

# Linked List

Singly Linked Lists, Chains, & Linked Stacks and Queues

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# Outline

1 Singly Linked List and Chains

2 Representing Chains in C

3 Linked Stacks and Queues

- Linked Stacks
- Linked Queues

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# Definition

- We have learned **array** and **sequential mapping** (e.g., polynomial ADT).
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  - no more available storage
  - waste of storage

# Definition

- We have learned **array** and **sequential mapping** (e.g., polynomial ADT).
  - Successive nodes of the data objects are stored in a fixed distance.
- **Issue:** When a sequential mapping is used for ordered lists:
  - no more available storage
  - waste of storage
  - Excessive data movement is required for deletions and insertions.

# Example

Alan	Bill	Carter	David	Elvis	Frank	
------	------	--------	-------	-------	-------	--

- Insert “Charlie” after Carter.

# Example

Alan	Bill	Carter	David	Elvis	Frank	
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- Insert “Charlie” after Carter.

Alan	Bill	Carter	Charlie	David	Elvis	Frank
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# Example

Alan	Bill	Carter	David	Elvis	Frank	
------	------	--------	-------	-------	-------	--

- Insert “Charlie” after Carter.

Alan	Bill	Carter	Charlie	David	Elvis	Frank
------	------	--------	---------	-------	-------	-------

Three elements are moved.

# Example

Alan	Bill	Carter	Charlie	David	Elvis	Frank
------	------	--------	---------	-------	-------	-------

- Delete “Carter” after Bill.

# Example

Alan	Bill	Carter	Charlie	David	Elvis	Frank
------	------	--------	---------	-------	-------	-------

- Delete “Carter” after Bill.

Alan	Bill	Charlie	David	Elvis	Frank	
------	------	---------	-------	-------	-------	--

# Example

Alan	Bill	Carter	Charlie	David	Elvis	Frank
------	------	--------	---------	-------	-------	-------

- Delete “Carter” after Bill.

Alan	Bill	Charlie	David	Elvis	Frank	
------	------	---------	-------	-------	-------	--

Four elements are moved.

# Solution: linked presentation



- A linked list is comprised of nodes; each node has zero or more data fields and **one or more** link or pointer fields.
  - The nodes may be placed anywhere in memory.
  - The address of the next (or another) node in the list.

# Singly Linked List

- In a singly linked list, each node has a pointer field.
- A singly linked list in which **the last node has a null link** is called a **chain**.

# Singly Linked List

- In a singly linked list, each node has **exactly one** pointer field.
- A singly linked list in which **the last node has a null link** is called a **chain**.

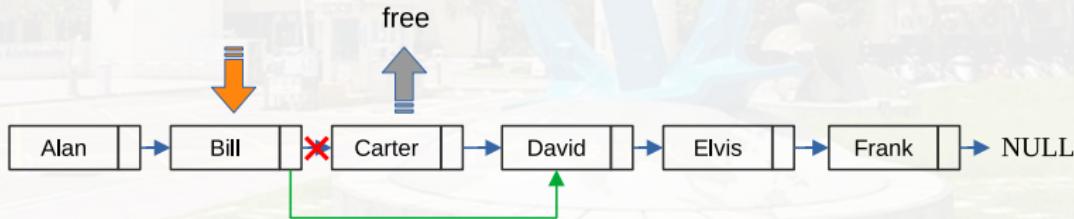
# Functions of Linked Lists (1/2)

- Insert (“Charlie”) after “Carter”.
  - ① Get an unused node *a* and set the data field of *a* to “Charlie”.
  - ② Set the link field of *a* to the node after “Carter”, which contains “David”.
  - ③ Set the link field of the node containing “Carter” to *a*.



# Functions of Linked Lists (2/2)

- Delete the node containing “Carter”.
  - ① Find the node  $a$  that **immediately precedes** the node containing “Carter”.
  - ② Set the link of  $a$  to point to “Carter”’s link.
    - ★ We don’t need to move any data.
    - ★ If possible, free the memory space of node containing “Carter”.



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# Pointers

- C provides extensive supports for pointers.

`&`: address operator

`*`: dereferencing (indirect) operator

```
int i, *pi; // i:integer variable; pi: a pointer to an integer.  
pi = &i; // pi gets the address of i.  
i = 10; // assign the value 10 to i  
*pi = 20; // assign the value 20 to i  
if (pi == NULL) ... // or if (!pi); test if the pointer is null.
```



# Dynamically Allocated Storage

- C provides a mechanism, called **heap**, for allocating storage at run-time.
  - **malloc** or **calloc**: dynamic memory allocation.
  - **free**: free the memory previously (dynamically) allocated.

```
int i, *pi;  
float f, *pf;  
pi = (int *) malloc(sizeof(int));  
pf = (float *)malloc(sizeof(float));  
*pi = 1024; *pf = 3.14;  
free(pi);  
free(pf);
```

# Dynamically Allocated Storage

- How about C++?

- `new` or `calloc`: dynamic memory allocation.
- `delete`: free the memory previously (dynamically) allocated.

```
int i, *pi;  
float f, *pf;  
pi = new int;  
pf = new float;  
*pi = 1024; *pf = 3.14;  
delete pi;  
delete pf;
```

# Using struct and typedef

```
struct employee {  
    char name[4];  
    struct employee *link;  
};  
typedef struct employee human; //usage: human h1, h2;  
typedef struct employee *hPointer; // usage: hPointer link;
```



# Variable or Structure?

```
struct {  
    char name[4];  
    int age;  
} person;
```

```
struct person {  
    char name[4];  
    int age;  
} human;
```

# Self-Referential Structure

- Demo code.

```
struct Node {  
    int data;  
    struct Node *link;  
};
```

```
typedef struct Node Node;  
  
struct Node {  
    int data;  
    Node *link;  
};
```

# Self-Referential Structure

- C allows us to create a pointer to a type that does not yet exist.

```
typedef struct listNode *listPointer; // listNode is still unknown!  
  
struct listNode {  
    char data[4];  
    listPointer link;  
};
```



# More functions for linked lists

- To create a new empty list:
  - `listPointer first = NULL;`
- To test for an empty set:
  - `#define IS_EMPTY (first) (!(first))`
- To obtain a new node:
  - `first = (listPointer) malloc(sizeof(*first));`
- Enter “data” into the new node:
  - `strcpy(first->data, "data");`
  - `first->link = NULL;`

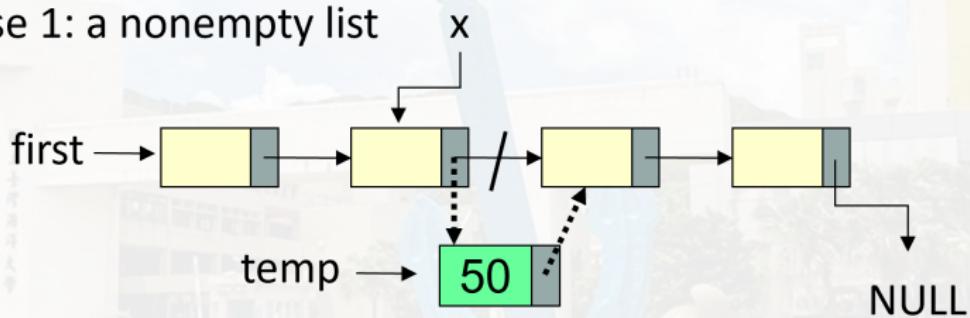
# Further example: Create a two-node list

```
listPointer createTwo() {
    /* create a linked list with two nodes */
    listPointer first, second;
    first = (listPointer)malloc(sizeof(*first));
    second = (listPointer)malloc(sizeof(*second));
    second->link = NULL;
    second->data = 20; // or (*second).data = 20;
    first->data = 10;
    first->link = second;
    return first;
}
```

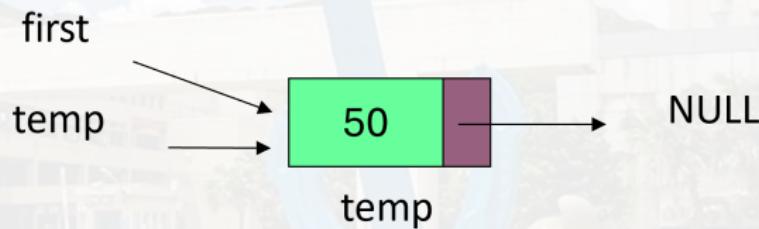
# Simple insert into front of the list

```
void insert(listPointer *first, listPointer x) {
    /* insert a new node with data = 50 into the chain first after node x */
    listPointer temp;
    temp = (listPointer)malloc(sizeof(*temp));
    if(IS_FULL(temp)){ // check the capacity of the list first!
        printf("The memory is full\n");
        exit(1);
    }
    temp->data = 50; // get the data ready!
    if(*first) {           //Case 1: nonempty list
        temp->link = x->link;
        x->link = temp;
    }
    else {                //Case 2: empty list
        temp->link = NULL;
        *first = temp;
    }
}
```

## Case 1: a nonempty list

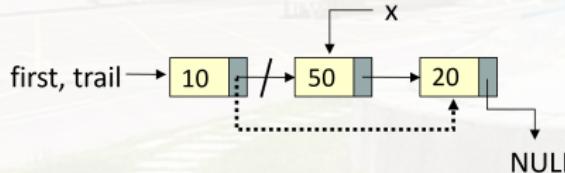
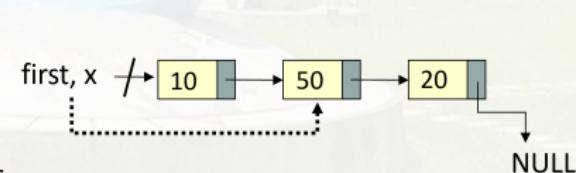


## Case 2: an empty list



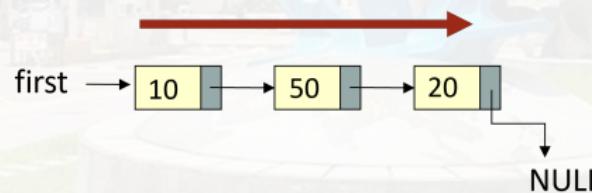
# Delete a node from the list

```
void delete(listPointer first, listPointer trail, istPointer x) {
/* delete x from the list, trail points to the preceding node of x
   and *first is the front of the list */
    if (trail)           // Case 1: nonempty list
        trail->link = x->link;
    else                  // Case 2:
        *first = (*first)->link;
    free(x);
}
```

Case 1:  $\text{trail} \neq \text{NULL}$ Case 2:  $\text{trail} = \text{NULL}$ 

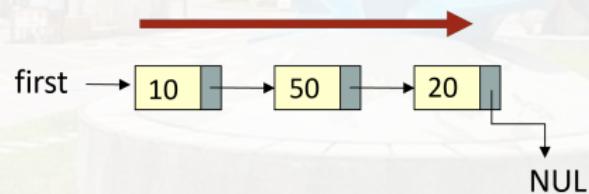
# Printing a list

```
void printList(listPointer first) {  
    printf("The list contains: ");  
    for ( ; first ; first = first->link )  
        printf("%4d", first->data);  
    printf("\n");  
}
```



# Printing a list

```
void printList(listPointer first) {  
    printf("The list contains: ");  
    while (first) {  
        printf("%4d", first->data);  
        first = first->link;  
    }  
    printf("\n");  
}
```



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# Linked Stacks & Queues

- The links facilitate the implementation of stacks and queues.



(a) Linked stack



(b) Linked queue

# Declarations & Initialization for Stacks

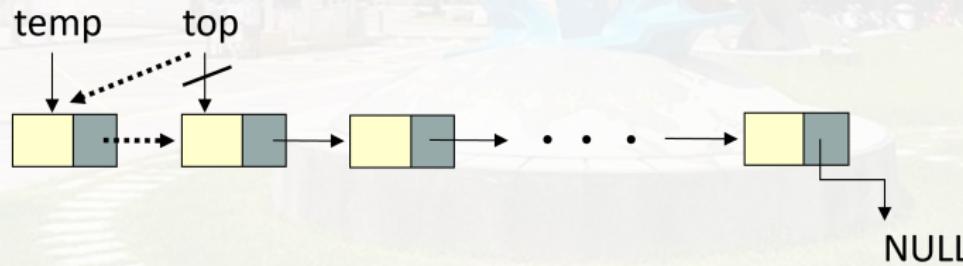
```
#define MAX_STACKS 10 /*maximum number of stacks*/
typedef struct {
    int key;
    /*other fields */
} element;

typedef struct stack* stackPointer;
struct stack {
    element data;
    stackPointer link;
};
stackPointer top[MAX_STACKS];
//Initialization
for (int i=0; i<MAX_STACKS; i++)
    top[i] = NULL;
```



# Stack: push

```
void push(int i, element item) {  
    /* add item to the i-th stack */  
    stackPointer temp;  
    MALLOC(temp, sizeof(*temp));  
    temp->data = item;  
    temp->link = top[i];  
    top[i] = temp;  
}
```



# Stack: pop

```
element pop(int i) { /* remove top element from the i-th stack*/
    stackPointer temp = top[i];
    element item;
    if (!temp)
        return stackEmpty();
    item = temp->data;
    top[i] = temp->link;
    free(temp); // Note: elements are dynamically allocated!
    return item;
}
```

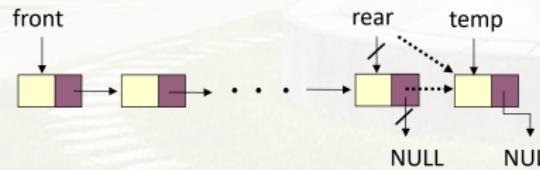
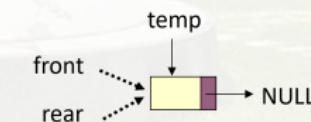


# Declarations & Initialization for Queues

```
#define MAX_QUEUES 10 /*maximum number of stacks*/  
  
typedef struct queue* queuePointer;  
  
struct queue {  
    element data;  
    queuePointer link;  
};  
queuePointer front[MAX_QUEUES], queuePointer rear[MAX_QUEUES];  
//Initialization  
for (int i=0; i<MAX_QUEUES; i++) {  
    front[i] = NULL; rear[i] = NULL;  
}
```

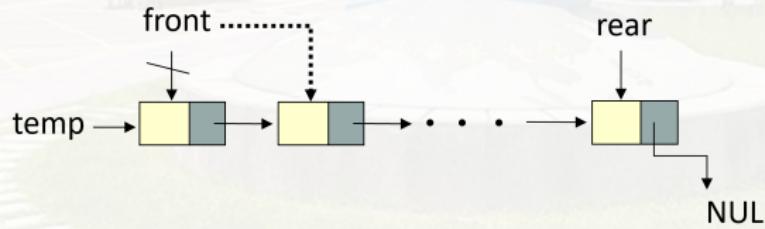
# Queue: add (enqueue)

```
void add(i, item) {
    /* add item to the rear of queue i */
    queuePointer temp;
    MALLOC(temp, sizeof(*temp));
    temp->data = item;
    temp->link = NULL;
    if (front[i])
        rear[i]->link = temp;
    else
        front[i] = temp;
    rear[i] = temp;
}
```

Case 1:  $\text{front} \neq \text{NULL}$ Case 2:  $\text{front} = \text{NULL}$ 

# Queue: delete (dequeue)

```
element delete(int i) {
    /* delete an element from queue i */
    queuePointer temp = front[i];
    element item;
    if (!temp)
        return queueEmpty();
    item = temp->data
    front[i] = temp->link;
    free(temp);
    return item;
}
```



# Discussions

