

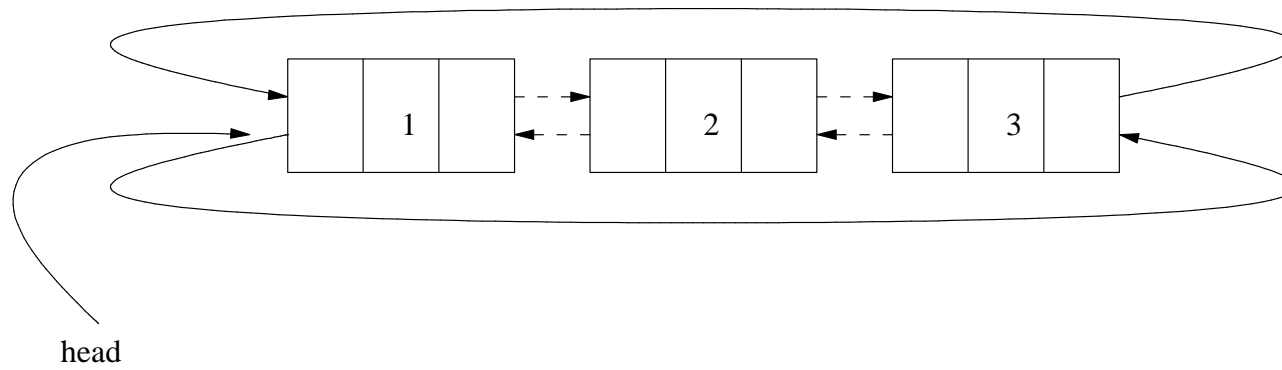
## Double linked list implementation in C++

- 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

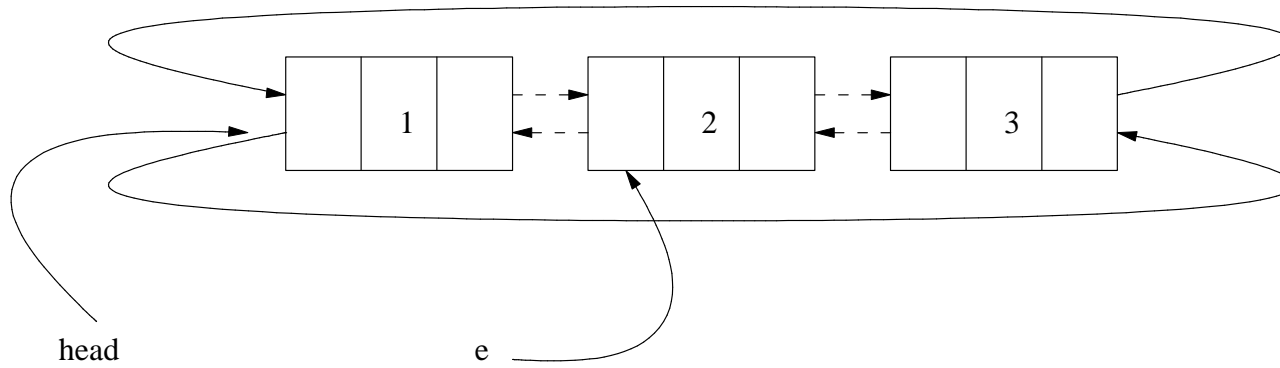
## Double linked list implementation in C++

- 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

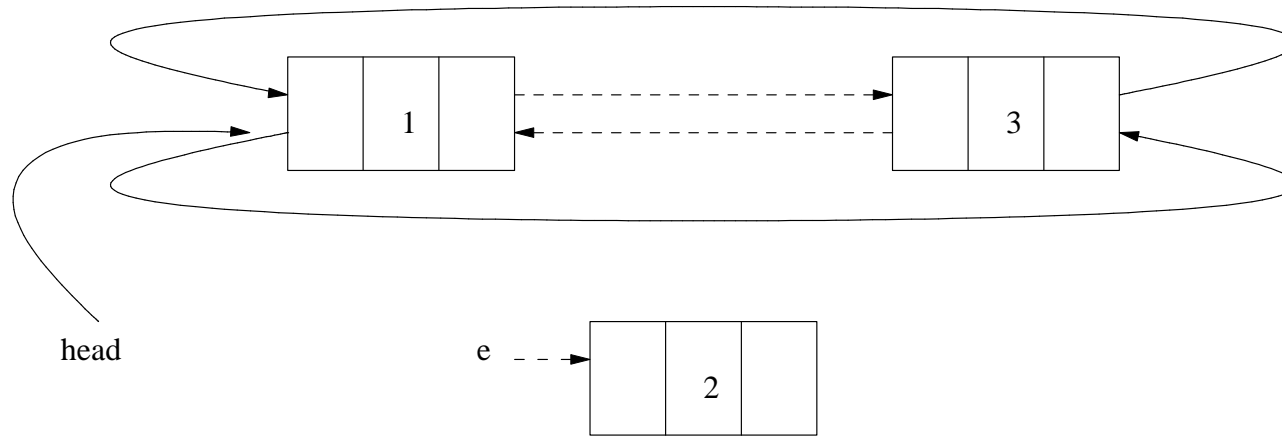
# Double linked list data structure



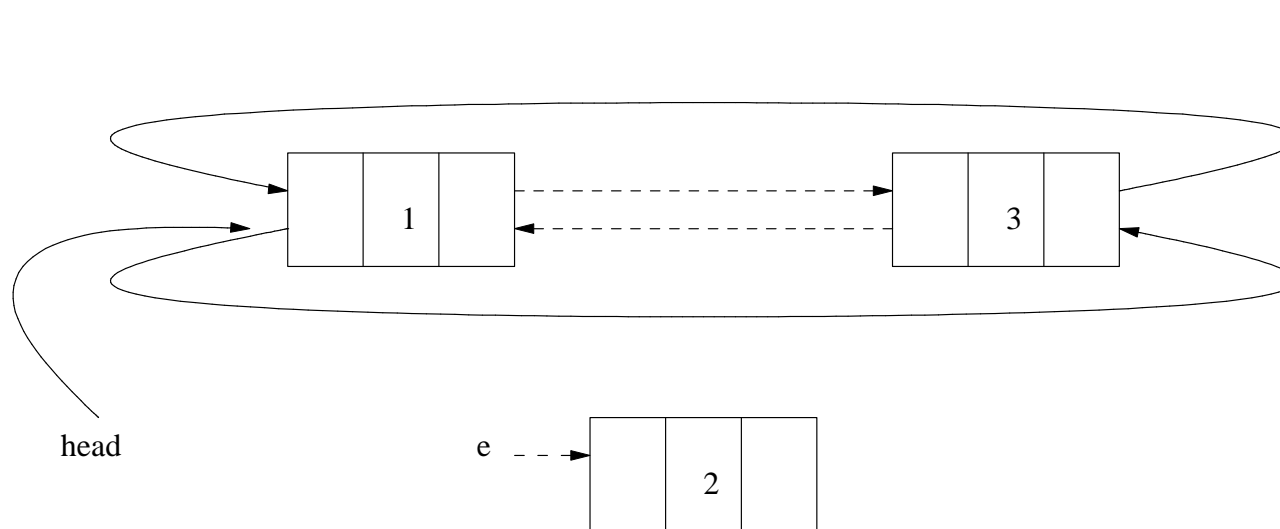
# Removing an element



# 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`

```
#if !defined(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 dlist& l);

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 = e;      // 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 end to e
    head_element->left->right = e; // add e to the end of the last
    head_element->left = e; // alter the left of head to point to e
}
}
```

- 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.
 *       post-condition: e is not on a list.
 *       post-condition: e is appended to the end of head.
 */

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 end to e
    (*head)->left->right = e; // add e to the end of the last
    (*head)->left = e; // alter the left of head to point to e
}
}
```

- `(*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`

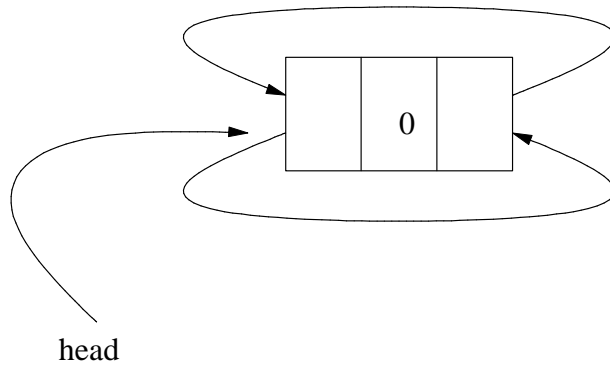
## Observations

- 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)

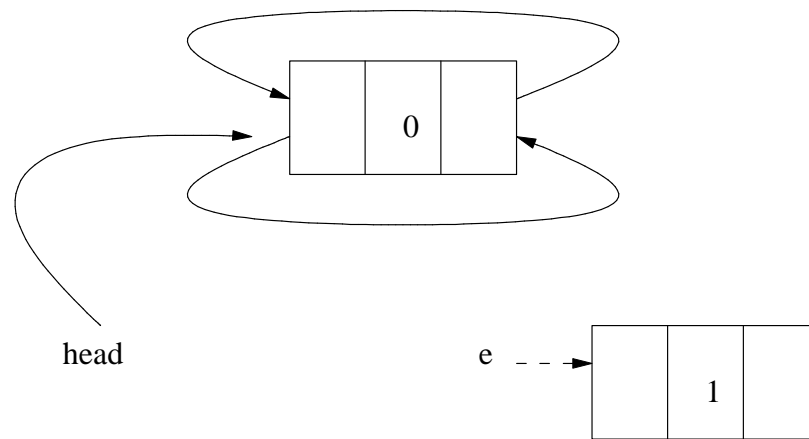
# Double linked list with sentinel value

- constructed as

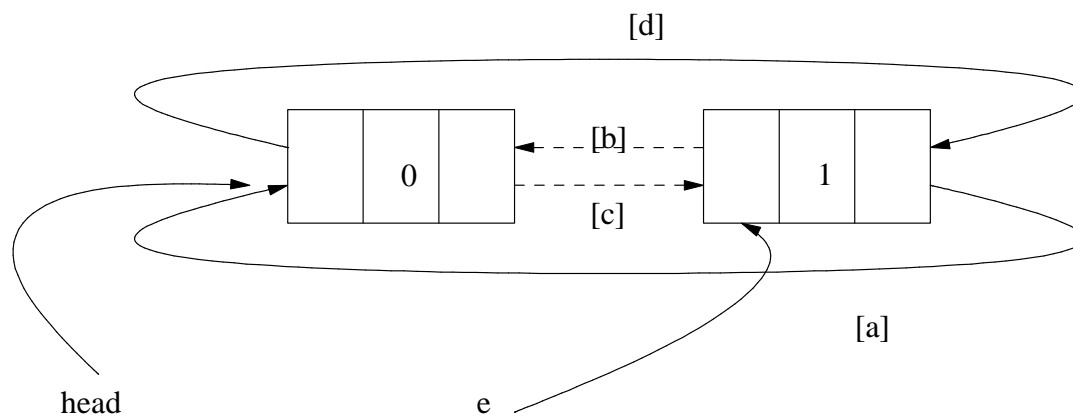
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# Adding to our initialised list



## Adding to our initialised list



`c++/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 last
[d] head->left = e; // alter the left of head to point to e
```



## Subtracting from our list

■ `c++/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 is  
 *       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);
```