Software design and implementation 2

Software engineering

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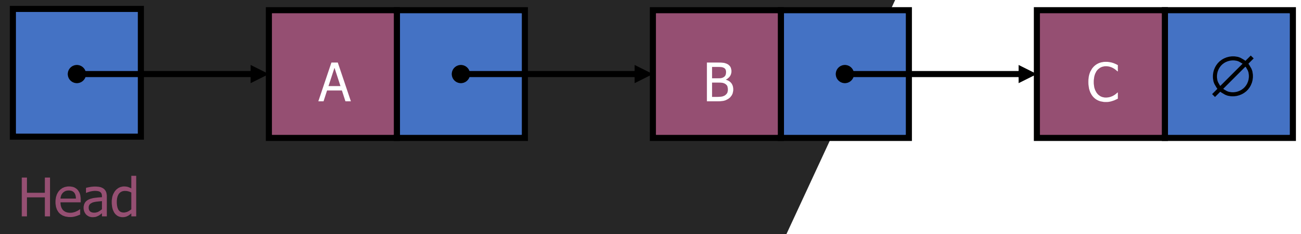
Overview

- Linked-Lists
- Queues
- Stacks
- Deques

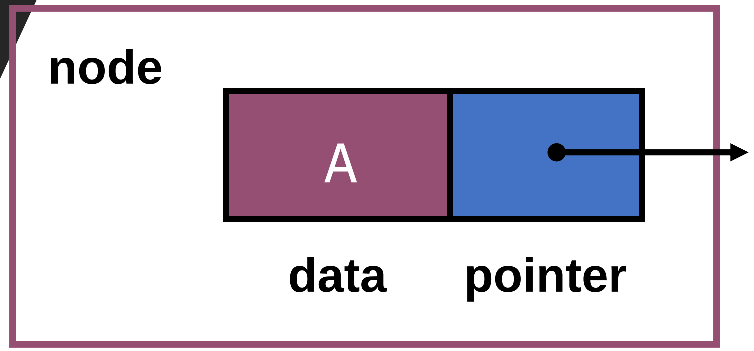
Linked Lists

- Abstract data type (ADT)
- Basic operations of linked lists
- Insert, find, delete, print, etc.
- Variations of linked lists
- Circular linked lists
- Doubly linked lists

Linked List



- A **linked list** is a series of connected **nodes**
- Each node contains at least
- A piece of data (any type)
- Pointer to the next node in the list
- **Head**: pointer to the first node
- The last node points to **NULL**



A Simple Linked List Class

- We use two classes: **Node** and **List**
- Declare **Node** class for the nodes
- *data*: **double**-type data in this example
- *next*: a pointer to the next node in the list

```
class Node {
public:
        double data;   // data
        Node*  next;   // pointer to next
};
```

A Simple Linked List Class

Declare `List`, which contains

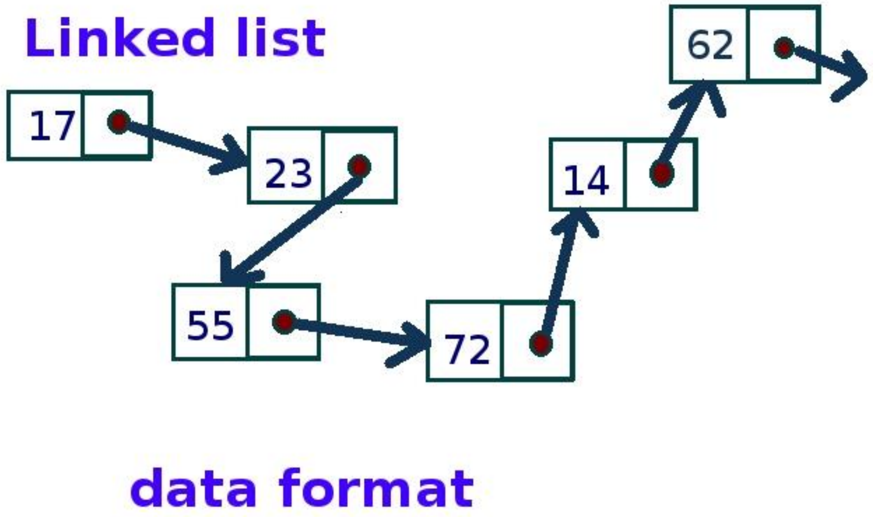
- `head`: a pointer to the first node in the list.
  Since the list is empty initially, `head` is set to `NULL`
- Operations on `List`

```
class List {
public:
      List(void) { head = NULL; }       // constructor
      ~List(void);                      // destructor

      bool IsEmpty() { return head == NULL; }
      Node* InsertNode(int index, double x);
      int FindNode(double x);
      int DeleteNode(double x);
      void DisplayList(void);
private:
```

A Simple Linked List Class

Operations of List

- *IsEmpty*: determine whether or not the list is empty
- *InsertNode*: insert a new node at a particular position
- *FindNode*: find a node with a given value
- *DeleteNode*: delete a node with a given value
- *DisplayList*: print all the nodes in the list

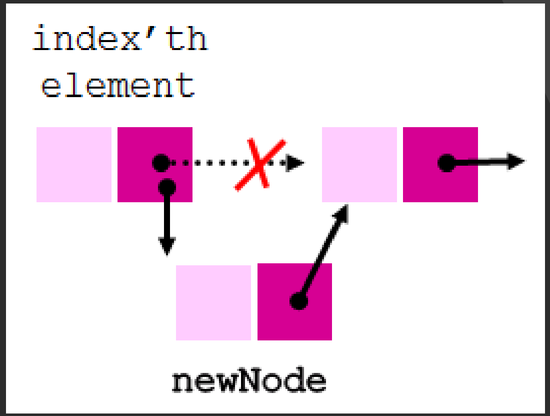


Inserting a new node

- Node* InsertNode(int index, double x)
- Insert a node with data equal to x after the index’th elements. (i.e., when index = 0, insert the node as the first element;
- when index = 1, insert the node after the first element, and so on)
- If the insertion is successful, return the inserted node.
- Otherwise, return NULL.
- (If index is < 0 or > length of the list, the insertion will fail.)

Steps

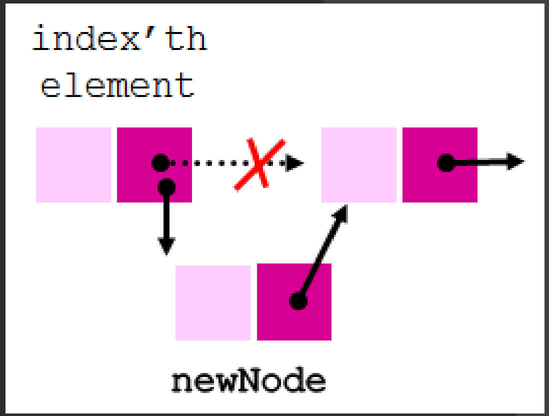
1. Locate index’th element
2. Allocate memory for the new node
3. Point the new node to its successor
4. Point the new node’s predecessor to the new node



Inserting a new node

Possible cases of InsertNode

1. Insert into an empty list
2. Insert in front
3. Insert at back
4. Insert in middle



But, in fact, only need to handle two cases

- Insert as the first node (Case 1 and Case 2)
- Insert in the middle or at the end of the list (Case 3 and Case 4)

Linked List

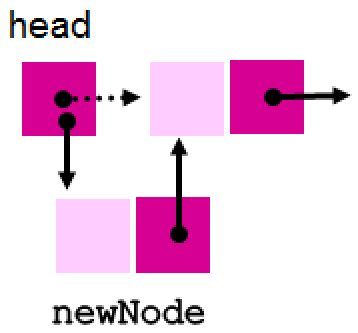
```
Node* List::InsertNode(int index, double x) {
        if (index < 0) return NULL;

        int currIndex = 1;
        Node* currNode = head;
        while (currNode && index > currIndex) {
                currNode = currNode->next;
                currIndex++;
        }
        if (index > 0 && currNode == NULL) return NULL;

        Node* newNode = new Node;
        newNode->data = x;
        if (index == 0) {
                newNode->next = head;
                head = newNode;
        }
        else {
                newNode->next = currNode->next;
                currNode->next = newNode;
        }
        return newNode;
}
```

Try to locate `index`'th node. If it doesn't exist, return `NULL`.

Create a new node

Insert as first element

Insert after `currNode`



Finding a node

int FindNode(double x)

Search for a node with the value equal to x in the list.

If such a node is found, return its position. Otherwise, return 0.

```
int List::FindNode(double x) {
      Node* currNode     =     head;
      int currIndex =      1;
      while (currNode && currNode->data != x) {
            currNode     =     currNode->next;
            currIndex++;
      }
      if (currNode) return currIndex;
      return 0;
}
```

Deleting a node

int DeleteNode(double x)

- Delete a node with the value equal to x from the list.
- If such a node is found, return its position. Otherwise, return 0.

Steps

1. Find the desirable node (similar to FindNode)
2. Release the memory occupied by the found node
3. Set the pointer of the predecessor of the found node to the successor of the found node

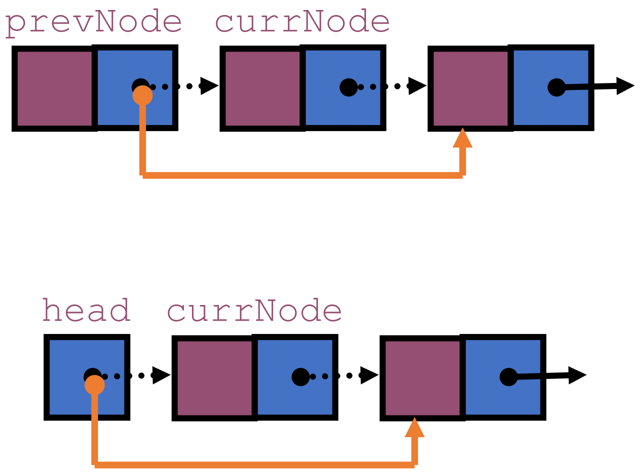
Like InsertNode, there are two special cases

- Delete first node
- Delete the node in middle or at the end of the list

Deleting a node

```
int List::DeleteNode(double x) {
        Node* prevNode = NULL;
        Node* currNode = head;
        int currIndex = 1;
        while (currNode && currNode->data != x) {
                prevNode = currNode;
                currNode = currNode->next;
                currIndex++;
        }
        if (currNode) {
                if (prevNode) {
                        prevNode->next = currNode->next;
                        delete currNode;
                }
                else {
                        head = currNode->next;
                        delete currNode;
                }
                return currIndex;
        }
        return 0;
}
```

Try to find the node with its value equal to x



Printing all the elements

- `void DisplayList(void)`
  - Print the data of all the elements
  - Print the number of the nodes in the list

```
void List::DisplayList()
{
    int num             =       0;
    Node* currNode      =       head;
    while (currNode != NULL){
        cout << currNode->data << endl;
        currNode        =       currNode->next;
        num++;
    }
    cout << "Number of nodes in the list: " << num << endl;
}
```

Destroying the list

- `~List(void)`
  - Use the destructor to release all the memory used by the list.
  - Step through the list and delete each node one by one.

```
List::~List(void) {
    Node* currNode = head, *nextNode = NULL;
    while (currNode != NULL)
    {
        nextNode      =      currNode->next;
        // destroy the current node
        delete currNode;
        currNode      =      nextNode;
    }
}
```

Using List

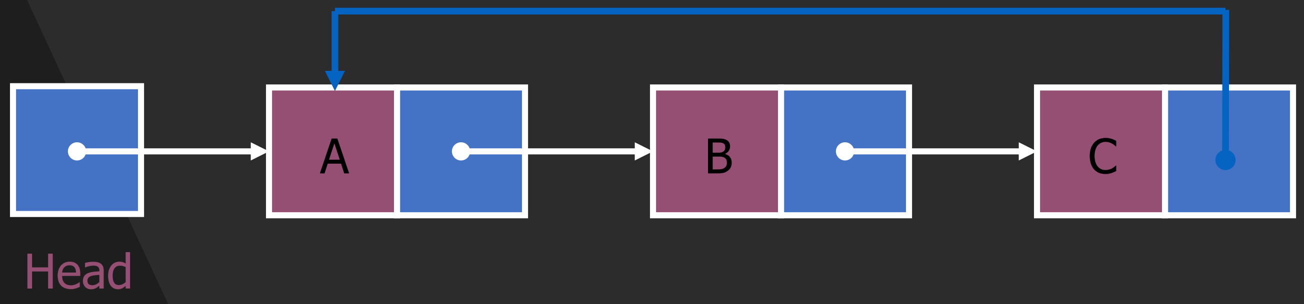
```
int main(void)
{
        List list;
        list.InsertNode(0, 7.0);    // successful
        list.InsertNode(1, 5.0);    // successful
        list.InsertNode(-1, 5.0);   // unsuccessful
        list.InsertNode(0, 6.0);    // successful
        list.InsertNode(8, 4.0);    // unsuccessful
        // print all the elements
        list.DisplayList();
        if(list.FindNode(5.0) > 0) cout << "5.0 found" << endl;
        else                       cout << "5.0 not found" << endl;
        if(list.FindNode(4.5) > 0) cout << "4.5 found" << endl;
        else                       cout << "4.5 not found" << endl;
        list.DeleteNode(7.0);
        list.DisplayList();
        return 0;
}
```

result

```
6
7
5
Number of nodes in the list: 3
5.0 found
4.5 not found
6
5
Number of nodes in the list: 2
```

Variations of Linked Lists

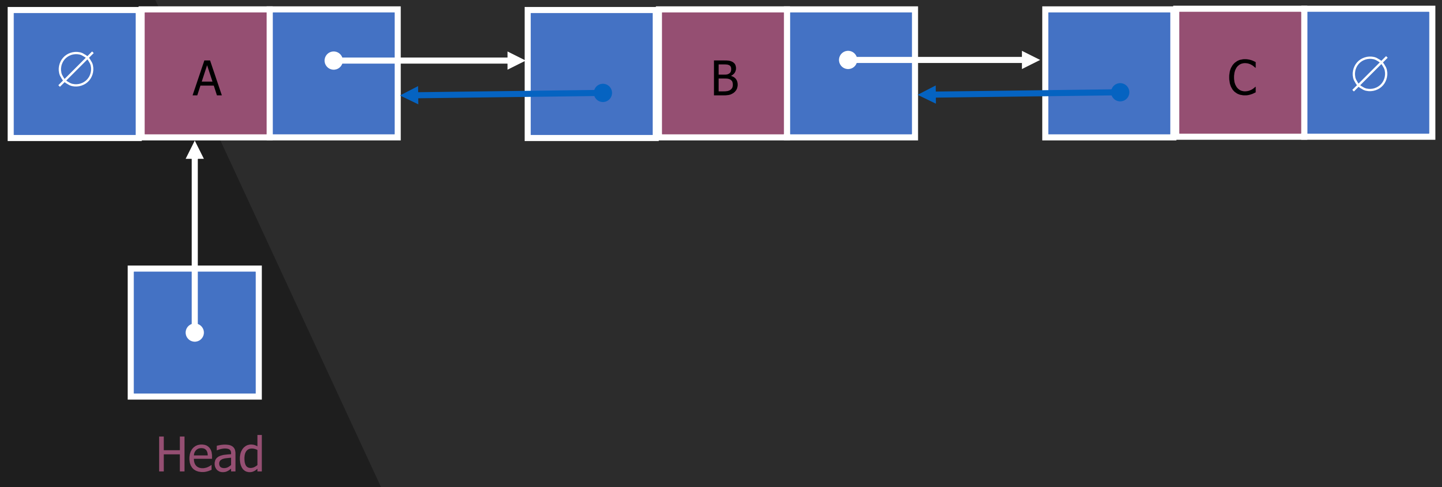
- *Circular linked lists*
  - The last node points to the first node of the list



  - How do we know when we have finished traversing the list? (Tip: check if the pointer of the current node is equal to the head.)

Variations of Linked Lists

- *Doubly linked lists*
  - Each node points to not only successor but the predecessor
  - There are two `NULL:` at the first and last nodes in the list
  - Advantage: given a node, it is easy to visit its predecessor. Convenient to traverse lists backwards



Arrays versus Linked Lists

- Linked lists are more complex to code and manage than arrays, but they have some distinct advantages.
  - **Dynamic**: a linked list can easily grow and shrink in size.
    - We don't need to know how many nodes will be in the list. They are created in memory as needed.
    - In contrast, the size of a C++ array is fixed at compilation time.
  - **Easy and fast insertions and deletions**
    - To insert or delete an element in an array, we need to copy to temporary variables to make room for new elements or close the gap caused by deleted elements.
    - With a linked list, no need to move other nodes. Only need to reset some pointers.

Other structures
Stacks, Queues and Deques

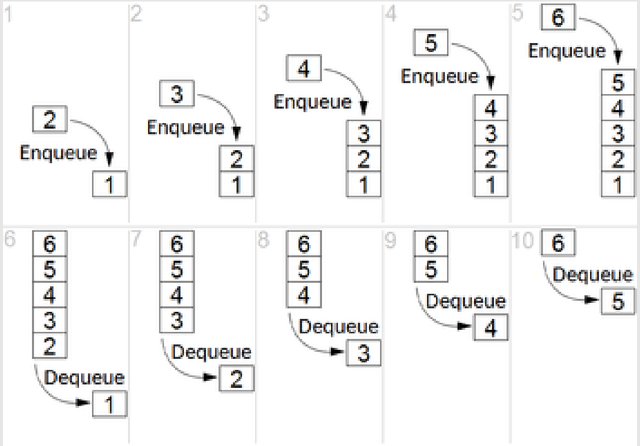
A stack is a last in, first out (LIFO) data structure

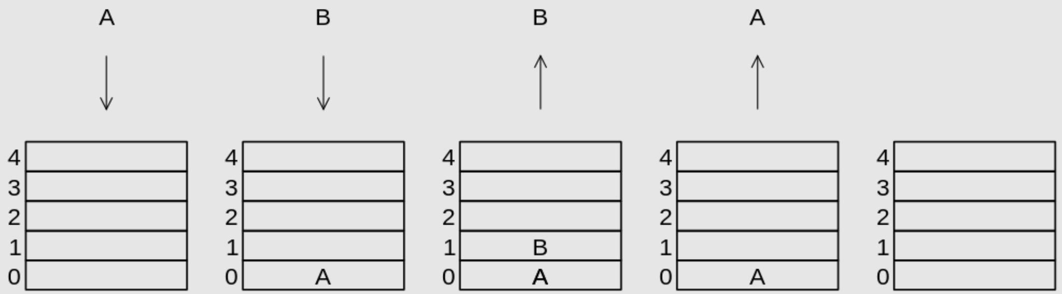
- Items are removed from a stack in the reverse order from the way they were inserted

A queue is a first in, first out (FIFO) data structure

- Items are removed from a queue in the same order as they were inserted

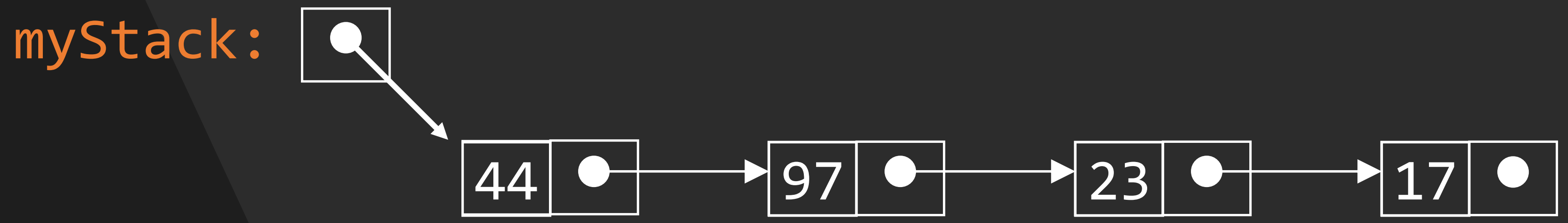
A deque is a double-ended queue—items can be inserted and removed at either end





Stacks Implementation

- Since all the action happens at the top of a stack, a singly-linked list (SLL) is a fine way to implement it
- The header of the list points to the top of the stack



- Pushing is inserting an element at the front of the list
- Popping is removing an element from the front of the list

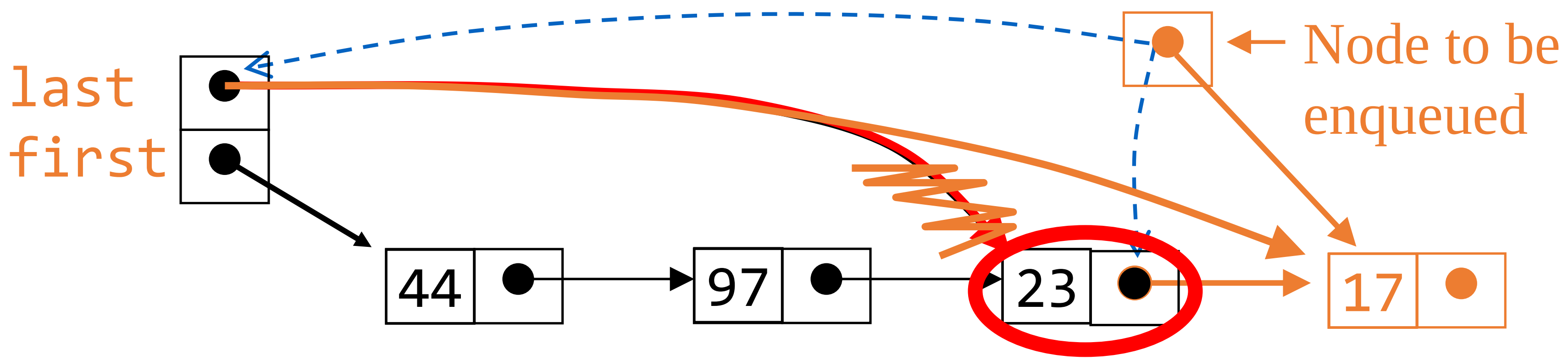
Stacks Implementation

- With a linked-list representation, overflow will not happen (unless you exhaust memory, which is another kind of problem)
- Underflow can happen, and should be handled the same way as for an array implementation
- When a node is popped from a list, and the node references an object, the reference (the pointer in the node) does not need to be set to null
- Unlike an array implementation, it really is removed--you can no longer get to it from the linked list
- Hence, garbage collection can occur as appropriate

Queues Implementation

- In a queue, insertions occur at one end, deletions at the other end
- Operations at the front of a singly-linked list (SLL) are O(1), but at the other end they are O(n)
- Because you have to find the last element each time
- BUT: there is a simple way to use a singly-linked list to implement both insertions and deletions in O(1) time
- You always need a pointer to the first thing in the list
- You can keep an additional pointer to the last thing in the list

Enqueueing a node



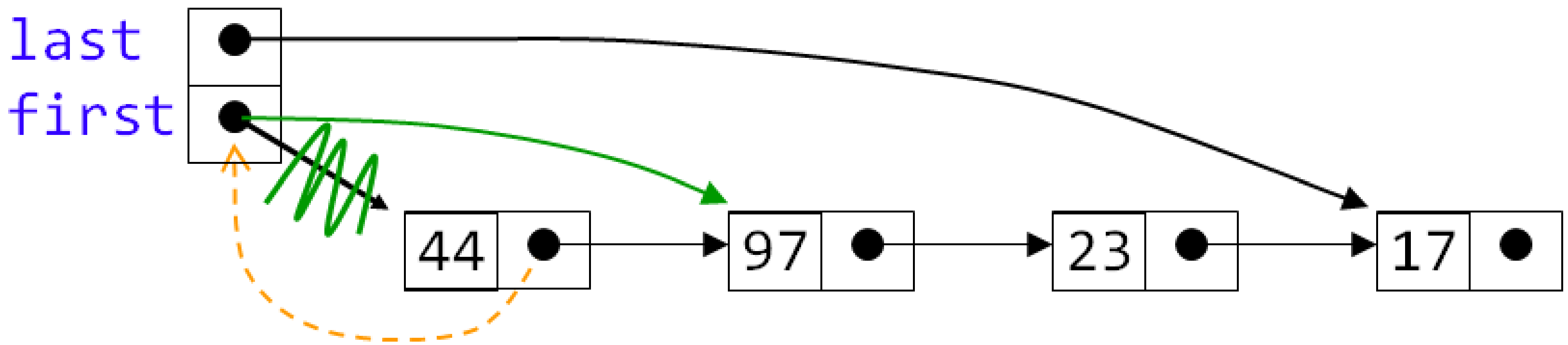
To enqueue (add) a node:

Find the current last node

Change it to point to the new last node

Change the `last` pointer in the list header

Dequeueing a node



- To dequeue (remove) a node:
  - Copy the pointer from the first node into the header

Queue implementation details

- With an array implementation:
- you can have both overflow and underflow
- you should set deleted elements to **null**

- With a linked-list implementation:
- you can have underflow
- overflow is a global out-of-memory condition
- there is no reason to set deleted elements to **null**

Deques

- A **deque** is a **d**ouble-**e**nded **que**ue
- Insertions and deletions can occur at either end
- Implementation is similar to that for queues
- Deques are not heavily used
- You should know what a deque is, but we won't explore them much further

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Summary

- Linked-Lists
- Queues
- Stacks
- Deques