School of Computer Science

COMP SCI 1103/2103 Algorithm Design & Data Structure

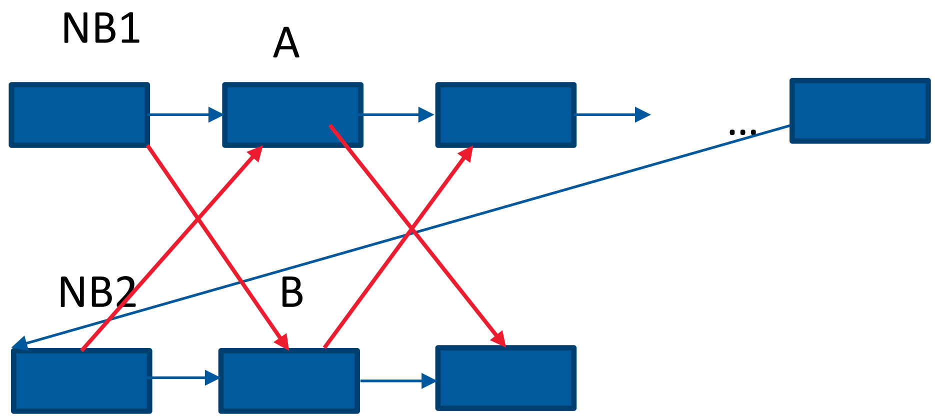
More Functions on Linked Lists, Stacks and Queues

Review

- Linked lists
  - Used for implementing stacks and queues
- Using singly linked lists we saw
  - Simple operations on a list
  - Search

- Today's topic:
  - Swap two nodes
  - Sort (not in detail)
  - Doubly linked lists
  - Priority Queue

Swap 2 nodes of a Linked Lists



Swap A and B.
Assume that A and B are not the first node. Let NB1 and NB2 be the predecessors of A and B, respectively.

```
void swap (Node* NB1, Node* NB2) {
  Node * temp1=NB1->next->next;
  NB1->next->next=NB2->next->next;
  NB2->next->next=temp1;

  Node* temp2=NB1->next;
  NB1->next=NB2->next;
  NB2->next=temp2;
}
```

Sorting Linked Lists

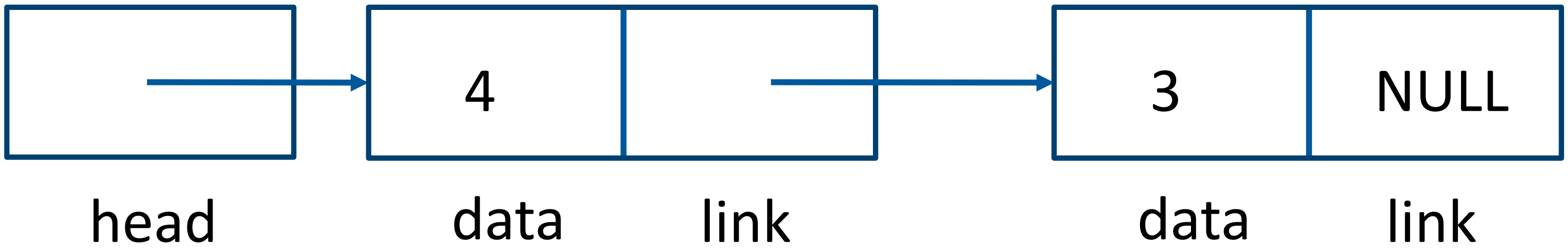
- If you are ready! let's see how a linked list can be sorted!

- Insertion sort
  - Same as array, but we need to traverse from the beginning to find the appropriate position of each new item
- Selection sort
  - Pretty much the same as on an array
- Think about
  - Merge sort (this is good for a linked list)
    - O(n) for splitting and merging
  - Quick sort (needs traversing from end as well)
    - Complexity?

Adding to the List

- We can now add elements anywhere in the list, but let's start at the front.
- Adding at the head:

```
Node *tmp;
tmp = new Node;
tmp->data = 4;
tmp->link = head;
head = tmp;
```



Walking the List

- We can immediately access the element at the head - that's easy.
- To get to any other value, we have to walk the list.
- Let's search for a value x:

```
here = head;   // Start at the head
while ((here->data != x) && (here->link != NULL))
  here = here->link;

if (here->data == x)
  return here;

return NULL;
```

Inserting a node

- We can insert anywhere in the linked list as long as we:
  - Create the new node
  - Find its insertion point
  - Point the new node's pointer to the post-insert point
  - Point the pre-insert point to this node

Deleting a node

- When deleting a node we have to make sure that we have copied out its link pointer before we delete it, or everything from that point on in the chain is lost forever
- Here’s some sample code, let’s say we want to delete node discard, where the list is:
  - head->before->discard->…

```
before->link = discard->link;
delete discard;   // Clean up
```

Pointers as Iterators

- An iterator is a construct that allows you to cycle through the data items stored in a data structure so that you can perform whatever action you want on each data item.

```
Node_Type *iter;
for(iter = head; iter != NULL; iter = iter->link)
  // do whatever you want on each item
```

Common mistakes

- Referring through a linked list, without checking for non-existent entries.
- Unless you know what you're doing, this is very likely to fail, for a Node *temp:
  int x = temp->link->link->data
  What if temp->link is NULL?

- Don't build complex testing conditions where a simple approach will work better.

- Common pitfall: trying to copy the list by setting newHead = head or newList=myList
  – This creates two pointers to the same head, not a copy of the list.
  – The second one works if you have provided a **copy constructor** for the linked list class and make a copy of each node it that

Implications of structure

- What can we say about the storage considerations of a linked list when compared to an array?
- What about a dynamic array?
- What are the time complexity implications compared to an array?
- Consider all of the operations.

Advantages of the linked list

- Linked lists have several advantages:
- Insertion and deletion are efficient
- We only allocate space as we need it - but what about dynamic arrays?
- Linked lists are easy to understand and explain.

Dynamic Arrays

- Dynamic arrays can fill up.
- A good implementation will expand as required, but to be efficient, the expansion occurs in fixed size blocks.

Efficient Linked Lists

- To be efficient, we must ensure that:
  - We only create as many elements as we need
  - We insert and delete correctly
  - We delete the elements removed from the list.
  - We use an appropriate pointer strategy
  - Keep track of the head

Some structures are more complex

- A linked list may consist of nodes that are, in turn, the heads of other linked lists.

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

- This would form a list of lists.

Some last words

- Linked lists are linear structures.
- You can draw them in a straight line, one after the other.
- There are no gaps.
- When in doubt, draw the structure to see how it should work.
- How do you search to find something?

Doubly linked lists

- If we add a prev pointer to our node, we can walk in either direction. Now our node would be:

```
struct Node {
   type data;
   Node* next;
   Node* prev;
};
```

- Memory usage
- Let’s see how to insert a new node in the middle

When to use doubly linked list

- You can
  - Traverse in both directions, think of
    - deleting a node
    - swapping two nodes
    - implementing a queue with a doubly linked list
    - Quick sort
- But
  - With more trouble and time (constant factor) for updating the links
  - And more memory usage

- Use doubly linked lists if you feel the need to traverse the list in opposite direction pretty often.
- Or when most operations happen often around the end of the list

Add a node to a linked list

- Insert at the beginning
  - O(1)
- Insert at end
  - O(n)
  - Keep a pointer to tail?
    - O(1)
- Insert before tail
  - O(n)
  - Doubly linked list
    - O(1)
- Insert in middle for singly or doubly linked lists
  - O(n)

Stacks in C++

- Stacks have a defined top of stack
  - Insertion and deletion are efficient as they occur at a single point, only one pointer has to be maintained
- Top returns the value and pop removes it

```
#include <stack>          // std::stack
int main ()
{
   std::stack<int> mystack;
   mystack.push(5);
   if (!mystack.empty())
   {
      std::cout << mystack.top(); //does not remove
      mystack.pop(); //does not return
   }
}
```

Implications of structure

- What if you want to insert an item in the middle of stacks and queues?

- We can only ‘see’ the top element (for a stack) or the front element (for a queue)
- These abstract data types provide very different ways of interacting with data than that of a simple array or Linked List.

No free walks

- Stacks have push, pop and empty as their basic operations.
- Queues have add, remove and empty (or enqueue, dequeue sometimes instead of add and remove)

- If you need an element in the middle, you need to pop or dequeue all elements that come before it
- Same situation if you need to insert an element in the middle (both are easier for a queue – no need for an auxiliary list)

Efficient Use

- Searching a stack or standard queue for a value requires 2 * O(n) operations to take everything out, look at it, and put it back again.
- We should design with these ADTs if the add and remove operations are efficient for our purposes.
- Not everything should be put into a stack or a queue! Depending on your requirements, you may need to use other structures.

Queues in C++

- Queues have a defined front and back
  - Insertion and deletion are efficient as they occur at well-defined points, two pointers have to be maintained for front and back.
- Front returns the value and pop removes it
- Queues are easy to understand and explain.

```
#include <queue>        // std::queue
int main ()
{
  std::queue<int> myqueue;
  myqueue.push (5);
  if (!myqueue.empty());
  {
    std::cout << ' ' << myqueue.front();
    myqueue.pop();
  }
}
```

Queue Example: Priority Queues

- A lot of useful queues have a notion of priority associated with them.
- Some people/processes will take precedence over others for a variety of reasons.
- This happens in networking, operating systems, printing and real life (if you're famous in America and trying to get into a restaurant).

Queue Example: Priority Queues

- There are at least two ways to approach a priority queue. The fundamental functions that we need to support are (enqueue and dequeue functions).
- Options
  - remove highest and simple add
    - Complexity
      - O(n), O(1)
  - add_with_priority and simple remove
    - Complexity (linked list)
      - O(n) and O(1)
    - Complexity (array)
      - Add O(log n)? Or O(n)?, remove O(1)
  - Given a queue (add, remove and isEmpty only!) how do you do it?
- What happens if everything has the same priority?
- Other solution: keep several queues (linked list- array)