CSC 212: Data Structures and Abstractions

11: Linked Lists (part 1)

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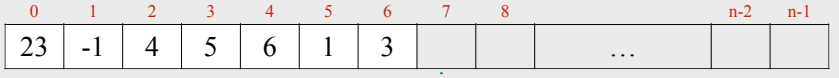
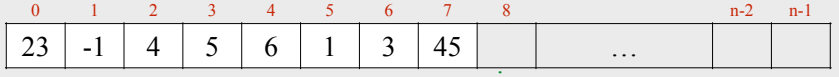
Array insertions



`push_back(45)`



Computational cost?

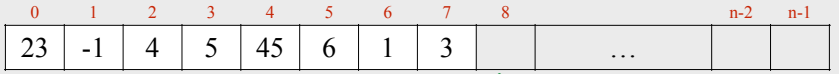
Array insertions

`push_front(45)`

Computational cost?

Array insertions

`insert(4, 45)`



Computational cost?

(*) repeat the same analysis for remove (front, back, at index)

Memory representation of arrays

Address	Value
…	
0x0A08	var1
0x0A0C	var2
0x0A10	var3
0x0A14	
0x0A18	
0x0A1C	
0x0A20	
0x0A24	
0x0A28	
0x0A2C	
0x0A30	
0x0A34	
0x0A38	
0x0A3C	
0x0A40	
0x0A44	
0x0A48	
0x0A4C	
0x0A50	
0x0A54	
…	

```
int var1;
int var2;
int var3[7];
```


Linked lists

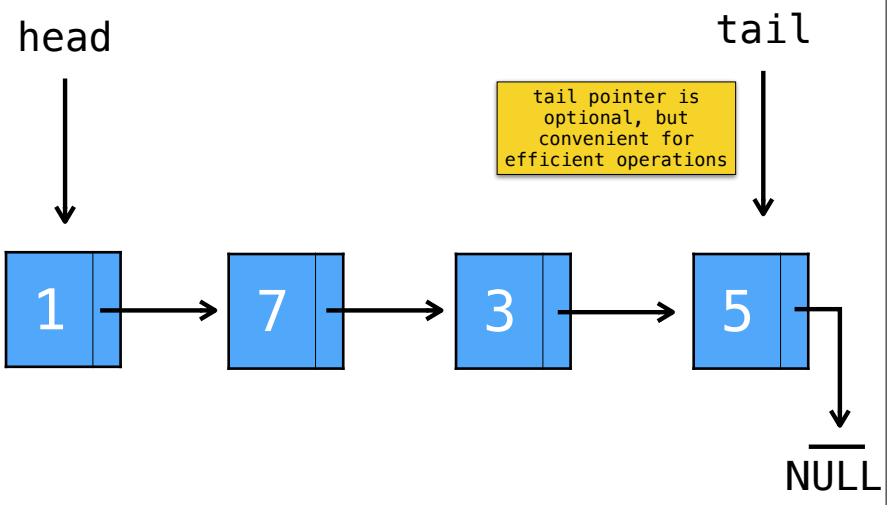
Linked lists

- Definition
  - a linked list is a **linear data structure** in which elements (called **nodes**) are stored at **non-contiguous** memory locations
  - each node contains **data** and typically a **pointer** to the next node in the sequence
- Operations
  - **insert**: add a new node (at the front, rear, specific index, or by value)
  - **delete**: remove a node (from the front, rear, specific index, or by value)
  - **search**: find a node containing a specific value
  - **get**: retrieve the value at a specific position (requires traversal)
  - **traverse**: sequentially "visit" each node in the list

Types of linked lists

- Singly-linked list
  - each **node** contains a value and a pointer to the next node
  - the first node is called the **head**, the last node is the **tail**
  - the tail node points to **null**
  - the **length** of the linked list is the number of nodes
  - enables traversal only from the head towards the tail
- Doubly-linked list
  - each **node** contains a value, a pointer to the next node, a pointer to the previous node
  - the first node is called the **head**, the last node is the **tail**
  - the head node's previous pointer and the tail node's next pointer are **null**
  - the **length** of the linked list is the number of nodes
  - enables traversal in both directions

Singly-linked list



Memory representation of linked lists

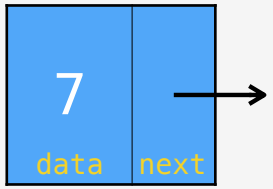
Address	Value	
…		
0x0A08	−5 0x0A20	
0x0A0C		
0x0A10		
0x0A14		
0x0A18	33 0x0000	
0x0A1C		
0x0A20	6 0x0A48	
0x0A24		
0x0A28		
0x0A2C		
0x0A30	21 0x0A18	
0x0A34		
0x0A38	3 0x0A08	
0x0A3C		
0x0A40		
0x0A44		
0x0A48	18 0x0A30	
0x0A4C		
0x0A50	0x0A38	head
0x0A54	0x0A18	tail
…		

{3, −5, 6, 18, 21, 33}

Implementing a linked list

Representing a node

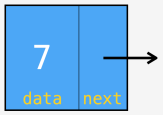
```
template <typename T>
struct Node {
    T data;
    Node<T> *next;

    Node(const T& value) {
        data = value;
        next = nullptr;
    }
};
```

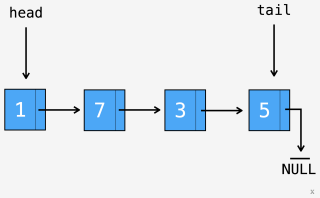


`struct` representing a node in a linked list using templates. It contains a value of type `T`, a pointer to the next node, and a constructor that initializes the value and sets the next pointer to `nullptr`

Representing a singly-linked list

```
template <typename T>
class SLList {

    private:
        struct Node {
            T data;
            Node *next;
            Node(const T& value) { data = value; next = nullptr; }
        };

        Node *head;
        Node *tail;
        size_t size;

    public:
        SLList() { head = tail = nullptr; size = 0; }
        ~SLList() { clear(); }

        size_t get_size() { return size; }
        bool empty() { return size == 0; }
        void clear();
        T& front();
        T& back();
        void push_front(const T& value);
        void pop_front();
        void push_back(const T& value);
        void pop_back();
        void print();
};
```





Methods

- constructor
  - ✓ invoked automatically
  - ✓ initializes an empty list
  - ✓ sets head and tail to nullptr and size to zero
- destructor
  - ✓ invoked automatically
  - ✓ calls clear() to delete all dynamically allocated nodes
- clear()
  - ✓ traverse the list and deletes each node
  - ✓ resets head and tail to nullptr and size to zero

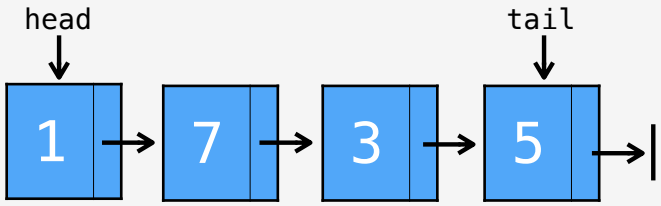
Methods

- get_size()
  - ✓ returns the current number of nodes in the list
- empty()
  - ✓ returns true if the list is empty, false otherwise
- front()
  - ✓ throws an exception if the list is empty
  - ✓ otherwise, returns the value stored in the first node
- back()
  - ✓ throws an exception if the list is empty
  - ✓ otherwise, returns the value stored in the last node

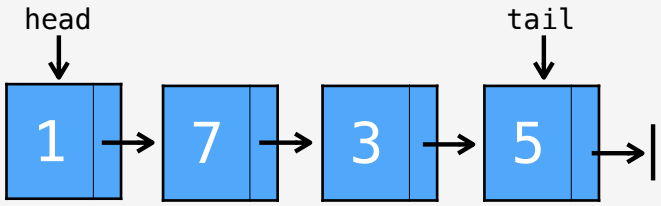
Methods

- push_back(value)
  - ✓ creates a new node containing the given value
  - ✓ adds the node to the end of the list
  - ✓ updates all necessary pointers, including the tail
  - ✓ increments the size counter
  - ✓ if the list was empty, the new node becomes both head and tail
- pop_back()
  - ✓ throws an exception if the list is empty
  - ✓ traverses the list to find the second-to-last node
  - ✓ removes the last node from the list and frees its memory
  - ✓ updates all necessary pointers, with tail now pointing to the second-to-last node
  - ✓ decrements the size counter
  - ✓ if the list becomes empty, sets head and tail to nullptr

push_back(10)



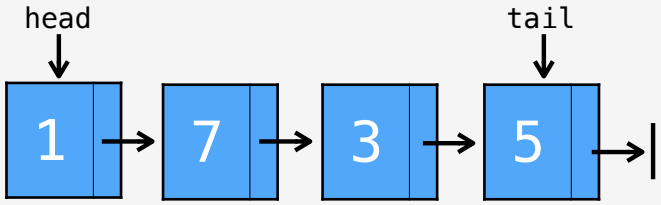
pop_back()



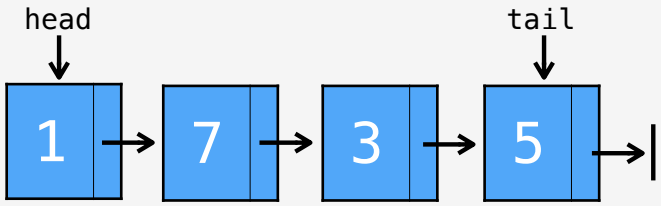
Methods

- push_front(value)
  - creates a new node containing the given value
  - adds the node to the beginning of the list
  - updates all necessary pointers, including the head
  - increments the size counter
  - if the list was empty, the new node becomes both head and tail
- pop_front()
  - throws an exception if the list is empty
  - removes the first node from the list and frees its memory
  - updates all necessary pointers, with head now pointing to the second node
  - decrements the size counter
  - if the list becomes empty, sets head and tail to nullptr

push_front(10)



pop_front()



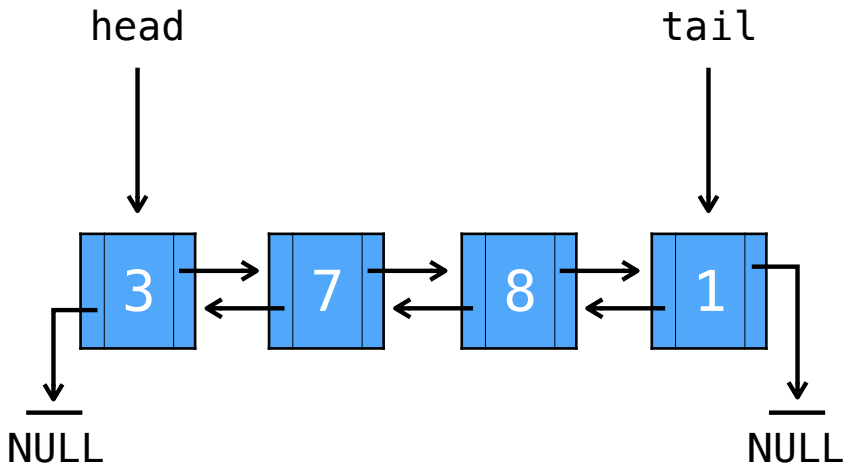
Methods

- print()
  - ✓ uses a temporary pointer to traverse the list starting from the head
  - ✓ prints the value stored in each node during traversal
- search(value)
  - ✓ uses a temporary pointer to traverse the list starting from the head
  - ✓ compares each node's value with the target value
  - ✓ returns true if the value is found; otherwise, returns false
- at(index)
  - ✓ returns the element at the specified index (starting from 0)

Practice

- Provide the computational cost for each of the operations listed in the previous slides
- Design, implement and provide the computational cost for the following methods
  - ✓ insert_at(index, value)
  - ✓ remove_at(index)

Doubly linked list

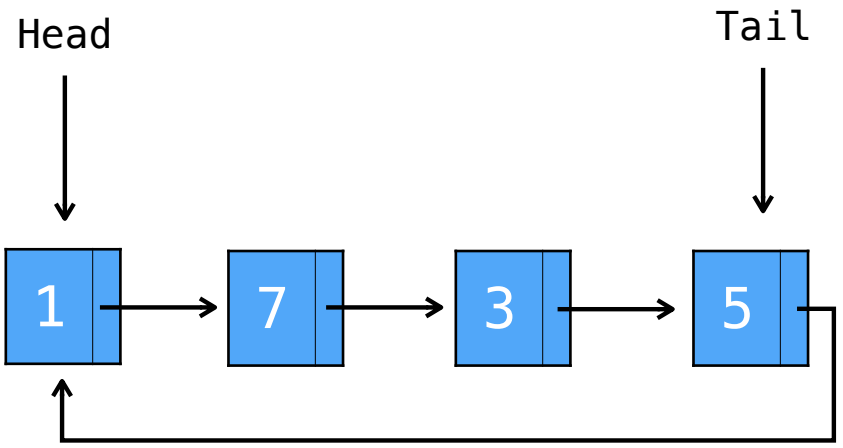


Practice

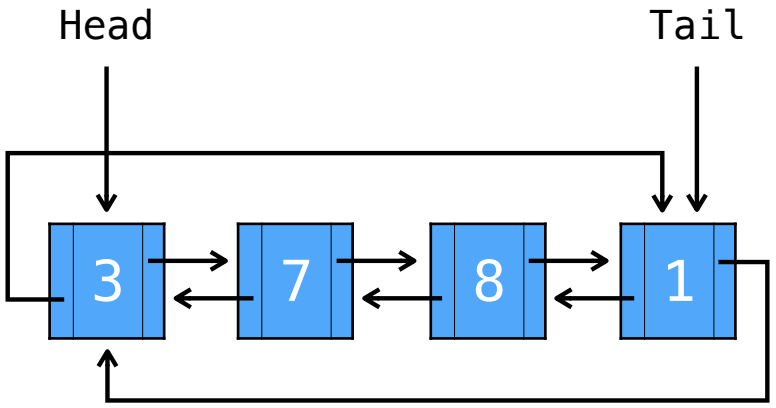
- Implement a class DoublyLinkedList
  - ✓ include all the methods seen for the singly linked list
- Complete the following table with rates of growth
  - ✓ assume all linked lists use a “tail” pointer

Operation	Dynamic Array	Singly-linked list	Doubly-linked list
Append 1 element			
Remove 1 element from the end			
Insert 1 element at index idx			
Remove 1 element from index idx			
Read element from index idx			
Write (update) element at index idx			

Circular singly linked list



Circular doubly linked list



STL containers

Collection	Description	Implementation	Random Access	Insertion/Deletion	Memory Overhead
`std::string`	character sequence	contiguous memory	O(1)	O(n) at arbitrary positions; O(1) amortized at end	low
`std::array`	fixed-size array	contiguous memory	O(1)	Not designed for insertion/deletion	none
`std::vector`	dynamic array	contiguous memory	O(1)	O(n) at arbitrary positions; O(1) amortized at end	low
`std::deque`	double-ended queue	segmented array	O(1)	O(1) at both ends; O(n) in middle	medium
`std::list`	doubly-linked list	non-contiguous nodes	O(n)	O(1) at any position with iterator	high
`std::forward_list`	singly-linked list	non-contiguous nodes	O(n)	O(1) at front; O(n) elsewhere	medium