ADT Specification

- The key idea is that we have not specified how the lists are to be implemented, merely their values and the operations of which they can be operands
- This ‘old’ idea of data abstraction is one of the key features of object-oriented programming
- C++ is a particular implementation of this object-oriented methodology

ADT Implementation

- Of course, we still have to implement this ADT specification
- The choice of implementation will depend on the requirements of the application

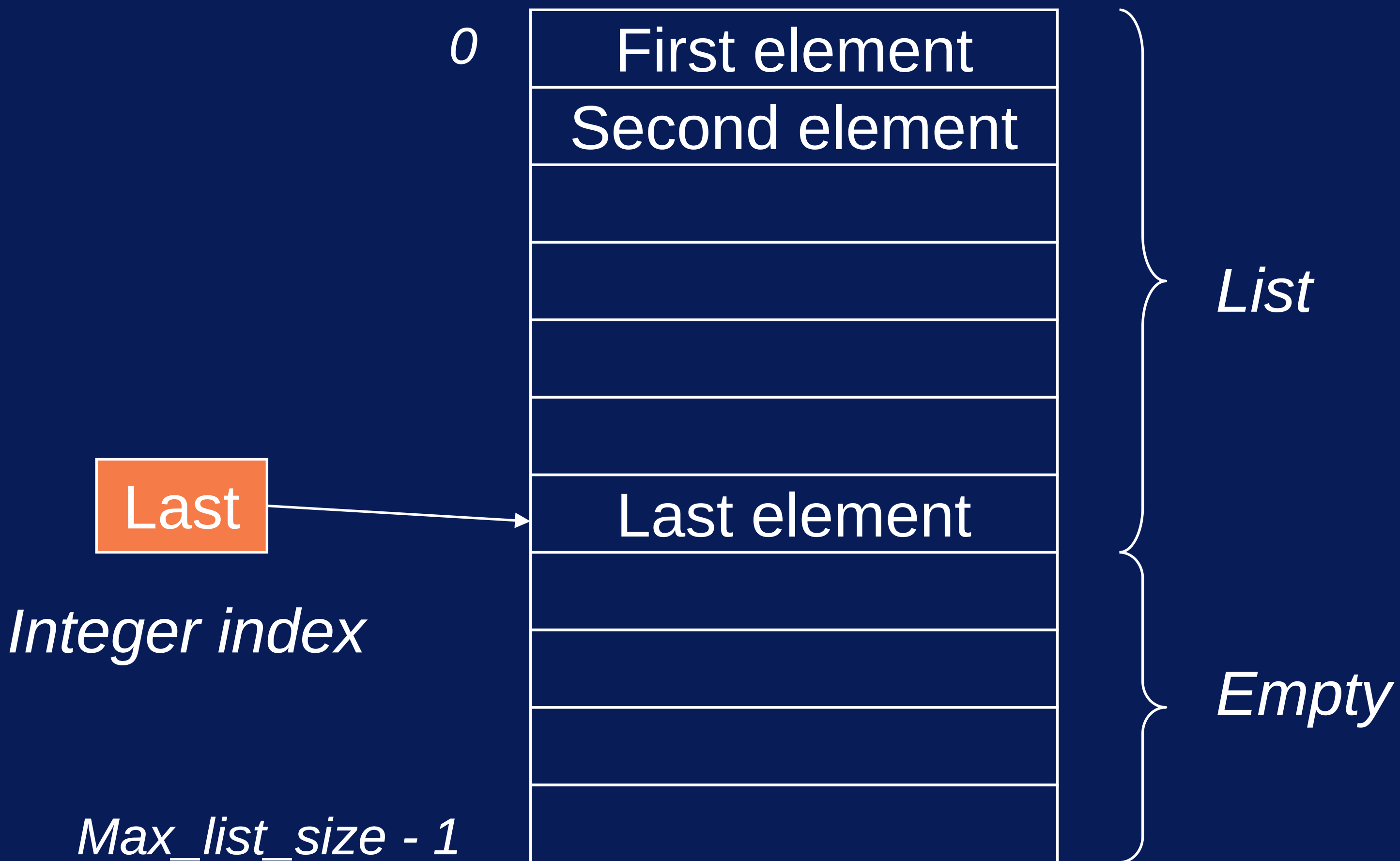
ADT Implementation

- We will look at two implementations
  - Array implementation
    - » uses a static data-structure
    - » reasonable if we know in advance the maximum number of elements in the list
  - Pointer implementation
    - » Also known as a linked-list implementation
    - » uses dynamic data-structure
    - » best if we don’t know in advance the number of elments in the list (or if it varies significantly)
    - » overhead in space: the pointer fields

LIST: Array Implementation

- We will do this in two steps:
  - *the implementation (or representation) of the four constituents datatypes of the ADT:*
    - » *list*
    - » *elementtype*
    - » *Boolean*
    - » *windowtype*
  - *the implementation of each of the ADT operations*

LIST: Array Implementation



LIST: Array Implementation

- type *elementtype*
- type LIST
- type Boolean
- type *windowtype*

LIST: Array Implementation

```
/* array implementation of LIST ADT */

#include <stdio.h>
#include <math.h>
#include <string.h>

#define MAX_LIST_SIZE 100
#define FALSE 0
#define TRUE 1

typedef struct {
           int number;
           char *string;
        } ELEMENT_TYPE;
```

LIST: Array Implementation

```
typedef struct {
           int last;
           ELEMENT_TYPE a[MAX_LIST_SIZE];
        } LIST_TYPE;

typedef int WINDOW_TYPE;

/** position following last element in a list ***/

WINDOW_TYPE end(LIST_TYPE *list) {
   return(list->last+1);
}
```

LIST: Array Implementation

```
/*** empty a list ***/

WINDOW_TYPE empty(LIST_TYPE *list) {
   list->last = -1;
   return(end(list));
}

/*** test to see if a list is empty ***/

int is_empty(LIST_TYPE *list) {
   if (list->last == -1)
      return(TRUE);
   else
      return(FALSE)
}
```

LIST: Array Implementation

```
/*** position at first element in a list ***/

WINDOW_TYPE first(LIST_TYPE *list) {
   if (is_empty(list) == FALSE) {
      return(0);
   else
      return(end(list));
}
```

LIST: Array Implementation

```
/*** position at next element in a list ***/

WINDOW_TYPE next(WINDOW_TYPE w, LIST_TYPE *list) {
   if (w == last(list)) {
      return(end(list));
   else if (w == end(list)) {
      error("can't find next after end of list");
   }
   else {
      return(w+1);
   }
}
```

LIST: Array Implementation

```
/*** position at previous element in a list ***/

WINDOW_TYPE previous(WINDOW_TYPE w, LIST_TYPE *list) {
   if (w != first(list)) {
      return(w-1);
   else {
      error(“can’t find previous before first element of
  list”);
      return(w);
   }
}
```

LIST: Array Implementation

```
/*** position at last element in a list ***/

WINDOW_TYPE last(LIST_TYPE *list) {
return(list->last);
}
```

LIST: Array Implementation

```
/*** insert an element in a list ***/

LIST_TYPE *insert(ELEMENT_TYPE e, WINDOW_TYPE w,
                  LIST_TYPE *list) {
   int i;
   if (list->last >= MAX_LIST_SIZE-1) {
      error(“Can’t insert - list is full”);
   }
   else if ((w > list->last + 1) ¦¦ (w < 0)) {
      error(“Position does not exist”);
   }
   else {
      /* insert it … shift all after w to the right */
```

LIST: Array Implementation

```
    for (i=list->last; i>= w; i--) {
       list->a[i+1] = list->a[i];
    }

    list->a[w] = e;
    list->last = list->last + 1;

    return(list);
  }
}
```

LIST: Array Implementation

```
/*** delete an element from a list ***/

LIST_TYPE *delete(WINDOW_TYPE w, LIST_TYPE *list) {
   int i;
   if ((w > list->last) ¦¦ (w < 0)) {
      error(“Position does not exist”);
   }
   else {
      /* delete it … shift all after w to the left */
      list->last = list->last - 1;
      for (i=w; i <= list->last; i++) {
         list->a[i] = list->a[i+1];
      }
      return(list);
}}
```

LIST: Array Implementation

```
/*** retrieve an element from a list ***/

ELEMENT_TYPE retrieve(WINDOW_TYPE w, LIST_TYPE *list) {
   if ( (w < 0)) ¦¦  (w > list->last)) {

      /* list is empty */

      error(“Position does not exist”);
   }
   else {
      return(list->a[w]);
   }
}
```

LIST: Array Implementation

```
/*** print all elements in a list ***/

int print(LIST_TYPE *list) {
   WINDOW_TYPE w;
   ELEMENT_TYPE e;
printf("Contents of list: \n");
   w = first(list);
   while (w != end(list)) {
      e = retrieve(w, list);
      printf("%d %s\n", e.number, e.string);
      w = next(w, list);
   }
   printf("---\n");
   return(0);
}
```

LIST: Array Implementation

```
/*** error handler: print message passed as argument and
     take appropriate action                            ***/
int error(char *s); {
   printf(“Error: %s\n”, s);
   exit(0);
}

/*** assign values to an element ***/

int assign_element_values(ELEMENT_TYPE *e, int number,
  char s[]) {
   e->string = (char *) malloc(sizeof(char)* strlen(s+1));
   strcpy(e->string, s);
   e->number = number;
}
```

LIST: Array Implementation

```
/*** main driver routine ***/

   WINDOW_TYPE w;
   ELEMEN_TYPE e;
   LIST_TYPE list;
   int i;

   empty(&list);
   print(&list);

   assign_element_values(&e, 1, “String A”);
   w = first(&list);
   insert(e, w, &list);
   print(&list);
```

LIST: Array Implementation

```
assign_element_values(&e, 2, “String B”);
insert(e, w, &list);
print(&list);

assign_element_values(&e, 3, “String C”);
insert(e, last(&list), &list);
print(&list);

assign_element_values(&e, 4, “String D”);
w = next(last(&list), &list);
insert(e, w, &list);
print(&list);
```

LIST: Array Implementation

```
    w = previous(w, &list);
    delete(w, &list);
    print(&list);

}
```

LIST: Array Implementation

- Key points:
  - *we have implemented all list manipulation operations with dedicated access functions*
  - *we never directly access the data-structure when using it but we always use the access functions*
  - *Why?*

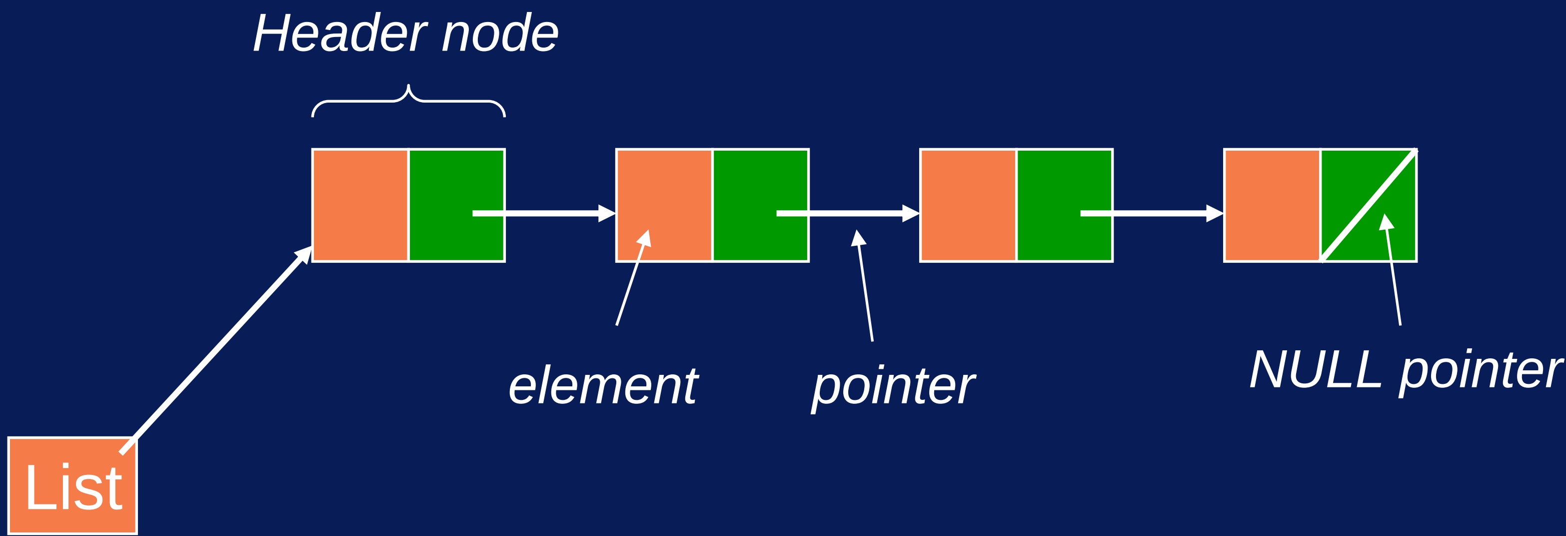
LIST: Array Implementation

- Key points:
  - *greater security: localized control and more resilient software maintenance*
  - *data hiding: the implementation of the data-structure is hidden from the user and so we can change the implementation and the user will never know*

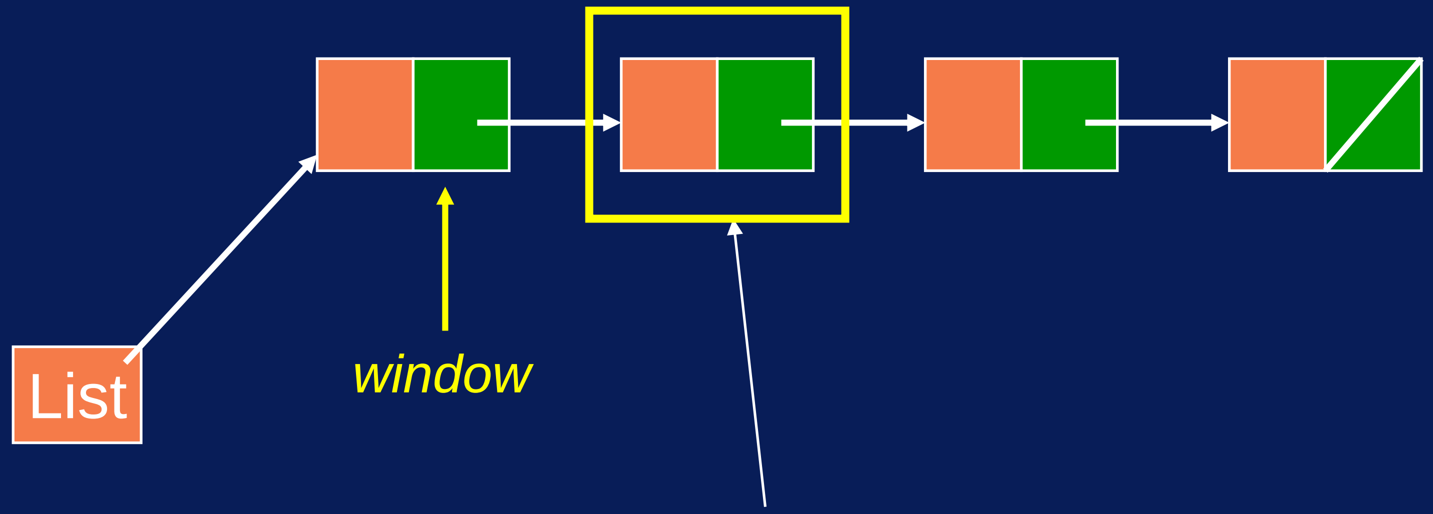
LIST: Array Implementation

- Possible problems with the implementation:
  - *have to shift elements when inserting and deleting (i.e. insert and delete are O(n))*
  - *have to specify the maximum size of the list at compile time*

LIST: Linked-List Implementation

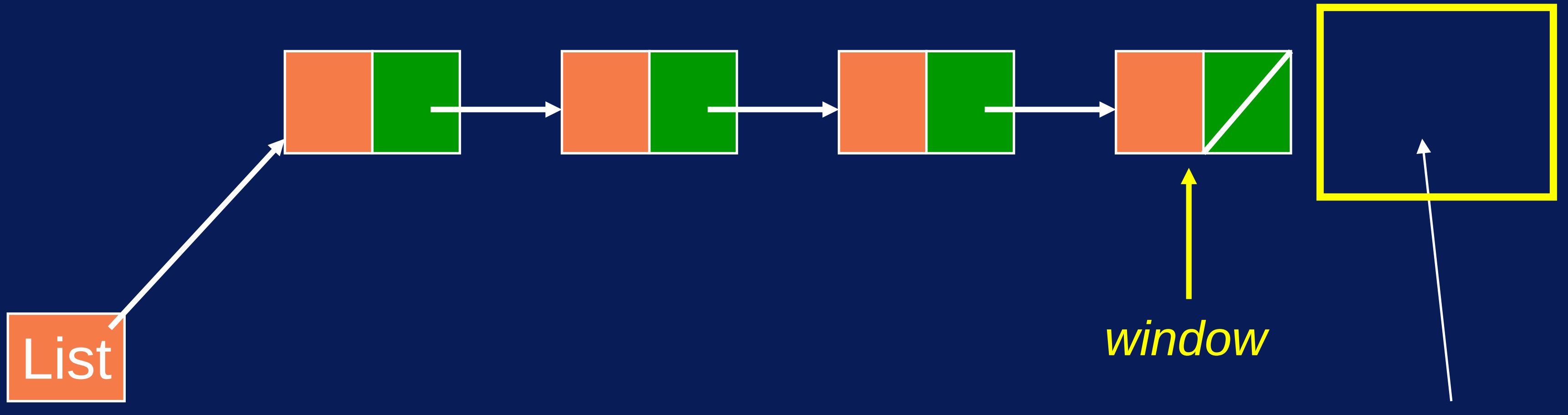


LIST: Linked-List Implementation



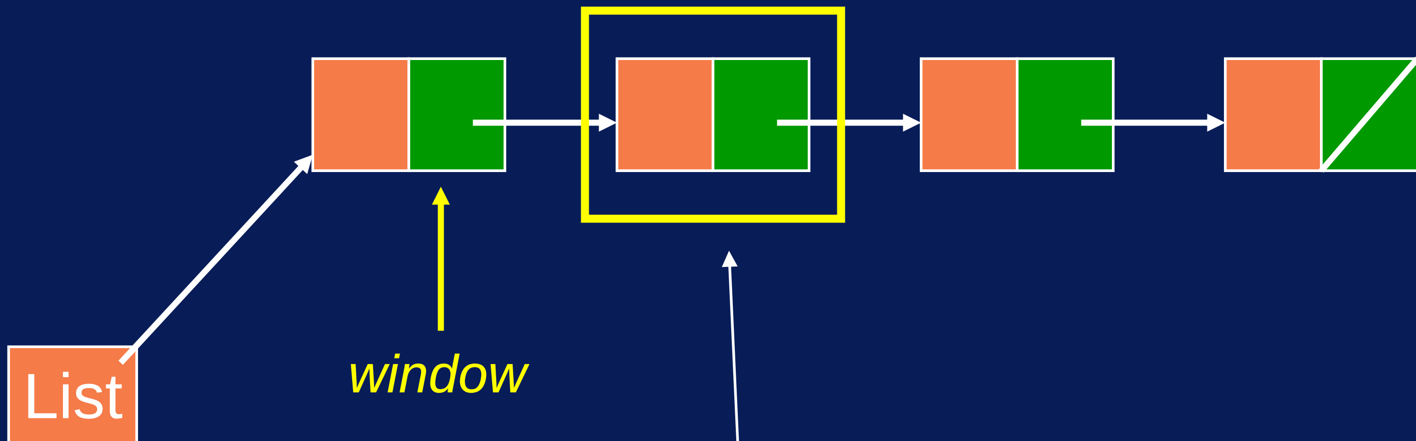
To place the window at this position
we provide a link to the previous node
(this is why we need a header node)

LIST: Linked-List Implementation



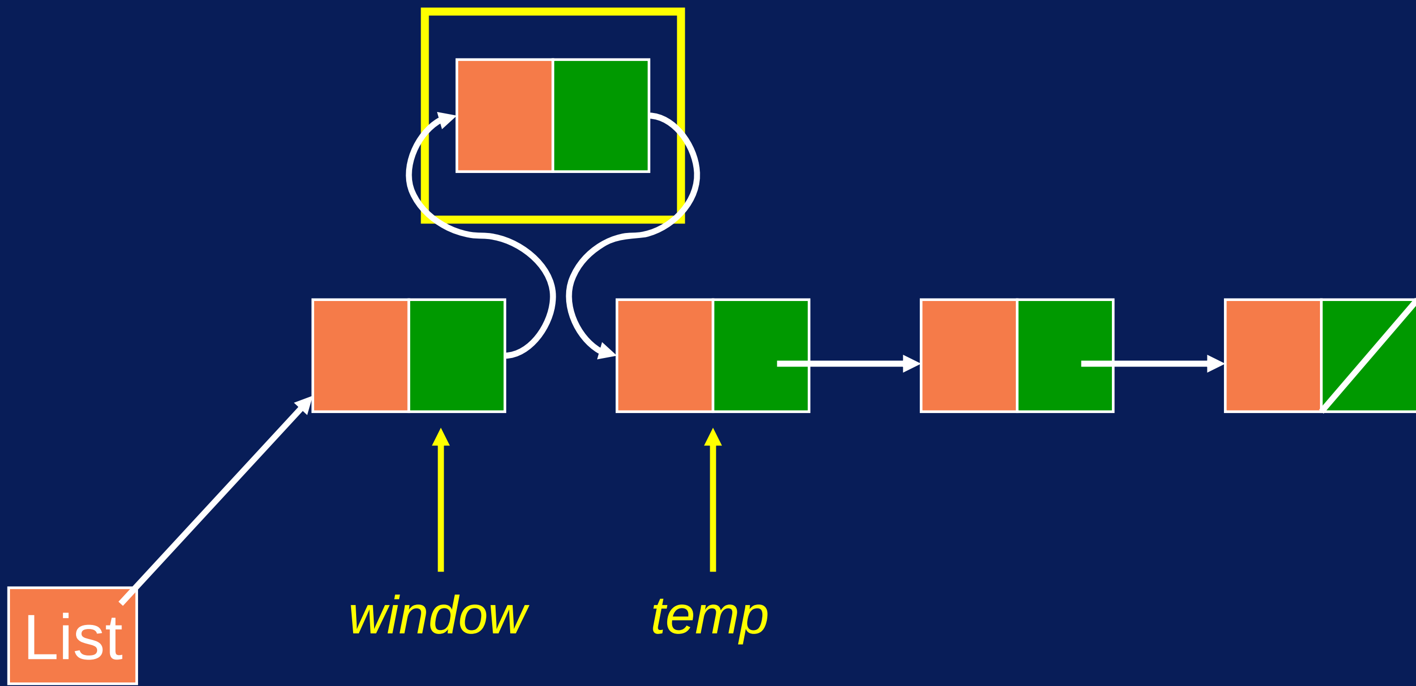
To place the window at end of the list
we provide a link to the last node

LIST: Linked-List Implementation



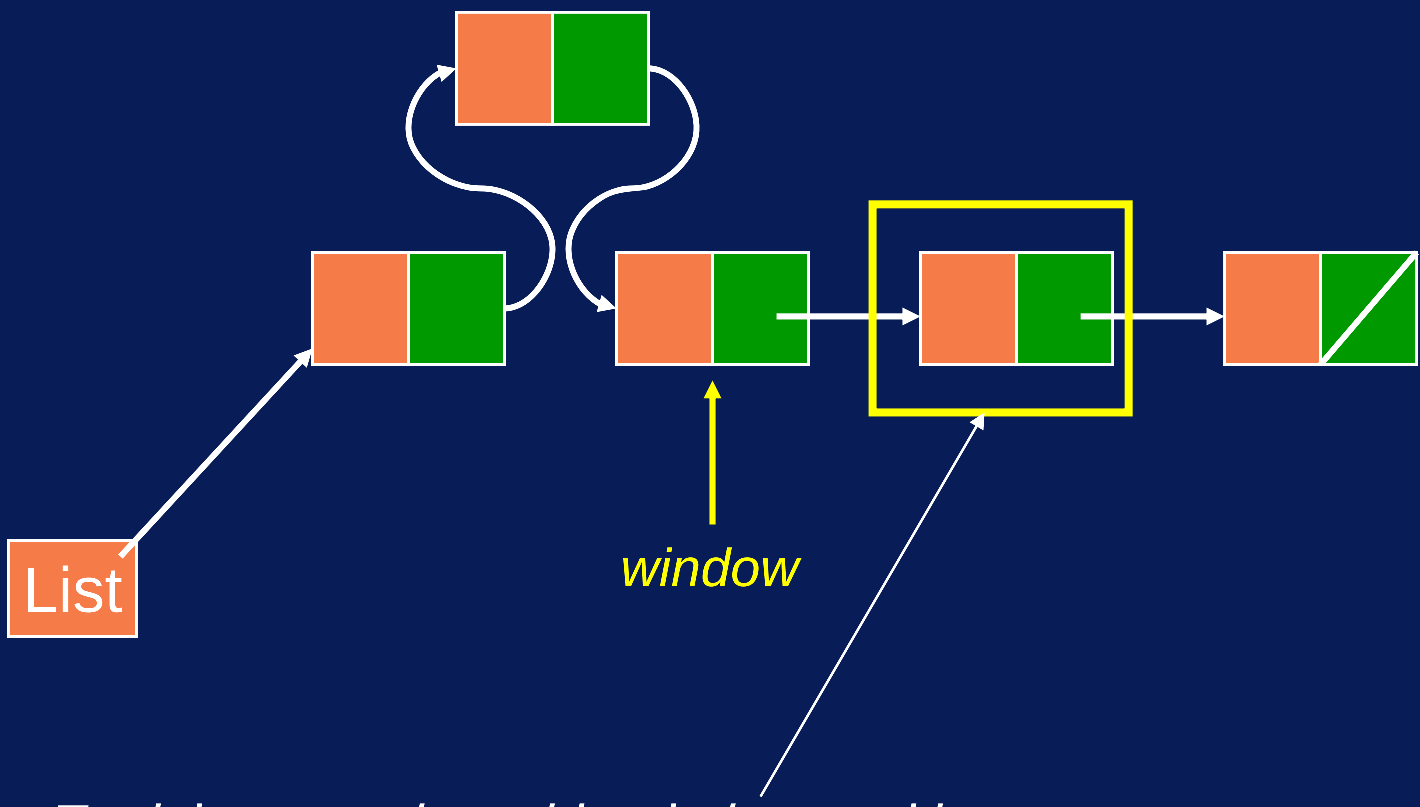
To insert a node at this window position
we create the node and re-arrange the links

LIST: Linked-List Implementation



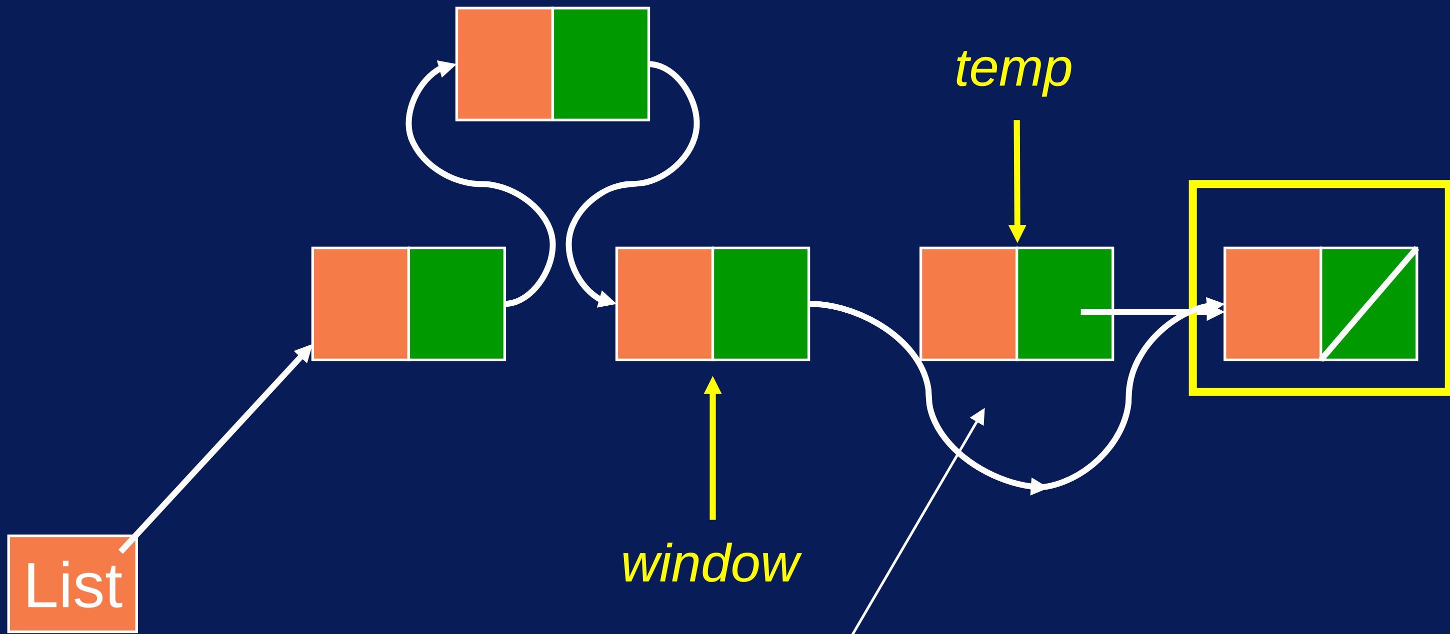
To insert a node at this window position
we create the node and re-arrange the links

LIST: Linked-List Implementation



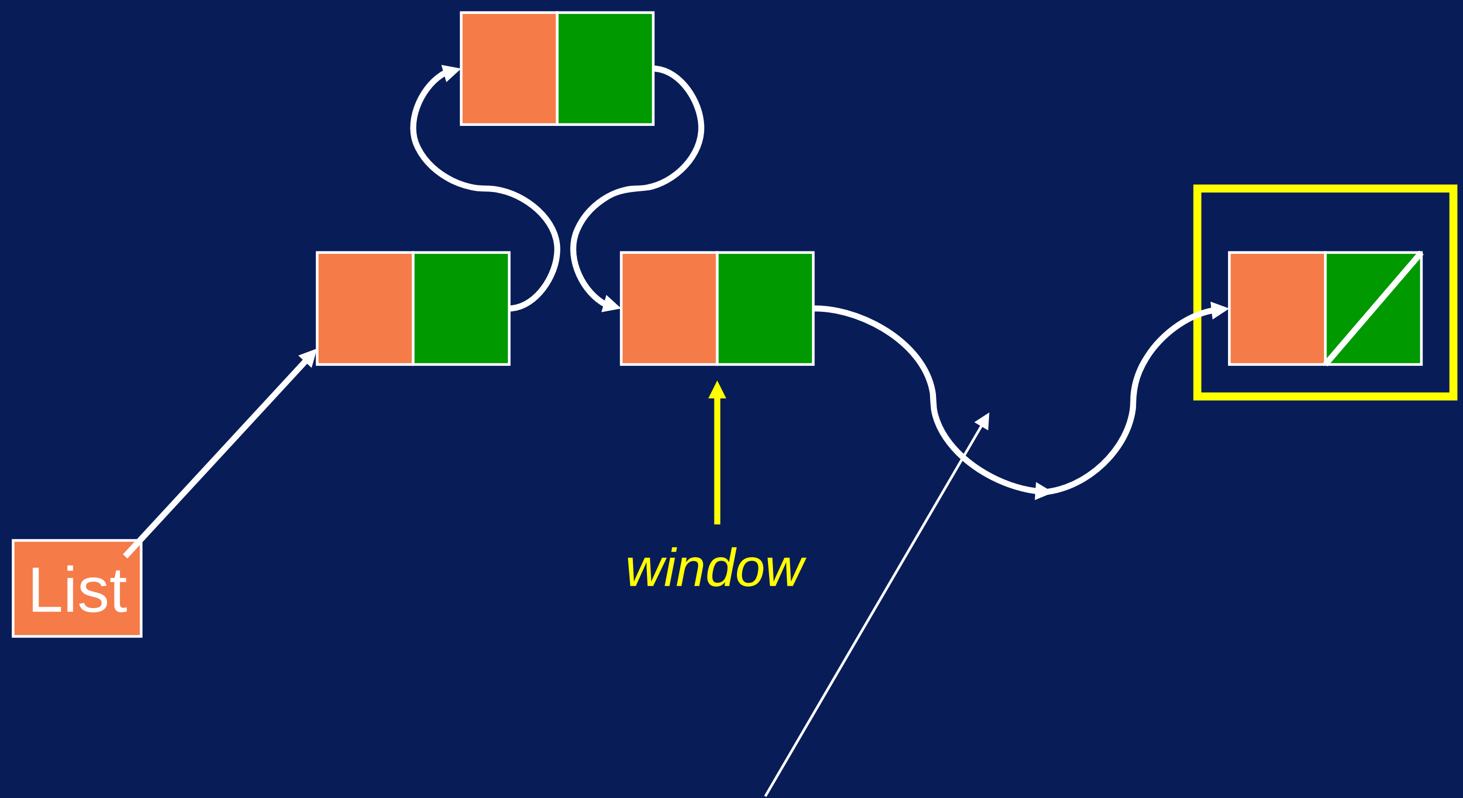
To delete a node at this window position
we re-arrange the links and free the node

LIST: Linked-List Implementation



To delete a node at this window position we re-arrange the links and free the node

LIST: Linked-List Implementation



To delete a node at this window position
we re-arrange the links and free the node

LIST: Linked-List Implementation

- type *elementtype*
- type *LIST*
- type *Boolean*
- type *windowtype*

LIST: Linked-List Implementation

```
/* linked-list implementation of LIST ADT */

#include <stdio.h>
#include <math.h>
#include <string.h>

#define FALSE 0
#define TRUE 1

typedef struct {
           int number;
           char *string;
        } ELEMENT_TYPE;
```

LIST: Linked-List Implementation

```
typedef struct node *NODE_TYPE;

typedef struct node{
           ELEMENT_TYPE element;
           NODE_TYPE next;
        } NODE;

typedef NODE_TYPE LIST_TYPE;
typedef NODE_TYPE WINDOW_TYPE;
```

LIST: Linked-List Implementation

```
/** position following last element in a list ***/

WINDOW_TYPE end(LIST_TYPE *list) {
   WINDOW_TYPE q;
   q = *list;
   if (q == NULL) {
      error(“non-existent list”);
   }
   else {
      while (q->next != NULL) {
         q = q->next;
      }
   }
   return(q);
}
```

LIST: Linked-List Implementation

```
/*** empty a list ***/

WINDOW_TYPE empty(LIST_TYPE *list) {
   WINDOW_TYPE p, q;
   if (*list != NULL) {
      /* list exists: delete all nodes including header */
      q = *list;
      while (q->next != NULL) {
         p = q;
         q = q->next;
         free(p);
      }
      free(q)
   }
   /* now, create a new empty one with a header node */
```

LIST: Linked-List Implementation

```
/* now, create a new empty one with a header node */

if ((q = (NODE_TYPE) malloc(sizeof(NODE))) == NULL)
   error("function empty: unable to allocate memory");
else {
   q->next = NULL;
   *list = q;
}
return(end(list));
}
```

LIST: Linked-List Implementation

```
/*** test to see if a list is empty ***/

int is_empty(LIST_TYPE *list) {
   WINDOW_TYPE q;
   q = *list;
   if (q == NULL) {
      error("non-existent list");
   }
   else {
      if (q->next == NULL) {
         return(TRUE);
      else
         return(FALSE);
   }
}
```

LIST: Linked-List Implementation

```
/*** position at first element in a list ***/

WINDOW_TYPE first(LIST_TYPE *list) {
   if (is_empty(list) == FALSE) {
      return(*list);
   else
      return(end(list));
}
```

LIST: Linked-List Implementation

```
/*** position at next element in a list ***/

WINDOW_TYPE next(WINDOW_TYPE w, LIST_TYPE *list) {
    if (w == last(list)) {
        return(end(list));
    }
    else if (w == end(list)) {
        error("can't find next after end of list");
    }
    else {
        return(w->next);
    }
}
```

LIST: Linked-List Implementation

```
/*** position at previous element in a list ***/

WINDOW_TYPE previous(WINDOW_TYPE w, LIST_TYPE *list) {
   WINDOW_TYPE p, q;
   if (w != first(list)) {
      p = first(list);
      while (p->next != w) {
         p = p->next;
         if (p == NULL) break; /* trap this to ensure   */
      }                        /* we don't dereference  */
      if (p != NULL)           /* a null pointer in the */
         return(p);            /* while condition       */
```

LIST: Linked-List Implementation

```
        else {
            error("can't find previous to a non-existent node");
        }
    }
    else {
        error("can't find previous before first element of list");
        return(w);
    }
}
```

LIST: Linked-List Implementation

```
/*** position at last element in a list ***/

WINDOW_TYPE last(LIST_TYPE *list) {
   WINDOW_TYPE p, q;
   if (*list == NULL) {
      error(“non-existent list”);
   }
   else {
      /* list exists: find last node */
```

LIST: Linked-List Implementation

```
    /* list exists: find last node */

    if (is_empty(list)) {
       p = end(list);
    }
    else {
       p = *list;
       q = p=>next;
       while (q->next != NULL) {
          p = q;
          q = q->next;
       }
    }
    return(p);
}  }
```

LIST: Linked-List Implementation

```
/*** insert an element in a list ***/

LIST_TYPE *insert(ELEMENT_TYPE e, WINDOW_TYPE w,
                  LIST_TYPE *list) {
   WINDOW_TYPE temp;
   if (*list == NULL) {
      error(“cannot insert in a non-existent list”);
   }
```

LIST: Linked-List Implementation

```
 else {
    /* insert it after w */
    temp = w->next;
    if ((w->next = (NODE_TYPE) malloc(sizeof(NODE))) =
NULL)
       error(“function insert: unable to allocate
memory”);
    else {
       w->next->element = e;
       w->next->next = temp;
    }
    return(list);
 }
}
```

LIST: Linked-List Implementation

```
/*** delete an element from a list ***/

LIST_TYPE *delete(WINDOW_TYPE w, LIST_TYPE *list) {
   WINDOW_TYPE p;
   if (*list == NULL) {
      error(“cannot delete from a non-existent list”);
   }
   else {
      p = w->next; /* node to be deleted */
      w->next = w->next->next;  /* rearrange the links */
      free(p);     /* delete the node */
      return(list);
   }
}
```

LIST: Linked-List Implementation

```
/*** retrieve an element from a list ***/

ELEMENT_TYPE retrieve(WINDOW_TYPE w, LIST_TYPE *list) {
   WINDOW_TYPE p;

   if (*list == NULL) {
      error("cannot retrieve from a non-existent list");
   }
   else {
      return(w->next->element);
   }
}
```

LIST: Linked-List Implementation

```
/*** print all elements in a list ***/

int print(LIST_TYPE *list) {
   WINDOW_TYPE w;
   ELEMENT_TYPE e;

   printf(“Contents of list: \n”);
   w = first(list);
   while (w != end(list)) {
      printf(“%d %s\n”, e.number, e.string);
      w = next(w, list);
   }
   printf(“---\n”);
   return(0);
}
```

LIST: Linked-List Implementation

```
/*** error handler: print message passed as argument and
     take appropriate action                           ***/
int error(char *s); {
    printf(“Error: %s\n”, s);
    exit(0);
}

/*** assign values to an element ***/

int assign_element_values(ELEMENT_TYPE *e, int number,
   char s[]) {
    e->string = (char *) malloc(sizeof(char) * strlen(s));
    strcpy(e->string, s);
    e->number = number;
}
```

LIST: Linked-List Implementation

```
/*** main driver routine ***/

   WINDOW_TYPE w;
   ELEMEN_TYPE e;
   LIST_TYPE list;
   int i;

   empty(&list);
   print(&list);

   assign_element_values(&e, 1, “String A”);
   w = first(&list);
   insert(e, w, &list);
   print(&list);
```

LIST: Linked-List Implementation

```
assign_element_values(&e, 2, “String B”);
insert(e, w, &list);
print(&list);

assign_element_values(&e, 3, “String C”);
insert(e, last(&list), &list);
print(&list);

assign_element_values(&e, 4, “String D”);
w = next(last(&list), &list);
insert(e, w, &list);
print(&list);
```

LIST: Linked-List Implementation

```
    w = previous(w, &list);
    delete(w, &list);
    print(&list);

}
```

LIST: Linked-List Implementation

- Key points:
  - *All we changed was the implementation of the data-structure and the access routines*
  - *But by keeping the interface to the access routines the same as before, these changes are transparent to the user*
  - *And we didn't have to make any changes in the main function which was actually manipulating the list*

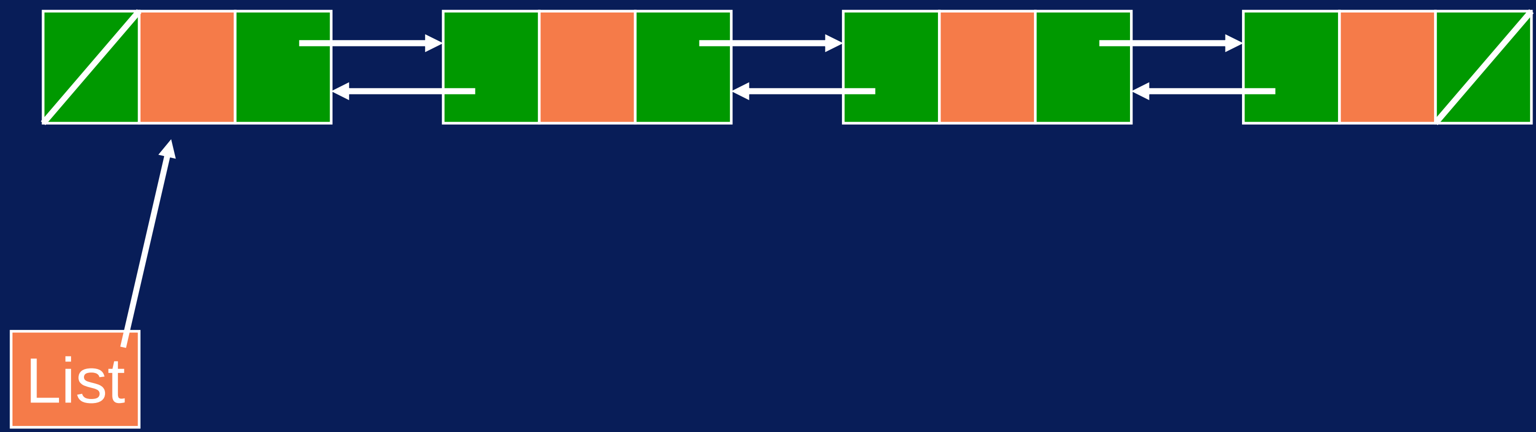
LIST: Linked-List Implementation

- Key points:
  - *In a real software system where perhaps hundreds (or thousands) of people are using these list primitives, this transparency is critical*
  - *We couldn’t have achieved it if we manipulated the data-structure directly*

LIST: Linked-List Implementation

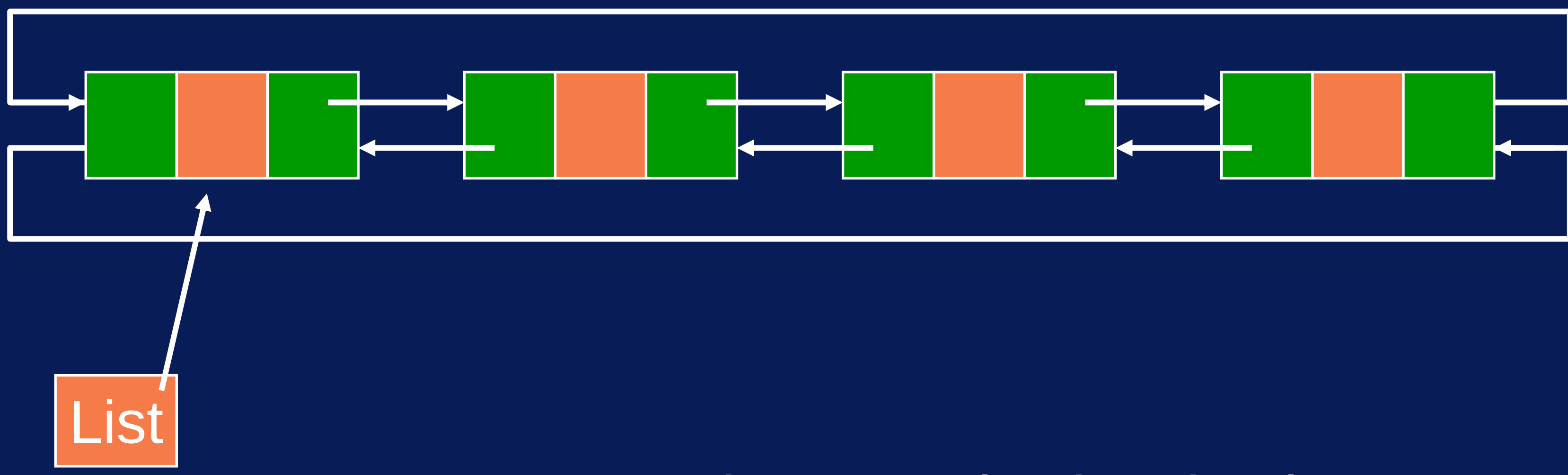
- Possible problems with the implementation:
  - *we have to run the length of the list in order to find the end (i.e. end(L) is O(n))*
  - *there is a (small) overhead in using the pointers*
- *On the other hand, the list can now grow as large as necessary, without having to predefine the maximum size*

LIST: Linked-List Implementation



We can also have a doubly-linked list;
this removes the need to have a header node
and make finding the previous node more efficient

LIST: Linked-List Implementation



Lists can also be circular