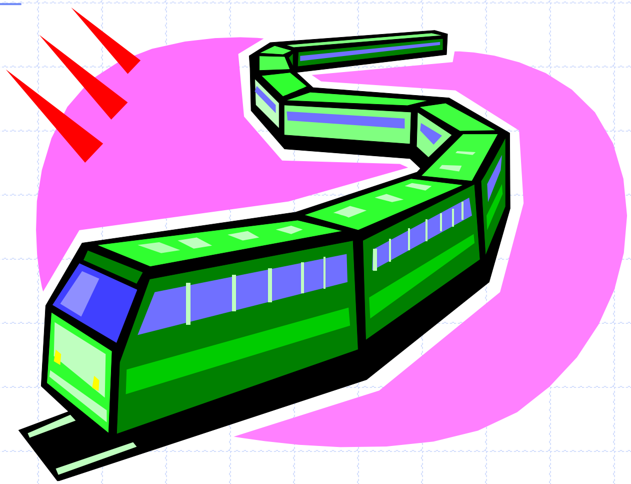
Lists

Section 6.2



Containers

- We call any data structure or ADT that stores any collection of elements a container.
- A container may contain elements in a sequence or an unordered collection, such as a set.
- However, it is assumed that the elements of a container can be arranged in some linear order.

Position ADT

- The Position ADT models the notion of the place within a container data structure where a single object is stored
- It gives a unified view of diverse ways of storing data, such as
  - a cell of an array
  - a node of a linked list
- Just one method:
  - object p.element(): returns the element at position
  - In C++ it is convenient to implement this as *p

Position ADT

- Positions are always defined with respect to their neighbors. Unless it is the first or last element in the container, a position q is always "after" some position p and "before" some position r. This is all relative to the linear ordering we assumed for the container.
- A position does not change if the element moves within the container, or if the element is swapped or replaced by another.
- A position is invalidated if the element it is associated with is explicitly removed.

Iterator ADT

- Extends the concept of position by adding a traversal capability
- An iterator abstracts the process of scanning through a collection of elements
- An iterator behaves like a pointer to an element
  - *p: returns the element referenced by this iterator
  - ++p: advances to the next element

Containers, refined

- We re(de)fine container to mean a data structure that stores a collection of elements and that supports element access through iterators
  - begin(): returns an iterator to the first element
  - end(): return an iterator to an imaginary position just after the last element
- Examples include Stack, Queue, Vector, List
- Various notions of iterator:
  - (standard) iterator: allows read-write access to elements
  - const iterator: provides read-only access to elements
  - bidirectional iterator: supports both ++p and --p
  - random-access iterator: supports both p+i and p-i

Iterating through a Container

- Let C be a container and p be an iterator for C

```
for (p = C.begin(); p != C.end(); ++p)
    loop_body
```

- Example: (with an STL vector V)

```
typedef vector<int>::iterator Iterator;
int sum = 0;
for (Iterator p = V.begin(); p != V.end(); ++p)
    sum += *p;
return sum;
```

Implementing Iterators

- Array-based
  - array A of the n elements
  - index i that keeps track of the cursor
  - begin() = 0
  - end() = n (index following the last element)
- Linked list-based
  - doubly-linked list L storing the elements, with sentinels for header and trailer
  - pointer to node containing the current element
  - begin() = front node
  - end() = trailer node (just after last node)

List ADT

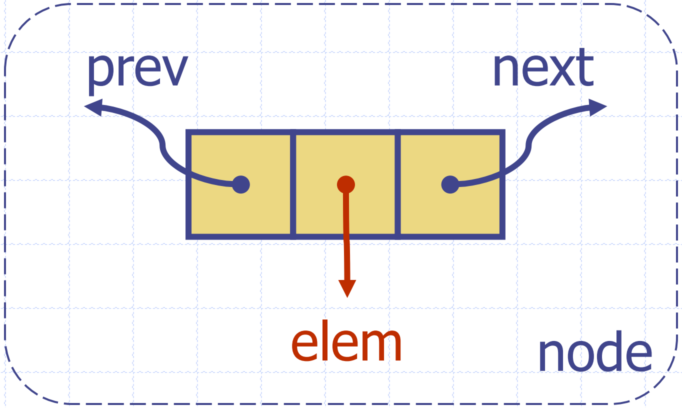
- The List ADT models a sequence of positions storing arbitrary objects
- It establishes a before/after relation between positions
- Generic methods:
  - size(), empty()
- Iterators:
  - begin(), end()
- Update methods:
  - insertFront(e), insertBack(e)
  - eraseFront(), eraseBack()
- Iterator-based update:
  - insert(p, e)
  - remove(p)

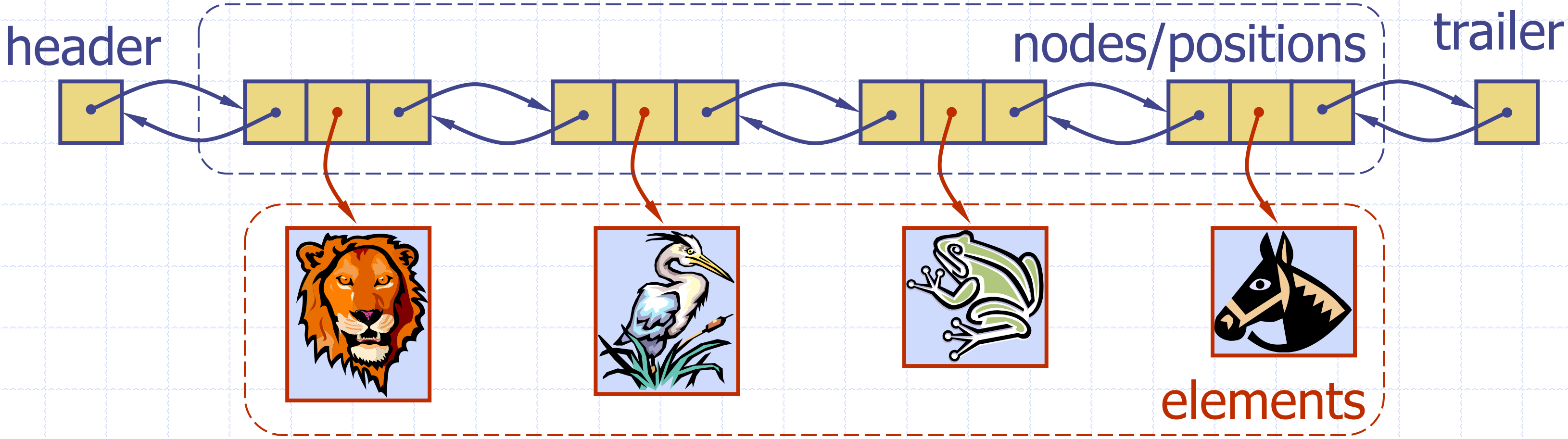
List ADT

- The update methods are for convenience. For example, insertFront(e) is short for insert(L.begin(), e).
- An error condition occurs if an invalid iterator is passed as an argument to an iterator-based update method.

Doubly Linked List Implementation

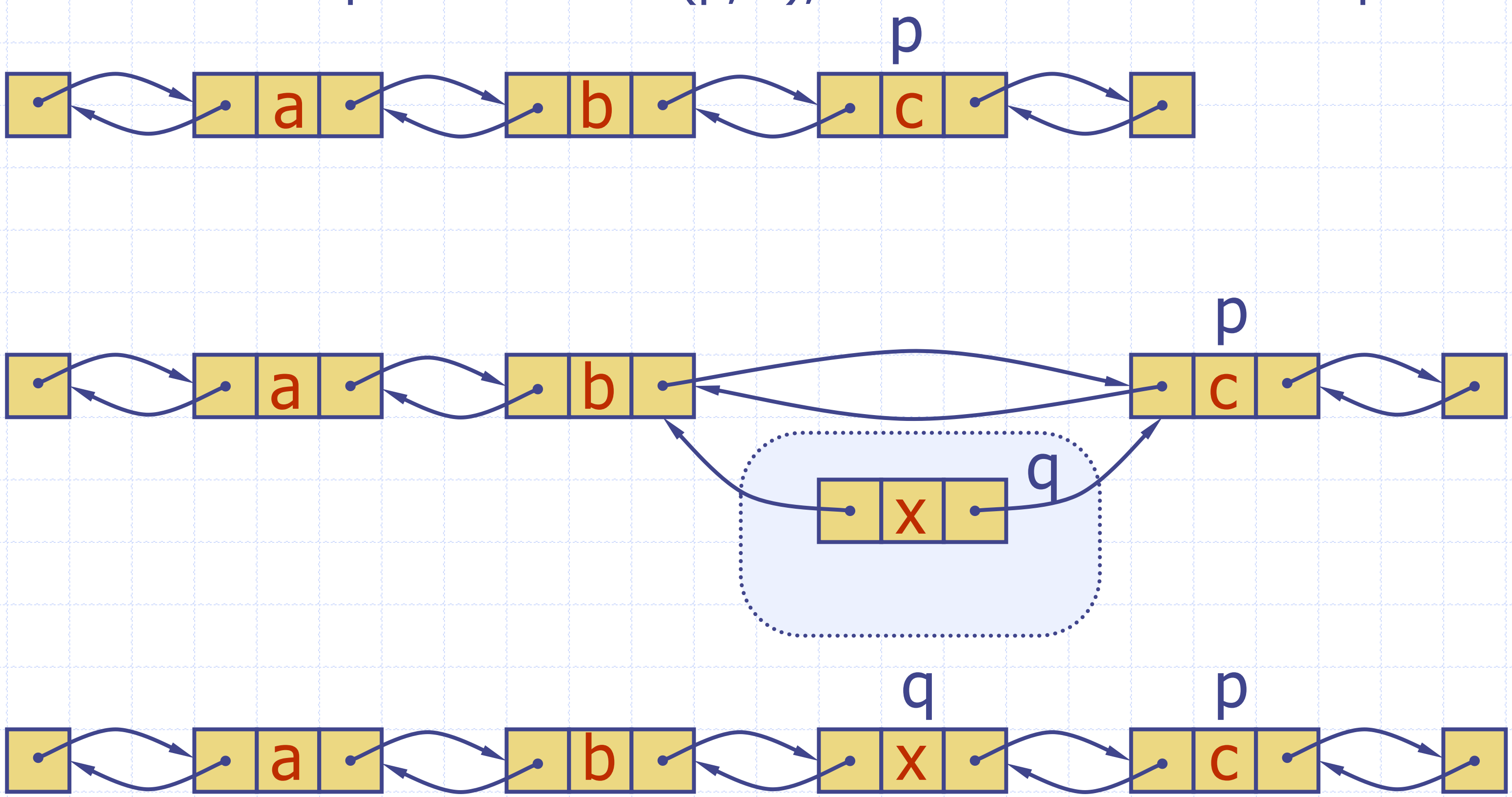
- A doubly linked list provides a natural implementation of the List ADT
- Nodes implement Iterator and store:
  - element
  - link to the previous node
  - link to the next node
- Special trailer and header nodes





Insertion

- We visualize operation insert(p, x), which inserts x before p



Insertion Algorithm

Algorithm insert(p, e): {insert e before p}

Create a new node v

v→element = e

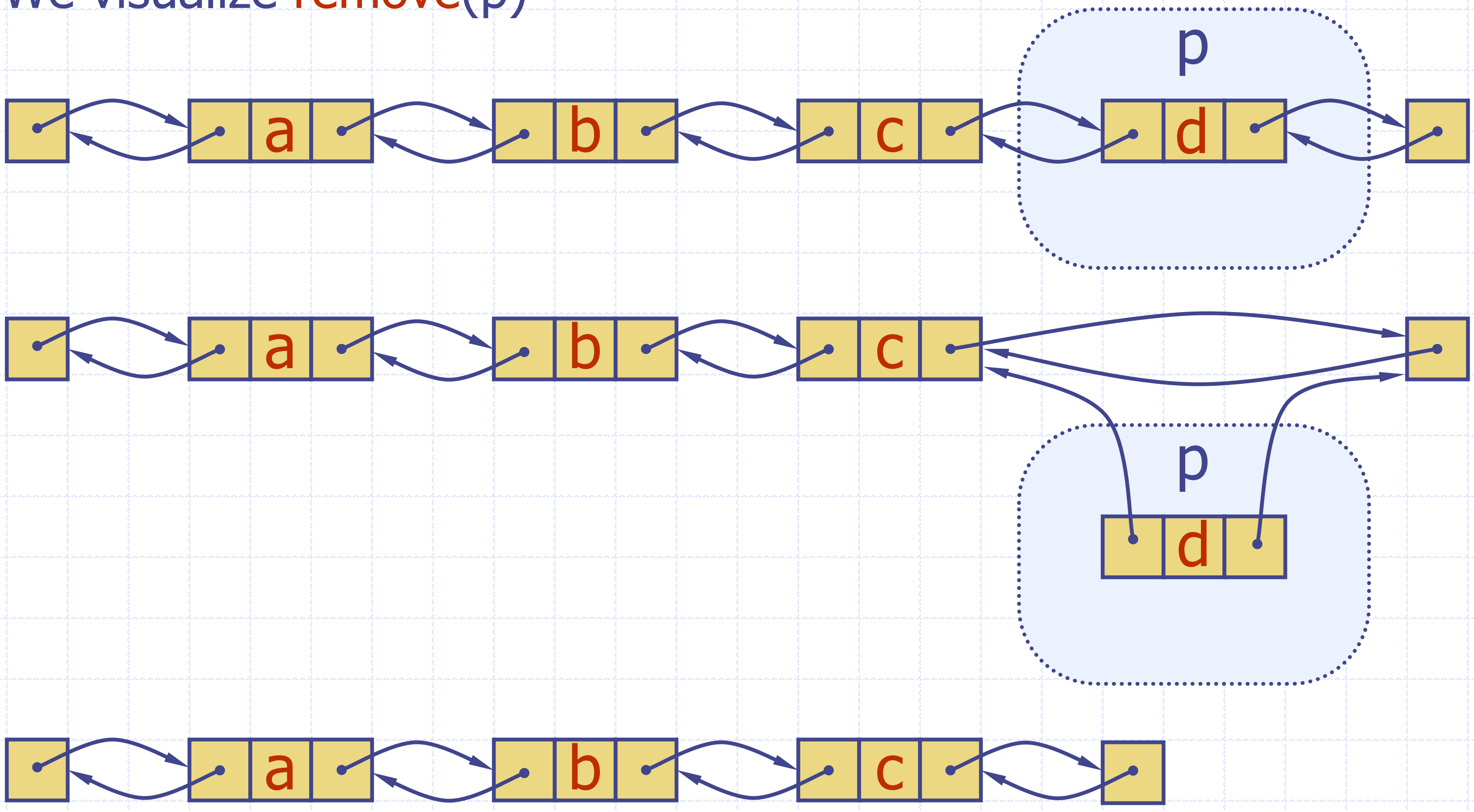
u = p→prev

v→next = p; p→prev = v {link in v before p}

v→prev = u; u→next = v {link in v after u}

Deletion

- We visualize remove(p)



Deletion Algorithm

Algorithm remove(p):

```
    u = p→prev
    w = p→next
    u→next = w {linking out p}
    w→prev = u
                {invalidate p}
```

TIMTOWTDI

- The text shows a doubly-linked list implementation where there are separate Node and Iterator classes.
- In this approach, the Node class remains simple:

```
class Node {
    Elem elem;
    Node* prev;
    Node* next;
};
```

TIMTOWTDI, continued

- The iterator class requires a number of its own functions, which would water down Node's interface if the two were combined.

```
class Iterator {
public:
    Elem& operator*();
    bool operator==(const Iterator& p) const;
    bool operator!=(const Iterator& p) const;
    Iterator& operator++();
    Iterator& operator—();
    friend class NodeList;
private:
    Node* v;
    Iterator(Node* v);
}
```

NodeList class

The NodeList class includes the Node class and the Iterator class as nested classes.

```
class NodeList {
private:
    // insert Node declaration here
public:
    // insert Iterator declaration here

    NodeList();
    int size() const;
    bool empty() const;
    Iterator begin() const;
    Iterator end() const;
    void insertFront(const Elem& e);
    void insertBack(const Elem& e);
    void insert(const Iterator& p,
        const Elem& e);
    void eraseFront();
    void eraseBack();
    void erase(const Iterator& p);
    // …
private:
    int n;
    Node* header;
    Node* trailer;
};
```

NodeList class

- The implementation of the Iterator must refer to the Iterator as NodeList::Iterator.

```
NodeList::Iterator::Iterator(Node* u)
    { v = u; }

Elem& NodeList::Iterator::operator*()
    { return v->elem; }

bool NodeList::Iterator::operator==(const Iterator& p) const
    { return v == p.v; }

NodeList::Iterator& NodeList::Iterator::operator++()
    { v = v->next; return *this}

// (operator!= and operator-- are similar)
```

Performance

- In the implementation of the List ADT by means of a doubly linked list
  - The space used by a list with n elements is $O(n)$
  - The space used by each position of the list is $O(1)$
  - All the operations of the List ADT run in $O(1)$ time
  - Operation element() of the Position ADT runs in $O(1)$ time