COMP 2012H Honors Object-Oriented Programming and Data Structures

Topic 9: Linked List

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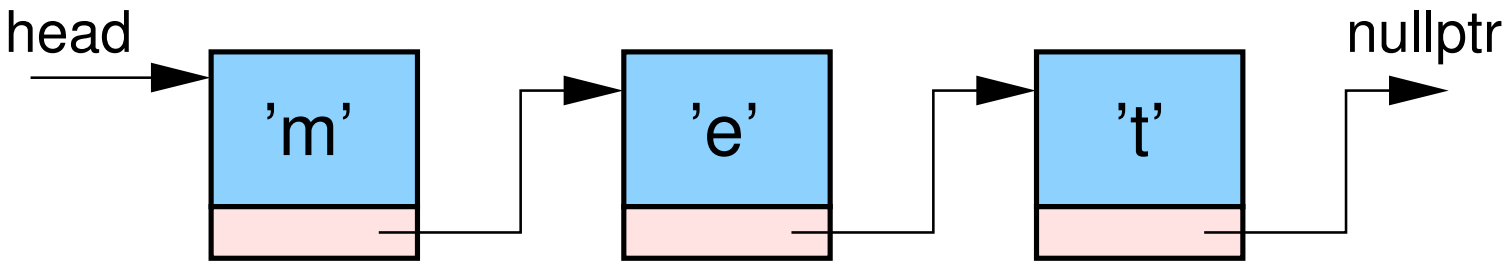
What is a Linked List?

- A *list* is a linear sequence of objects.
- You may implement a list by an array. e.g. `int x[5];`
  - Advantage: array is an efficient data structure that works well with loops and recursion.
  - Disadvantage: size of the array is determined in advance.
- A linked list links objects together by pointers so that each object is pointing to the next object in the sequence (list).
  - Advantage: It is dynamic; it grows and shrinks to any size as you want at runtime.
  - Disadvantage:
    - ★ requires additional memory for the linking pointers
    - ★ takes more time to manipulate its items



A Typical C++ Linked List Definition

- Each object in a linked list is usually called a "node".
- The typical C++ definition for a node in a linked list is a struct (or later class):

```
struct ll_node
{
    <type> data;   // contains useful information
    ll_node* next; // the link to the next node
};
```

- The first and the last node of a linked list always need special attention.
- For the last node, its next pointer is set to nullptr to tell that it is the end of the linked list.
- We need a pointer variable, usually called head to point to the first node.
- Once you get the head of the linked list, you get the whole list!

Basic Operations of a Linked List

```
/* To create a node */
ll_node* p = new ll_node;

/* To access/modify the data in a node */
cout << p->data;
cout << (*p).data;

cin >> p->data;
p->next = nullptr;

/* To set up the head of a linked list */
ll_node* head = nullptr; // An empty linked list
head = p;                // head points to the node that p points to

/* To delete a node */
delete p;                // Dangling pointer
p = nullptr;             // Reset the pointer for safety reason
```

Example: Create the LL-String "met"

```
#include "ll_cnode.h"   /* File: ll_main.cpp */

int main()  // Create the LL-string "met"
{   // Create each of the 3 ll_cnodes
    ll_cnode* mp = new ll_cnode; mp->data = 'm';
    ll_cnode* ep = new ll_cnode; ep->data = 'e';
    ll_cnode* tp = new ll_cnode; tp->data = 't';

    // Hook them up in the required order to create the LL
    mp->next = ep;
    ep->next = tp;
    tp->next = nullptr;

    // Traverse the LL and print out the data sequentially
    for (ll_cnode* p = mp; p; p = p->next)
        cout << p->data;
    cout << endl;

    // Clean up
    delete mp; delete ep; delete tp; return 0;
}
```

Common Operations on a Linked List

- Common operations:
  - Create a new linked list.
  - Search data in the list.
  - Delete a node in the list.
  - Insert a new node in the list.
- For all these operations, again special attention is usually needed when the operation involves the first or the last node.

Example: LL-String — ll_cnode.h

Let's use a linked list (instead of an array) of characters to represent a string.

```
#include <iostream> /* File: ll_cnode.h */
using namespace std;

struct ll_cnode
{
    char data;          // Contains useful information
    ll_cnode* next;     // The link to the next node
};

const char NULL_CHAR = '\0';
ll_cnode* ll_create(char);
ll_cnode* ll_create(const char []);
int ll_length(const ll_cnode*);
void ll_print(const ll_cnode*);
ll_cnode* ll_search(ll_cnode*, char c);
void ll_insert(ll_cnode*&, char, unsigned);
void ll_delete(ll_cnode*&, char);
void ll_delete_all(ll_cnode*&);
```

Example: LL-String — ll_create.cpp

```
#include "ll_cnode.h"   /* File: ll_create.cpp */
// Create a ll_cnode and initialize its data
ll_cnode* ll_create(char c)
{
    ll_cnode* p = new ll_cnode; p->data = c; p->next = nullptr; return p;
}

// Create a linked list of ll_cnodes with the contents of a char array
ll_cnode* ll_create(const char s[])
{
    if (s[0] == NULL_CHAR) // Empty linked list due to empty C string
        return nullptr;

    ll_cnode* head = ll_create(s[0]); // Special case with the head

    ll_cnode* p = head; // p is the working pointer
    for (int j = 1; s[j] != NULL_CHAR; ++j)
    {
        p->next = ll_create(s[j]); // Link current cnode to the new cnode
        p = p->next; // p now points to the new ll_cnode
    }

    return head; // The WHOLE linked list can be accessed from the head
}
```

Example: LL-String — ll_length.cpp, ll_print.cpp

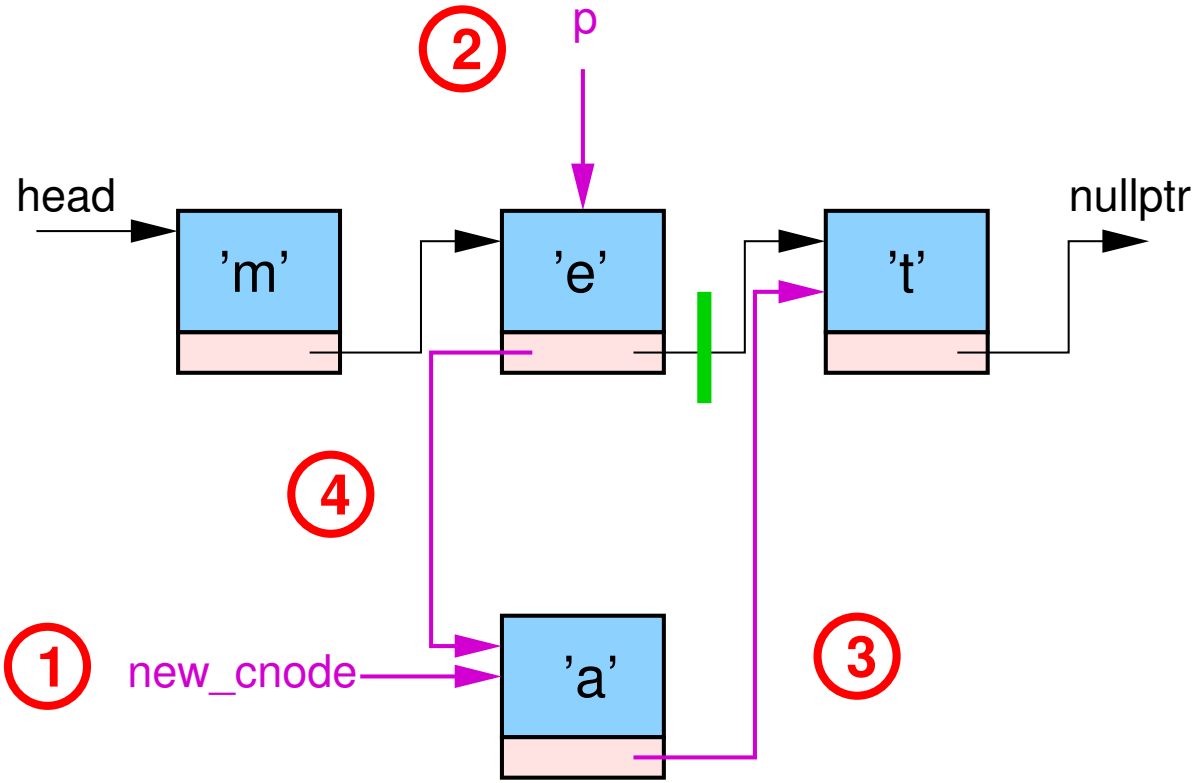
```
#include "ll_cnode.h" /* File: ll_length.cpp */

int ll_length(const ll_cnode* head)
{
    int length = 0;
    for (const ll_cnode* p = head; p != nullptr; p = p->next)
        ++length;
    return length;
}
```

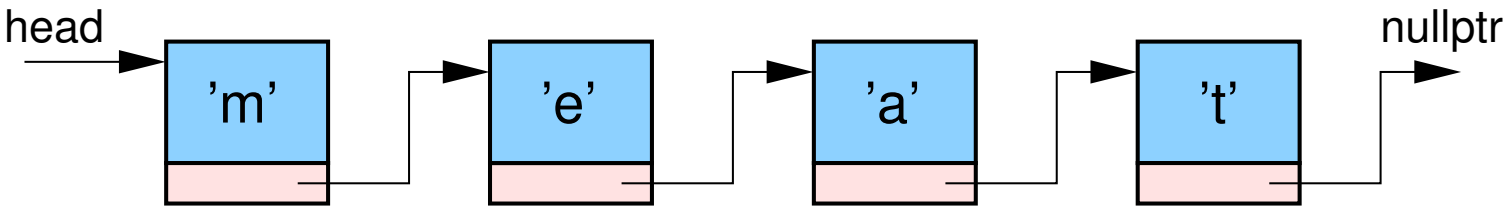
```
#include "ll_cnode.h"   /* File: ll_print.cpp */

void ll_print(const ll_cnode* head)
{
    for (const ll_cnode* p = head; p != nullptr; p = p->next)
        cout << p->data;
    cout << endl;
}
```

Example: LL-String — ll_search.cpp

```
#include "ll_cnode.h"   /* File: ll_search.cpp */

// The returned pointer may be used to change the content
// of the found ll_cnode. Therefore, the return type
// should not be const ll_cnode*.

ll_cnode* ll_search(ll_cnode* head, char c)
{
    for (ll_cnode* p = head; p != nullptr; p = p->next)
    {
        if (p->data == c)
            return p;
    }

    return nullptr;
}
```

Example: LL-String — Insertion Algorithm



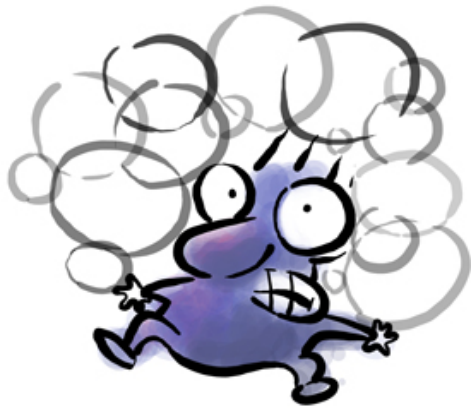


Example: LL-String — ll_insert.cpp I

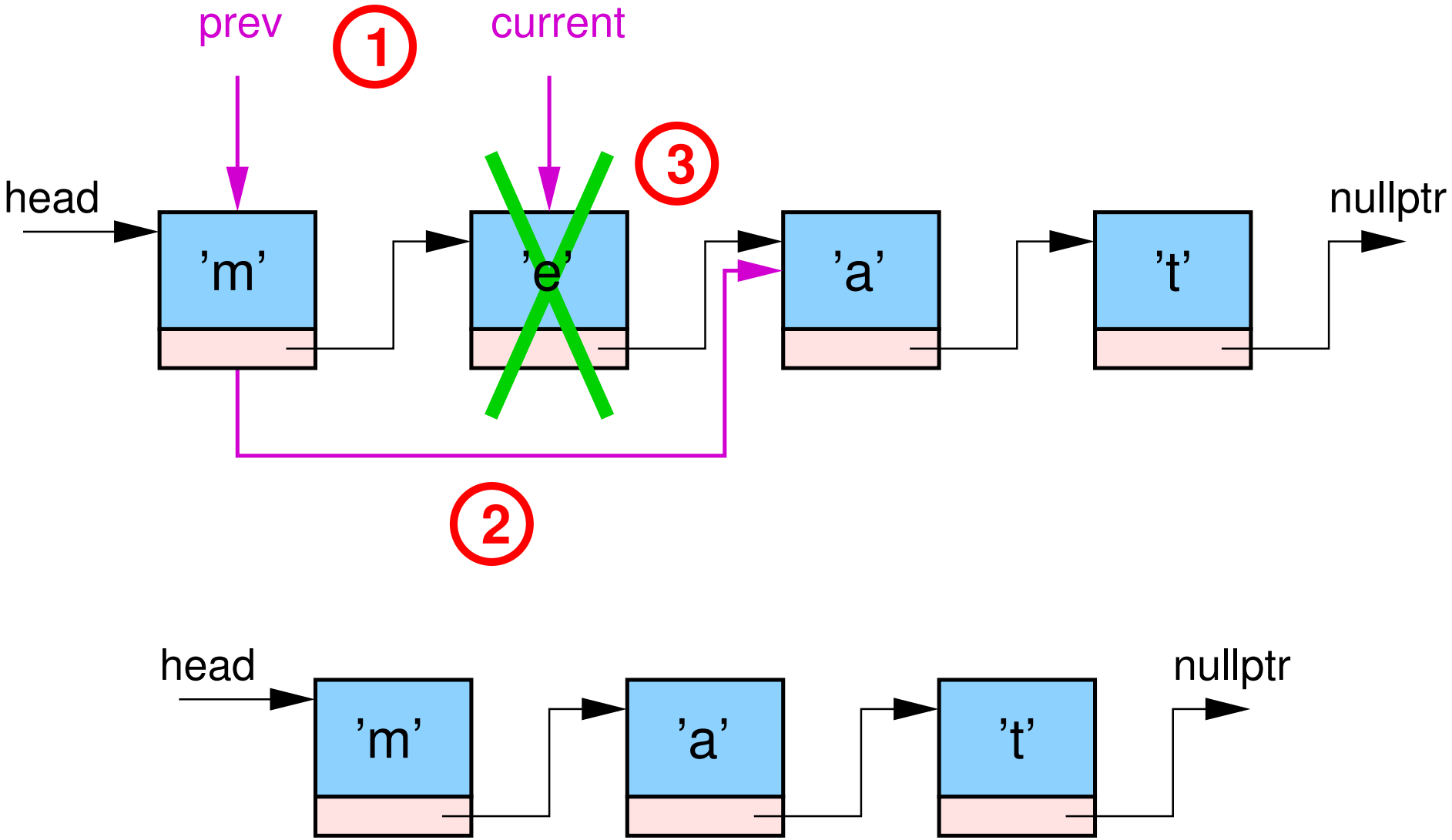
```
#include "ll_cnode.h"   /* File: ll_insert.cpp */

// To insert character c to the linked list so that after insertion,
// c is the n-th character (counted from zero) in the list.
// If n > current length, append to the end of the list.

void ll_insert(ll_cnode*& head, char c, unsigned n)
{
    // STEP 1: Create the new ll_cnode
    ll_cnode* new_cnode = ll_create(c);

    // Special case: insert at the beginning
    if (n == 0 || head == nullptr)
    {
        new_cnode->next = head;
        head = new_cnode;
        return;
    }
```

Example: LL-String — ll_insert.cpp II

```
    // STEP 2: Find the node after which the new node is to be added
    ll_cnode* p = head;
    for (int position = 0;
         position < n-1  &&  p->next != nullptr;
         p = p->next, ++position)
         ;

    // STEP 3,4: Insert the new node between
    //           the found node and the next node
    new_cnode->next = p->next; // STEP 3
    p->next = new_cnode;       // STEP 4
}
```



Example: LL-String — Deletion Algorithm



Example: LL-String — ll_delete.cpp

```
#include "ll_cnode.h"   /* File: ll_delete.cpp */
// To delete the character c from the linked list.
// Do nothing if the character cannot be found.
void ll_delete(ll_cnode*& head, char c)
{
    ll_cnode* prev = nullptr; // Point to previous ll_cnode
    ll_cnode* current = head; // Point to current ll_cnode

    // STEP 1: Find the item to be deleted
    while (current != nullptr && current->data != c)
    {
        prev = current;      // Advance both pointers
        current = current->next;
    }

    if (current != nullptr)  // Data is found
    {   // STEP 2: Bypass the found item
        if (current == head) // Special case: delete the first item
            head = head->next;
        else
            prev->next = current->next;

        delete current;      // STEP 3: Free up the memory of the deleted item
    }
}
```

Example: LL-String — ll_delete_all.cpp

```
#include "ll_cnode.h"   /* File: ll_delete_all.cpp */

// To delete the WHOLE linked list, given its head by recursion.
void ll_delete_all(ll_cnode*& head)
{
    if (head == nullptr) // An empty list; nothing to delete
        return;

    // STEP 1: First delete the remaining nodes
    ll_delete_all(head->next);

    // For debugging: this shows you what are deleting
    cout << "deleting " << head->data << endl;

    delete head;         // STEP 2: Then delete the current nodes
    head = nullptr;      // STEP 3: To play safe, reset head to nullptr
}
```

Example: LL-String — ll_test.cpp I

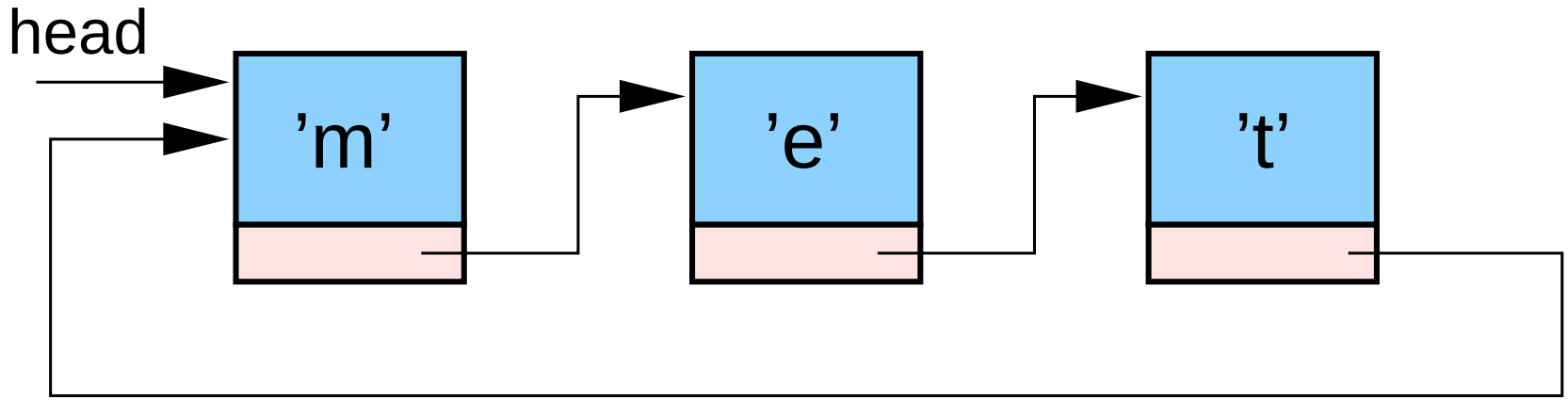
```
#include "ll_cnode.h"   /* File: ll_test.cpp */
int main()
{
    ll_cnode* ll_string = ll_create("met");
    cout << "length of ll_string = " << ll_length(ll_string) << endl;
    ll_print(ll_string);
    ll_print(ll_search(ll_string, 'e'));

    cout << endl << "After inserting 'a'" << endl;
    ll_insert(ll_string, 'a', 2); ll_print(ll_string);
    cout << endl << "After deleting 'e'" << endl;
    ll_delete(ll_string, 'e'); ll_print(ll_string);
    cout << endl << "After deleting 'm'" << endl;
    ll_delete(ll_string, 'm'); ll_print(ll_string);

    cout << endl << "After inserting 'e'" << endl;
    ll_insert(ll_string, 'e', 9); ll_print(ll_string);
    cout << endl << "After deleting 't'" << endl;
    ll_delete(ll_string, 't'); ll_print(ll_string);
    cout << endl << "After deleting 'e'" << endl;
```

Example: LL-String — ll_test.cpp II

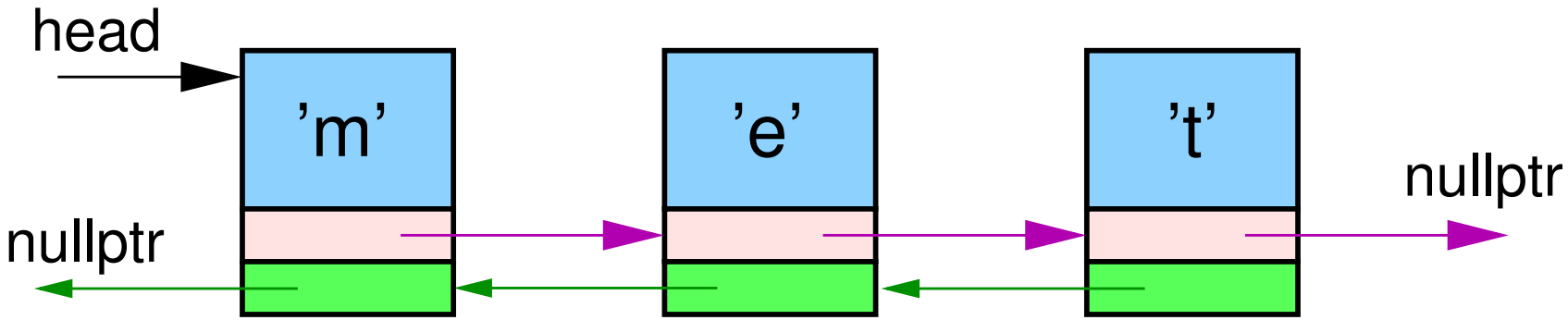
```
    ll_delete(ll_string, 'e'); ll_print(ll_string);
    cout << endl << "After deleting 'a'" << endl;
    ll_delete(ll_string, 'a'); ll_print(ll_string);

    cout << endl << "After deleting 'z'" << endl;
    ll_delete(ll_string, 'z'); ll_print(ll_string);
    cout << endl << "After inserting 'h'" << endl;
    ll_insert(ll_string, 'h', 9); ll_print(ll_string);
    cout << endl << "After inserting 'o'" << endl;
    ll_insert(ll_string, 'o', 0); ll_print(ll_string);

    ll_delete_all(ll_string);
    return 0;
}
```

Other Common Variants of Linked List

- Circular Linked List



- Doubly Linked List



That's all!

Any questions?