CSC230

Intro to C++ Lecture 13

Outline

- **Singly Linked List**
- **Lab 5 discussion**

Review: Arrays & ArrayList

Benefits of Arrays

- Random access with index numbers
  - int MyID = MyArray[2]
- No waste in memory
  - The element stores as itself
- Fast sequential access
  - The elements are stored continuously in memory

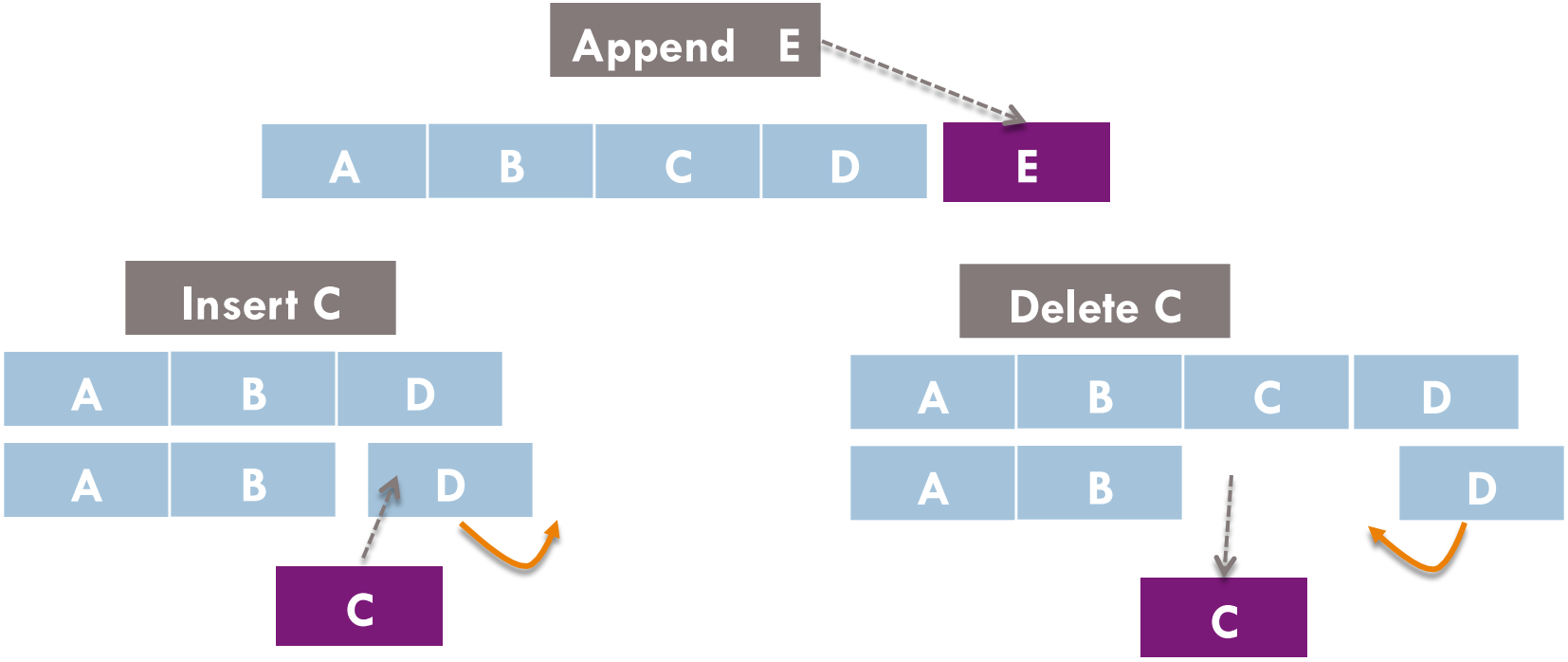
Limitations of Arrays

- Need to know the size beforehand
  - int MyID[5]
- Can not change the size at run-time
  - Array is static data structure, fixed at compile time
- Difficult to insert / delete element
  - Insertion and deletion result in element shifting

Review: Arrays & ArrayList

Resizing Arrays : ArrayList

- ArrayList allows run-time resizing
- It is efficient to append an object at the end
- It enables insertion and deletion, however, elements still need to be shifted



Alternative: Linked list

- The size of linked list can easily grow or shrink based on the number of items currently in the list
- Usually, arrays are allocated and de-allocated by large chunk
- Usually, Linked lists grow or shrink by small chunk.

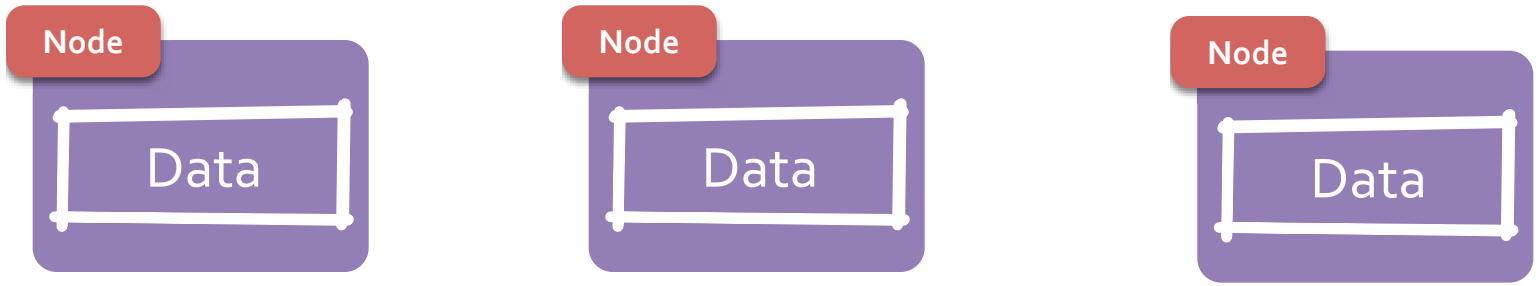
Single item
(linked list)

Bulk item
(array)

Introduction to Linked List

What is Singly Linked List ?

- A singly linked list is a concrete data structure consisting of a sequence of nodes
- Is it a linked list ?



It is a list of nodes

NOT a linked list of nodes

Linked List: a class implementation

- The data type of the item/node can be structure or class, depending on whether there is any operation associated with the item.
- The items are linked by pointers.

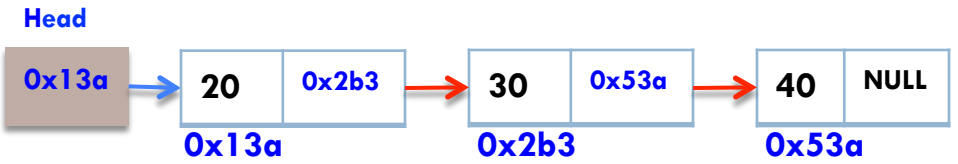
A list is

- **Arbitrarily** sized
- Can add any number of new values by dynamic memory allocation
- Supports typical list operations:
  - Append
  - At
  - Remove
  - Size
  - Empty
- Can define a List class

```
#include<iostream> using namespace std;
struct Node{
  int val;
    Node* next;
};

class List
{
public: List();
~List();
void append(int v); ... private:
Node* head;
};
```

Item :



Linked List: without a class

To access a linked list, you need the address of the some node/item, which is pointed by a pointer.

Starting from the head pointer, we can access every node of the linked list.

- A class acts as a wrapper around the header pointer and the related operations.
- It is easy for user to manipulate the list.

If list is implemented without a class, each function will use header pointer as an argument.

```
#include<iostream>
using namespace std;
struct Node{
  int val;
  Node* next;
};

void append(Node*& head, int v);

int main(){
  Node* head1 = NULL;
  Node* head2 = NULL;
}
```

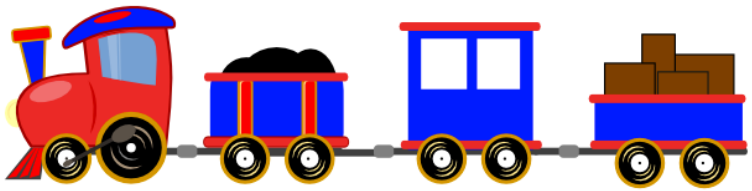
Head is a reference (alias) to a Node pointer (address)

Linked List: without a class

To access a linked list, you need the address of the some node/item, which is pointed by a pointer.

Starting from the head pointer, we can access every node of the linked list.

What if?
Node *ptr You can't reassign a reference



Head Node Node Node

```
#include<iostream>
using namespace std;
struct Node{
  int val;
  Node* next;
};

void append(Node* &ptr, int v);

int main(){
  Node* headPtr1 = NULL;
  Node* headPtr2 = NULL;
}
```

ptr is a reference (alias) to a Node pointer

Append a node to the linked list

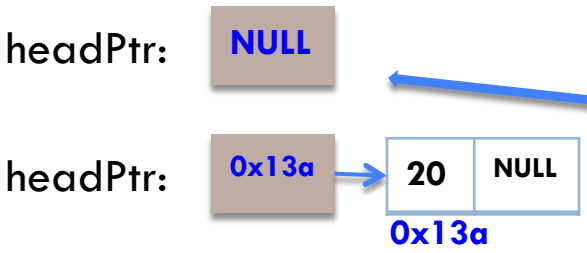
Where can we insert an element ?

- the beginning of the list,
- or the end of the list,
- or somewhere in the middle of the list.

Adding a node to the end of the list (**append**). There is two cases:

- The current list is empty
- The current list is not empty

List has ONE node, headPtr is **not** part of the list itself.




```
#include<iostream>
using namespace std;
struct Node{
  int val;
  Node* next;
};

void append(Node*& head, int v){
  if(head == NULL){
    head = new Node;
    head->val = v;
    head->next = NULL;
  }
  else{

  }
}

int main(){
  Node* headPtr = NULL;
  append(headPtr, 20);
}
```

Append a node to the linked list

To **add** a new node to an existing linked list, you can add it to

- the beginning of the list,
- or the end of the list,
- or somewhere in the middle of the list.

Adding a node to the end of the list (**append**). There is two cases:

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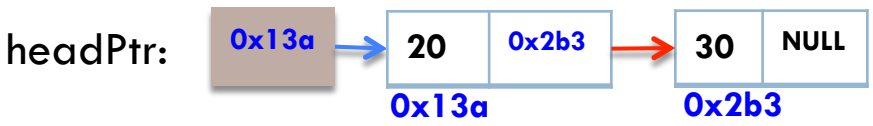

List has TWO nodes, headPtr is **not** part of the list itself.

```
#include<iostream>
using namespace std;
struct Node{
  int val;
  Node* next;
};

void append(Node*& head, int v){
  if(head == NULL){
    head = new Node;
    head->val = v;
    head->next = NULL;
  }
  else{
     ...
  }
}

int main(){
  Node* headPtr = NULL;
  append(headPtr, 20);
  append(headPtr, 30);
}
```

Append a node to the linked list

To **add** a new node to an existing linked list, you can add it to

- the beginning of the list,
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- or somewhere in the middle of the list.

Adding a node to the end of the list (**append**). There is two cases:

- The current list is empty
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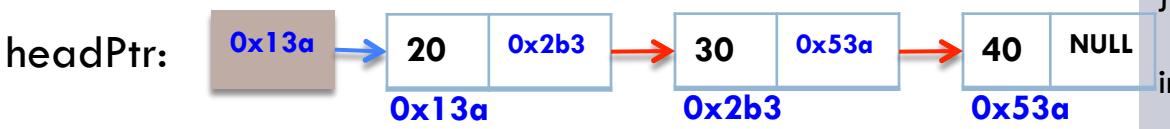


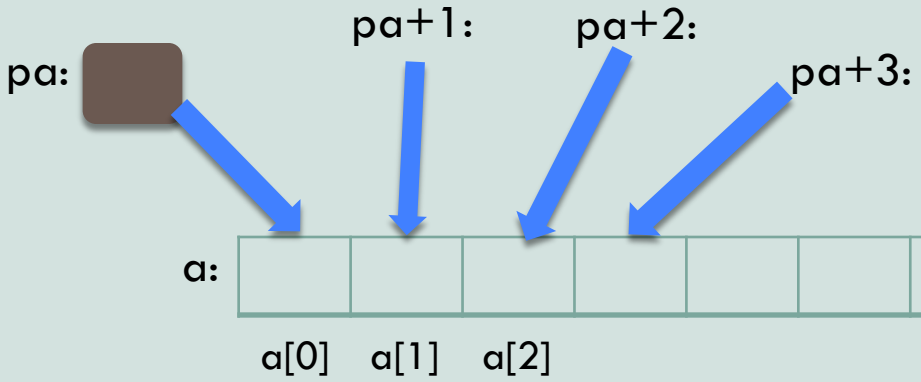
List has THREE nodes, headPtr is **not** part of the list itself.

```
#include<iostream>
using namespace std;
struct Node{
  int val;
  Node* next;
};

void append(Node*& head, int v){
  if(head == NULL){
    head = new Node;
    head->val = v;
    head->next = NULL;
  }
  else{
    ...
  }
}

int main(){
  Node* headPtr = NULL;
  append(headPtr, 20);
  append(headPtr, 30);
  append(headPtr, 40);
}
```

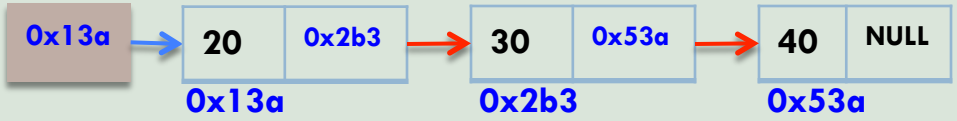
Array vs. Linked List



- Array uses a piece of contiguous memory.
- To access one item in an array, you need
  - The starting address (array name)
  - Which element we want (the index value)

a[6] = 10;

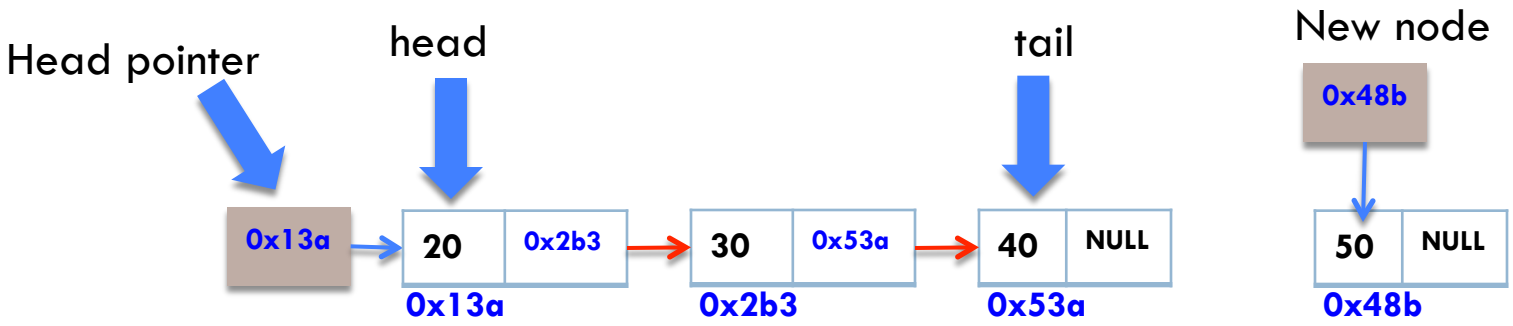
- Linked list is **NOT** contiguous in memory.
- The address of each node is explicitly stored.
- To access one node in a list, you need to
  - Have the starting address
  - Iterate the nodes before reaching the end or the intermediate node



Append()

Start from head and iterate to the end of the list.

- Create a new node, initialize it.
- Copy head pointer to temp pointer
- Use temp pointer to iterate through the list until reaching the tail
- Attach the new node to the tail



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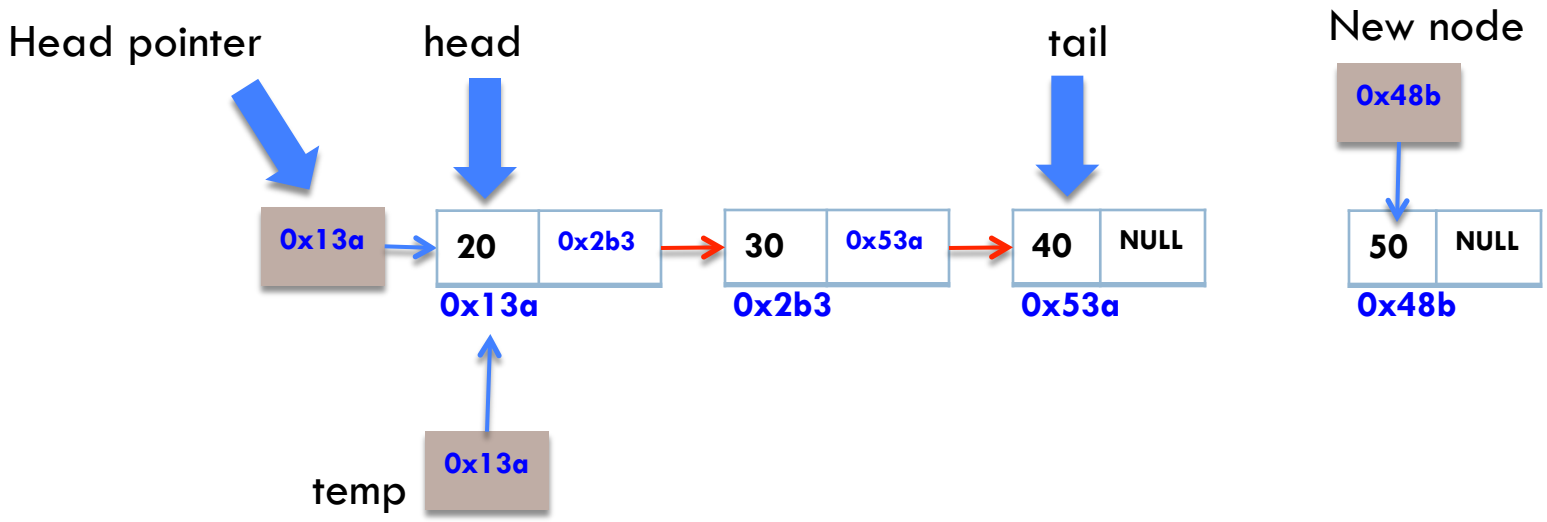

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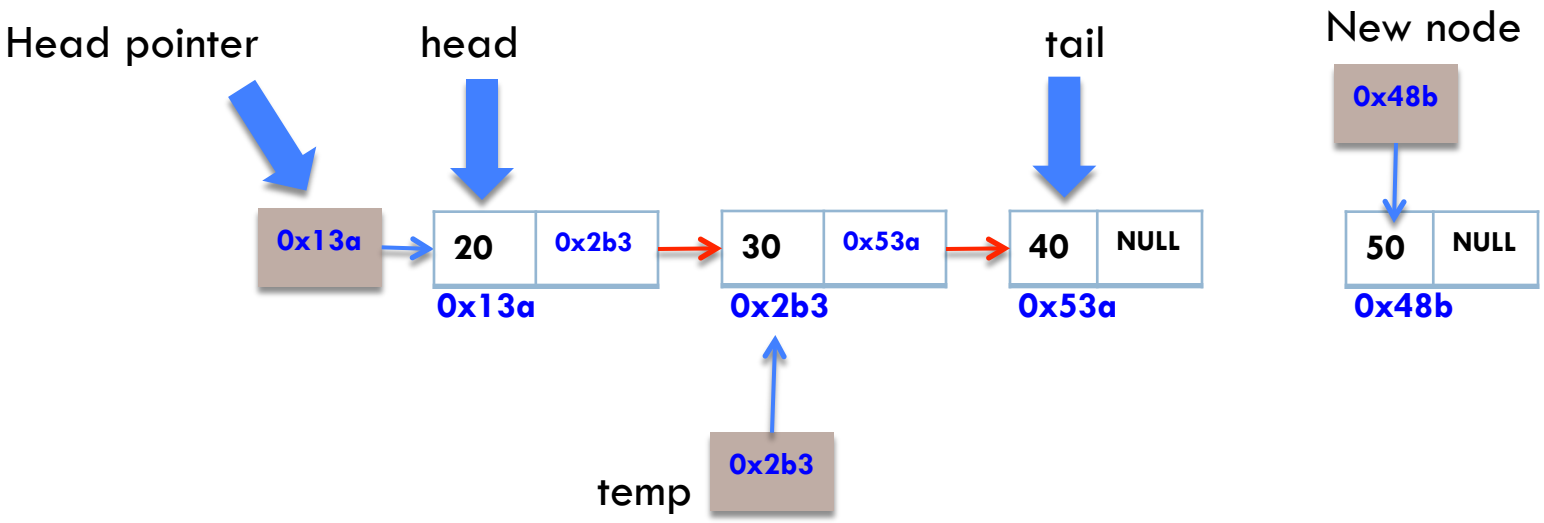

Append()

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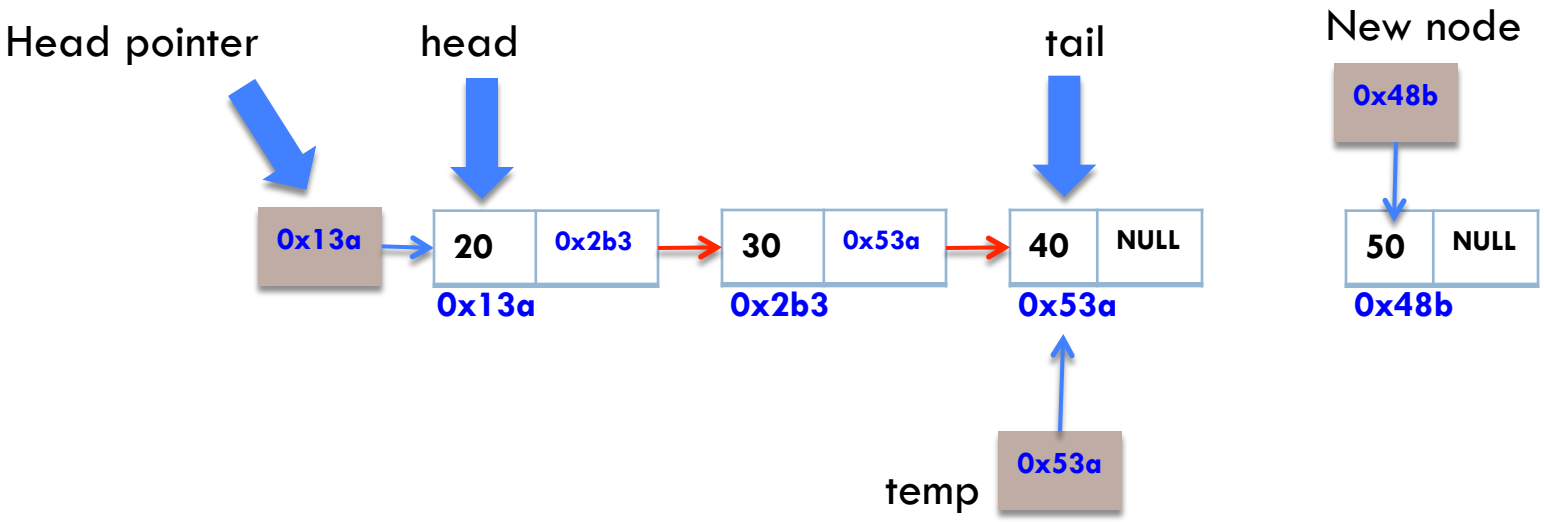

Append()

Start from head and iterate to the end of the list.

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- Copy head pointer to temp pointer
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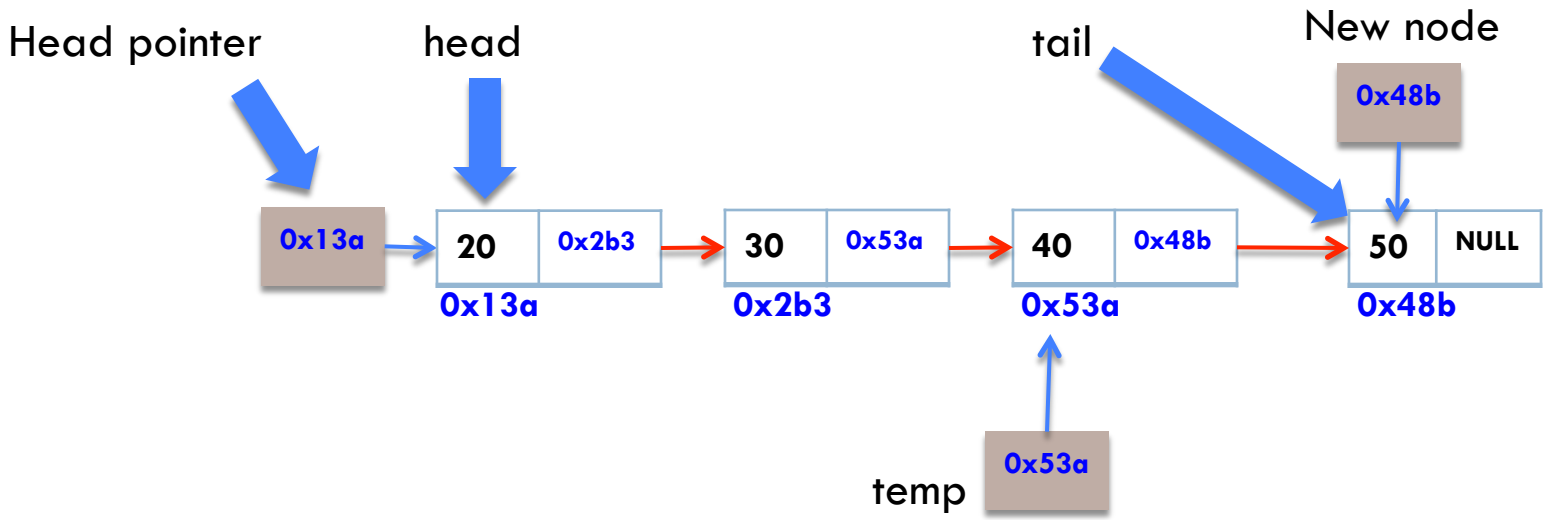


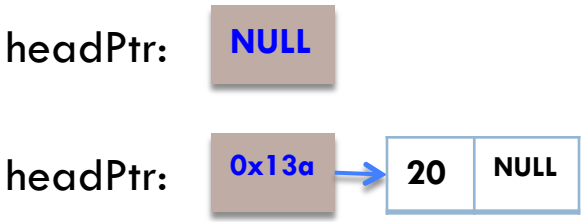
Append()

- We use head pointer to access the list
- The head pointer points to the first node
- If the address of the first node changes, the head pointer must points to the new address
- If a Node pointer is the parameter, the function will get the address of the first NODE, not head pointer itself.
- By using a reference to the Node pointer, we access head pointer

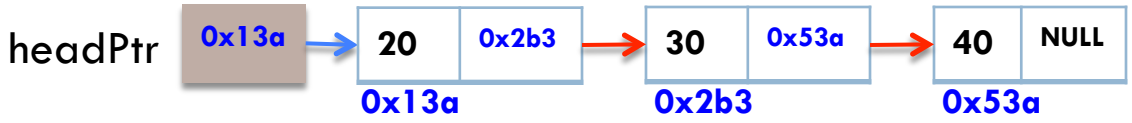
```
#include<iostream>
using namespace std;
struct Node{
  int val;
  Node* next;
};

void append(Node*& ptr, int v);

int main(){
  Node* headPtr1 = NULL;
  Node* headPtr2 = NULL;
}
```

ptr is a reference (alias) to a Node pointer

What if?
Node *ptr



Head pointer



- Head pointer is **NOT** a node
- Head pointer is a **variable**, which points to the first node
- What does headPtr->next points to ?
  - not point to the first node, it points to the second node.

Append()

If the current is not empty.

- The head pointer should not be changed.
- Copy head pointer to a temp pointer, which will iterate through the list
- How to iterate through the list?

```
while(temp->next != NULL){
    temp = temp->next;
}
```

```
void append(Node*& head, int v){
  Node * newPtr = new Node;
  newPtr->val = v;
  newPtr->next = NULL;
  if(head == NULL){
    head = newPtr;
  }
  else{
    Node* temp = head;
    while(temp->next != NULL){
      temp = temp->next;
    }
    temp->next = newPtr;
  }
}
```

Append()

Create a new node

If current list is empty

If current list is not empty

```
void append(Node*& head, int v){
  Node * newPtr = new Node;
  newPtr->val = v;
  newPtr->next = NULL;
  if(head == NULL){
    head = newPtr;
  }
  else{
    Node* temp = head;
    while(temp->next != NULL){
      temp = temp->next;
    }
    temp->next = newPtr;
  }
}
```

While loop or for loop?


```
void append(Node*& head, int v){
  Node * newPtr = new Node;
  newPtr->val = v;
  newPtr->next = NULL;
  if(head == NULL){
    head = newPtr;
  }
  else{
    Node* temp = head;
    while(temp->next != NULL){
       temp = temp->next;
    }
    temp->next = newPtr;
  }
}
```

```
void append(Node*& head, int v){
  Node * newPtr = new Node;
  newPtr->val = v;
  newPtr->next = NULL;
  if(head == NULL){
    head = newPtr;
  }
  else{
    for(temp = head;
        temp->next;
        temp = temp->next);
    temp->next = newPtr;
  }
}
```

for loop body is empty

Print out the values in each node


```
void display(Node* head){
  Node* temp = head;
  while(temp != NULL){
    cout << temp->val << endl;
    temp = temp->next;
  }
}
```

```
void display(Node* head){
  Node* temp;
  for(temp = head;
      temp;
      temp = temp->next){
      cout << temp->val << endl;
  }
}
```

Tail pointer

To append a node to the linked list:

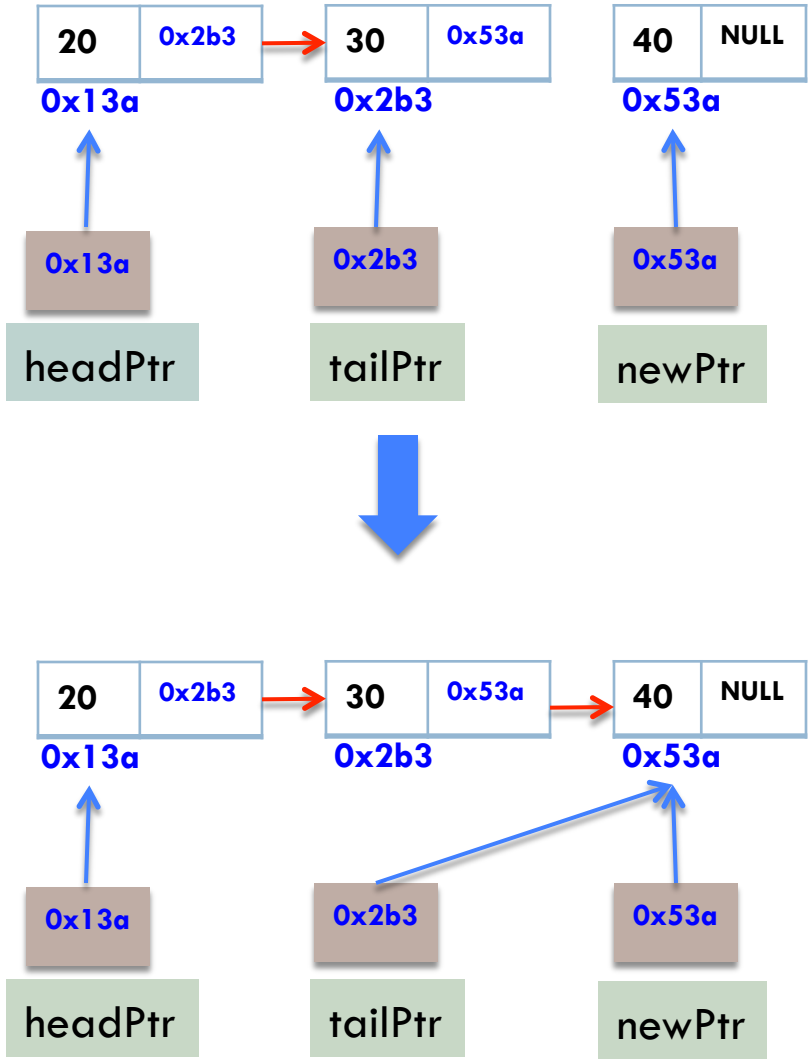
- Get a copy of the head pointer
- Iterate through to the end of the list

What if the list is **REALLY** long?

- Do you really want to iterate every node for every append operation?

Add a tail pointer to the linked list

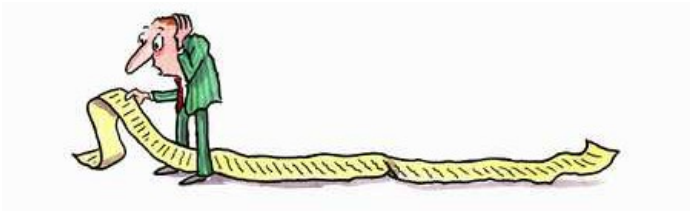
- Every time appends a new node, just add the new node after the node pointed by tail pointer (**fast**)
- What if we need to remove the tail node? (**slow**)



Delete

To **delete** the **last** node from the linked list.

- Start from the head
- Iterate through the **second last** node, why?
  - Change the next value of the second last node to be NULL
- It is **expensive** to delete one node in a long list
  - Doubly-linked list can make it less expensive



Performance Analysis

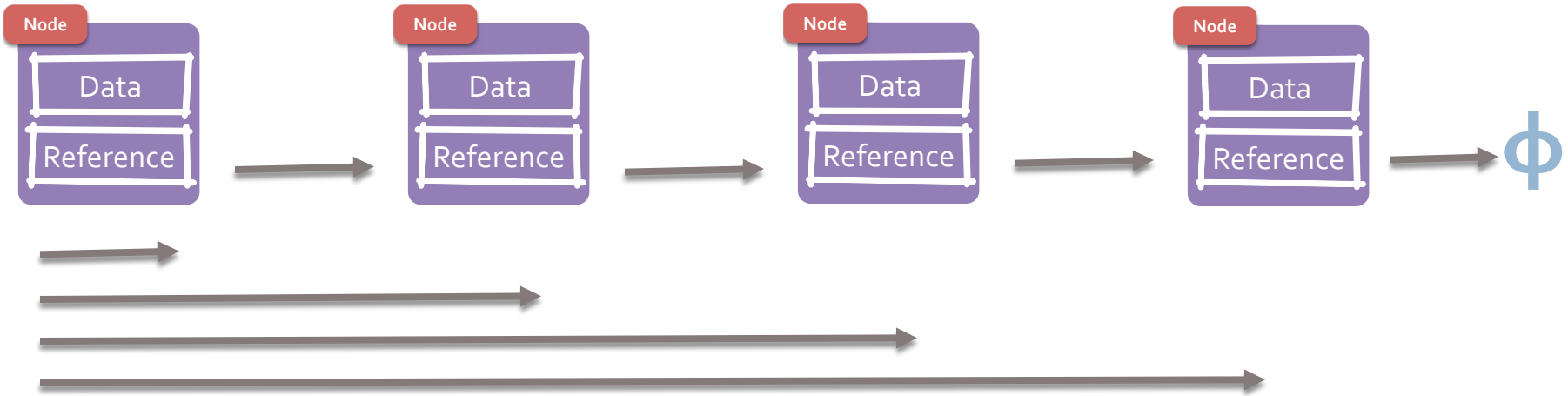
Performances of Linked List operations

- Insertion & Deletion Tests
  - **Workload**
    - 5M numbers for add function
    - 10M numbers for insertion and deletion
    - 10K numbers for enumerating and iterating
  - **What has been tested ?**
    - Add one element at the tail
    - Insert one element at a given position
    - Delete one element at a given position
    - Traverse with get() and next() methods

Performance Analysis

Performances of Linked List operations

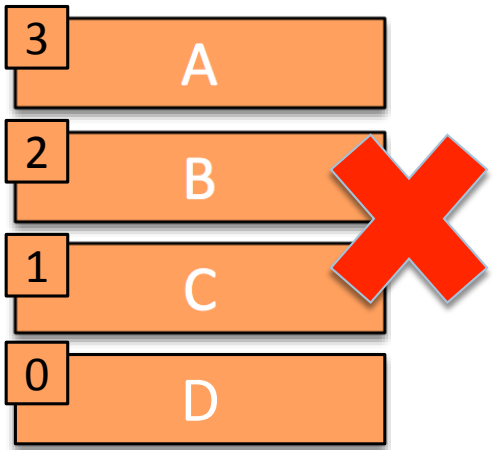
- Insertion & Deletion Tests
  - **Now we run the examples**
    - Q1: Why add an element is usually 0 ms ?
    - Q2: Why insertion at a position grows with the numbers?
    - Q3: Why deletion time cost grows ?
    - Q4: Why there is a huge difference in the last test ?

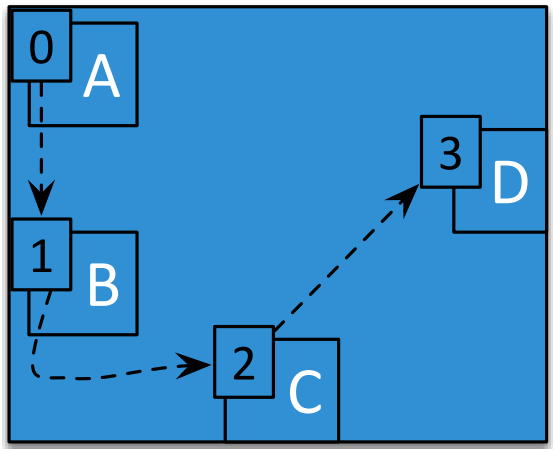


Performance Analysis

Linked List in memory

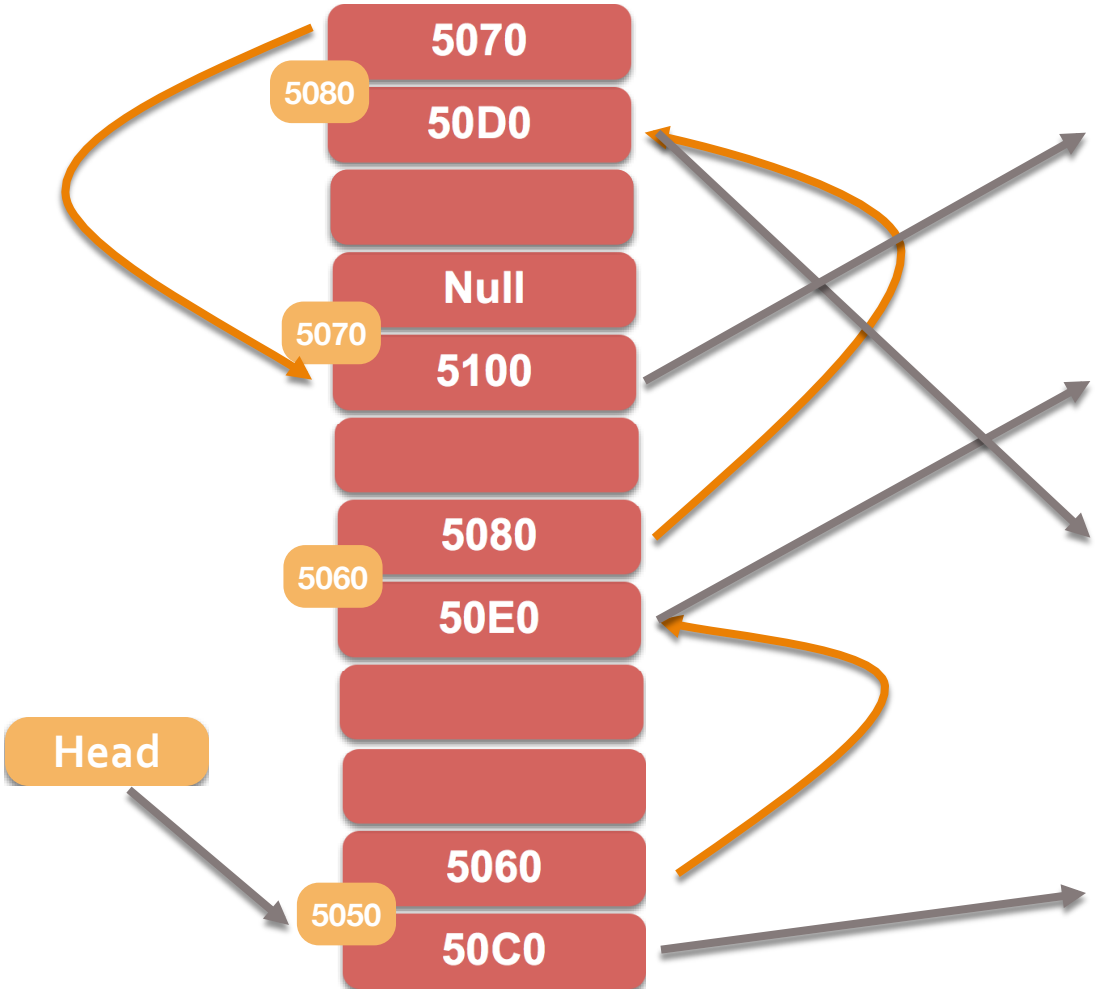
- Each node contains a data block and a reference
- The position in memory may not be continuous.
- Demo with C++





Performance Analysis

Linked List in memory



Lab discussion

- In lab 4, we read a file and store the data into a array;

- This week, we read a file and store the data into a singly linked list
  - Define the node with / without class
  - Implement the append function
  - Print out the singly linked list
  - Implement the search function