Dynamic Memory Allocation

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

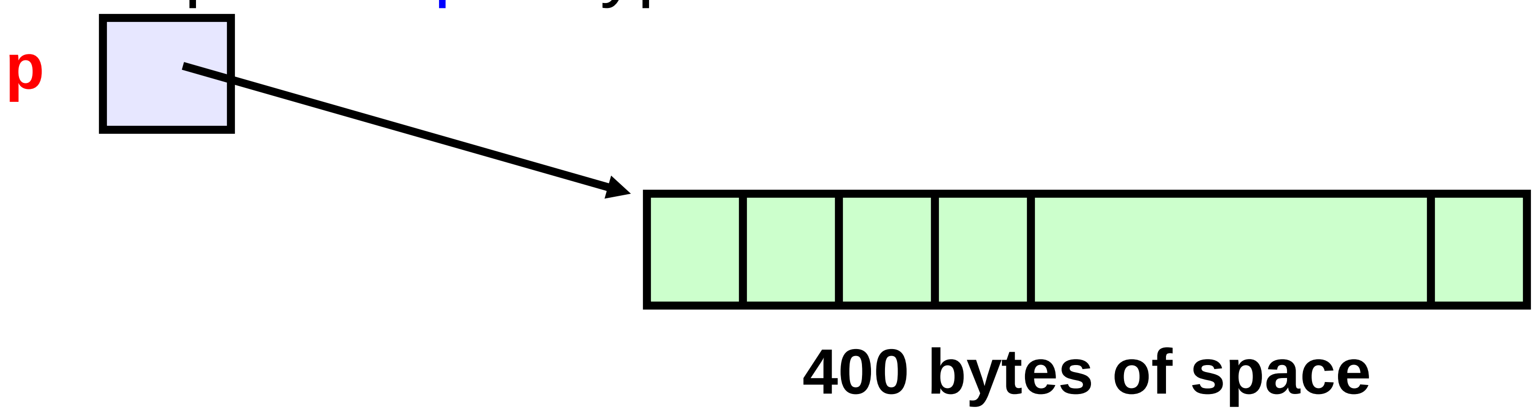
- A block of memory can be allocated using the function malloc
  - Reserves a block of memory of specified size and returns a pointer of type void
  - The return pointer can be type-casted to any pointer type
- General format:

```
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;
void 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);
    }
}
```

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;
}
```

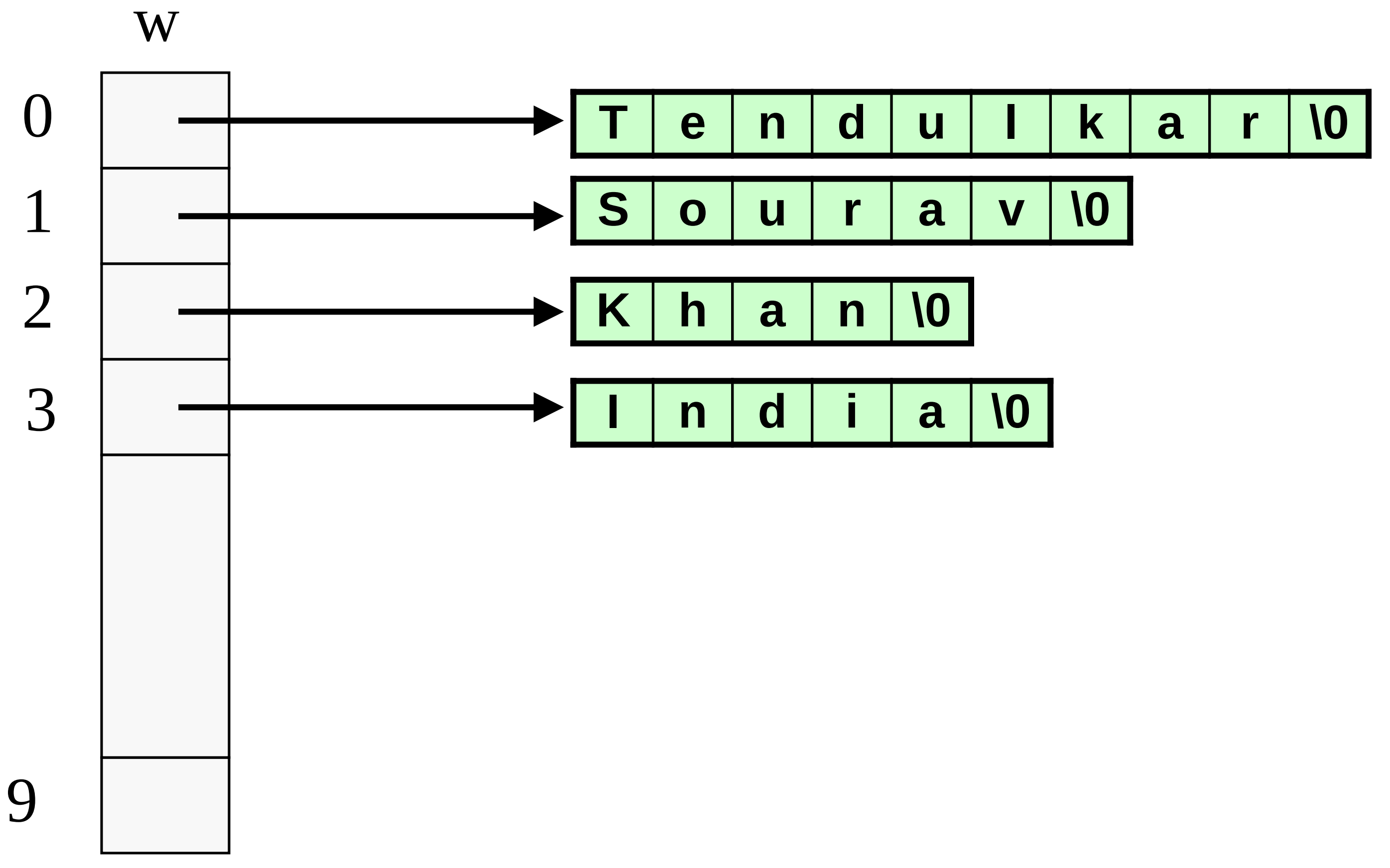
Static array of pointers

```
#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

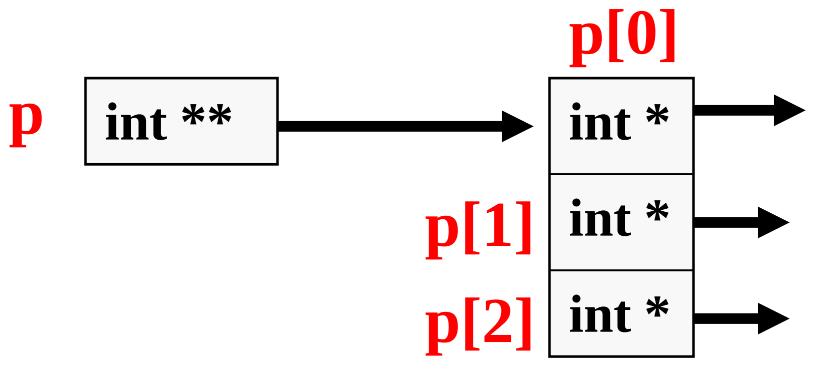
- Pointers are also variables (storing addresses), so they have a memory location, so they also have an address
- Pointer to pointer – stores the address of a pointer variable

```
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;
}
```

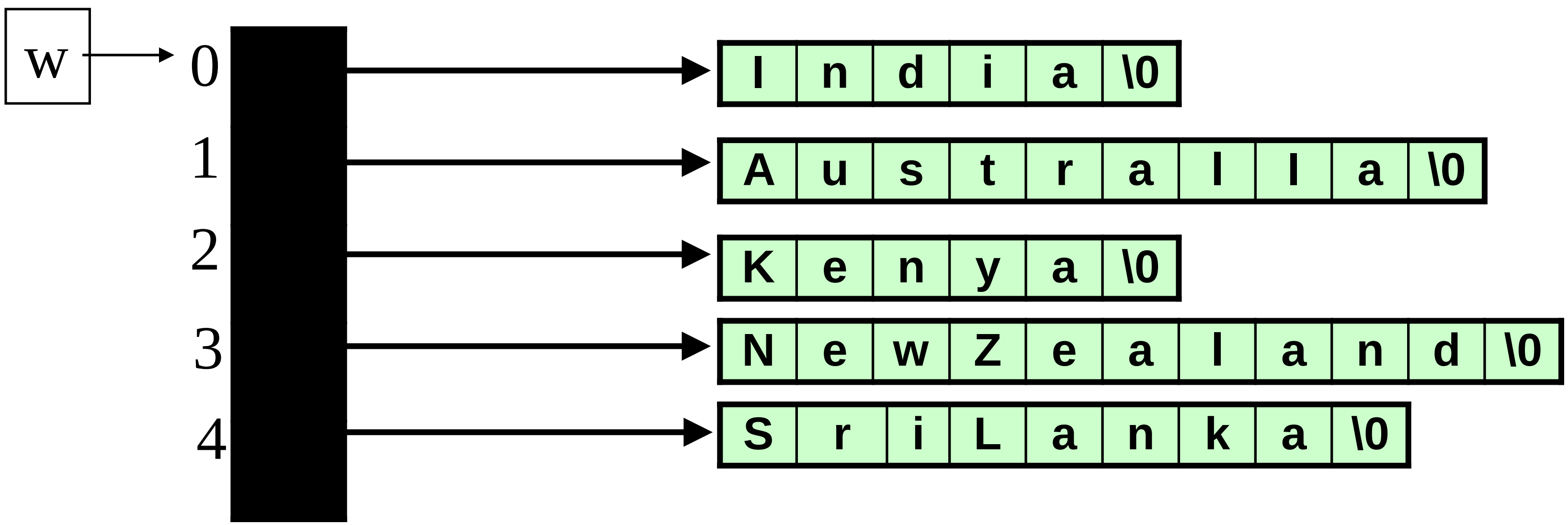
Dynamic Arrays of pointers

```
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

- Recall that address of [i][j]-th element is found by first finding the address of first element of i-th row, then adding j to it
- Now think of a 2-d array of dimension [M][N] as M 1-d arrays, each with N elements, such that the starting address of the M arrays are contiguous (so the starting address of k-th row can be found by adding 1 to the starting address of (k-1)-th row)
- This is done by allocating an array p of M pointers, the pointer p[k] to store the starting address of the k-th row

Contd.

- Now, allocate the M arrays, each of N elements, with p[k] holding the pointer for the k-th row array
- Now p can be subscripted and used as a 2-d array
- Address of p[i][j] = *(p+i) + j (note that *(p+i) is a pointer itself, and p is a pointer to a pointer)

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][j]);
      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
```

```
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;
  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 ("%10d", &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("%10d", &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