Arrays and pointers

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Motivation with Example usage

```
int func(void) {
    int states[5], i;  //defining
    for (i=0; i<5; i++)
        states[i]=i;  //initializing
    for (i=0; i<5; i++)
     printf("%d, ", states[i]);  //accessing the value
    return 0;
}
```

- array is used in storing multiple objects of same type
- objects in the array are indexed starting from 0
- array scope is limited to the function in which it is defined

sizeof operator

```
int func(void) {
    int a[5];
    printf("%d, %d, %d \n",
        sizeof(int), sizeof(a[3]), sizeof(a));
        //outputs 4, 4, 20
}
```

sizeof is a compile-time unary operator to find the size (in byes) of a type or the size of the type returned by an expression:

- size_t *sizeof*(type)
- size_t *sizeof* expression[1]

[1] object is an expression

Two-dimensional arrays

```
int func(void) {
    int a[2][3], i, j;   //defining

    for (i=0; i<2; i++)
        for (j=0; j<3; j++)
            a[i][j] = i+j;  //initializing

    for (i=0; i<2; i++)
        for (j=0; j<3; j++)
            printf("%d, ", a[i][j]);  //accessing the value

    printf("\n %d, %d, %d", sizeof(a),
        sizeof(a[1]), sizeof(a[1][2]));
        //prints 24, 12, 4

    return 0;
}
```

Three-dimensional arrays

```
int func(void) {
    int a[2][3][4], i, j, k;   //defining

    for (i=0; i<2; i++)
        for (j=0; j<3; j++)
            for (k=0; k<4; k++)
                a[i][j][k] = i+j;  //initializing
    for (i=0; i<2; i++)
        for (j=0; j<3; j++)
            for (k=0; k<4; k++)
                printf("%d, ", a[i][j][k]);  //accessing

    printf("\n %d, %d, %d, %d \n", sizeof(a), sizeof(a[1]),
        sizeof(a[0][2]), sizeof(a[1][0][2]));
        //prints ?
    return 0;
}
```

Address vs Value

```
int a, b[2];

a = 10;
printf("%d, %p \n", a, &a);
   //prints 10, 0xbfeac818

b[0] = 22; b[1] = 24;
printf("%d, %p, %d, %p \n", b[0], &b[0], b[1], &b[1]);
   //prints 22, 0xbfeac820, 24, 0xbfeac824
```

- memory for arrays is allocated contiguously

Arrays are stored in row-major order

```
int c[2][3], i, j;
for (i=0; i<2; i++)
    for (j=0; j<3; j++) {
        printf("%p, ", &c[i][j]);
    }
    //prints 0xbfd8f650, 0xbfd8f654, 0xbfd8f658,
    //0xbfd8f65c, 0xbfd8f660, 0xbfd8f664,
```

- contiguous memory is allocated for the zeroth row, immediately thereafter for the first row, etc., — known as *row-major order*
- further, two-dimensional array is treated as *an array of arrays*: the elements of c are $c[0], c[1]$, each of which is an array i.e., the i^{th} row of c is named $c[i]$

Arrays are stored in row-major order (cont)

```
int a[2][5][3], i, j, k;
for (i=0; i<2; i++)
    for (j=0; j<5; j++)
        for (k=0; k<3; k++)
            printf("%p, ", &a[i][j][k]);
   //observed: difference between any two successive
   //addresses printed is four
```

- three-dimensional array is treated as an *array of arrays of arrays*: elements of a are $a[0], a[1]$, each of which is an array i.e., the i^{th} row of a is denoted with $a[i]$ each element of which is an array i.e., j^{th} element of $a[i]$ is denoted with $a[i][j]$, which is again an array in depth
- further, contiguous memory is allocated for arrays in the following order: $c[0][0], \ldots, c[0][4], c[1][0], \ldots, c[1][4]$ — known as *row-major order*

Initializing arrays while defining

```
int i, j;
int a[2][5] = {  //also allowed a[][5]
    {0, 11, 22, 33, 44},
    {1, 12, 23, 34, 45}
      //with no flower brackets is fine too
    };

for (i=0; i<2; i++)
    for (j=0; j<5; j++)
        printf("%d, ", a[i][j]);
   //prints 0, 11, 22, 33, 44, 1, 12, 23, 34, 45,
```

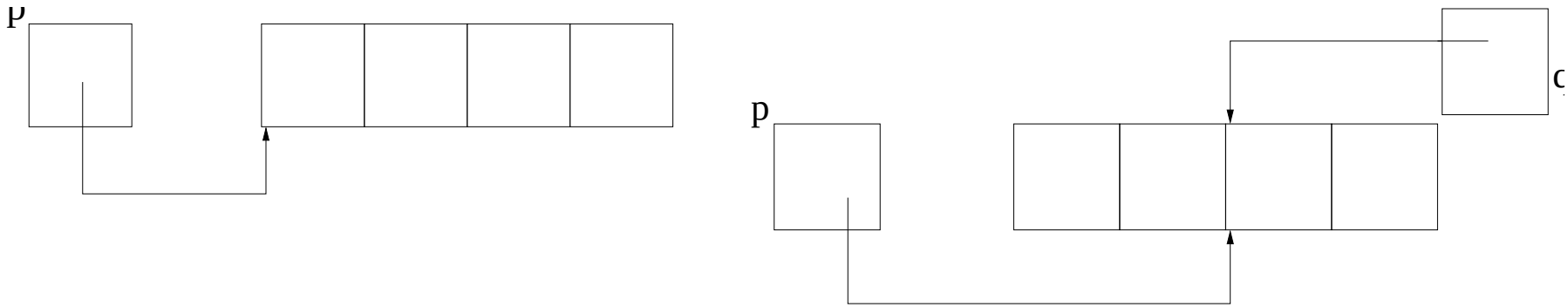
Introducing pointers

```
int x = 1, y = 2, z[2];
int *p = NULL;
    //p is a pointer to int, initialized with NULL

p = &x;          //p points to x
y = *p;          //y is 1
*p = 0;          //x is now 0
p = &z[1];       //p points to z[1]
*p = 5;          //z[1] is 5
*p = *p + 5;     //z[1] is 10
```

- *pointer* is jut a variable that saves the address of a memory location that contains an object (or value) of specific type
- when p points to a *typeA*, p is termed as a *pointer to typeA*
- *dereferencing pointer* p is denoted with $*p$

Incrementing a pointer




```
int z[4];
int *p = &z[0];
*(p+1) = 7;          //*(p+(1*sizeof(int))) = 7
                     //i.e., z[1] has 7
p += 2;              //p = p + (2*sizeof(int))
*p = 5;              //z[2] has 5
*p = *p + 3;         //z[2] has 8
*p += 2;             //z[2] has 10
++(*p);              //z[2] has 11
int *q = p;          //q also points to z[2]
*q = 89;             //z[2] has 89
```

- when p is a pointer to typeA, expression $p + i$ increments p by $i * sizeof(typeA)$

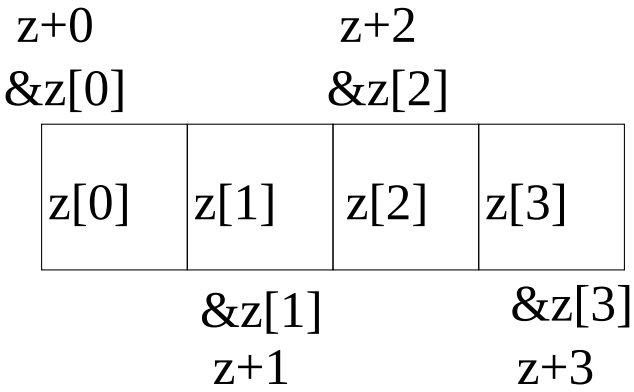
Valid pointer operations

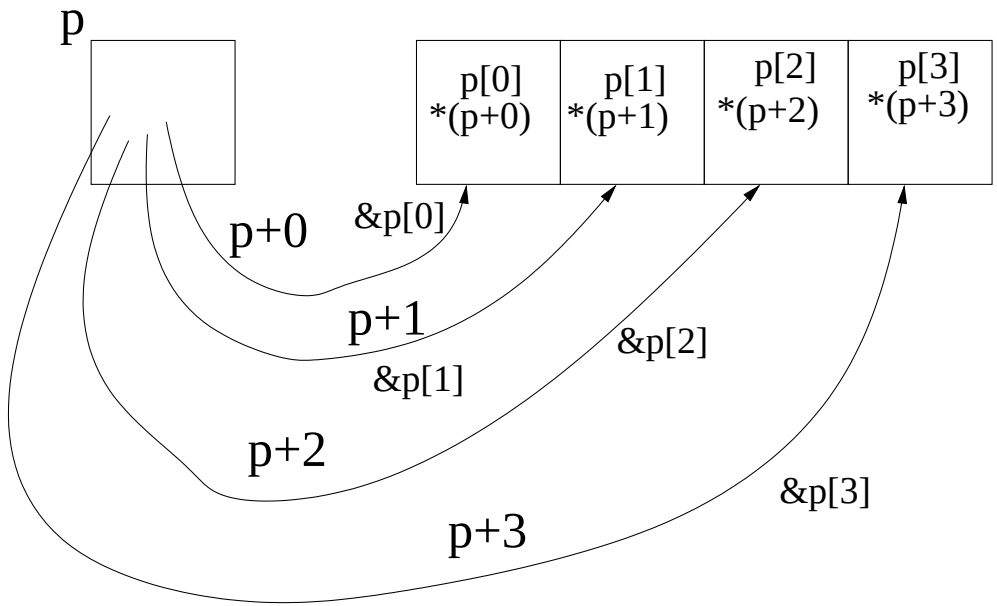
- assignment of pointers of the same type
- adding (resp. subtracting) an integer to (resp. from) a pointer p
  (new address is meaningful whenever p points to an appropriate entry in an array)
- subtracting[2] or comparing two pointers to members of the same array
- assigning or comparing to zero

All other pointer arithmetic is illegal: not legal to add two pointers, or to multiply or divide or shift or mask them, or to add float or double to them, or even, except for void * , to assign a pointer of one type to a pointer of another type without a cast.

[2] for an array that holds objects of type T, such a subtraction yields the number of objects of type T that block of array memory can hold (consistent with the way the compiler expands $p + i$)

Ways to access an array






```
double z[4], *p = z;
...
z[3] = 10;
...
```

- ex. compiler replaces $z[i]$ with $*(z + (i * sizeof(double)))$
  same is true in case of multi-dimensional arrays

Name of an array

```
float z[4], *p=z;
printf("%d, %d, %d \n", sizeof(p),
    sizeof(float), sizeof(*p));
   //prints 4, 4, 4

printf("%p, %p, %p \n", z, &z[0], &z);
   //identical values are printed: 0xbfd30990

printf("%p, %p,  \n", z+1, &z[0]+1);
   //identical values (&z[1]) are printed: 0xbfd30994

printf("%p \n", &z+1);
   //prints (&z[0] + (1*sizeof(z))): 0xbfd309a0
```

- name of an array z is an alias for the address of zeroth element of z; further, $\&z[i] + j$ denotes the address of $z[i + j]$
- statements like z = p and z++ are illegal as z is not a variable

Array name and pointer variable

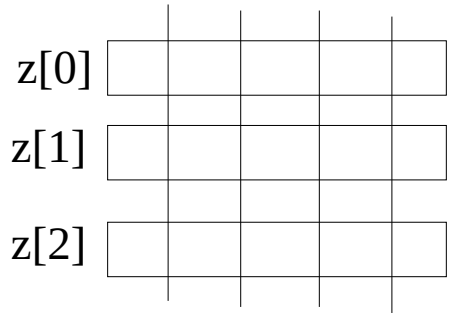
```
float z[4];
float *p = &z[0], *q;

q = z;
printf("%p, %p, %p \n", z, p, q);
   //identical values are printed
printf("%p, %p \n", p, &p);
   //addressed stored in p vs address of p

z[2] = 30;          //z[2] has 30
*(z+2) = 20;        //z[2] has 20
q[3] = 52;          //z[3] has 52
*(q+3) = 58;        //z[3] has 58
```

- $z[i]$ gets expanded as $*(z+i)$

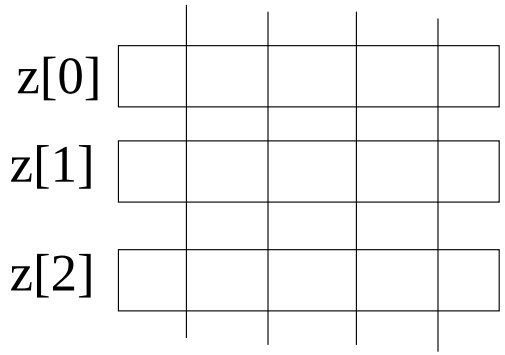
Row-major order of arrays




```
int z[3][4];
printf("%p, %p, %p, \n", z[0], z[1], z[2]);
    //prints addresses of three rows
printf("%p, %p, %p \n", &z[0], &z[1], &z[2]);
    //prints addresses of three rows
printf("%p, %p \n", &z[1]+1, &z[0]+2);
    //prints identical values; z is interpreted as &z[0]
printf("%p, %p \n", z[2]+1, &z[2][1]);
    //prints identical values
```

- two-dimensional array is an array of rows:
  $z[i]$ is the name of the array that comprises the i^{th} row;
  and, $\&z[i]$ is the address of the i^{th} row

Row-major order of arrays (cont)




```
int z[3][4];
printf("%p, %p \n" z[1], &z[1]);
//prints identical addresses
printf("%p, %p, %p \n", z, z+1, z+2);
//prints z[0], z[1], z[2]
```

- $z[i]$ is the name of the array containing i^{th} of row of z
- for any i, $z[i]$ does not occupy additional space; exists only for notational convenience
- z is the name of the array comprising $z[0], \ldots, z[n]$; further, z is the symbol for the address of $z[0]$

Row-major order of arrays (cont)

```
int b[3][4];
b[2][1] = 23;
```

b[2][1] gets expanded to *(*(b+2) + 1):

- *(b+2) is *(&b[0]+2) i.e., *(&b[0] + (2*sizeof(b[0])), meaning b[2]
- further, *(b[2]+1) is *(&b[2][0]+1) i.e., *(&b[2][0] + (1*sizeof(b[2][0])), meaning b[2][1]

Row-major order of arrays (review)

- consider 'double z[3]':

  z[0], z[1], z[2]
  &z[0], &z[1], &z[2]
  z[0]+1, &z[0]+1, &z[0]+2
  z, z+1, z+2
  &z, &z+1

- consider 'double z[3][4]':

  z[0], z[1], z[2]
  &z[0], &z[1], &z[2]
  z[0]+1, &z[0]+1
  z[0][0]+1, &z[0][0]+1
  z, z+1, z+2
  &z, &z+1

homework: analyze the same for higher dimensional arrays

Operator precedence and associativity

Precedence (highest to lowest)	Associativity
() [] -> .	left to right
! ++ -- & *(type) sizeof	right to left
* / %	left to right
+ -	left to right
= += -= *= /=	right to left

```
a+b*c-d/e;   //(a+(b*c))-(d/e)
*p[];        //*(p[])
val = *--p; //val = *(--p)
*p++ = val; //*(p++) = val i.e., *p = val; p = p+1
val = *p++; //val = *(p++) i.e., val = *p; p = p+1
```

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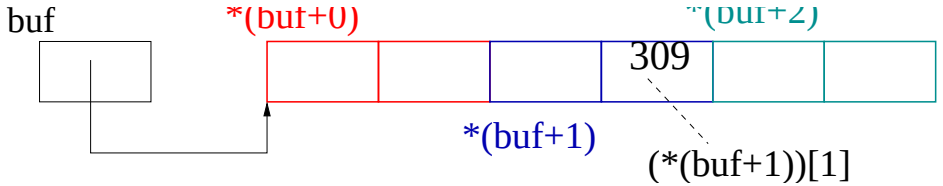
[3] result of the postfix increment (resp. decrement) operation is the value of the operand; after the value is obtained, the value of the operand is incremented (resp. decremented) as a side effect

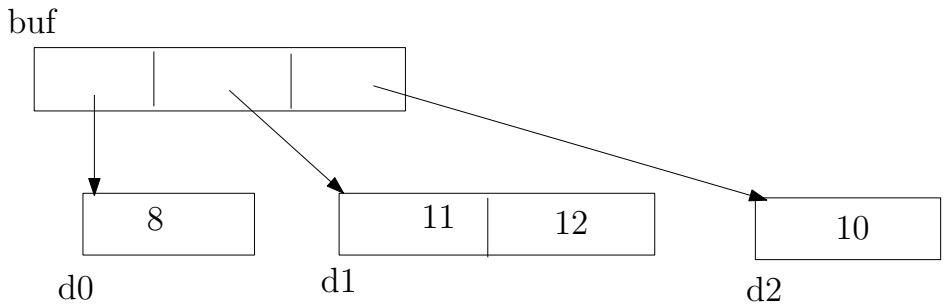
Pointer to an array



buf points to double[2] i.e., two doubles that are contiguously allocated

```
double (*buf)[2];
...
printf("%d, %d, %d \n", sizeof(double), sizeof(*buf),
sizeof(*(buf+2)));
//prints 8, 16, 16
printf("%p, %p \n", buf, buf+1);
//prints 0xbffd7e30, 0xbffd7e40
buf[1][1] = 309;
printf("%p, %lf \n", &buf[1][1], buf[1][1]);
//prints 0xbffd7e48, 309.000000
```

Array of pointers



buf is an array of pointers to doubles

```
double *buf[3];
double d0 = 8, d1[2] = {11, 12}, d2 = 10;
buf[0] = &d0; buf[1] = &d1[0]; buf[2] = &d2;

printf("%d, %d \n", sizeof(void*), sizeof(buf));
//prints 4, 12
printf("%p, %p, %p, %lf \n",
       buf, &buf[0], buf[1], *buf[1]);
//prints 0xbfed51d4, 0xbfed51d4, 0xbfed51e0, 11.000000
```