

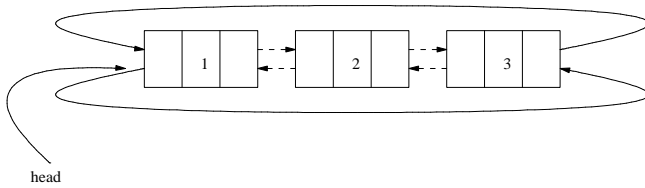
Double linked list implementation in C++

- recall our single list implementation earlier in the series
- many times in Computer Science we need to maintain dynamically adjustable lists
- consider if we had two lists and we had a number of elements on each
 - and your application needed to frequently move elements from one list to another and visa versa
- this could prove costly if implemented with a single linked list

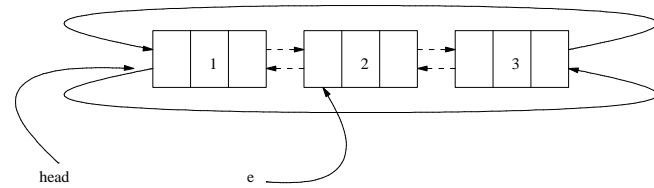
Double linked list implementation in C++

- especially if you know the element which needs to be removed
 - the single list implementation needs to always scan from the head down to the known element
 - there after it can remove it

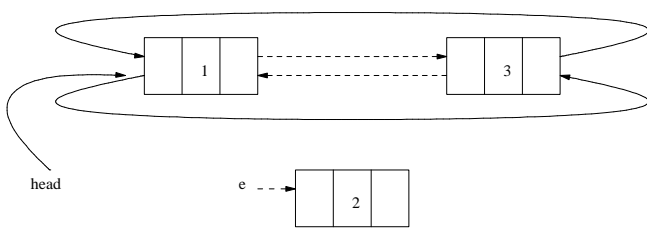
Double linked list data structure



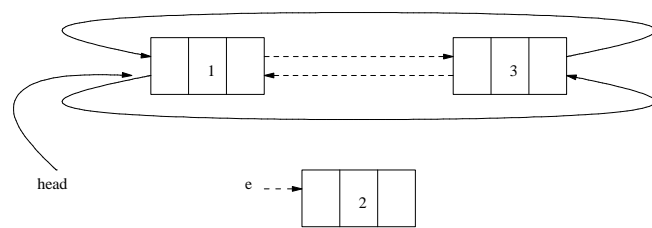
Removing an element



Removing an element



Pointer reminder



- which boxes are affected by the following operations?
 - `e->right = 100`
 - `head->right = 100`
 - `head->right->right = 100`
 - `head->left->right = 100`
 - `head->left->left = 100`

Advantages of double linked list

- we notice that we can remove an element without, knowing where on the list it resides
- can easily find the tail element (`head->left`)
- can easily add an element to the end without having to traverse chain using `next` as in our `slist` implementation

Disadvantages of double linked list

- slightly more complexity
- an additional pointer per element (`right` and `left` rather than `next`)
- slightly harder to write the code for list iteration as it is now circular
 - no easy `null` pointer to signify end of list

Definition of the class

c++/lists/double-list/int/v1/dlist.h

```

#ifndef DLISTH
#define DLISTH

#include <iostream>

class element
{
public:
    element *left;
    element *right;
    int data;
};

```

Definition of the class

c++/lists/double-list/int/v1/dlist.h

```

class dlist
{
private:
    element *head_element;
    element *duplicate_elements (element *e);
    void delete_elements (void);
    dlist cons (element *e);
    friend std::ostream& operator<< (std::ostream& os, const
public:
    dlist (void);
    ~dlist (void);
    dlist (const dlist &from);
    dlist& operator= (const dlist &from);

```

Definition of the class

c++/lists/double-list/int/v1/dlist.h

```

dlist empty (void);
bool is_empty (void);
dlist cons (int i);
int head (void);
dlist tail (void);
dlist cons (dlist l);
dlist reverse (void);
int length (void);

void add (element **head, element *e);
void delete_element (element *e);
element *sub (element *e);

```

Definition of the class

c++/lists/double-list/int/v1/dlist.h

```

dlist append (int i);
dlist cut (int low, int high);
dlist slice (int low, int high);
dlist ordered_insert (int i);
};
#endif

```

dlist constructor

c++/lists/double-list/int/v1/dlist.cc

```

/*
 * dlist - constructor, builds an empty list.
 *       pre-condition:  none.
 *       post-condition: list is created and is empty.
 */
dlist::dlist (void)
: head_element(0)
{
}

```

How do we remove an element from the list?

c++/lists/double-list/int/v1/dlist.cc

```

/*
 * sub - remove, e, from the list.
 *       Pre-condition : e is on the list.
 *       Post-condition: e is removed and returned.
 */
element *dlist::sub (element *e)
{
    if ((e->right == head_element) && (e == head_element))
        /*
         * e is the only element on the list.
         */
        head_element = 0;
    else

```

How do we remove an element from the list?

c++/lists/double-list/int/v1/dlist.cc

```

{
    if (head_element == e)
        /*
         * be prepared to move head_element on one element
         */
        head_element = head_element->right;

    /*
     * now unhook, e, from our double linked list
     */
    e->left->right = e->right;
    e->right->left = e->left;
}
return e;
}

```

Addition to the list

```

/*
 * add - add, e, to the end of list.
 *       pre-condition : e is not on a list.
 *       post-condition: e is appended to the end of the list.
 */
void dlist::add (element *e)
{
    if (head_element == 0)
        {
            head_element = e; // head is empty therefore make
            e->left = 0;      // e the only entry on this
            e->right = e;    // list.
        }
}

```

Addition to the list

```

else
{
    e->right = head_element; // add e to the end of list
    e->left = head_element->left; // copy the current left
    head_element->left->right = e; // add e to the end of list
    head_element->left = e; // alter the left of head element
}

```

- however we find in the `dlist` implementation we need to create new lists of elements which must not be referred to by `head_element`
 - for example `duplicate_elements`

add

```

c++/lists/double-list/int/v1/dlist.cc

/*
 * add - add, e, to the end of list, defined by (*head).
 * pre-condition : (*head) points to a list.
 * e is not on a list.
 * post-condition: e is appended to the end of list.
 */

void dlist::add (element **head, element *e)
{
    if (*head == 0)
    {
        *head = e; // head is empty therefore make
        e->left = e; // e the only entry on this
        e->right = e; // list.
    }
}

```

add

```

c++/lists/double-list/int/v1/dlist.cc

else
{
    e->right = *head; // add e to the end of list
    e->left = (*head)->left; // copy the current left
    (*head)->left->right = e; // add e to the end of list
    (*head)->left = e; // alter the left of head element
}

```

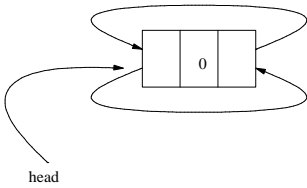
- (`*head`) can be thought of as `head_element`
 - `add` is implemented using (`*head`) so that other methods can build up lists independent of `head_element`

Observations

- notice that in both `add` and `sub` we need to test whether `head_element == 0`
- we could remove these conditional tests if we ensure we always have at least one element on the list
 - sentinel element (see D. Knuth, Fundamental Algorithms Volume 1, 2nd Edition, 1973, P.278)

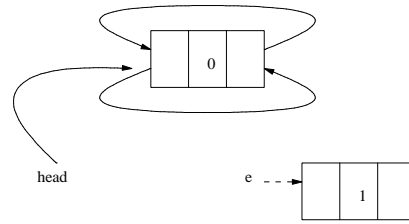
Double linked list with sentinel value

- constructed as



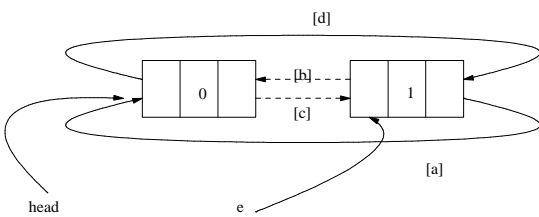
Adding to our initialised list

-



Adding to our initialised list

-



`++/lists/double-list/int/v2/dlist.cc`

```
[a] e->right = head; // add e to the end of list
[b] e->left = head->left; // copy the current end to e
[c] head->left->right = e; // add e to the end of the list
[d] head->left = e; // alter the left of head to point to e
```

Subtracting from our list

-

`++/lists/double-list/int/v2/dlist.cc`

```
/*
 * sub - remove, e, from the list.
 *       Pre-condition : e is on the list.
 *       Post-condition: e is removed and returned.
 */
element *dlist::sub (element *e)
{
    assert (! (head_element == e));
    assert (! ((e->right == head_element) && (e == head_element)));
    /*
     * now unhook, e, from our double linked list
     */
    e->left->right = e->right;
    e->right->left = e->left;
    return e;
}
```

Subtracting from our list

- notice that ignoring any asserts we no longer need to check whether `head_element == 0`

Performance gains

- this can be a large win in time critical code as we avoid cache misses
 - no branching necessary
- often used in microkernels and real-time systems
 - where we need to move a process from the running list to a blocked list
 - and visa-versa

Tutorial

- run the `sub` code by hand redrawing the diagram after each pointer change
- run the `add` code by hand redrawing the diagram after each pointer change

Tutorial

- examine the implementation of the method:


```
dlist::cons (element *e)
```

 - in file `c++/lists/double-list/int/v2/dlist.cc`
- draw two example lists of two element each
 - let one list exist in `this` and another defined by `e`
 - now execute the method by hand
 - redraw your diagram every time a pointer is changed

Tutorial

- implement the following methods:

Tutorial

- ```

/*
 * slice - return a copy of the list between low..high-1
 * pre-condition: an initialised non empty list
 * post-condition: the original list is unaltered
 * A new list is returned which
 * a copy of elements, low..high-1
 * Negative values of low and high
 * index from the right (aka Python)
 */
dlist dlist::slice (int low, int high);

```

**Tutorial**

- ```

/*
 * cut - return a region of the list.
 * pre-condition: an initialised non empty list.
 * post-condition: elements low..high are removed from
 * the original list.
 * A new list is returned which contains
 * the elements, low..high-1
 * Negative values of low and high
 * index from the right (aka Python)
 */
dlist dlist::cut (int low, int high);

```