

Array and Pointer

We can write,

`&(*(a+e))` ≡ `&a[e]` ≡ `a+e`, and

`*(&a[e])` ≡ `*(a+e)` ≡ `a[e]`.

The * and & operators are inverse to each other.

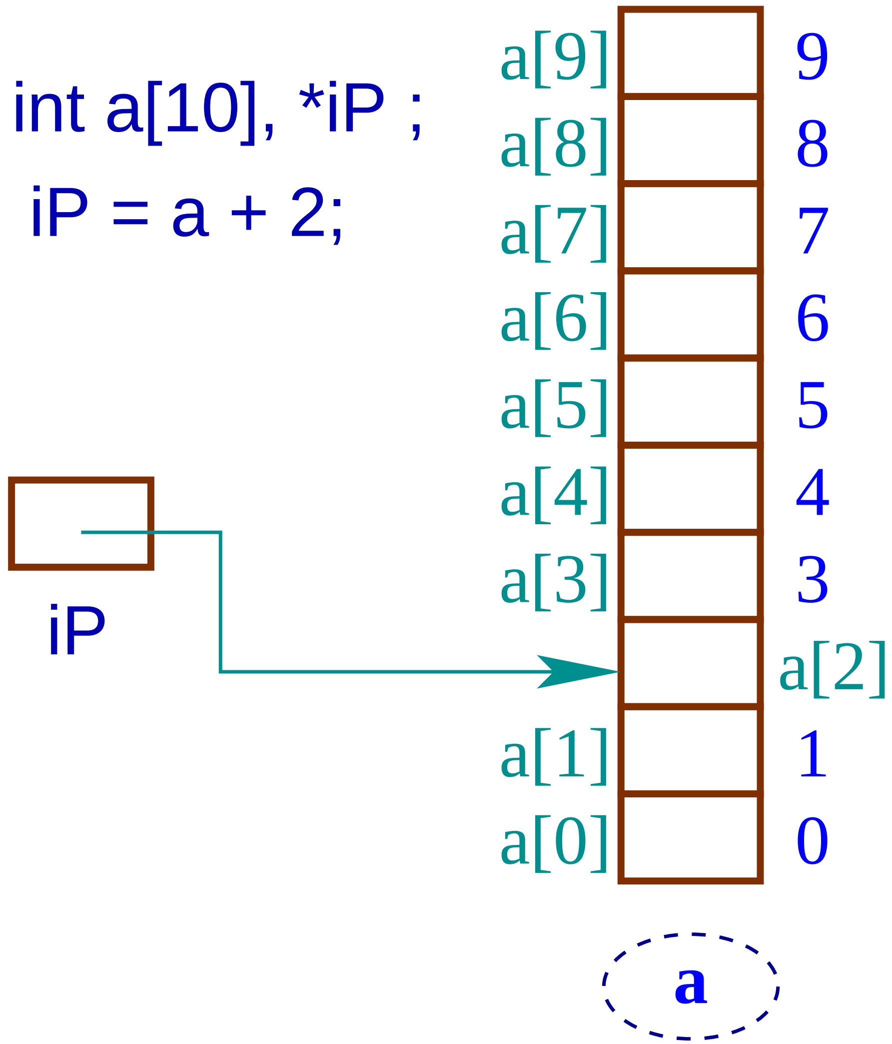
Pointer Arithmetic

The address of an element of a 1-D array can be assigned to a pointer variable of appropriate type and the array elements can be accessed using the pointer variable. This in general is

not a good programming practice

.

```
int a[10], *iP ;
iP = a + 2;
```



Pointer Arithmetic

```
#include <stdio.h>
int main() // ptrArith2.c
{
    int a[10] = {0, 10, 20, 30, 40, 50,
                 60, 70, 80, 90}, *iP ;

    iP = a + 2;
    printf("a[2]: %d\t*iP: %d\t\tiP[0]: %d\n", a[2], *iP, i
    printf("a[5]: %d\t*(iP+3): %d\tiP[3]: %d\n", a[5], *(iP
    return 0;
}
```

Example

Write a C program that

1. reads a positive integer n ($n \leq$ `MAXSIZE`);
2. reads n integers in an array of type `int` starting from the index 0;
3. prints the data present in the array from the index 0;
4. reverse the data positions in the array `data[i]` $\leftrightarrow$ `data[n-1-i]`,
5. again prints the data present in the array from the index 0.

C Program

```
#include <stdio.h>
#define MAXSIZE 100
int main()
{  // revArray.c
    int noOfData, data[MAXSIZE], i, halfNo ;

    printf("Enter the No. of Data (<= %d): ",
                                        MAXSIZE);
    scanf("%d", &noOfData) ;
    printf("\nEnter the Data\n") ;
    for(i = 0; i < noOfData; ++i)
        scanf("%d", &data[i]) ;  // data+i

    printf("%d data present are\n", noOfData) ;
```

```
for(i = 0; i < noOfData; ++i)
     printf("%d ", data[i]) ; // *(data+i)
halfNo = (noOfData - 1)/2 ;
for(i = 0; i <= halfNo; ++i) {
    int temp ;

    temp = data[i] ;
    data[i] = data[noOfData-1-i] ;
    data[noOfData-1-i] = temp ;
}
printf("\nData After Reversal\n") ;
for(i = 0; i < noOfData; ++i)
       printf("%d ", data[i]) ;
```

```
    printf("\n") ;
    return 0 ;
}
```

Another C Program

```
#include <stdio.h>
#define MAXSIZE 100
int main() // revArray2.c
{
    int noOfData, data[MAXSIZE], i, j ;

    printf("Enter the No. of Data (<= %d): ",
                                        MAXSIZE);
    scanf("%d", &noOfData) ;
    printf("\nEnter the Data\n") ;
    for(i = 0; i < noOfData; ++i)
        scanf("%d", &data[i]) ;  // data+i

    printf("%d data present are\n", noOfData) ;
```

```
for(i = 0; i < noOfData; ++i)
     printf("%d ", data[i]) ; // *(data+i)
for(i = 0, j=noOfData-1; i < j; ++i, --j) {
    int temp ;

    temp = data[i] ;
    data[i] = data[j] ;
    data[j] = temp ;
}
printf("\nData After Reversal\n") ;
for(i = 0; i < noOfData; ++i)
       printf("%d ", data[i]) ;
printf("\n") ;
```

```
    return 0 ;
}
```

Example

Solve the previous problem by writing a function to reverse the data in the array.

Function Interface

- `void reverseData(int [], int) ;`
- The first parameter is the starting address of the array. This is equivalent to writing `int *`. The second parameter is the number of data present in the array.
- This function does not return any value, so the return type is `void`.

Command Abstraction

The purpose of this function is to change the content of different locations of the array. The job is similar to that of a sequence of statements or commands and not like an expression (does not compute and return a value).

Command Abstraction

This type of object is called a procedure or a subprogram in programming languages like Pascal or FORTRAN. But in C it also is called a function. Here the function is an abstraction of a sequence of commands.

Actual Parameters for an 1-D Array?

- It is necessary to access the array elements, `a[e]` within a called function.
- An array element can be accessed if its address is known.
- The compiler can can generate code to compute the address of `a[e]` if it gets the starting address of the array, the value of `e`, and the size of each array element.

Address of an Array Element: `a[e]`

$$a + v \times s$$

- a is the starting address of the array,
- v is the value of the expression `e`.
- s is the size of each element of the array

An Example

```
#include <stdio.h>
int main() // arrayAddr.c
{
    int a[10] ;
    printf("sizeof(int) = %u\n", sizeof(int));
    printf("Address of a[0]=%u:%u\n",
         (unsigned)a, (unsigned)&a[0]);
    printf("Address of a[1]=%u:%u\n",
         (unsigned)a+1*sizeof(int), (unsigned)&a[1]);
    printf("Address of a[2]=%u:%u\n",
         (unsigned)a+2*sizeof(int), (unsigned)&a[1]);
    printf("Address of a[7]=%u:%u\n",
         (unsigned)a+7*sizeof(int), (unsigned)&a[7]);
    return 0 ; }
```

A Run

```
$ ./a.out
sizeof(int) = 4
Address of a[0]=3220264176:3220264176
Address of a[1]=3220264180:3220264180
Address of a[2]=3220264184:3220264180
Address of a[7]=3220264204:3220264204
$
```

Address of an Array Element: `a[e]`

- The value of `e` is computed (compiler generates coed for that).
- The size of an array element depends on its type, the programming language, compiler and the machine. But all these information are known a priori.

Address of an Array Element: `a[e]`

In case of an 1-D array, the only unknown within a called function (callee) is the starting address of the array which has been declared in the caller or even at a higher level.

So the only actual parameter passed in this case is the starting address of the array.

Formal Parameter `int x[]` or `int *x`

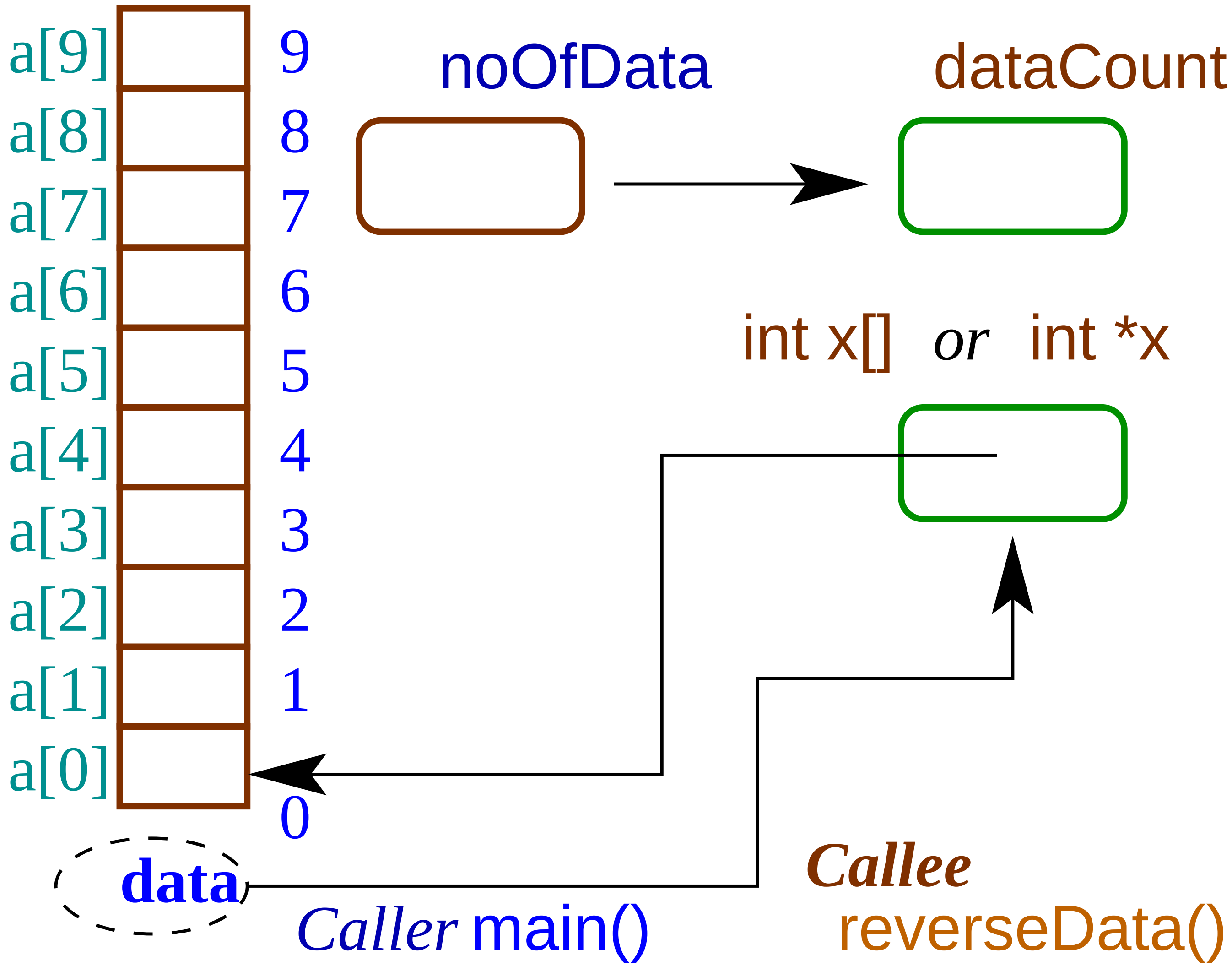
The formal parameter `x` receives the address of an `int` location. It is usually treated as the starting address of an 1-D array. But it is essentially a pointer of type `int`.

Formal Parameter `int x[]` or `int *x`

The language does not stop a programmer to pass any address as the actual parameter, but the result may be memory access violation (segmentation fault) or incorrect value.

Passing an 1-D Array

```
#define MAXSIZE 100
void reverseData(int [], int); // Interface
int main()
{
 int .... data[MAXSIZE], noOfData ;
 ...................
 ..... reverseData(data, noOfData)
}
void reverseData(int x[], int dataCount) {
    .... x[e] ........
}
```


a[9]
a[8]
a[7]
a[6]
a[5]
a[4]
a[3]
a[2]
a[1]
a[0]
9
8
7
6
5
4
3
2
1
0
noOfData
dataCount
int x[] or int *x
data
Caller main()
Callee
reverseData()

C Program

```
#include <stdio.h>
#define MAXSIZE 100
void reverseData(int [], int);
int main() // revArray1.c
{
    int noOfData, data[MAXSIZE], i ;
    printf("Enter the No. of Data (<= %d): ",
                                MAXSIZE);
    scanf("%d", &noOfData) ;
    printf("\nEnter the Data\n") ;
    for(i=0; i<noOfData; ++i) scanf("%d", &data[i]);
    printf("%d data present are\n", noOfData) ;
    for(i=0; i<noOfData; ++i) printf("%d ", data[i]);
    reverseData(data, noOfData) ;
```

```
    printf("\nData After Reversal\n") ;
    for(i = 0; i < noOfData; ++i)
                     printf("%d ", data[i]) ;
    printf("\n") ;
    return 0;
}
void reverseData(int x[], int dataCount) {
     int halfNo, i ;

     halfNo = (dataCount - 1)/2 ;
     for(i = 0; i <= halfNo; ++i) {
         int temp ;

         temp = x[i] ;
```

```
            x[i] = x[dataCount-1-i] ;
            x[dataCount-1-i] = temp ;
        }
}
```

Array and Pointer

What will happen if the function `reverseData()` is called as `reverseData(a+2, noOfData-2)` ?

Array Initialization

```
/*
 * arrayInit1.c
 */
#include <stdio.h>
#define MAXSIZE 5
int main()
{
    int a[MAXSIZE], b[MAXSIZE] = {0, 1, 2, 3, 4},
                        c[MAXSIZE] = {10},  i ;
    float x[MAXSIZE], z[MAXSIZE] = {10.0},
             y[MAXSIZE] = {0, 10.1, 20, 30, 40};
    for(i = 0; i < MAXSIZE; ++i)
```

```
        printf("a[%d]=%d,\t\tb[%d]=%d,\tc[%d]=%d\n",
                                   i,a[i],i,b[i],i,c[i]) ;
    printf("\n") ;
    for(i = 0; i < MAXSIZE; ++i)
    printf("x[%d]=%f,\t\ty[%d]=%f,\tz[%d]=%f\n",
                         i, x[i], i, y[i], i, z[i]) ;
    return 0 ;
}
```

Size is Implicit

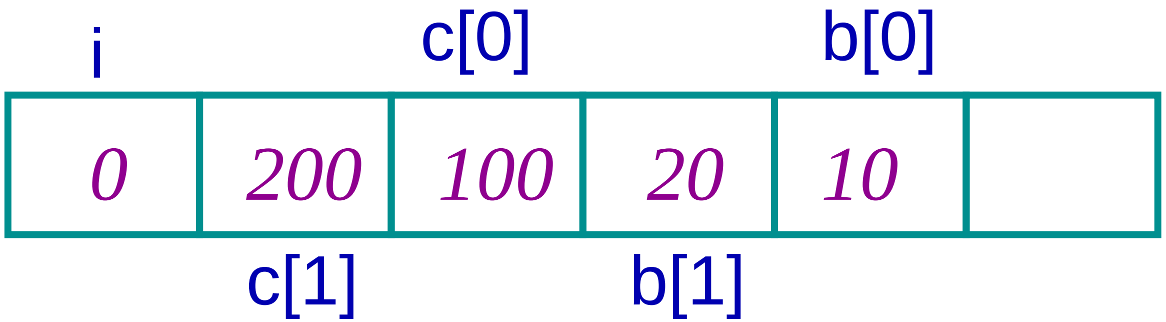
```c
#include <stdio.h>
int main() // arrayInit2.c
{
    int c[] = {100, 200}, b[]={10, 20} ;
    int i;

    for(i = 0; i < 5; ++i)
         printf("b[%d] = %d,\tc[%d] = %d\n",
                   i, b[i], i, c[i]) ;
    printf("\n") ;
    return 0;
}
```

Interesting Output

```
$ ./a.out
b[0] = 10,c[0] = 100
b[1] = 20,c[1] = 200
b[2] = 100,c[2] = 2
b[3] = 200,c[3] = 134513840
b[4] = 4,c[4] = 0
$
```

Memory Allocation



Space Allocation

- Two locations of type `int` are allocated and initialized to 10, 20 for `b[ ]`.
- Two more locations are allocated and initialized for `c[ ]` with 100, 200.
- One location is allocated for `i`.

Space Allocation

- The compiler does not prohibit access to `b[2]`, `b[3]` or `c[2]`, `c[3]`.
- `b[4]` and `2[2]` overlaps with `i`!

C Compiler Does Not Check for the Array Limit

- Beyond the limit you get meaningless data.
- There may be memory protection violation.

```
        .....................
b[368] = 809330281, c[368] = 778121006
b[369] = 892549937, c[369] = 7632239
b[370] = 1029636154, c[370] = 0
Segmentation fault (core dumped)
$
```