Lecture 11
Doubly Linked Lists
& Array of Linked Lists

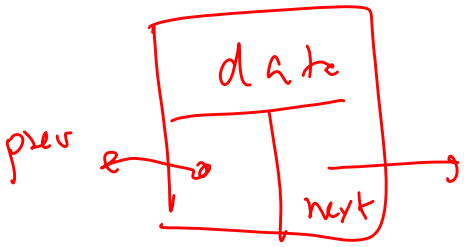
In this lecture

- Doubly linked lists
- Array of Linked Lists
- Creating an Array of Linked Lists
- Representing a Sparse Matrix
- Defining a Node for a Sparse Matrix
- Exercises
- Solutions

Doubly Linked Lists

A doubly linked list is a list that contains links to next and previous nodes. Unlike singly linked lists where traversal is only one way, doubly linked lists allow traversals in both ways. A generic doubly linked list node can be designed as:

```
typedef struct node {
    void* data;
    struct node* next;
    struct node* prev;
} node;
```




```
node* head = (node*) malloc(sizeof(node));
```

The design of the node allows flexibility of storing any data type as the linked list data. For example,

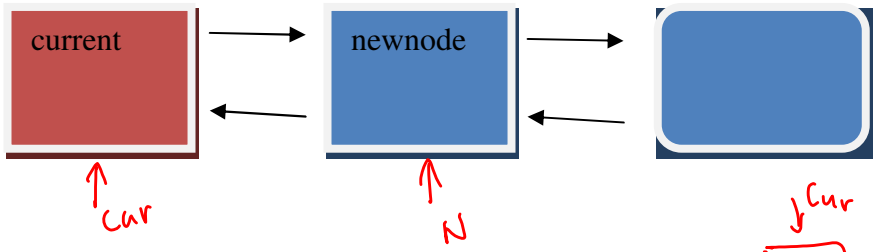
```
head➔ data = malloc(sizeof(int));  head➔ data = 12;
```

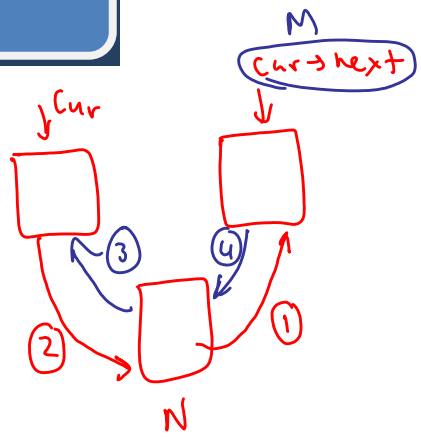
or

```
head➔ data = malloc(strlen("guna")+1);  strcpy(head➔ data, "guna");
```

Inserting to a Doubly Linked Lists

Suppose a new node, **newnode** needs to be inserted after the node current





The following code can then be written

newnode➔ next = current➔next; current➔next = newnode;

newnode➔prev = current; (current➔next)➔prev = newnode;

N

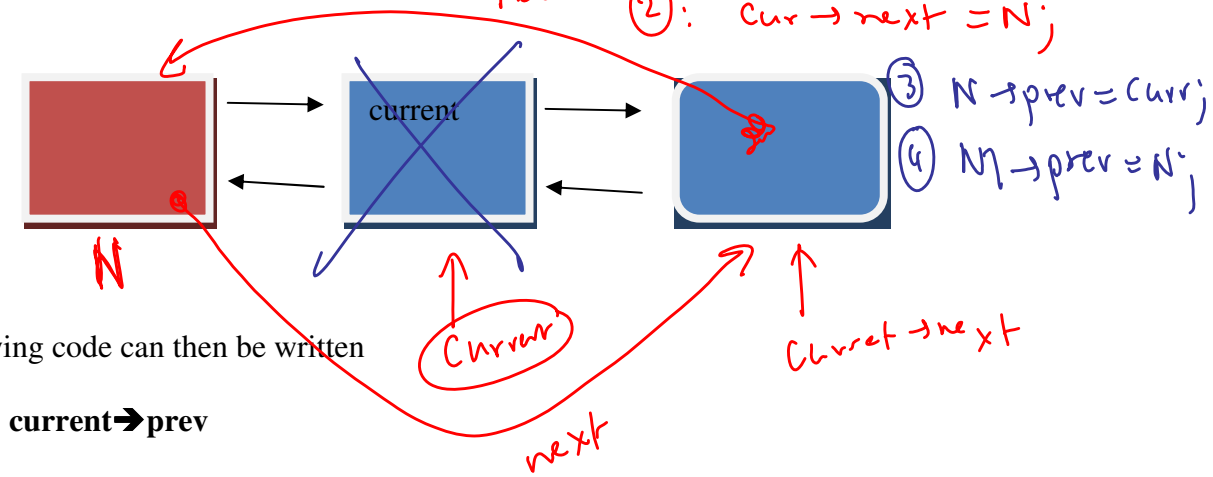
M = Cur → next;

① : N → next = M ;

② : Cur → next = N ;

Deleting a Node from a Doubly Linked Lists

Suppose a new node, **current** needs to be deleted



The following code can then be written

node* N = current➔prev

N➔ next = current➔next;

(N➔next)➔prev = N;

free(current);

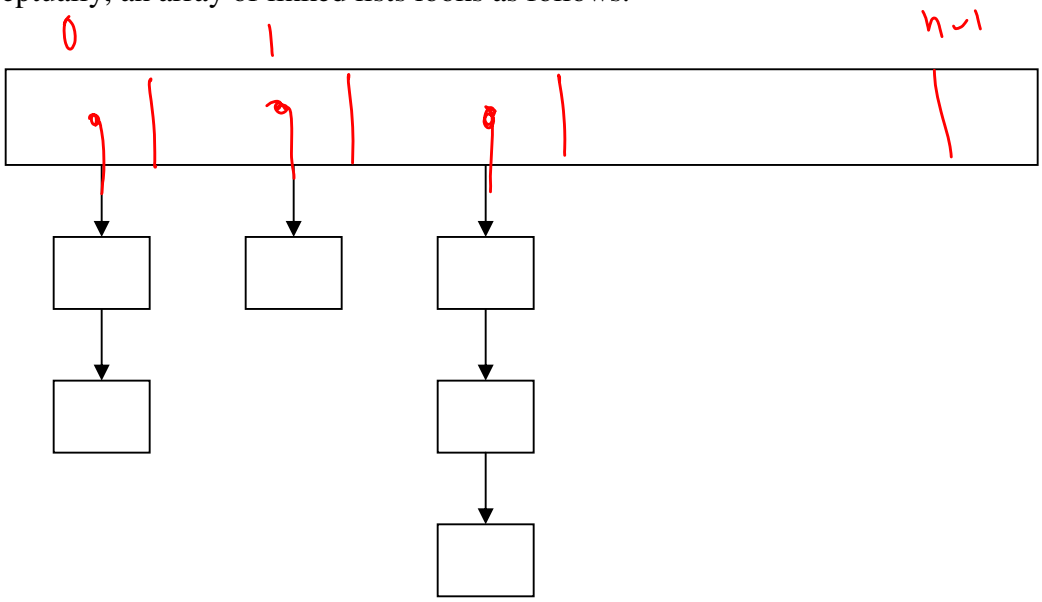
if any memory is malloced inside Current, free it first

Doubly linked lists (DLL) are also widely used in many applications that deals with dynamic memory allocation and deallocation. Although an additional pointer is used to

allow traversal in both ways, DLL's are ideal for applications that requires frequent insertions and deletions from a list.

An Array of Linked Lists

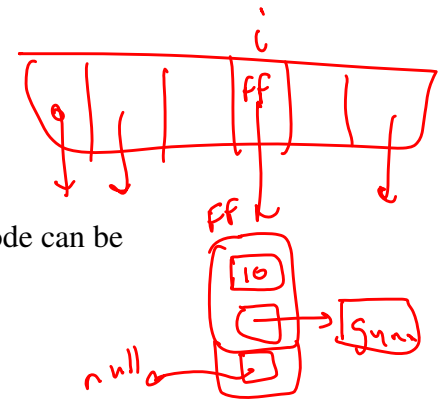
A linked list is defined as a collection of nodes that can be traversed starting at the head node. It is important to note that head is not a node, rather the address of the first node of the list. Linked lists are very useful in situations where the program needs to manage memory very carefully and a contiguous block of memory is not needed. An array of linked lists is an important data structure that can be used in many applications. Conceptually, an array of linked lists looks as follows.



An array of linked list is an interesting structure as it combines a static structure (an array) and a dynamic structure (linked lists) to form a useful data structure. This type of a structure is appropriate for applications, where say for example, number of categories is known in advance, but how many nodes in each category is not known. For example, we can use an array (of size 26) of linked lists, where each list contains words starting with a specific letter in the alphabet.

The following code can be used to create an array of linked lists as shown in the figure above. Assume that all variables are declared.

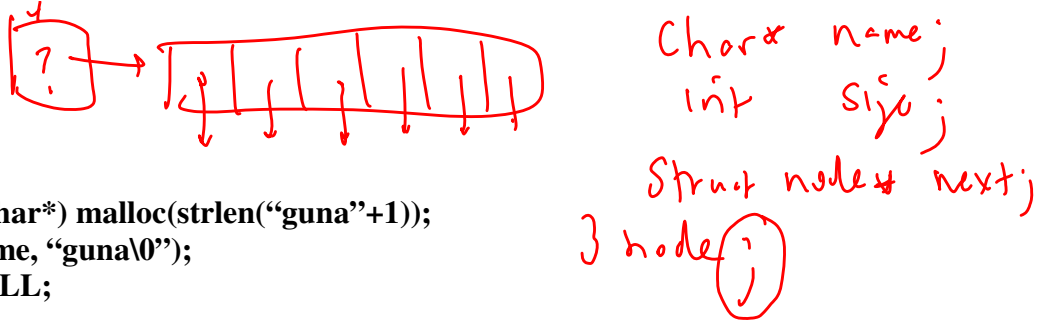
```
node* A[n] ;    // defines an array of n node pointers
for (i=0; i<n; i++)  A[i] = NULL;  // initializes the array to NULL
```



Creating an Array of Linked Lists

Suppose that a linked list needs to be created starting at A[i]. The first node can be created as follows.

```
A[i] = (node*)malloc(sizeof(node)); // allocate memory for  node
A[i] → size = 10;
```



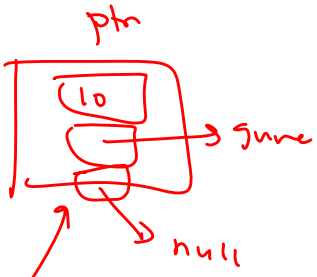
A[i] → name = (char*) malloc(strlen("guna"+1));
strcpy(A[i] → name, "guna\0");
A[i] → next = NULL;

Now to insert more nodes into the list let us assume that we have a function insertnodes with the following prototype.

int inserrnodes(node* arrayhead, int index, node* ptr);**

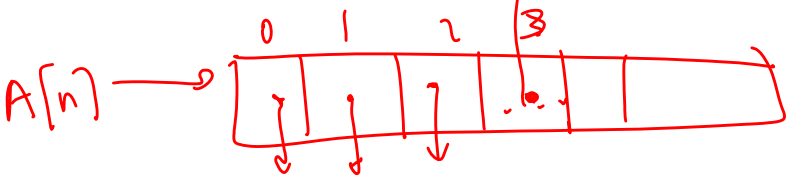
Here we pass the address of the array of node*, a pointer to a node, and the array index.

A call to the function can be as follows.

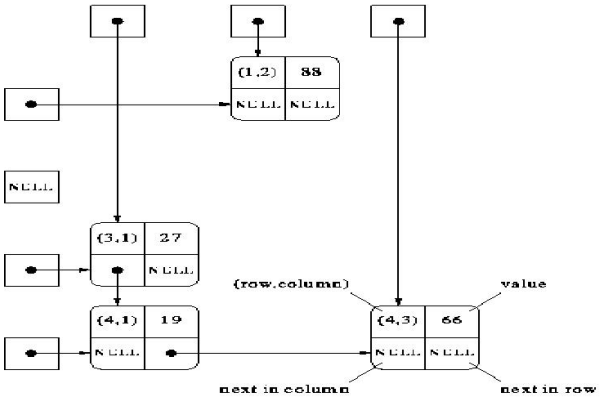


node* ptr = (node*)malloc(sizeof(node));
ptr → size = 10;
ptr → name = (char*) malloc(strlen("guna"+1));
strcpy(ptr → name, "guna\0");
ptr → next = NULL;
insertnodes(&A, ptr, 3); // insert node ptr to array location 3.

In lab 4, we will implement a sparse matrix, a matrix where most entries are zero using a structure as follows.



Representing a Sparse Matrix



A suggested data structure to implement the above is given by two structs, node and matrix.

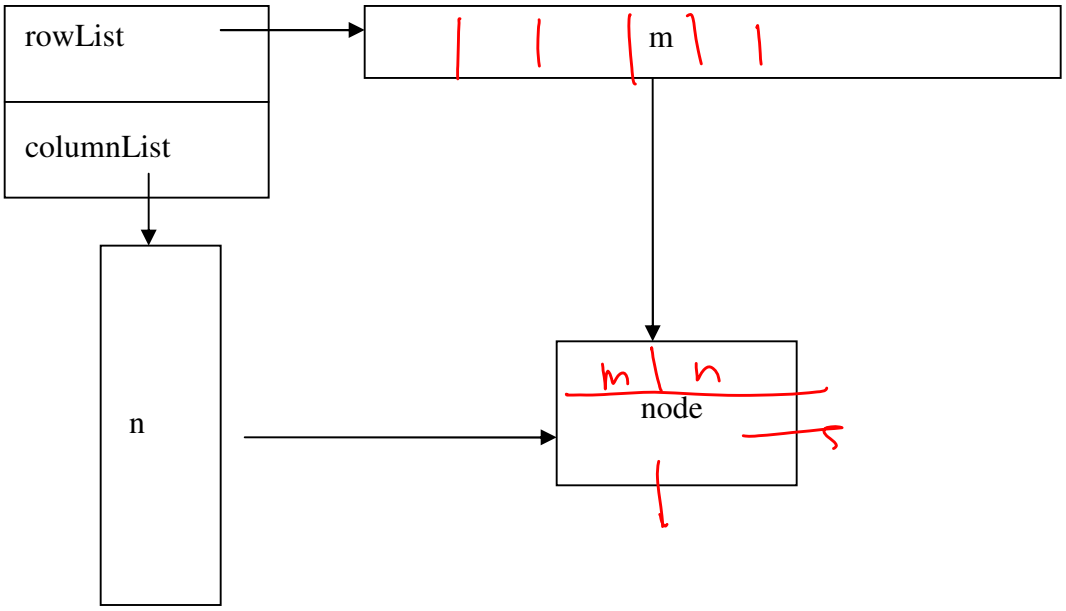
```
typedef struct node {
        int row, column,
        double value;
        struct node*  rowPtr;
        struct node*  colPtr;
} node;
```

The node is a self-referencing structure that can be used to form nodes in a linked list.

The matrix component of the data structure is a struct that contains two arrays of node pointers, each pointing to first element in a row or column. The overall matrix is stored in a structure as follows.

Defining a Sparse Matrix Node

```
typedef struct matrix {
     node**  rowList;     // rowList is a pointer to the array of rows
     node** columnList; // column list is a pointer to the array of columns.
     int  rows, columns;  // store the number of rows and columns of the matrix
} matrix;
```



In the structure above, we are using two arrays of linked nodes to create a structure that can be traversed starting from any row index or column index. Although the above structure seems complicated to implement, once we understand that each linked list is a separate singly linked list, it becomes easy to think about this and implement this structure. When a new node needs to be inserted, we must traverse the list from corresponding row index and corresponding column index and then link the node into the structure. You can use same logic in both cases, except that row indices are traversed and linked using the row_ptr and columns are traversed and linked using the column_ptr.

EXERCISES

1. Suppose M is a matrix*, where matrix is as defined above. Write code to allocate enough space to initialize a matrix of n by m.
2. Given a pointer to a node called ptr (assume all memory is allocated and node initialized), write code to insert the node to the beginning of the each list.
3. Write a function **int duplicatevalue(matrix* M, double value)** that returns 1 if a node with the value exists in the matrix. Return 0 if not.
4. Write a function **int resize(matrix**)** that doubles the rows and columns of the matrix. The old nodes need to be copied to the new matrix. Return 0 if success, 1 if failure.
5. Write a function **int transpose(matrix**)** that takes the transpose of the matrix. Transpose of a matrix M is defined as a matrix M1 where rows of M are equivalent to columns of M1 and columns of M are equivalent to rows of M1. For example the transpose of M = {{1,2},{3,4}} is M1 = {{1,3},{2,4}}

SOLUTIONS

1. Suppose M is a matrix*, where matrix is as defined above. Write code to allocate enough space to initialize a matrix of n by m.

```
matrix* M = malloc(sizeof(matrix));
M->rowList = malloc(n*sizeof(node*));
M->colList = malloc(m*sizeof(node*));
```

2. Given a pointer to a node called ptr (assume all memory is allocated and node initialized), write code to insert the node to the beginning of the each list.

```
for (i=0; i<n;i++) {
  ptr -> next = A[i] ;
  A[i] = ptr;
}
```

6. Write a function **int duplicatevalue(matrix* M, double value)** that returns 1 if a node with the value exists in the matrix. Return 0 if not.

```
int duplicatevalue(matrix* M, double value) {
      int i=0;
      for (i=0; i<M->rows; i++) {
            node* head = M->rowList[i];
            while (head != NULL)
                 { if (head->value == value) return 1;
                   head = head -> next;
                 }
      }
      return 0;
 }
```

3. Write a function **int resize(matrix**)** that doubles the rows and columns of the matrix. The old nodes need to be copied to the new matrix. Return 0 if success, 1 if failure.

```
int resize(matrix** M){
      (*M)->rowList = realloc((*M)->rowList, 2*M->rows);
      (*M)->colList = realloc((*M)->colList, 2*M->cols);

}
```

4. Write a function **int transpose(matrix**)** that converts the matrix to its transpose. Transpose of a matrix M is defined as a matrix M1 where rows of M are equivalent to columnsof M1 and columns of M are equivalent to rows of M1. For example the transpose of M = {{1,2},{3,4}} is M1 = {{1,3},{2,4}}

```
int transpose(matrix**  M) {
        node** tmp = (*M)->rowList;
        (*M)->rowList = (*M)->colList;
        (*M)->colList = tmp;
        int temp = (*M)->rows;
        (*M)->rows = (*M)->cols;
}
```

Midterm Review

The written midterm exam is 10% of your course grade. The test will cover all concepts we have covered in the course during the first 5 weeks. This includes

- Basic C syntax
- C strings, strcmp, strcpy
- C file I/O
- Formatting
- Binary, Octal and hex Numbers and binary addition
- One's compliment and two's compliment
- sizeof function
- Fundamentals of pointers, address of a variable
- malloc, calloc, realloc and free
- working with *, **, ***
- Passing pointers to/from functions
- Heap versus stack variables
- Linked Lists and Operations
- Shell commands
- Shell Scripts

In general you should be able to write short code fragments, trace code, debug code and know some of the fundamentals that we discussed in class. It is always a good idea to go over lecture notes and annotated notes. 50% of the test will cover issues related to fundamentals and the other 50% will require you to debug code or write some functions.

Practice Midterms Questions: There are a number of practice midterm questions (and answers) available from Bb → tests and quizzes. Although they do not cover the whole test, it can give you a good idea about the kind of things you will be tested on.

Debugging questions are designed so that you are able to recognize some common type of errors when coding C programs. They include:

A) dereference of uninitialized or otherwise invalid pointer
B) insufficient (or none) allocated storage for operation
C) storage used after free
D) allocation freed repeatedly
E) free of unallocated or potentially storage
F) free of stack space
G) return, directly or via argument, of pointer to local variable
H) dereference of wrong type
I) assignment of incompatible types
J) program logic confuses pointer and referenced type
K) incorrect use of pointer arithmetic
L) array index out of bounds

Here are more details about the type of errors.

A. Dereference of uninitialized or otherwise invalid pointer
   - This error occurs when the programmer tries to dereference a pointer variable w/o having a valid pointer assign to it. For example, if a pointer variable defined, but not any memory is malloc'ed then that pointer cannot be dereferenced.

B. Insufficient (or none) allocated memory for operation
   - It is possible that programmer may allocate insufficient memory for a data structure. Suppose a block of size 25 is assigned for 25 integers. This would be insufficient memory for 25 integers, but sufficient memory for 25 characters

C. Storage used after free
   - It is possible that a memory allocated for a ptr is freed using free(ptr) and then *ptr is referred. This would cause the program to crash

D. Allocation freed repeatedly
   - A block of memory once freed cannot be freed again. This would give a double free memory error

E. Free of unallocated or potentially storage
   - It is not possible to free memory that has not been allocated

F. Free of stack space

- Variables that are managed in the stack space by the compiler cannot be freed. In other words, programmer can free only the memory that was malloc'ed, calloc'ed or realloc'ed.

G. Return directly or via argument, of pointer to a local variable

- Local variables do not exist upon return from a function. Therefore if a pointer to local variable is returned, then the calling program cannot dereferenced the variable.

H. Dereference of wrong type

- Programmer must be careful in dereferencing a correct type. For example, dereference of a char type as an int would cause some problems.

I. Assignment of incompatible types

- C is a strongly typed language. Do not assign incompatible types, for example, assignment of * to a ** could cause some big headaches

J. Program logic confuses pointer and referenced types

- C clearly distinguishes the reference to a variable versus its address. This is a problem for java programmers.

K. Incorrect use of pointer arithmetic

- Pointer arithmetic refers to adding integers to pointers. For example if p is an int* then p +1 would mean adding 4 bytes to p to compute the address of p+1

L. Array index out of bounds

- Great care must be taken to make sure array indices do not go out of bounds.

- C strings, strcmp, strcpy

- C file I/O

- Formatting

- Binary, Octal and hex Numbers and binary addition

- One's compliment and two's compliment

- sizeof function

- Fundamentals of pointers, address of a variable

- malloc, calloc, realloc and free

- working with *, **, ***

- Passing pointers to/from functions

- Heap versus stack variables

- Linked Lists and Operations

- Shell commands

- Shell Scripts