Pointers and Arrays

Lecture 27

Pointers and Arrays

- When an array is declared,
  - The compiler allocates sufficient amount of storage to contain all the elements of the array in contiguous memory locations
  - The base address is the location of the first element (index 0) of the array
  - The compiler also defines the array name as a constant pointer to the first element

Example

- Consider the declaration:

  ```
  int x[5] = {1, 2, 3, 4, 5};
  ```

- Suppose that each integer requires 4 bytes
- Compiler allocates a contiguous storage of size 5x4 = 20 bytes
- Suppose the starting address of that storage is 2500

Element	Value	Address
x[0]	1	2500
x[1]	2	2504
x[2]	3	2508
x[3]	4	2512
x[4]	5	2516

Contd.

- The array name x is the starting address of the array
  - Both x and &x[0] have the value 2500
  - x is a constant pointer, so cannot be changed
    - x= 3400, x++, x += 2 are all illegal
- If int *p is declared, then

  p = x; and p = &x[0]; are equivalent
- We can access successive values of x by using p++ or p-- to move from one element to another

- Relationship between p and x:

  p = &x[0] = 2500
  p+1 = &x[1] = 2504
  p+2 = &x[2] = 2508
  p+3 = &x[3] = 2512
  p+4 = &x[4] = 2516

In general, *(p+i) gives the value of x[i]

- C knows the type of each element in array x, so knows how many bytes to move the pointer to get to the next element

Example: function to find average

```
int main()
{
  int x[100], k, n;

  scanf ("%d", &n);

  for (k=0; k<n; k++)
     scanf ("%d", &x[k]);

  printf  ("\nAverage is %f",
               avg (x, n));
  return 0;
}
```

```
float avg (int array[], int size)
{
  int  *p, i , sum = 0;

  p = array;

  for (i=0; i<size; i++)
      sum = sum + *(p+i);

  return ((float) sum / size);
}
```

The pointer p can be subscripted also just like an array!

```
int main()
{
  int x[100], k, n;

  scanf ("%d", &n);

  for (k=0; k<n; k++)
     scanf ("%d", &x[k]);

  printf  ("\nAverage is %f",
                avg (x, n));
  return 0;
}
```

```
float avg (int array[], int size)
{
  int  *p, i , sum = 0;

  p = array;

  for (i=0; i<size; i++)
      sum = sum + p[i];

  return ((float) sum / size);
}
```

Important to remember

- Pitfall: An array in C does <u>not</u> know its own length, & bounds not checked!
  - Consequence: While traversing the elements of an array (either using [ ] or pointer arithmetic), we can accidentally access off the end of an array (access more elements than what is there in the array)
  - Consequence: We must pass the array <u>and its size</u> to a function which is going to traverse it, or there should be some way of knowing the end based on the values (Ex., a –ve value ending a string of +ve values)
- Accessing arrays out of bound can cause strange problems
  - Very hard to debug
  - Always be careful when traversing arrays in programs

2D Array

A[0][0]	A[0][1]	A[0][2]
A[1][0]	A[1][1]	A[1][2]
A[2][0]	A[2][1]	A[2][2]

2D Array

A[0][0]	A[0][1]	A[0][2]
A[1][0]	A[1][1]	A[1][2]
A[2][0]	A[2][1]	A[2][2]

In Memory:

A[0][0]	A[0][1]	A[0][2]	A[1][0]	A[1][1]	A[1][2]	A[2][0]	A[2][1]	A[2][2]

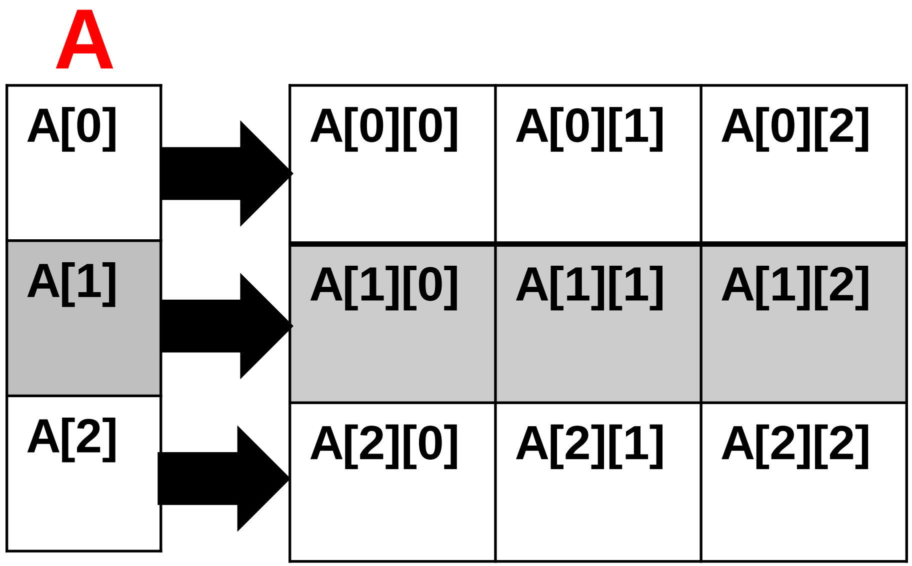
2D Array

A[0]	→	A[0][0]	A[0][1]	A[0][2]
A[1]	→	A[1][0]	A[1][1]	A[1][2]
A[2]	→	A[2][0]	A[2][1]	A[2][2]

In Memory:

A[0][0]	A[0][1]	A[0][2]	A[1][0]	A[1][1]	A[1][2]	A[2][0]	A[2][1]	A[2][2]

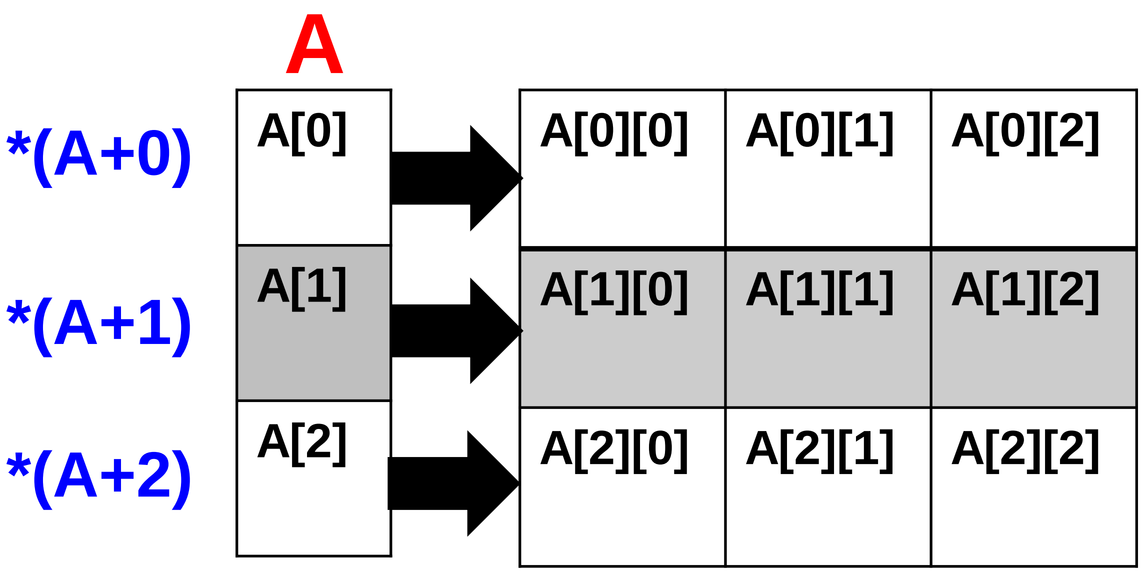
2D Array



In Memory:

A[0][0]	A[0][1]	A[0][2]	A[1][0]	A[1][1]	A[1][2]	A[2][0]	A[2][1]	A[2][2]

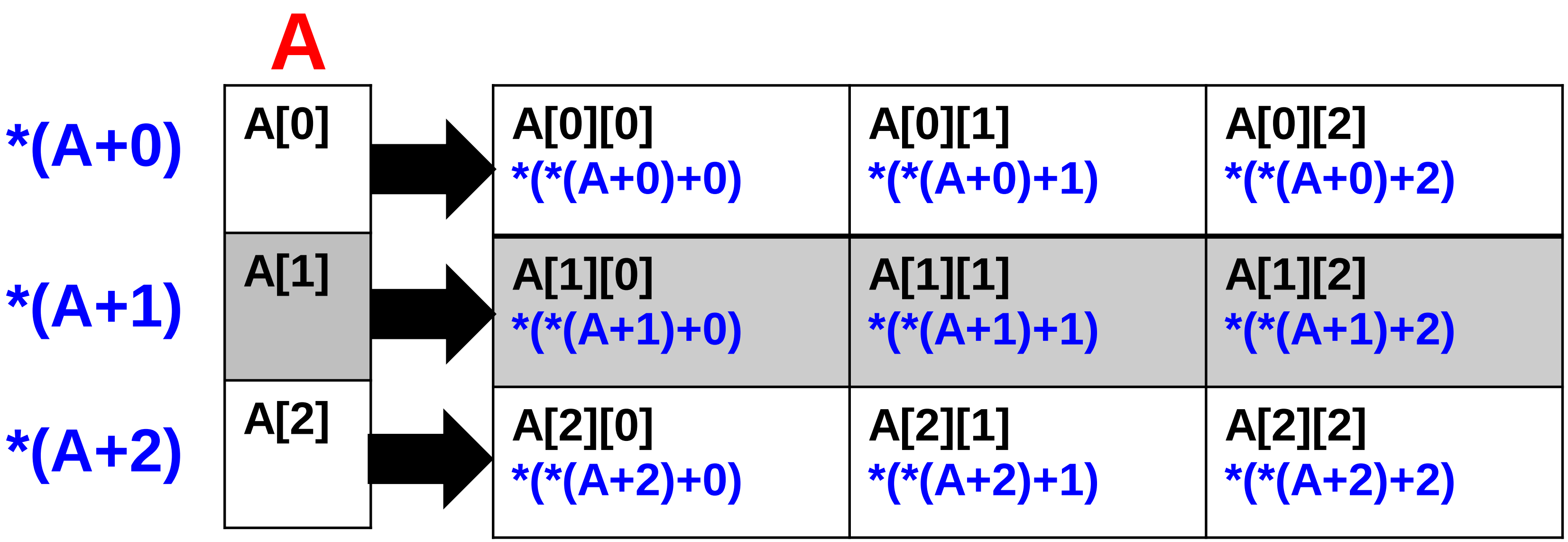
2D Array



In Memory:

A[0][0]	A[0][1]	A[0][2]	A[1][0]	A[1][1]	A[1][2]	A[2][0]	A[2][1]	A[2][2]

2D Array



In Memory:

A[0][0]	A[0][1]	A[0][2]	A[1][0]	A[1][1]	A[1][2]	A[2][0]	A[2][1]	A[2][2]

2D Array

In general, A[i][j] = *(*(A+i)+j)

	A			
*(A+0)	A[0]	A[0][0] *(*(A+0)+0)	A[0][1] *(*(A+0)+1)	A[0][2] *(*(A+0)+2)
*(A+1)	A[1]	A[1][0] *(*(A+1)+0)	A[1][1] *(*(A+1)+1)	A[1][2] *(*(A+1)+2)
*(A+2)	A[2]	A[2][0] *(*(A+2)+0)	A[2][1] *(*(A+2)+1)	A[2][2] *(*(A+2)+2)

In Memory:

A[0][0]	A[0][1]	A[0][2]	A[1][0]	A[1][1]	A[1][2]	A[2][0]	A[2][1]	A[2][2]

2D Array

In general, A[i][j] = *(*(A+i)+j)

	A			
*(A+0)	A[0]	A[0][0] *(*(A+0)+0)	A[0][1] *(*(A+0)+1)	A[0][2] *(*(A+0)+2)
*(A+1)	A[1]	A[1][0] *(*(A+1)+0)	A[1][1] *(*(A+1)+1)	A[1][2] *(*(A+1)+2)
*(A+2)	A[2]	A[2][0] *(*(A+2)+0)	A[2][1] *(*(A+2)+1)	A[2][2] *(*(A+2)+2)

In Memory:

A[0][0]	A[0][1]	A[0][2]	A[1][0]	A[1][1]	A[1][2]	A[2][0]	A[2][1]	A[2][2]

((A+0)+0) *(*(A+0)+2)

2D Array

In general, A[i][j] = *(*(A+i)+j)

	A			
*(A+0)	A[0]	A[0][0] *(*(A+0)+0)	A[0][1] *(*(A+0)+1)	A[0][2] *(*(A+0)+2)
*(A+1)	A[1]	A[1][0] *(*(A+1)+0)	A[1][1] *(*(A+1)+1)	A[1][2] *(*(A+1)+2)
*(A+2)	A[2]	A[2][0] *(*(A+2)+0)	A[2][1] *(*(A+2)+1)	A[2][2] *(*(A+2)+2)

In Memory:

A[0][0]	A[0][1]	A[0][2]	A[1][0]	A[1][1]	A[1][2]	A[2][0]	A[2][1]	A[2][2]

((A+0)+0) *(*(A+0)+3) *(*(A+0)+5) *(*(A+0)+7)

Pointers to Structures

Pointers to Structures

- Pointer variables can be defined to store the address of structure variables
- Example:

```
struct student {
        int   roll;
        char  dept_code[25];
        float cgpa;
      };
struct student *p;
```

- Just like other pointers, p does not point to anything by itself after declaration
  - Need to assign the address of a structure to p
  - Can use & operator on a struct student type variable
  - Example:

```
struct student x, *p;
scanf(“%d%s%f”, &x.roll, x.dept_code, &x.cgpa);
p = &x;
```

- Once p points to a structure variable, the members can be accessed in one of two ways:
  - (*p).roll, (*p).dept_code, (*p).cgpa
    - Note the ( ) around *p
  - p –> roll, p –> dept_code, p –> cgpa
    - The symbol –> is called the arrow operator
- Example:
  - printf(“Roll = %d, Dept.= %s, CGPA = %f\n”, (*p).roll, (*p).dept_code, (*p).cgpa);
  - printf(“Roll = %d, Dept.= %s, CGPA = %f\n”, p->roll, p->dept_code, p->cgpa);

Pointers and Array of Structures

- Recall that the name of an array is the address of its 0-th element
  - Also true for the names of arrays of structure variables
- Consider the declaration:

```
struct student class[100],  *ptr ;
```

- The name class represents the address of the 0-th element of the structure array
  - ptr is a pointer to data objects of the type struct student
- The assignment

  ptr = class;

  will assign the address of class[0] to ptr
- Now ptr->roll is the same as class[0].roll. Same for other members
- When the pointer ptr is incremented by one (ptr++) :
  - The value of ptr is actually increased by sizeof(struct student)
  - It is made to point to the next record
  - Note that sizeof operator can be applied on any data type

```
struct student {
    char name[20];
    int roll;
}
int main()
{
    struct student class[50], *p;
    int i, n;
    scanf("%d", &n);
    for (i=0; i<n; i++)
        scanf("%s%d", class[i].name, &class[i].roll);
    p = class;
    for (i=0; i<n; i++) {
        printf("%s  %d\n", class[i].name, class[i].roll);
        printf("%s  %d\n", *(p+i).name, *(p+i).roll);
        printf("%s  %d\n", (p+i)->name, (p+i)->roll);
        printf("%s  %d\n", p[i].name, p[i].roll);
    }
}
```

Output

```
3
Ajit 1001
Abhishek 1005
Riya 1007
Ajit  1001
Ajit  1001
Ajit  1001
Ajit  1001
Abhishek  1005
Abhishek  1005
Abhishek  1005
Abhishek  1005
Riya  1007
Riya  1007
Riya  1007
Riya  1007
```

A Warning

- When using structure pointers, be careful of operator precedence
  - Member operator "." has higher precedence than "*"
    - ptr –> roll and (*ptr).roll mean the same thing
    - *ptr.roll will lead to error
  - The operator "->" enjoys the highest priority among operators
    - ++ptr –> roll will increment ptr->roll, not ptr
    - (++ptr) –> roll will access (ptr + 1)->roll (for example, if you want to print the roll no. of all elements of the class array)
- When not sure, use (and) to force what you you want

Practice Problems

- Look at all problems you have done earlier on arrays (including arrays of structures). Now rewrite all of them using equivalent pointer notations
  - Example: If you had declared an array

```
int A[50]
```

Now do

```
int A[50], *p;
p = A;
```

and then write the rest of the program using the pointer p (without using [ ] notation)

Dynamic Memory Allocation

Lecture 28

Problem with Arrays

- Sometimes
  - Amount of data cannot be predicted beforehand
  - Number of data items keeps changing during program execution
- Example: Seach for an element in an array of N elements
- One solution: find the maximum possible value of N and allocate an array of N elements
  - Wasteful of memory space, as N may be much smaller in some executions
  - Example: maximum value of N may be 10,000, but a particular run may need to search only among 100 elements
    - Using array of size 10,000 always wastes memory in most cases

Better Solution

- Dynamic memory allocation
  - Know how much memory is needed after the program is run
    - Example: ask the user to enter from keyboard
  - Dynamically allocate only the amount of memory needed
- C provides functions to dynamically allocate memory
  - malloc, calloc, realloc

Memory Allocation Functions

- malloc
  - Allocates requested number of bytes and returns a pointer to the first byte of the allocated space
- calloc
  - Allocates space for an array of elements, initializes them to zero and then returns a pointer to the memory.
- free
  - Frees previously allocated space.
- realloc
  - Modifies the size of previously allocated space.
- We will only do malloc and free

Allocating a Block of Memory

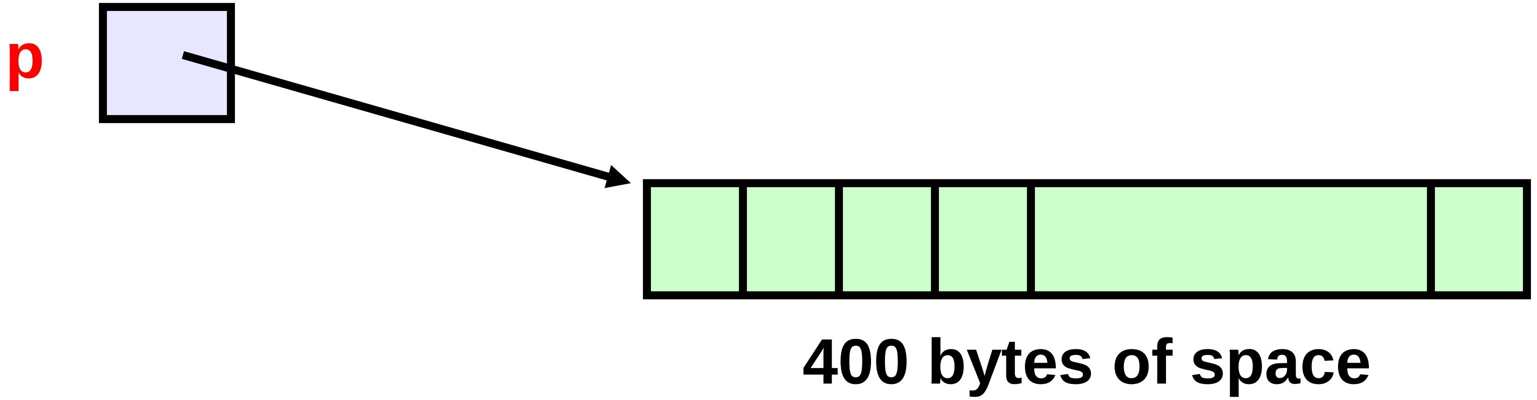
- A block of memory can be allocated using the function malloc
  - Reserves a block of memory of specified size and returns a pointer of type void
  - The return pointer can be type-casted to any pointer type
- General format:

```
type *p;
p =  (type *) malloc (byte_size);
```

Example

p = (int *) malloc(100 * sizeof(int));

- A memory space equivalent to 100 times the size of an int bytes is reserved
- The address of the first byte of the allocated memory is assigned to the pointer p of type int



Contd.

- cptr = (char *) malloc (20);

  Allocates 20 bytes of space for the pointer cptr of type char

- sptr = (struct stud *) malloc(10*sizeof(struct stud));

  Allocates space for a structure array of 10 elements. sptr points to a structure element of type struct stud

Always use sizeof operator to find number of bytes for a data type, as it can vary from machine to machine

Points to Note

- malloc always allocates a block of contiguous bytes
  - The allocation can fail if sufficient contiguous memory space is not available
  - If it fails, malloc returns NULL

```
if  ((p = (int *) malloc(100 * sizeof(int))) == NULL)
  {
        printf ("\n Memory cannot be allocated");
        exit();
   }
```

Using the malloc'd Array

- Once the memory is allocated, it can be used with pointers, or with array notation
- Example:

```
int *p, n, i;
scanf("%d", &n);
p = (int *) malloc (n * sizeof(int));
for (i=0; i<n; ++i)
    scanf("%d", &p[i]);
```

The n integers allocated can be accessed as *p, *(p+1), *(p+2),…, *(p+n-1) or just as p[0], p[1], p[2], …,p[n-1]

Example

```
int main()
{
  int i,N;
  float *height;
  float sum=0,avg;

  printf("Input no. of students\n");
  scanf("%d", &N);

  height = (float *)
       malloc(N * sizeof(float));
```

```
printf("Input heights for %d
students \n",N);
  for (i=0; i<N; i++)
   scanf ("%f", &height[i]);

  for(i=0;i<N;i++)
    sum += height[i];

  avg = sum / (float) N;

  printf("Average height = %f \n",
                avg);
  free (height);
  return 0;
}
```

Releasing the Allocated Space: free

- An allocated block can be returned to the system for future use by using the free function
- General syntax:

  free (ptr);

  where ptr is a pointer to a memory block which has been previously created using malloc
- Note that no size needs to be mentioned for the allocated block, the system remembers it for each pointer returned

Can we allocate only arrays?

- malloc can be used to allocate memory for single variables also
  - p = (int *) malloc (sizeof(int));
  - Allocates space for a single int, which can be accessed as *p
- Single variable allocations are just special case of array allocations
  - Array with only one element

malloc( )-ing array of structures

```
typedef  struct{
        char name[20];
        int roll;
        float SGPA[8], CGPA;
     } person;
int main()  {
     person *student;
     int i,j,n;
     scanf("%d", &n);
     student = (person *)malloc(n*sizeof(person));
     for (i=0; i<n; i++) {
        scanf("%s", student[i].name);
        scanf("%d", &student[i].roll);
        for(j=0;j<8;j++) scanf("%f", &student[i].SGPA[j]);
        scanf("%f", &student[i].CGPA);
     }
     return 0;
}
```

Static array of pointers

```
#define  N   20
#define  M  10
int main()
{
    char word[N], *w[M];
    int i, n;
    scanf("%d",&n);
    for (i=0; i<n; ++i) {
        scanf("%s", word);
        w[i] = (char *) malloc ((strlen(word)+1)*sizeof(char));
        strcpy (w[i], word) ;
    }
    for (i=0; i<n; i++) printf("w[%d] = %s \n",i,w[i]);
    return 0;
}
```

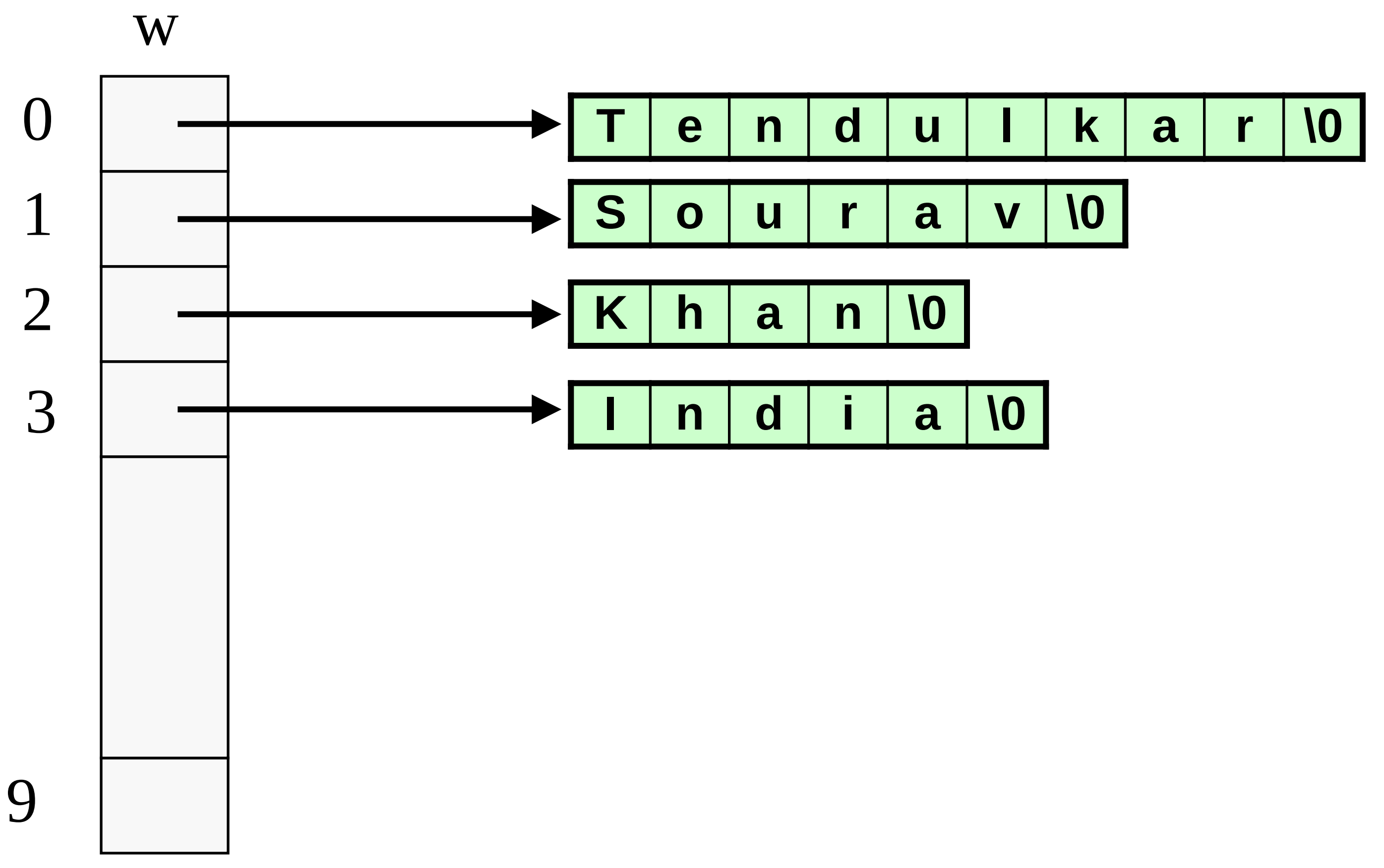
Static array of pointers

```
#define  N   20
#define  M  10
int main()
{
    char word[N], *w[M];
    int i, n;
    scanf("%d",&n);
    for (i=0; i<n; ++i) {
        scanf("%s", word);
        w[i] = (char *) malloc ((strlen(word)+1)*sizeof(char));
        strcpy (w[i], word) ;
    }
    for (i=0; i<n; i++) printf("w[%d] = %s \n",i,w[i]);
    return 0;
}
```

Output

```
4
Tendulkar
Sourav
Khan
India
w[0] = Tendulkar
w[1] = Sourav
w[2] = Khan
w[3] = India
```

How it will look like



Pointers to Pointers

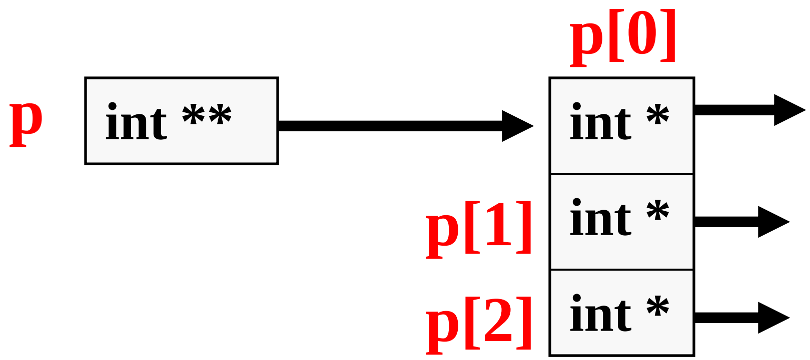
- Pointers are also variables (storing addresses), so they have a memory location, so they also have an address
- Pointer to pointer – stores the address of a pointer variable

```
int x = 10, *p, **q;
p = &x;
q = &p;
printf("%d  %d  %d", x, *p, *(*q));

will print 10  10  10 (since *q = p)
```

Allocating Pointer to Pointer

```
int **p;
p = (int **) malloc(3 * sizeof(int *));
```



Dynamic Arrays of pointers

```
int main()
{
  char word[20], **w;  /*  “**w” is a pointer to a pointer array */
  int i, n;
  scanf("%d",&n);
  w = (char **) malloc (n * sizeof(char *));
  for (i=0; i<n; ++i) {
    scanf("%s", word);
    w[i] = (char *) malloc ((strlen(word)+1)*sizeof(char));
    strcpy (w[i], word) ;
  }
  for (i=0; i<n; i++) printf("w[%d] = %s \n",i, w[i]);
  return 0;
}
```

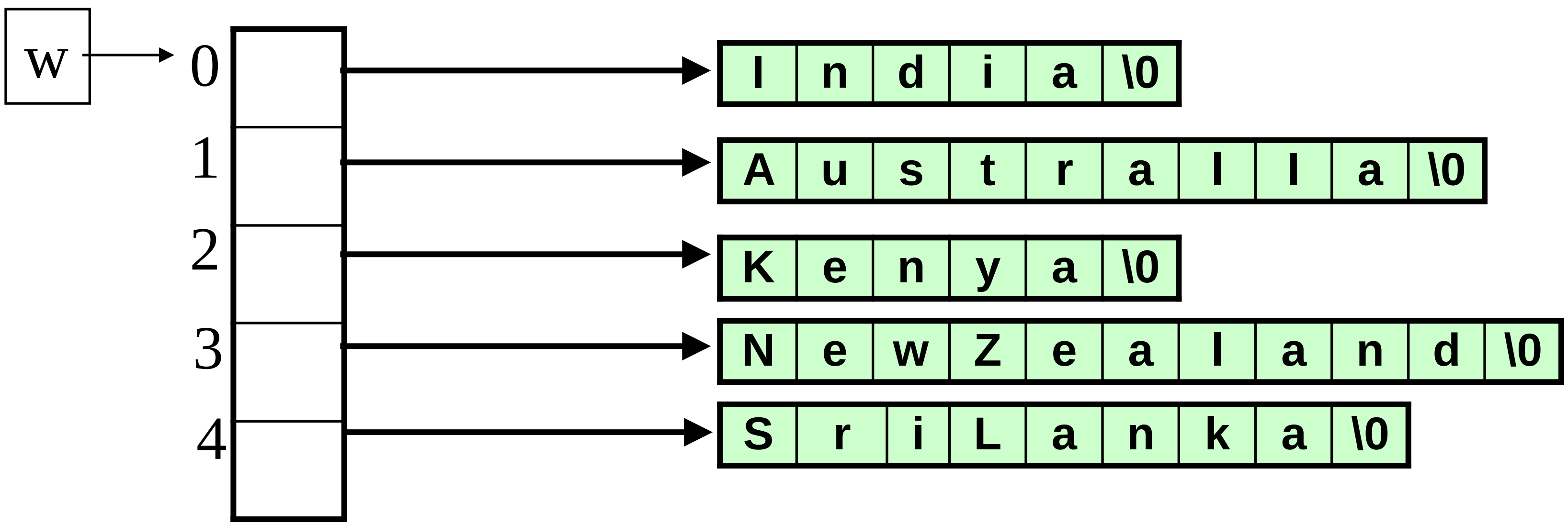
Dynamic Arrays of pointers

```
int main()
{
  char word[20], **w;  /*  “**w” is a pointer to a pointer array */
  int i, n;
  scanf("%d",&n);
  w = (char **) malloc (n * sizeof(char *));
  for (i=0; i<n; ++i) {
    scanf("%s", word);
    w[i] = (char *) malloc ((strlen(word)+1)*sizeof(char));
    strcpy (w[i], word) ;
  }
  for (i=0; i<n; i++) printf("w[%d] = %s \n",i, w[i]);
  return 0;
}
```

Output

```
5
India
Australia
Kenya
NewZealand
SriLanka
w[0] = India
w[1] = Australia
w[2] = Kenya
w[3] = NewZealand
w[4] = SriLanka
```

How this will look like



Dynamic Allocation of 2-d Arrays

```
int **allocate (int h, int w)
  {
    int **p;
    int i, j;

    p = (int **) malloc(h*sizeof (int *) );
    for (i=0;i<h;i++)
      p[i] = (int *) malloc(w * sizeof (int));
    return(p);
  }
```

Allocate array of pointers

Allocate array of integers for each row

```
void read_data (int **p, int h, int w)
 {
    int i, j;
    for (i=0;i<h;i++)
      for (j=0;j<w;j++)
        scanf ("%d", &p[i][j]);
 }
```

Elements accessed like 2-D array elements.

Contd.

```
void print_data (int **p, int h, int w)
  {
     int i, j;
      for (i=0;i<h;i++)
      {
      for (j=0;j<w;j++)
        printf ("%5d ", p[i][j]);
       printf ("\n");
      }
}
```

```
int main()
{
  int **p;
  int M, N;
  printf ("Give M and N \n");
  scanf ("%d%d", &M, &N);
  p = allocate (M, N);
  read_data (p, M, N);
  printf ("\nThe array read as \n");
  print_data (p, M, N);
  return 0;
}
```

Contd.

```
void print_data (int **p, int h, int w)
  {
     int i, j;
      for (i=0;i<h;i++)
      {
      for (j=0;j<w;j++)
        printf ("%5d ", p[i]
       printf ("\n");
      }
}
```

```
Give M and N
3 3
1 2 3
4 5 6
7 8 9
 The array read
as
    1    2    3
    4    5    6
    7    8    9
```

```
int main()
{
  int **p;
  int M, N;
  printf ("Give M and N \n");
  scanf ("%d%d", &M, &N);
  p = allocate (M, N);
  read_data (p, M, N);
  printf ("\nThe array read as \n");
  print_data (p, M, N);
  return 0;
}
```

Memory Layout in Dynamic Allocation

```
int main()
{
  int **p;
  int M, N, i, j;
  printf ("Give M and N \n");
  scanf ("%d%d", &M, &N);
  p = allocate (M, N);
  for (i=0;i<M;i++) {
        for (j=0;j<N;j++)
           printf ("%u", &p[i][j]);
        printf("\n");
  }
  return 0;
}
```

```
int **allocate (int h, int w)
{
     int **p;
     int i, j;

     p = (int **)malloc(h*sizeof (int *));
     for (i=0; i<h; i++)
        printf("%u", &p[i]);
     printf("\n\n");
     for (i=0;i<h;i++)
       p[i] = (int
     *)malloc(w*sizeof(int));
     return(p);
}
```

Output

```
3 3
31535120  31535128  31535136


31535152  31535156  31535160
31535184  31535188  31535192
31535216  31535220  31535224
```

Starting address of each row, contiguous (pointers are 8 bytes long)

Elements in each row are contiguous

Practice Problems

- Take any of the problems you have done so far using 1-d arrays or 2-d arrays. Now do them by allocating the arrays dynamically first instead of declaring then statically