Linked List

Singly Linked Lists, Chains, & Linked Stacks and Queues

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Outline

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Definition

- We have learned array and sequential mapping (e.g., polynomial ADT).
  - Successive nodes of the data objects are stored in a fixed distance.

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  - waste of storage

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- 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.

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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

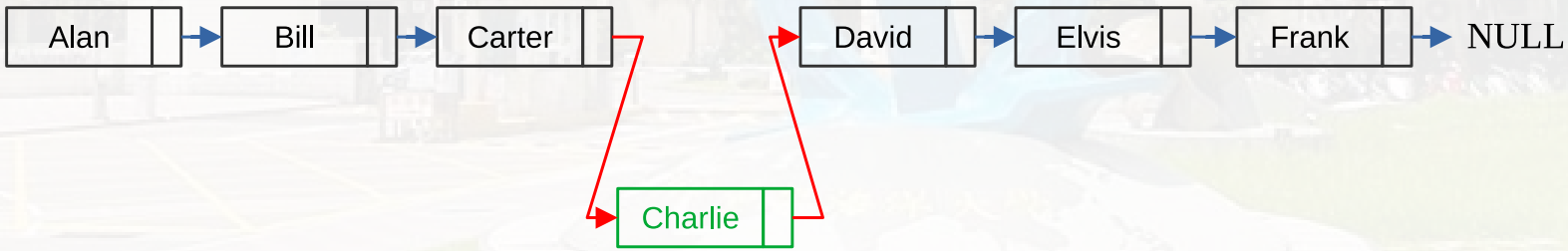
- In a singly linked list, each node has pointer field.
- A singly linked list in which **the last node has a null link** is called a chain.

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.

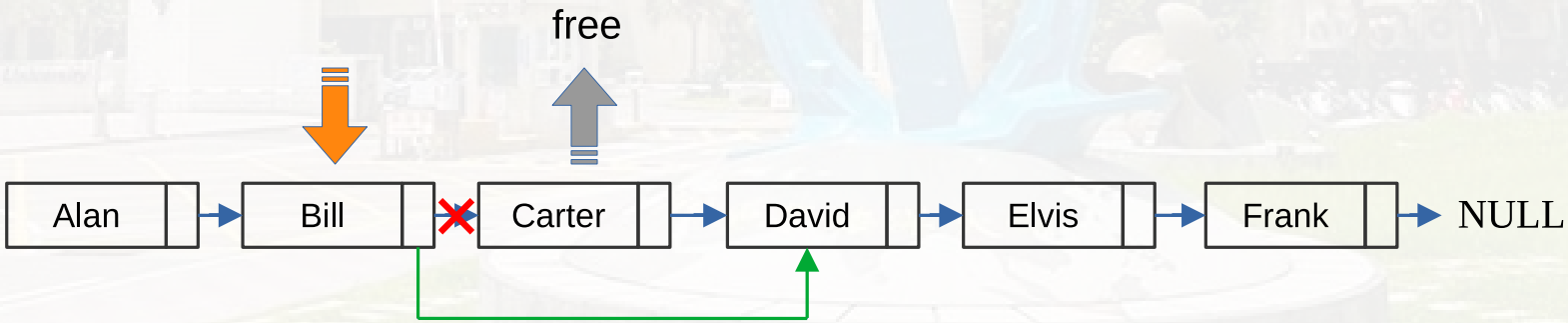
Functions of Linked Lists (1/2)

- 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".



Outline

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`: 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

```c
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

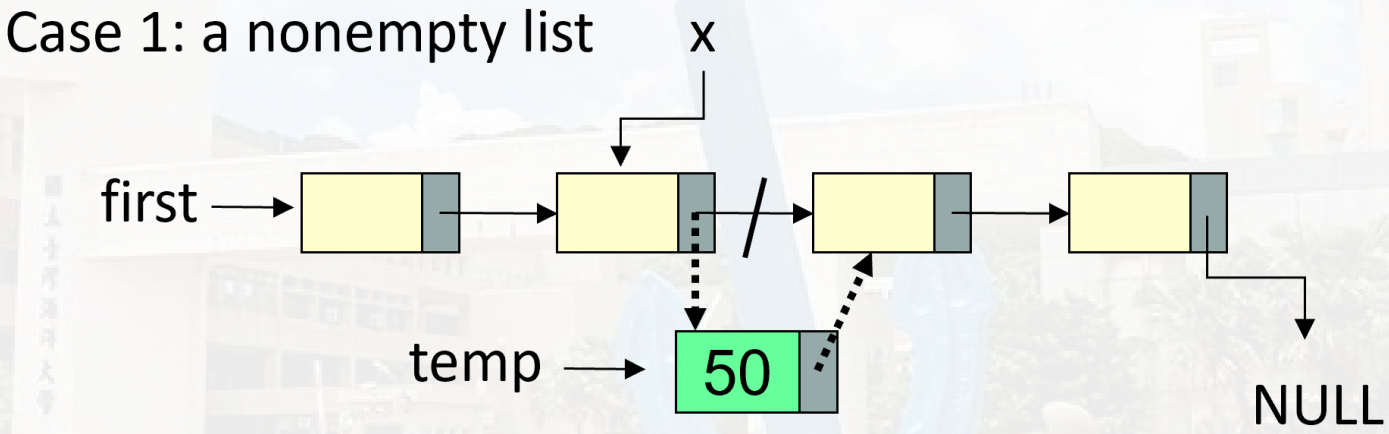
- To create a new empty list:
  - `listPointer first = NULL;`
- To test for an empty set:
  - `#define IS_EMPTY (first) (!(first))`
- To obtain a new node:
  - `first = (listPointer) malloc(sizeof(*first));`
- Enter "data" into the new node:
  - `strcpy(first->data, "data");`
    `first->link = NULL;`

Further example: Create a two-node list

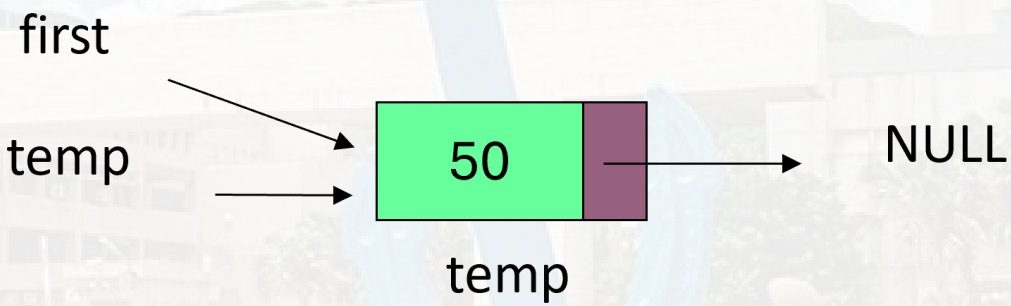
```
listPointer createTwo() {
       /* create a linked list with two nodes */
      listPointer first, second;
      first = (listPointer)malloc(sizeof(*first));
      second = (listPointer)malloc(sizeof(*second));
      second->link = NULL;
      second->data = 20; // or (*second).data = 20;
     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

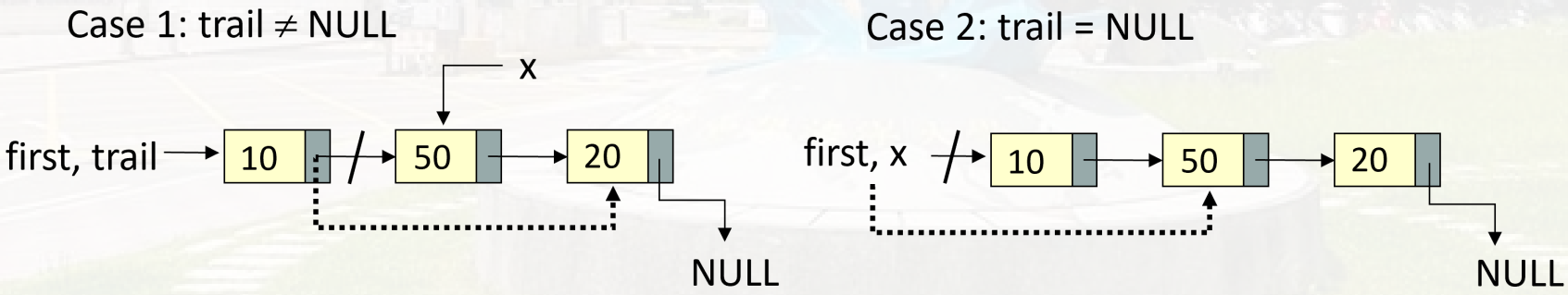


Case 1: a nonempty list
x
first
temp
50
NULL

Case 2: an empty list



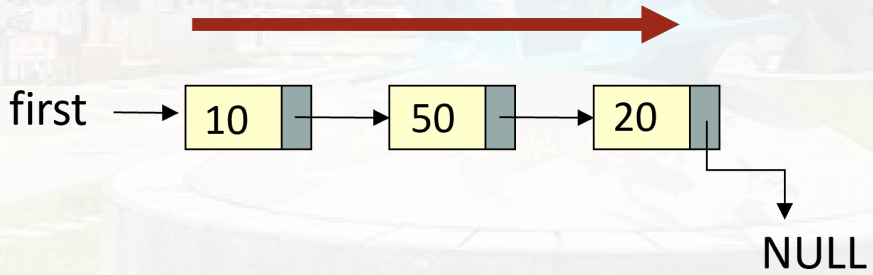
Delete a node from the list

```
void delete(listPointer first, listPointer trail, listPointer 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);
}
```



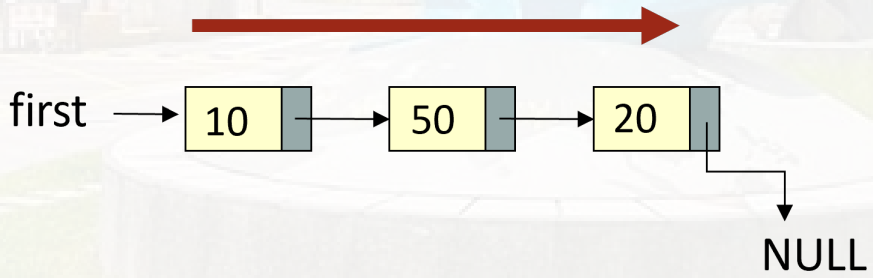
Printing a list

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



Printing a list

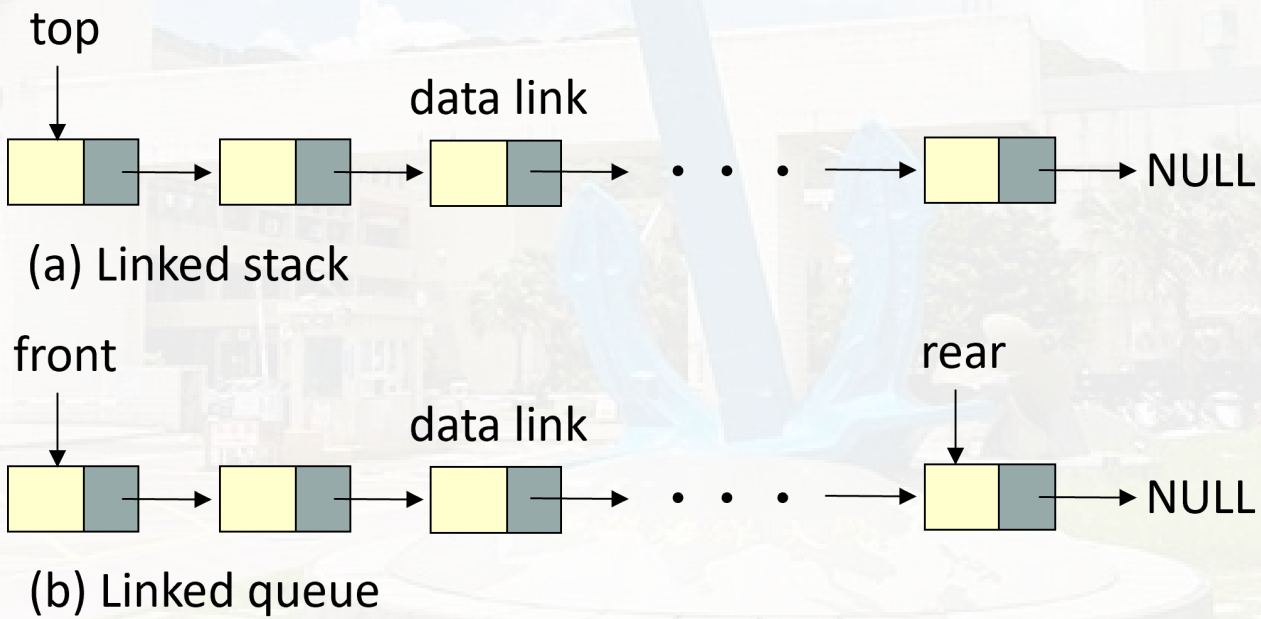
```c
void printList(listPointer first) {
     printf("The list contains: ");
     while (first) {
         printf("%4d", first->data);
         first = first->link;
     }
     printf("\n");
}
```



Outline

Linked Stacks & Queues

- The links facilitate the implementation of stacks and queues.

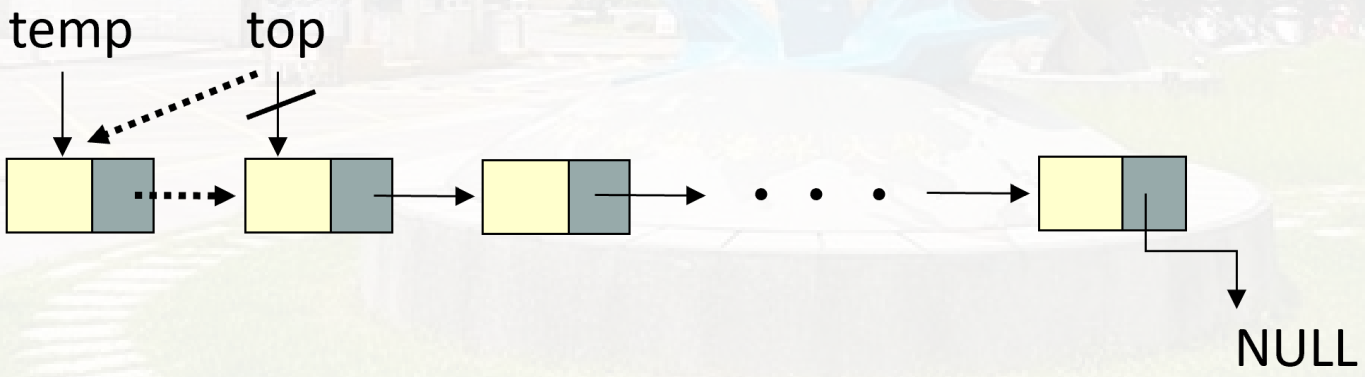


Declarations & Initialization for Stacks

```
#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;
```

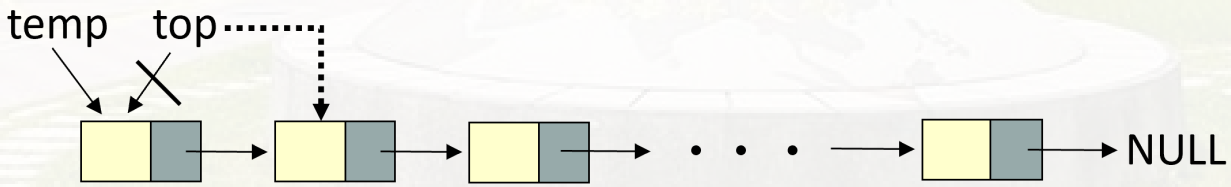
Stack: push

```
void push(int i, element item) {^^I
/* add item to the i-th stack */
    stackPointer temp = malloc(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;
}
```



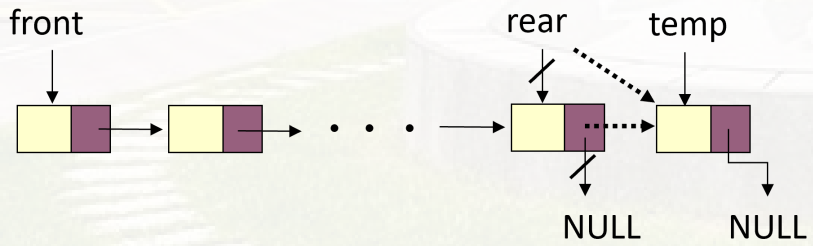
Declarations & Initialization for Queues

```
#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;
}
```

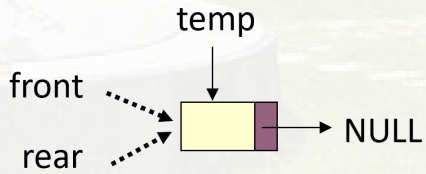

Queue: add (enqueue)

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

Case 1: front ≠ NULL

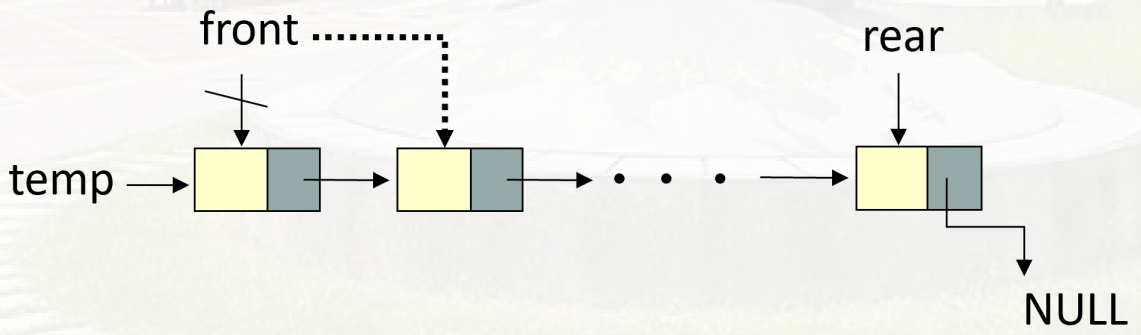


Case 2: front = NULL



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