Pointers and Memory Allocations

Pointers and `malloc()`

- ~~To my horror,~~ I discovered that memory allocation was not taught in CS1010, at least not in depth
  - In which, it was supposed to be taught there
- No matter what, you need to know and use that in this module.
  - Moreover, you need to *master* it in this course
- So in last lecture, some may not know what's going on

Last Lecture: Pointers

- You can think of a C/C++ pointer is a Pokeball
- And the object it's pointer to is the Pokemon

- You have to create a Pokemon to be put into the Pokeball by "new"

```
new int;
```

- At the same time, you "capture" (associate) your Pokemon(object) by the Pokeball (pointer)

```
int *ptr = new int;
```

Computer Memory

- For storage of data

```
int a = 3;
```

This space is allocated and labeled as “a”. And we store ‘3’ inside

Computer Memory

a

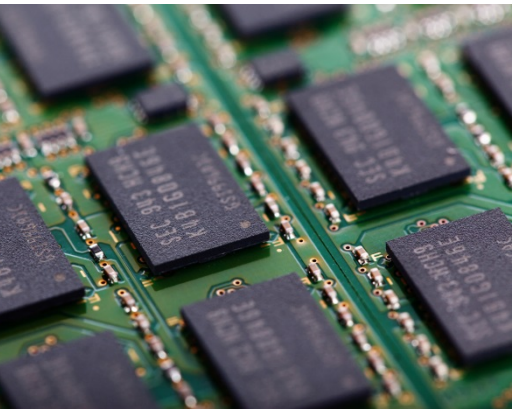
Computer

Address	Content
ffbff7d8	
ffbff7d9	
ffbff7da	
ffbff7db	
ffbff7dc	3
ffbff7dd	
ffbff7de	
ffbff7df	
ffbff7e0	3.14
ffbff7e1	
ffbff7e2	

The address of the variable **a**

The content is an integer

Another variable:
`float b = 3.14;`



Computer

When you have:

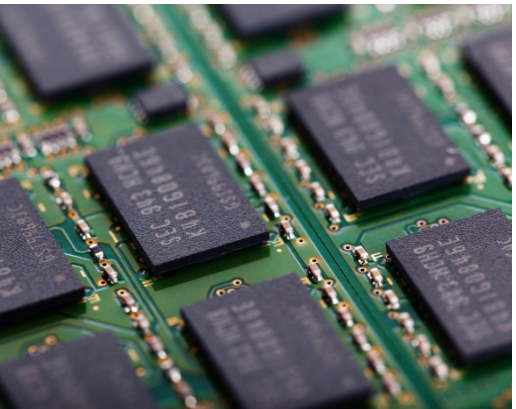
```
int a = 3;
```

In your code, the green space will be "chopped" for you automatically

Address	Content
ffbff7db	
ffbff7dc	3
ffbff7dd	
ffbff7de	
ffbff7df	
ffbff7e0	
ffbff7e1	
ffbff7e2	

The address of the variable **a**

The content is an integer

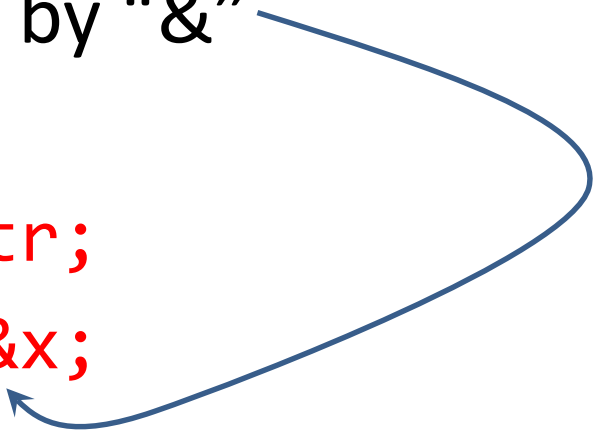


Last Lecture: Pointers

- You can think of a C/C++ pointer is a Pokeball
- And the object it's pointer to is the Pokemon

- Calling a Pokemon from a Pokeball by "*"
- If you have a Pokemon, you want to FIND it's Pokeball by "&"

```
int x;
int *ptr;
ptr = &x;
```



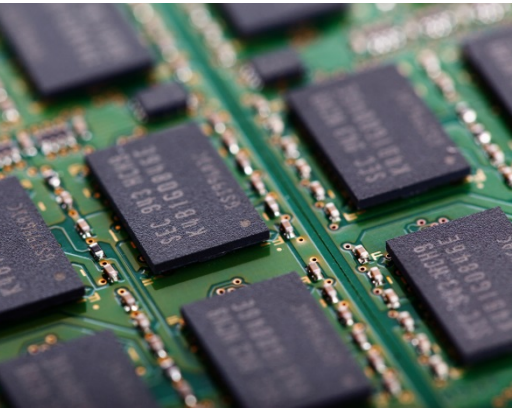
Computer

So `&a` will be the address **ffbff7dc**

Address	Content
ffbff7d8	
ffbff7db	
ffbff7dc	3
ffbff7dd	
ffbff7de	
ffbff7df	
ffbff7e0	
ffbff7e1	
ffbff7e2	

The address of the variable **a**

The content is an integer



What if I want to create a variable to store this?

Storing the Address of a

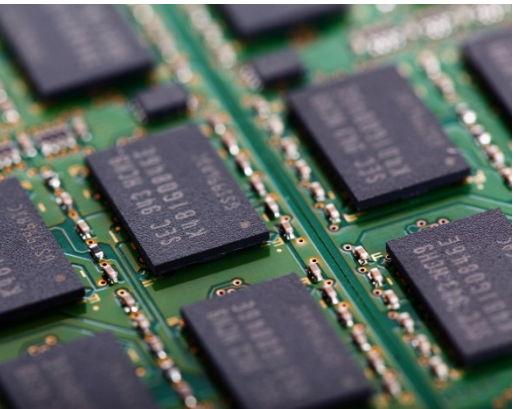
```
int a = 3
int *a_ptr = &a;
```

The address of the variable **a_ptr**

The address of the variable **a**

Address	Content
ffbff7d8	ffbff7dc
ffbff7d9	
ffbff7da	
ffbff7db	
ffbff7dc	3
ffbff7dd	
ffbff7de	
ffbff7df	
ffbff7e0	
ffbff7e1	
ffbff7e2	

The content of the address is an address

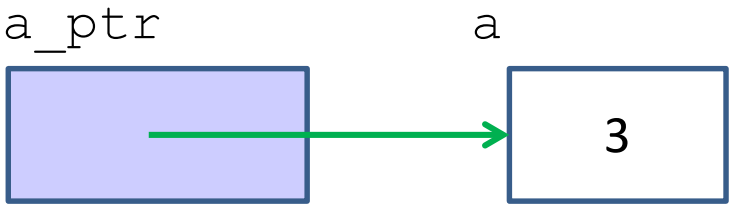


Pointer Variable

- Example: a pointer variable `a_ptr` is shown as the left box below. It contains the address of variable `a`.

(Assuming that variable `a` *is located at address* `ffbff7dc`.)

- Variable `a_ptr` is said to be pointing to variable `a`.
- Usually, we will simply **draw an arrow** to indicate this



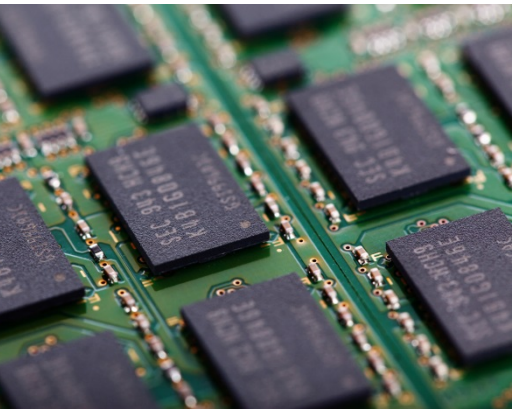
How

The address of the variable **a_ptr**

The content of the address is an address

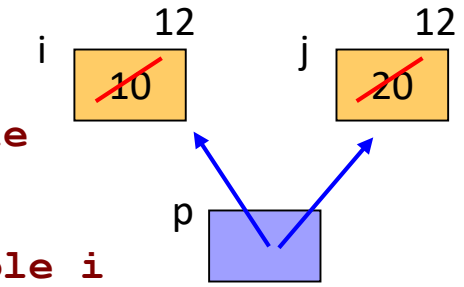
The address of the variable **a**

Address	Content
ffbff7d8	ffbff7dc
ffbff7d9	
ffbff7da	
ffbff7db	
ffbff7dc	3
ffbff7dd	
ffbff7de	
ffbff7df	
ffbff7e0	
ffbff7e1	
ffbff7e2	



Example #1

```
int i = 10, j = 20;
int *p; // p is a pointer to some int variable

p = &i; // p now stores the address of variable i
```



Important! Now ***p** is equivalent to **i**

```
printf("value of i is %d\n", *p);
```

```
value of i is 10
```

```
// *p accesses the value of pointed/referred variable
*p = *p + 2; // increment *p (which is i) by 2
             // same effect as: i = i + 2;
p = &j; // p now stores the address of variable j
```

Important! Now ***p** is equivalent to **j**

```
*p = i;  // value of *p (which is j now) becomes 12
         // same effect as: j = i;
```

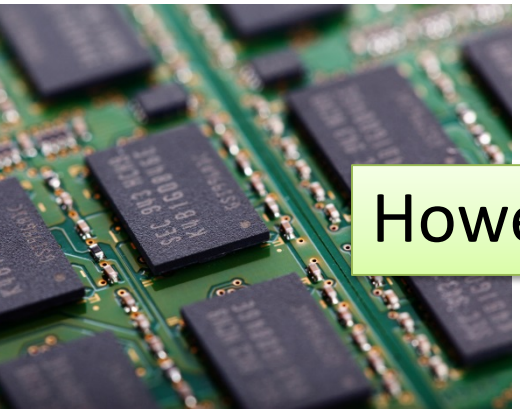
What is “new”?

How

When you use “new”, you “chop” a place in the memory by yourself, instead of automatically, e.g

```
new int;
```

Address	Content
ffbff7db	
ffbff7dc	?
ffbff7dd	
ffbff7de	
ffbff7df	
ffbff7e0	
ffbff7e2	



However, who knows your address?

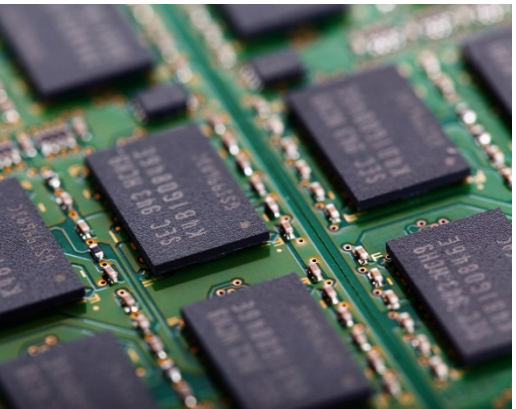
Analogy

- Maybe 5 or 10 years later, you got married in Singapore, and you applied for an HDB
- And yes, govt gave you one. Saying, we got one HDB for you.
- Ermm… where are you going to find your own HDB flat?
  - By…?

How

You need to remember your address!!!!!!

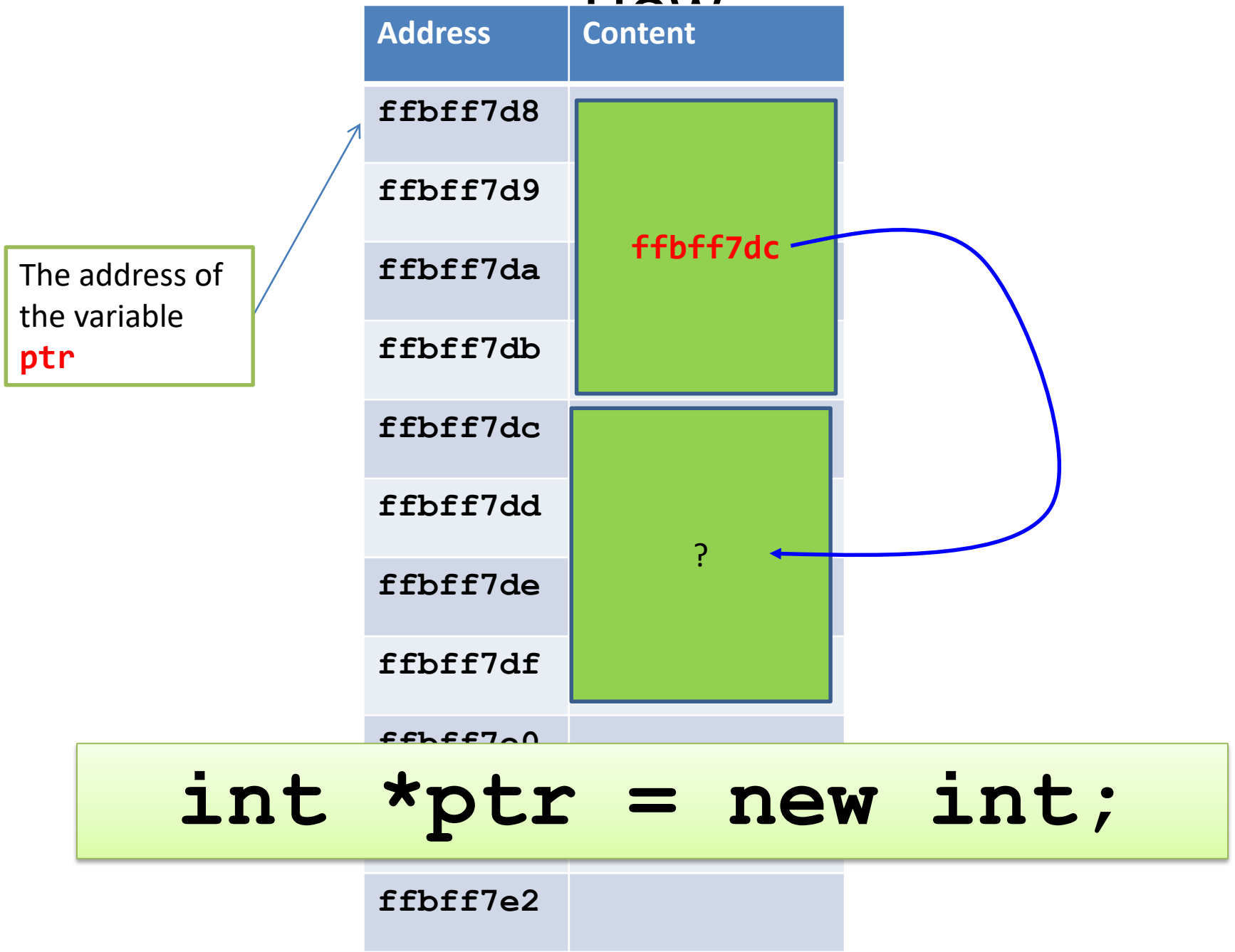
Address	Content
ffbff7d9	
ffbff7da	
ffbff7db	
ffbff7dc	?
ffbff7dd	
ffbff7de	
ffbff7df	
ffbff7e0	
ffbff7e1	
ffbff7e2	



Pointer Variable

- That's why, you want to store the address in a pointer variable

```
int *ptr = new int;
```

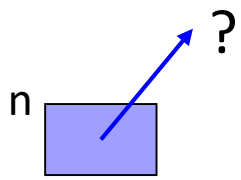

Address
Content
ffbff7d8
ffbff7d9
ffbff7da
ffbff7db
ffbff7dc
ffbff7dd
ffbff7de
ffbff7df
ffbff7e2
ffbff7dc
?
The address of the variable ptr
int *ptr = new int;

7. Common Mistake

Unit7_Common_Mistake.c

```
#include <stdio.h>

int main(void) {
   int *n;

   *n = 123;
   printf("%d\n", *n);

   return 0;
}
```

What's wrong with this?
Can you draw the picture?



- Where is the pointer n pointing to?
- Where is the value 123 assigned to?
- Result: Segmentation Fault (core dumped)
  - Remove the file "core" from your directory. It takes up a lot of space!

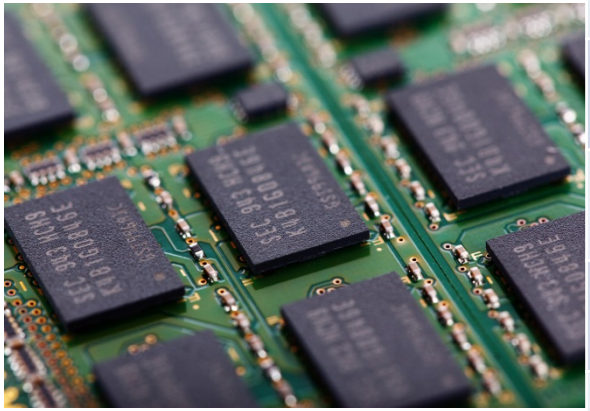
"Your shipment was delivered to the wrong address, so technically, it's your fault for choosing not to live there!"

Valid if a is allocated

The address of the variable **a_ptr**

The address of the variable **a**

Address	Content
ffbff7d8	ffbff7dc
ffbff7d9	
ffbff7da	
ffbff7db	
ffbff7dc	123
ffbff7dd	
ffbff7de	
ffbff7df	
ffbff7e0	
ffbff7e1	



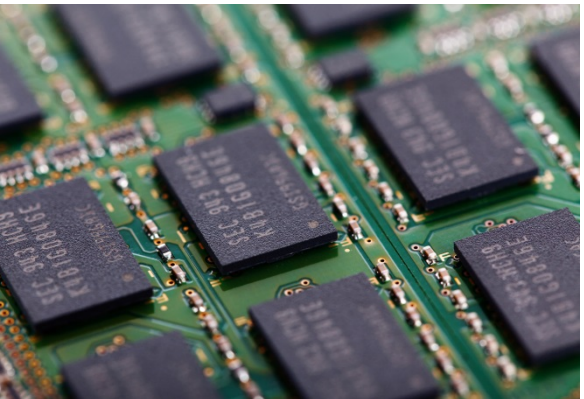
What if…?

The address of the variable **a_ptr**

The address of the variable **a**

Address	Content
ffbff7d8	aabbccdd
ffbff7d9	
ffbff7da	
ffbff7db	
ffbff7dc	123
ffbff7dd	
ffbff7de	
ffbff7df	
ffbff7e0	
ffbff7e1	

?



Computer Memory

- For storage of data

```
int a = 3;
```

This space is allocated and labeled as “a”. And we store ‘3’ inside

Computer Memory

a

Computer Memory

- For storage of data

```
int a = 3;
int *a_ptr = &a;
```

Computer Memory

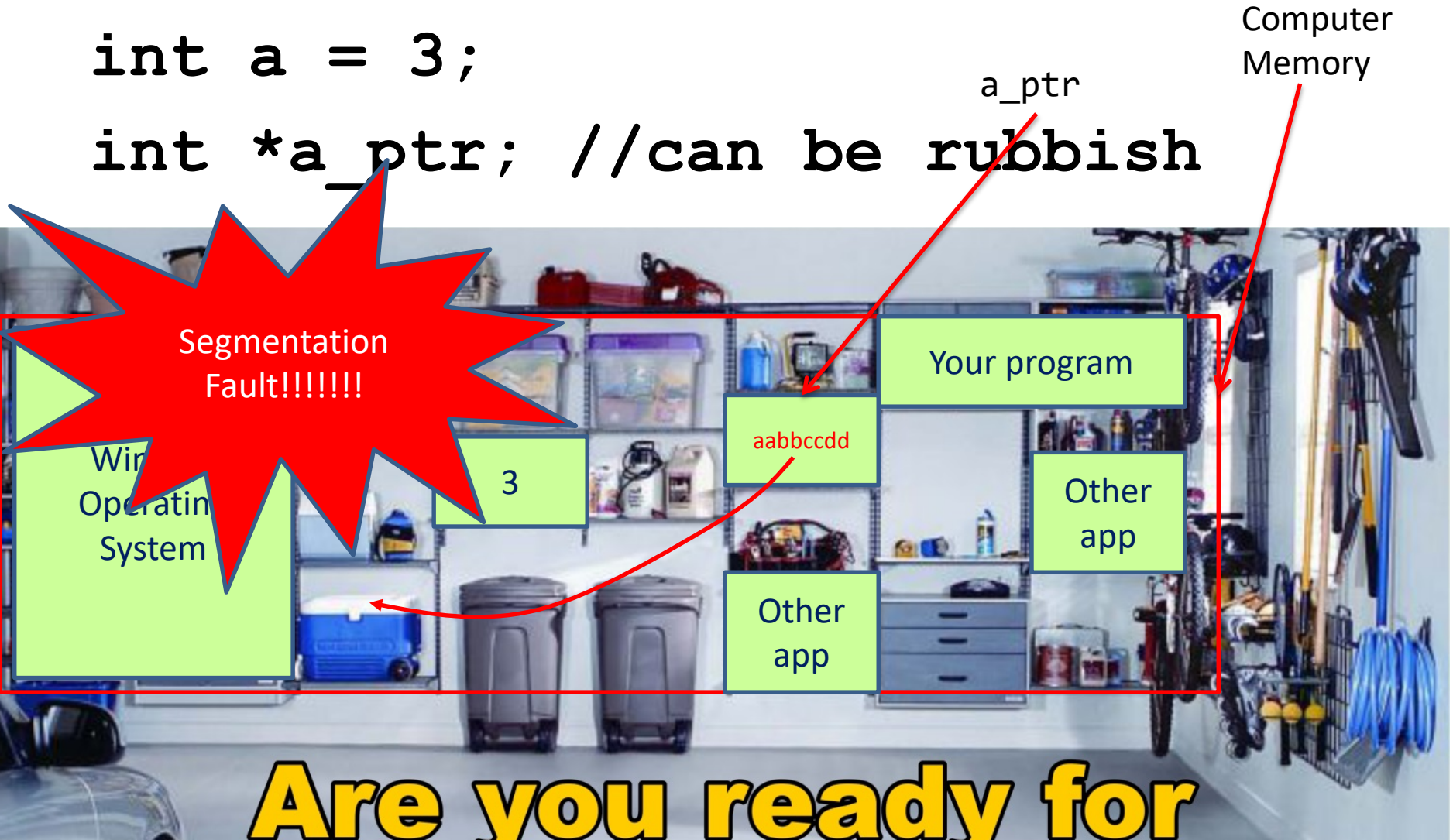
- For storage of data

```
int a = 3;
int *a_ptr; //can be rubbish
```

Invalid Area (Address)

- For storage of data

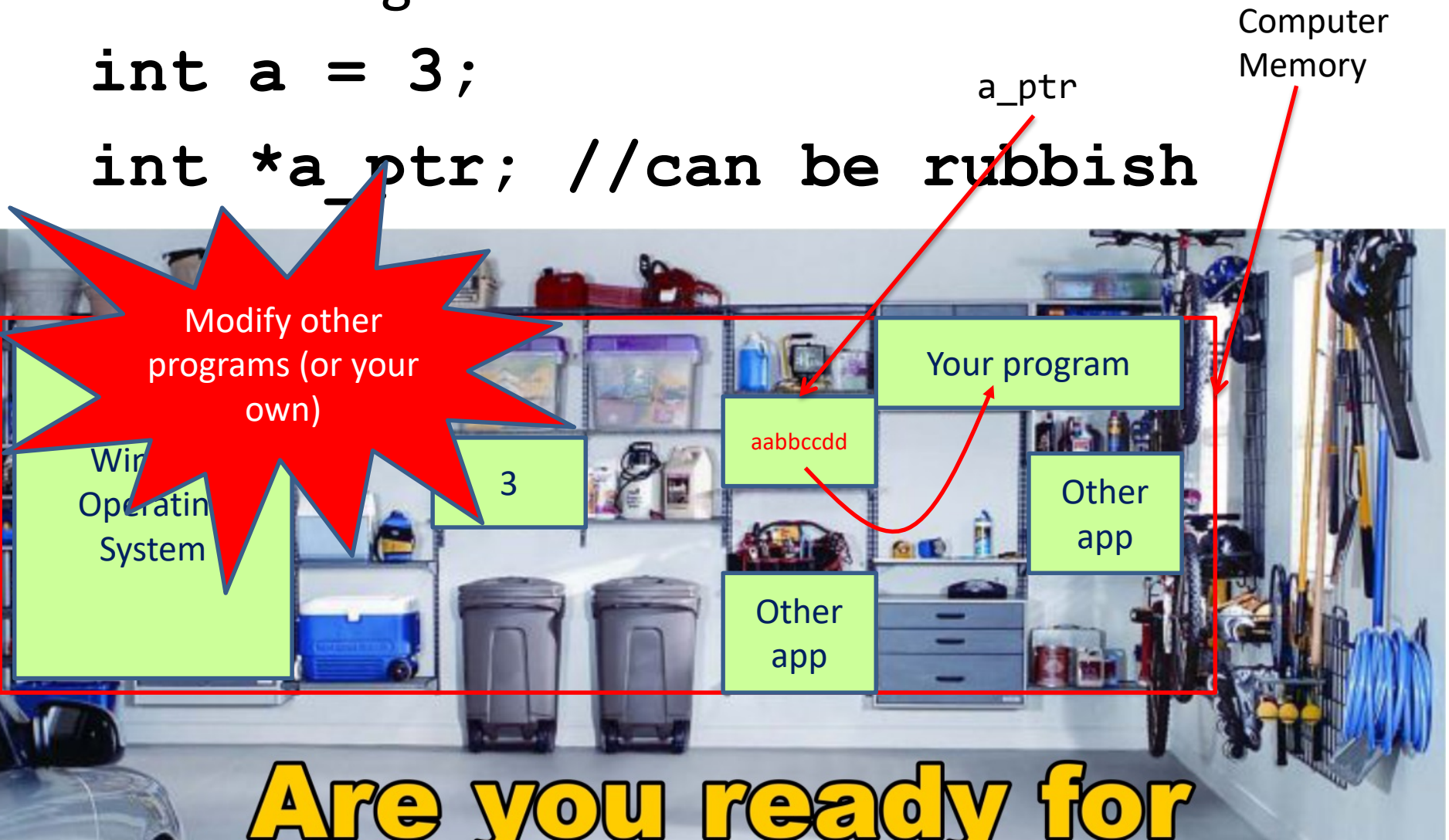
```
int a = 3;
int *a_ptr; //can be rubbish
```



Invalid Area (Address)

- For storage of data

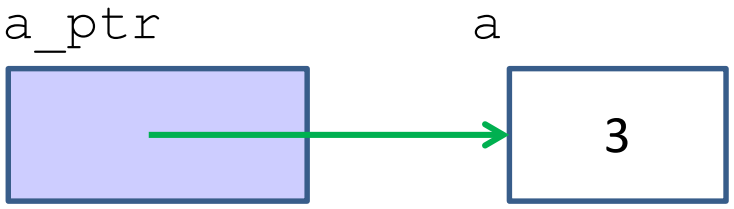
```
int a = 3;
int *a_ptr; //can be rubbish
```



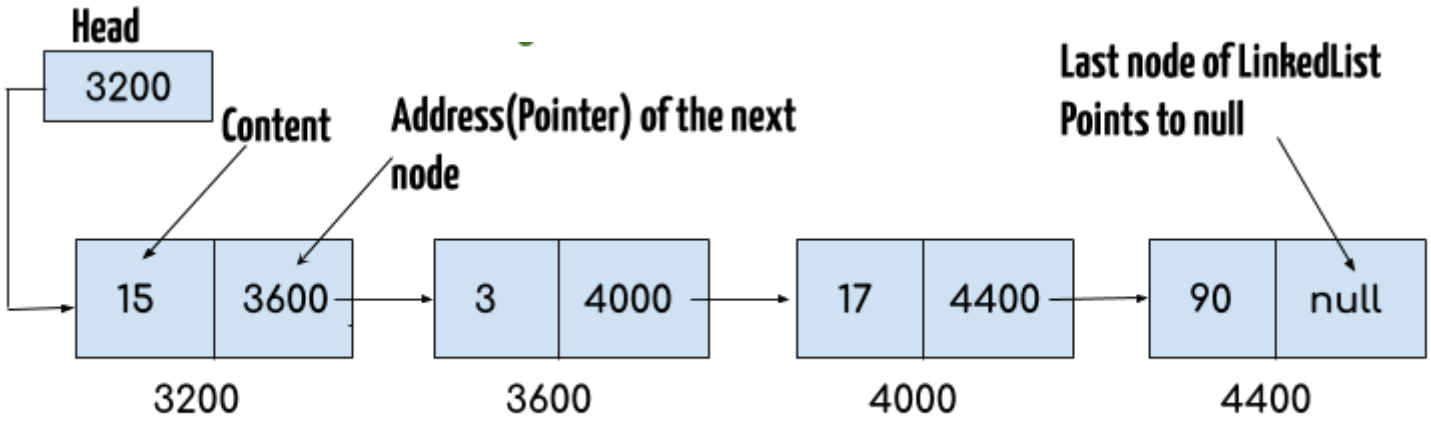
At now, you need to understand this

- Example: a pointer variable `a_ptr` is shown as the left box below. It contains the address of variable `a`.

- Variable `a_ptr` is said to be pointing to variable `a`.
- Usually, we will simply **draw an arrow** to indicate this



Linked Lists



Variable-size Storage

Return to CS2040C

Variable-sized Storage Problem

- Let's write a program to record all the marks of students in a course
  - So that, we can compute a lot of useful data, e.g. average mark
- However, how do we store all the marks
  - Make it easy, let's just store one single integer mark for each students

Let’s say we input the marks by hand

- Somewhere in your code will be *looping* this:
  - For each of the student:
    - From keyboard, input the mark of one student
    - Store *this* mark to…..?
      a) A Single variable
      b) An array
      c) Or….?

Natural to Use Arrays, but

- When we declare an array, we need to know the size of the array, e.g. for 100 students

```
int student_mark[100];
```

- But every course has a different number of students?!
  - 10? 100? 1000?

Can we……?

- Declare a large array, e.g.

```
int student_mark[10000];
```

- Problems?

- How then?

Linked List in C++

Why Linked List?

- Why not just store everything in an array?
- Variable/unknown size of data
  - Even the size will change *during* the running of the program
- No need to store all the data in ONE connected trunk of memory

Linked List is like a Train

Each Carriage

Contents

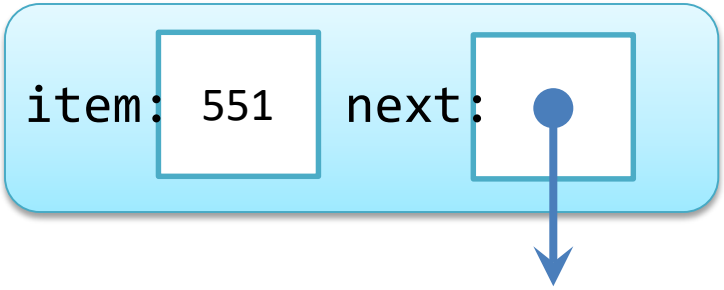
"Connector" to the other train

Linked List in C++

```
class ListNode {
private:
   int item;
   ListNode *next;

}
```

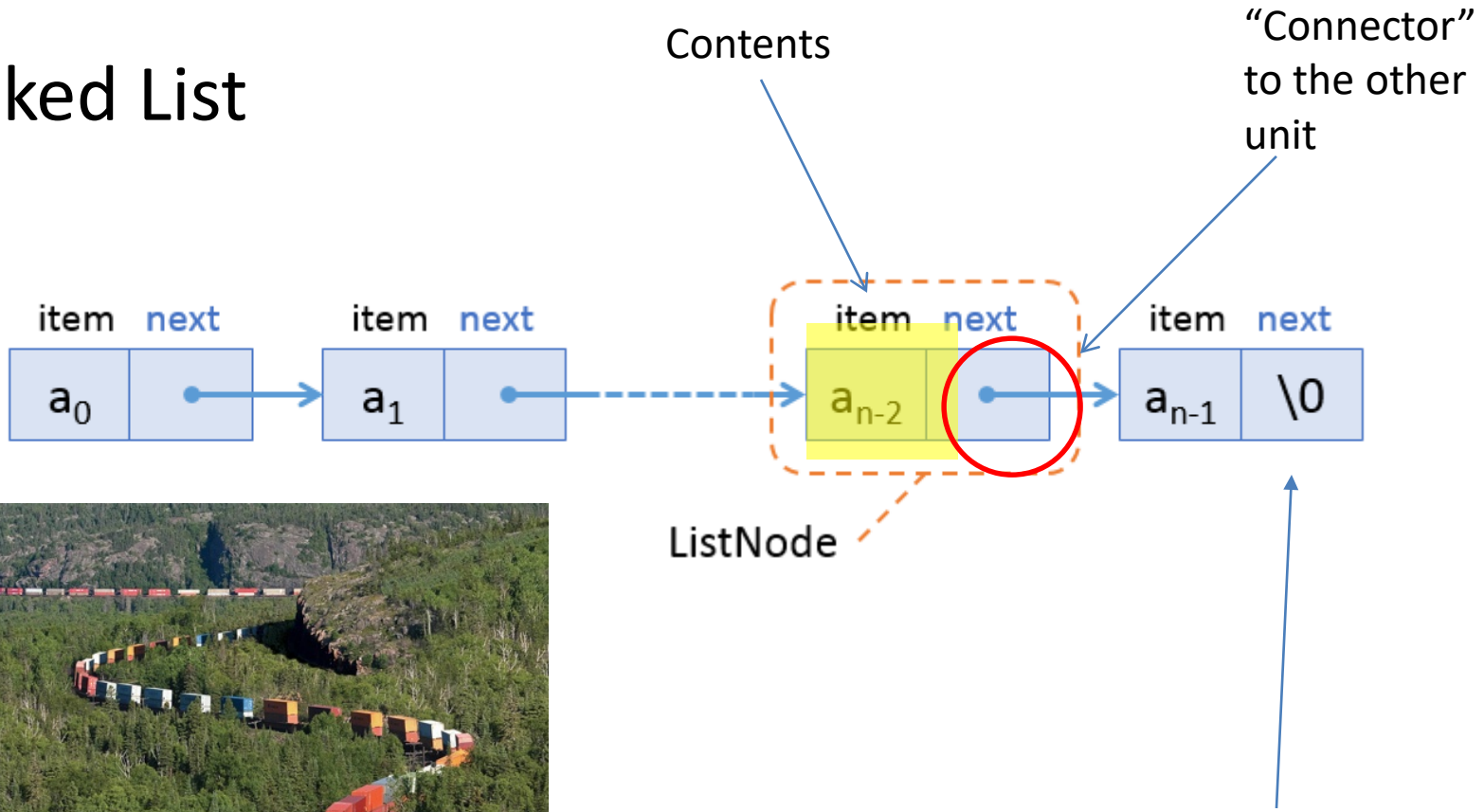
More to come

- In graphical form:

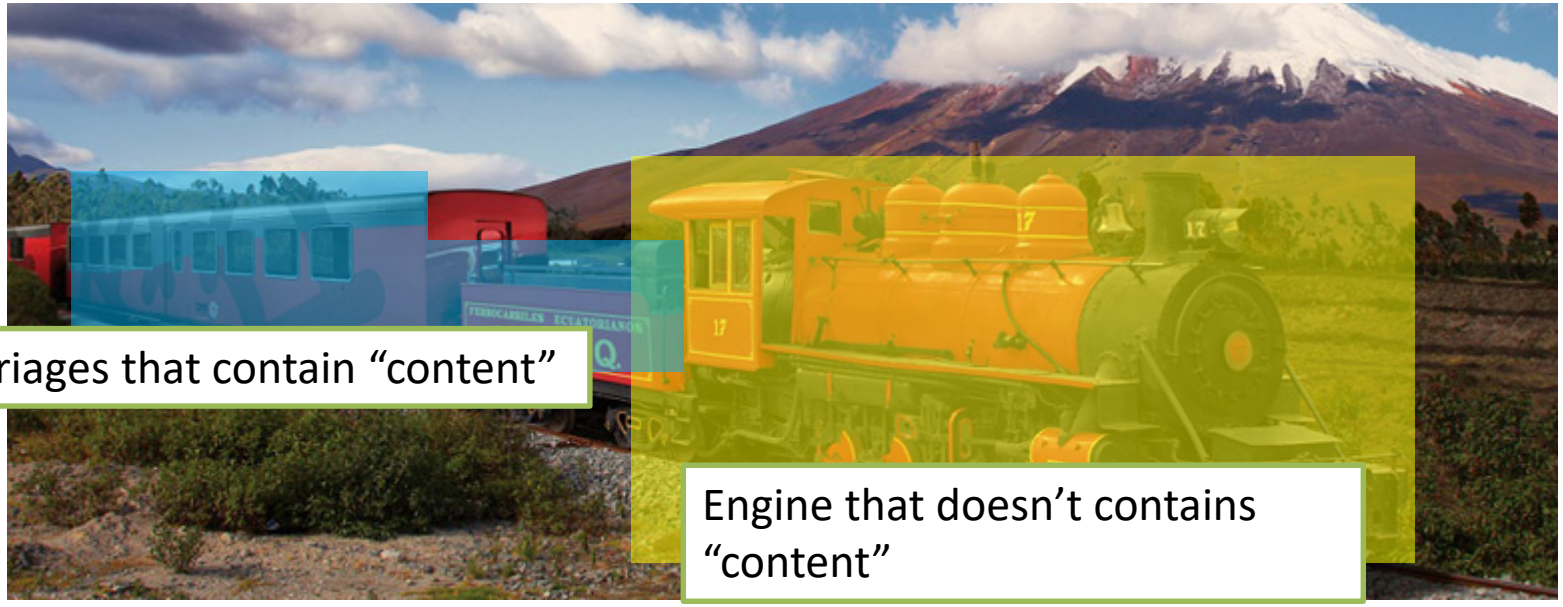


A Linked List with a lot of nodes

- Linked List

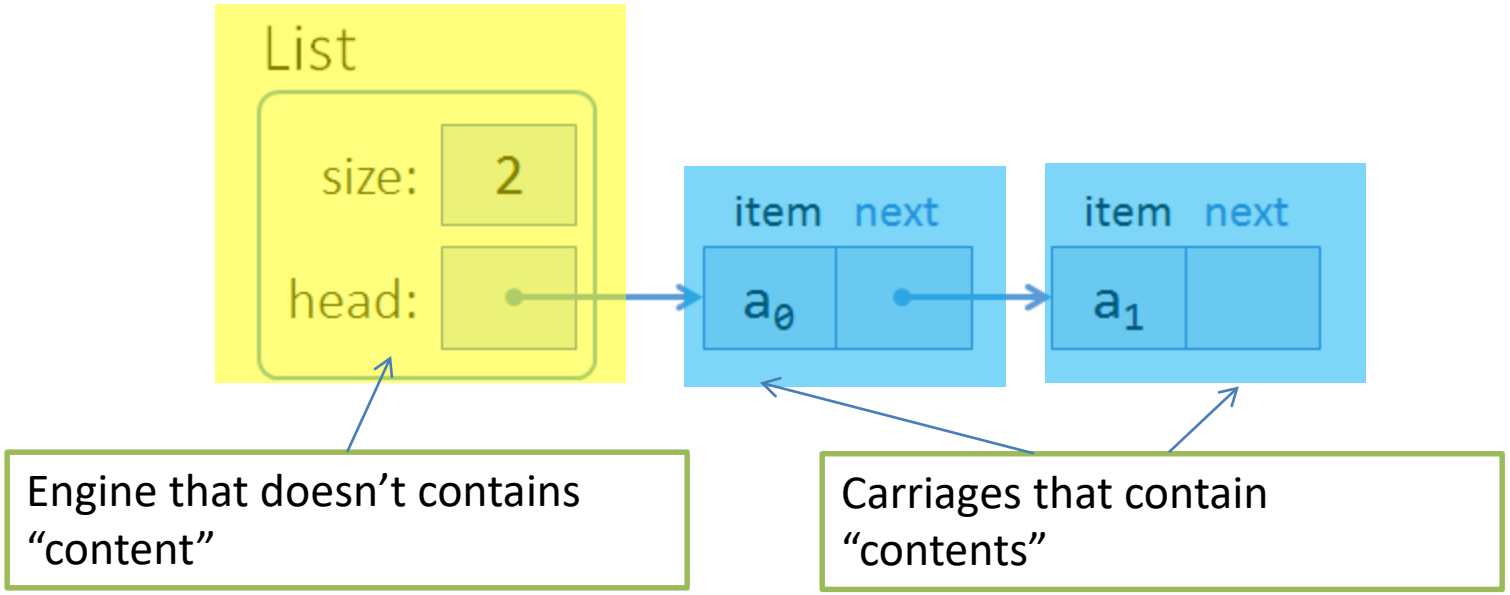


The Engine and the Carriages



The “Engine”

```
class List {
private:
   int size;
   ListNode *head;
};
```



Linked List in C++

```
class ListNode {
private:
   int item;
   ListNode *next;
```

More to come

```
}
```

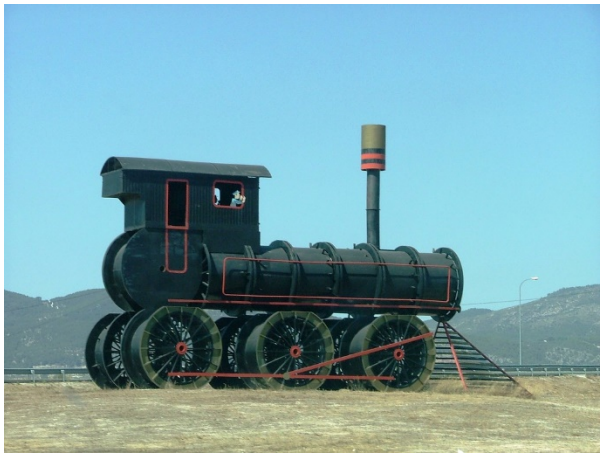
```
class List {
private:
   int size;
   ListNode *head;
```

More to come

```
}
```

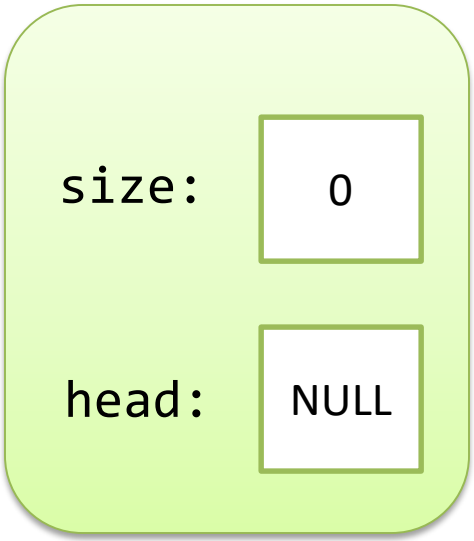
In the Beginning

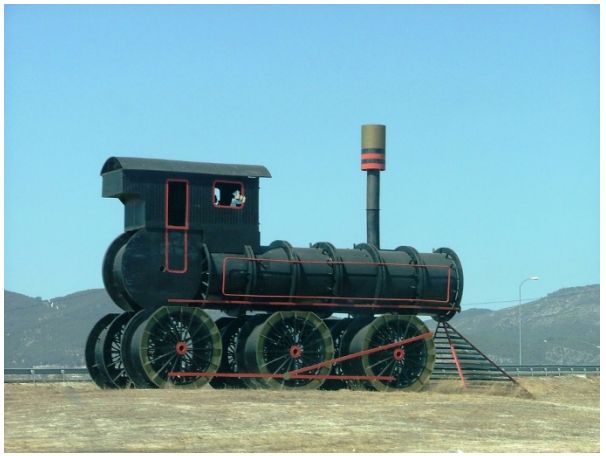
- When we create a list
  - There will be no content
  - Namely, no list node



How do we initialize the two variables?

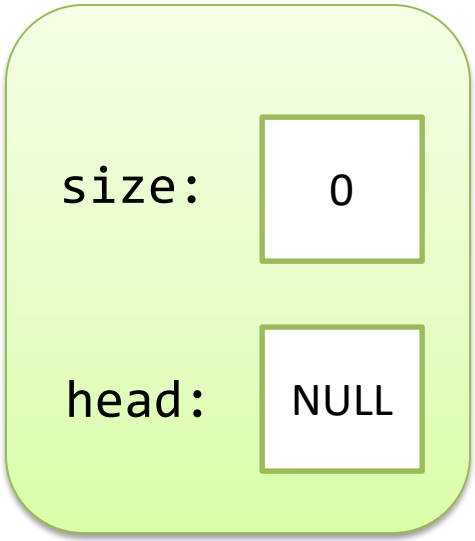
```
class List {
private:
   int size;
   ListNode *head;



}
```

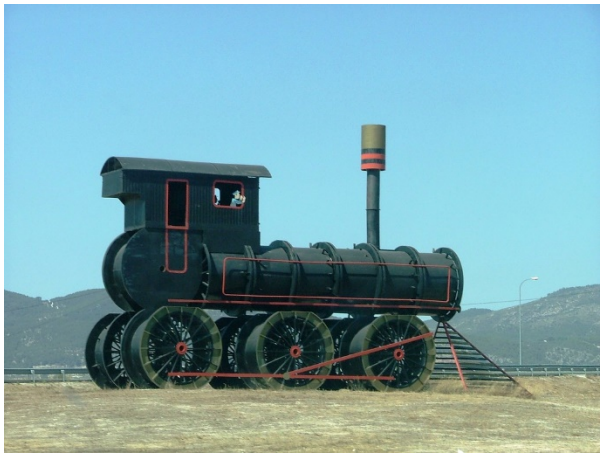




OOP: Constructors

```
class List {
private:
   int size;
   ListNode *head;
public:
   List();


}
```



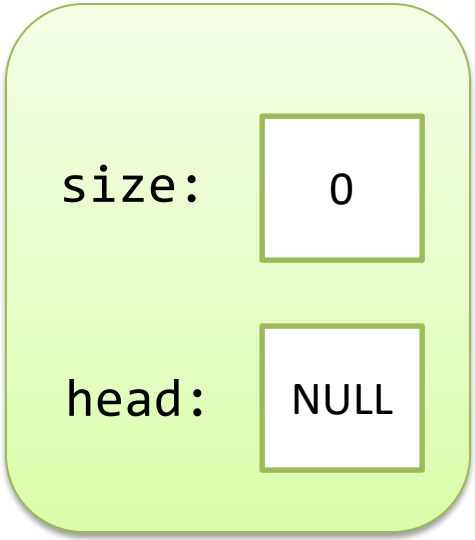


What is a Constructor?

- A Constructor is called when your object is just created automatically

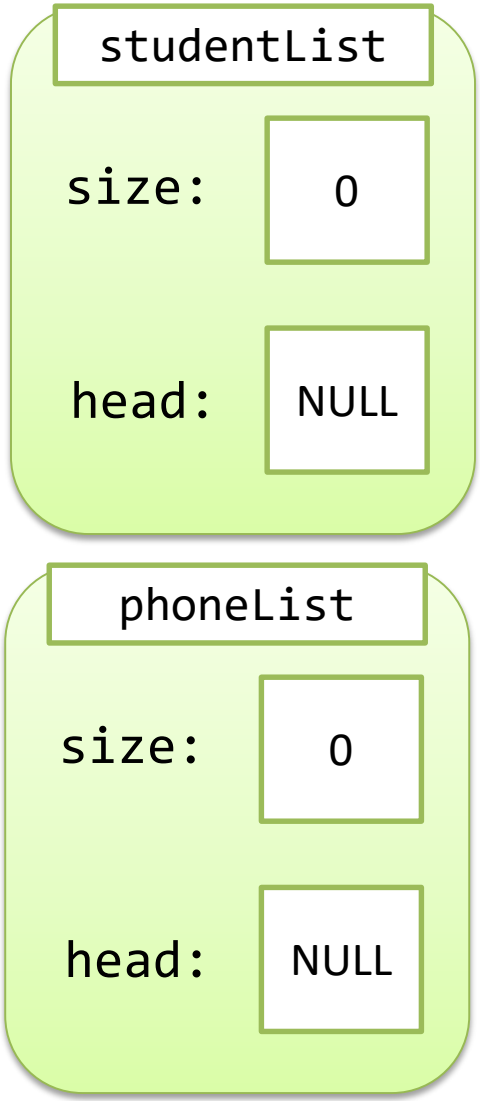
Constructor

```
List::List()
{
   size = 0;
   head = NULL;
}
```

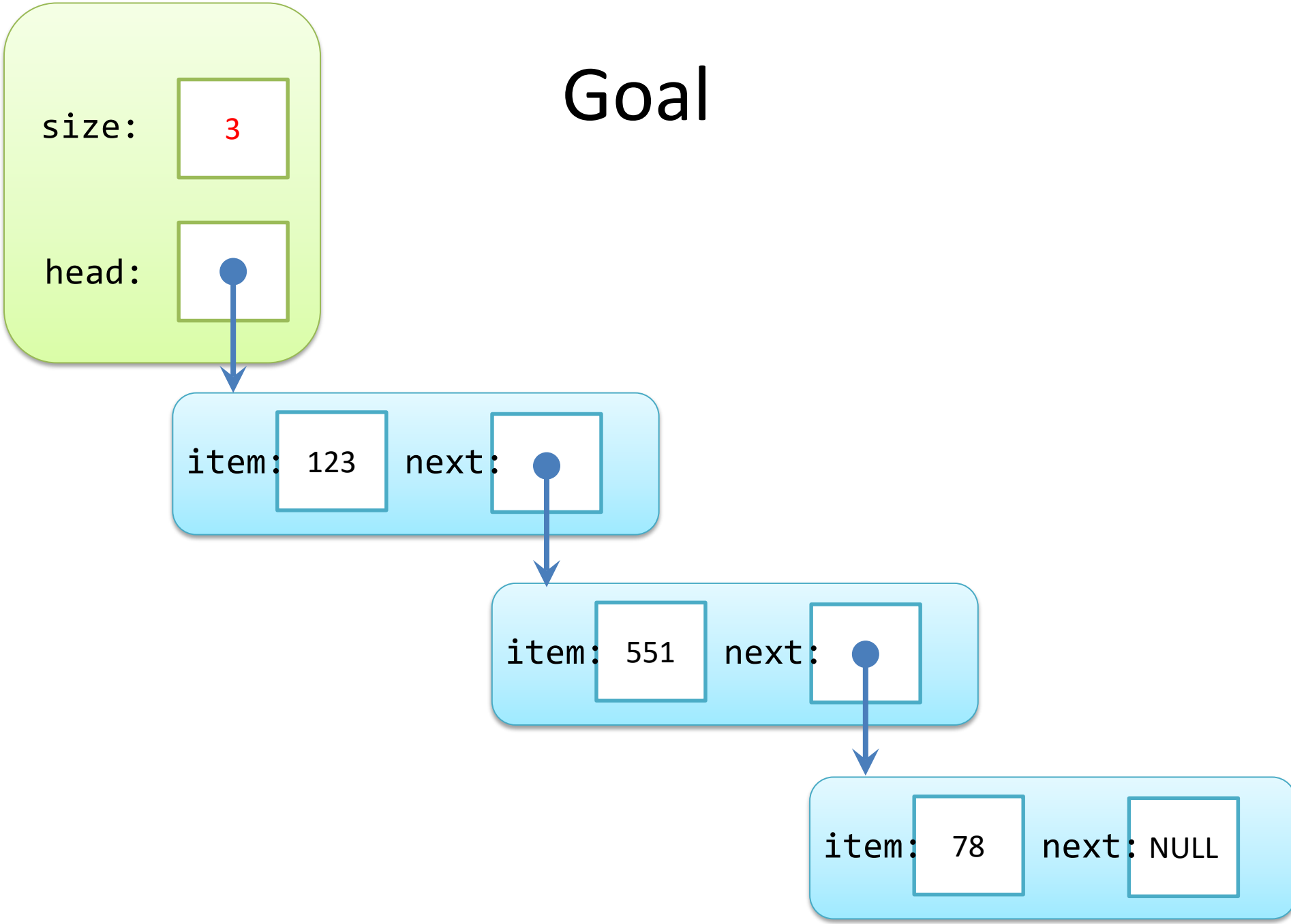


```
int main() {
   List studentList;
   List phoneList;

}
```

Two instances of ONE class



Goal

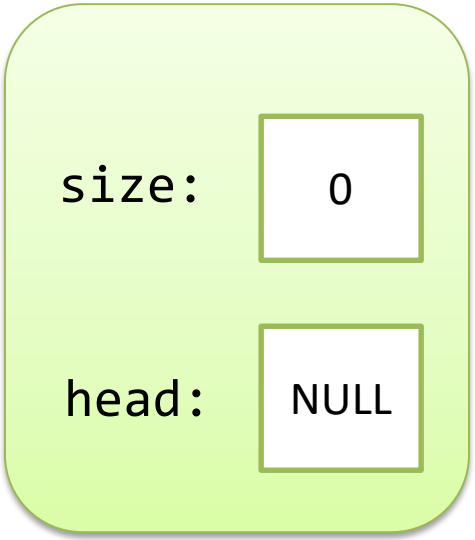


Add Nodes to the List

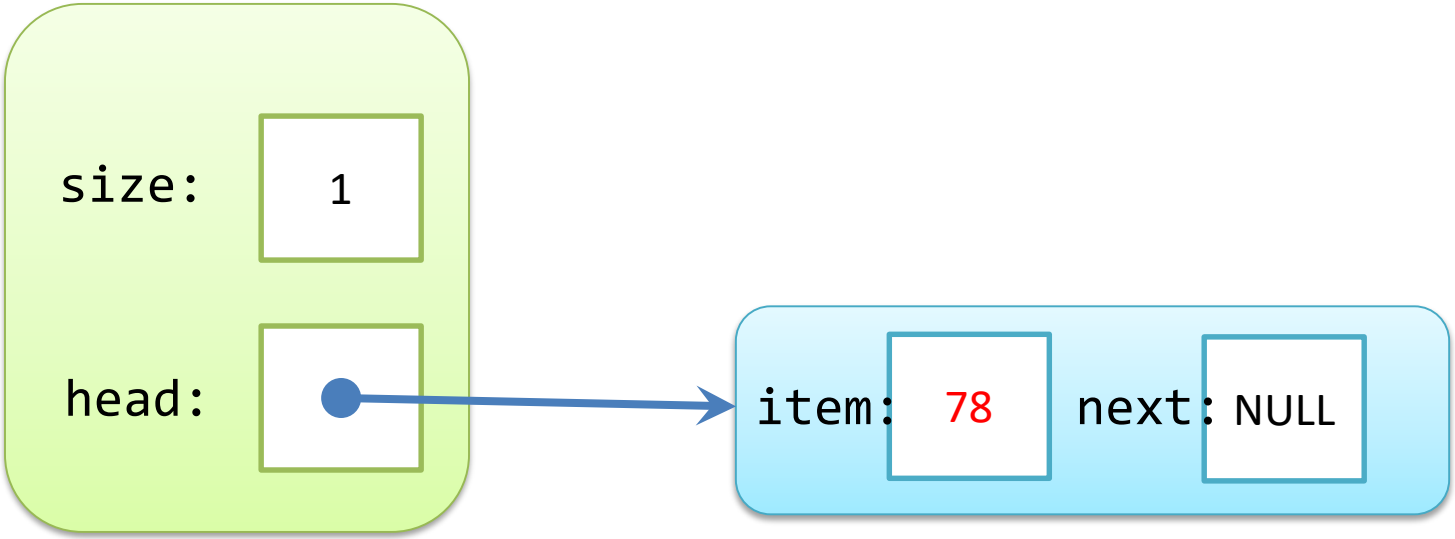
```
class List {
private:
   int size;
   ListNode *head;
public:
   List();
   insert(int);

};
```

Insert(): Goal

- From:



- To:

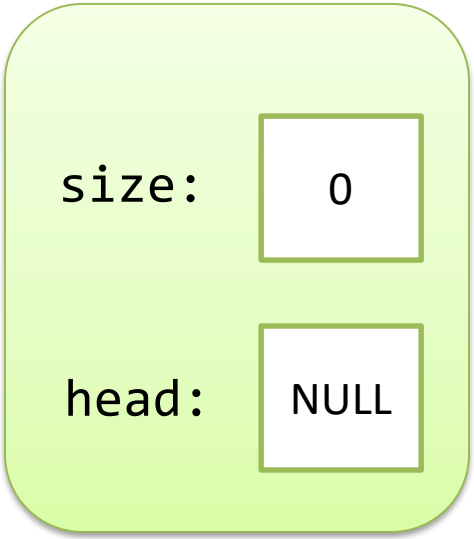


Coupling in Trains

https://www.youtube.com/watch?v=oYkugeI2zFI

Step 1

- Create a ListNode



Constructor for ListNode

```
class ListNode {
private:
   int item;
   ListNode *next;
public:
   ListNode(int);

};
```

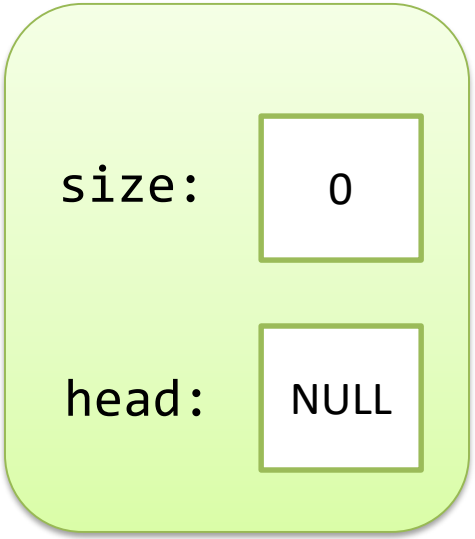
```
ListNode::ListNode(int n)
{
   item = n;
   next = NULL;
}
```

Step 1

- Create a ListNode by

```
aNewNode = new ListNode(78)
```

- This will call the constructor with 78 as a parameter



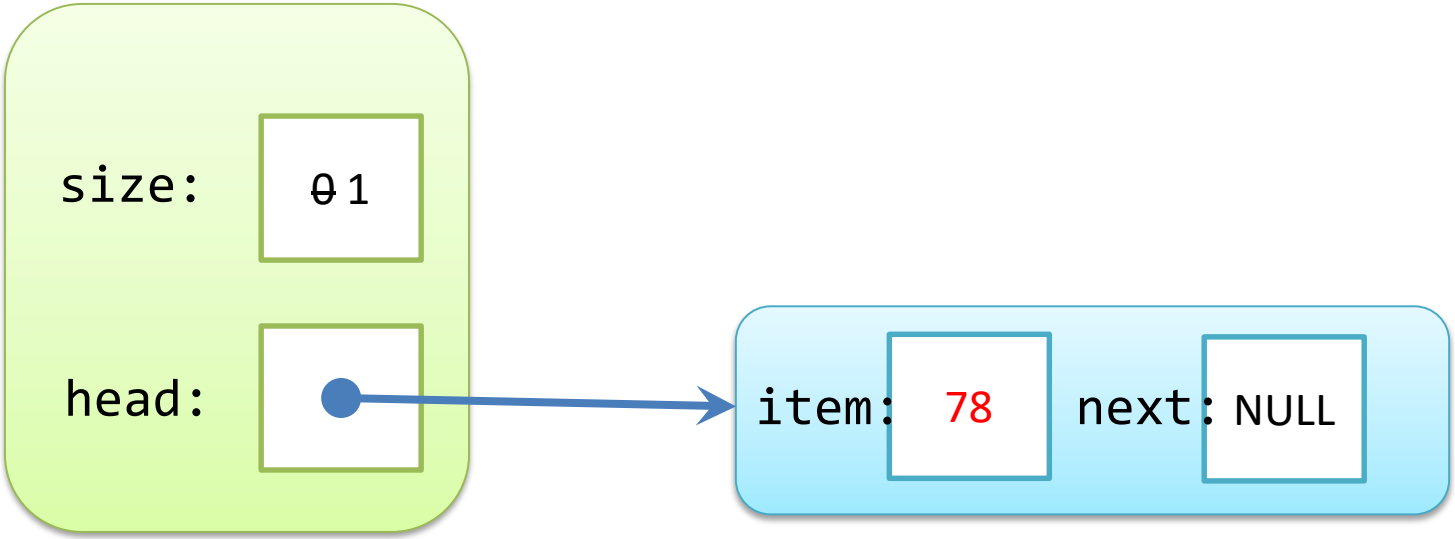
Step 2

- Connect the new node to “head”

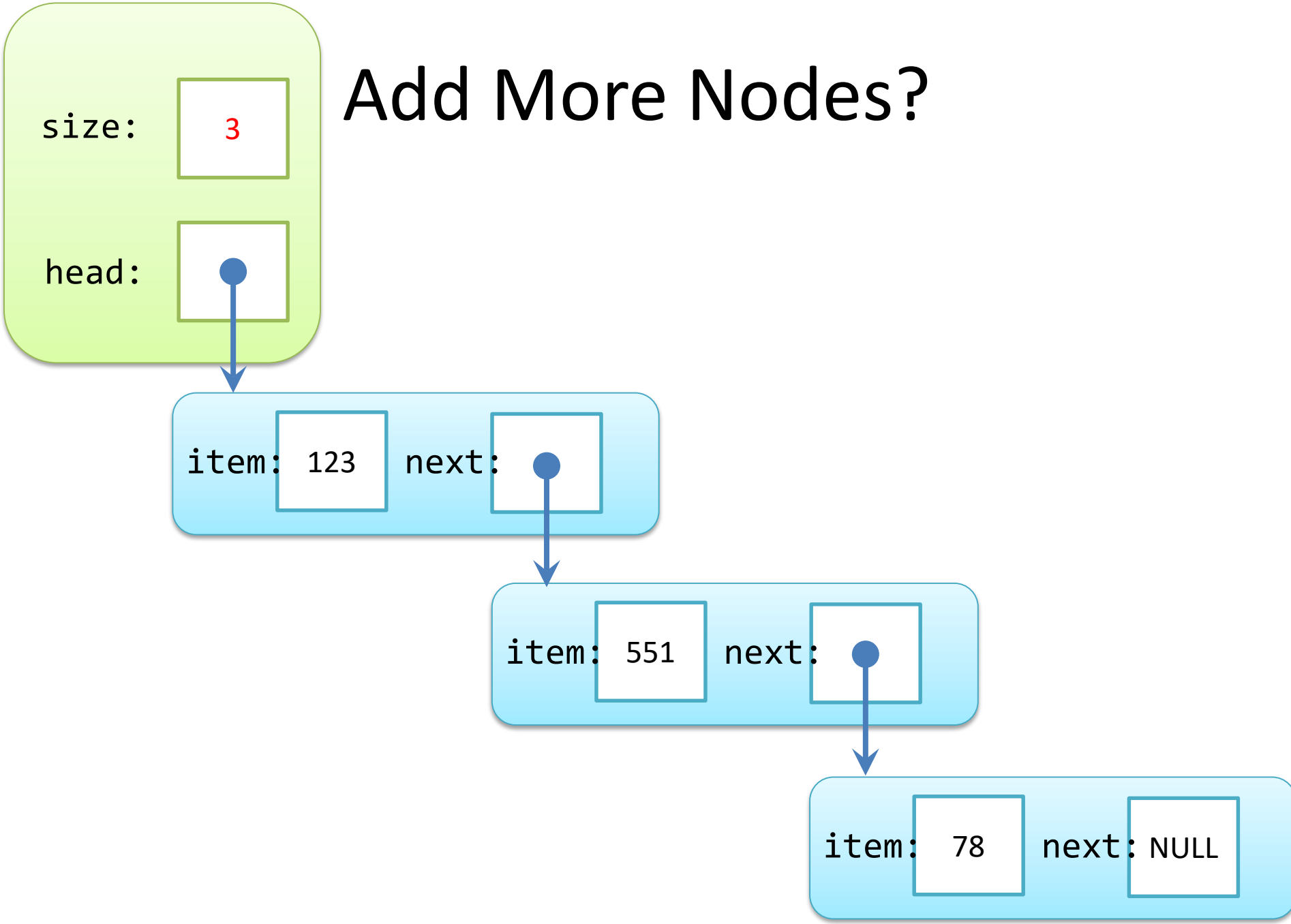
```
head = aNewNode
```

- And increment size by 1

```
size++;
```

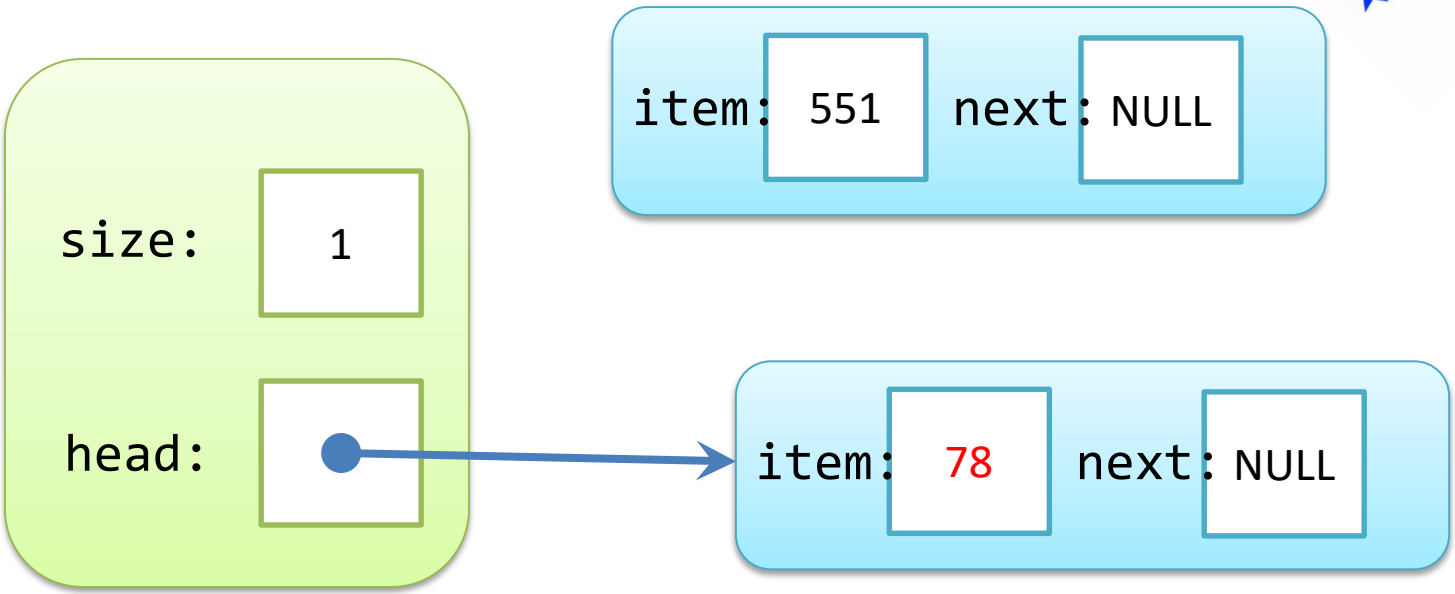


Add More Nodes?



Add More Nodes

- Same thing, create a node by “new”
- But how to connect them?



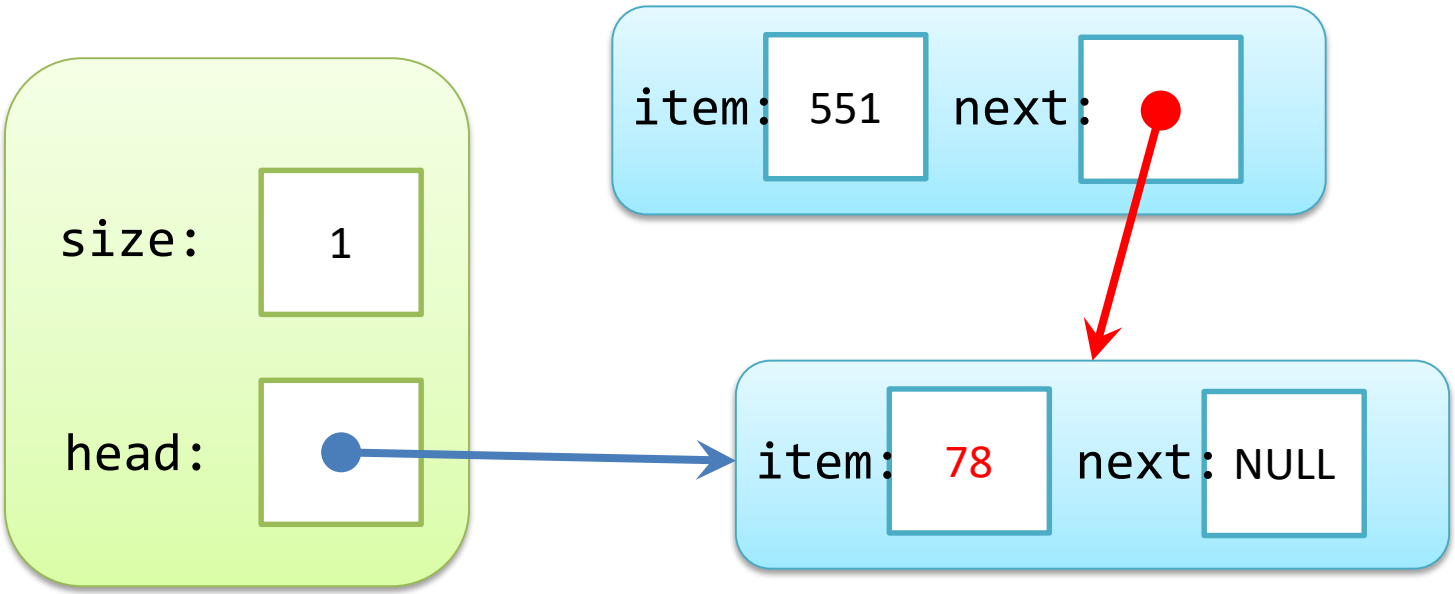
Inserting a Node

- Step 1: Create a new node by “new”

```
ListNode* aNewNode = new ListNode(551);
```

- Step 2: Point the new node TO the first node

```
aNewNode->next = head;
```

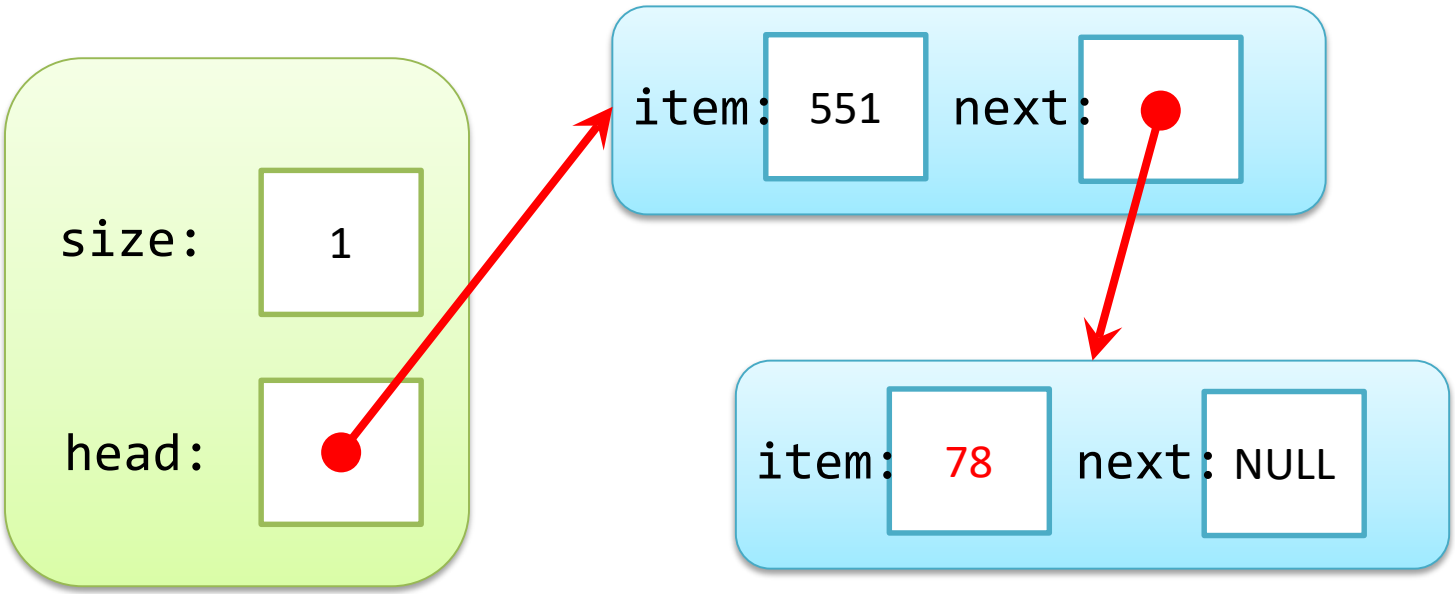


Inserting a Node

- Step 3: Point the head TO the new node

```
head = aNewnode;
```

- Step 4: Increase “size” by 1



Linked List in C++

```
class ListNode {
private:
  int item;
  ListNode *next;
```

More to come

```
};
```

```
class List {
private:
  int size;
  ListNode *head;
```

More to come

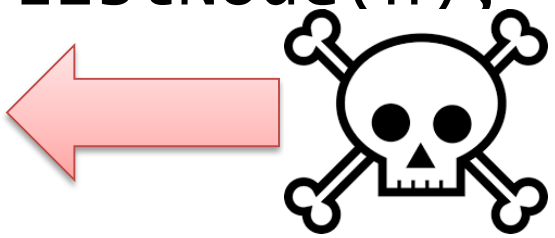
```
};
```

Linked List in C++

```
class List {
private:
   int size;
   ListNode *head;
public:
   List();
   void insert(int);

};
```

Four Steps of Insertion

```
void List::insert(int n) {
   ListNode *aNewNode = new ListNode(n);
   aNewNode->next = head;
   head = aNewNode;
   size++;
}
```



“next” is a **Private** Member of `ListNode`!

```
void List::insert(int n) {
  aNewNode = new ListNode(n);
  aNewNode->next = head;
  head = aNewNode;
  size++;
}
```


```
class ListNode {
private:
  int item;
  ListNode *next;
public:
  ListNode(int);

};
```

What Can We Do?

- Simply change `ListNode::next` to *public*
  - Then anyone can access it!

- Create another function `ListNode::setNext()` to allow changing of the pointer

```
ListNode::setNext(ListNode *ptr) {
  next = ptr;
}
```

  - Same as above!!

Maintain a Special Relationship

- Create a "relationship" such that class `List` can access "`next`" inside `ListNode`

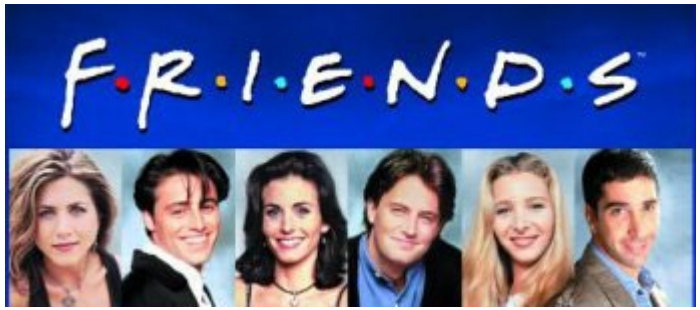
```
void List::insert(int n) {
  aNewNode = new ListNode(n);
  aNewNode->next = head;
  head = aNewNode;
  size++;
}
```

```
class ListNode {
private:
  int item;
  ListNode *next;
public:
  ListNode(int);

};
```

“friend” in C++

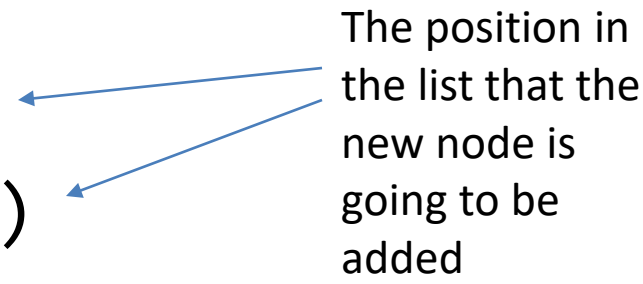
- Allow other class to access its private members or methods

```
class ListNode {
  private:
    int item;
    ListNode *next;
  public:
    ListNode(int);
  friend class List;
};
```



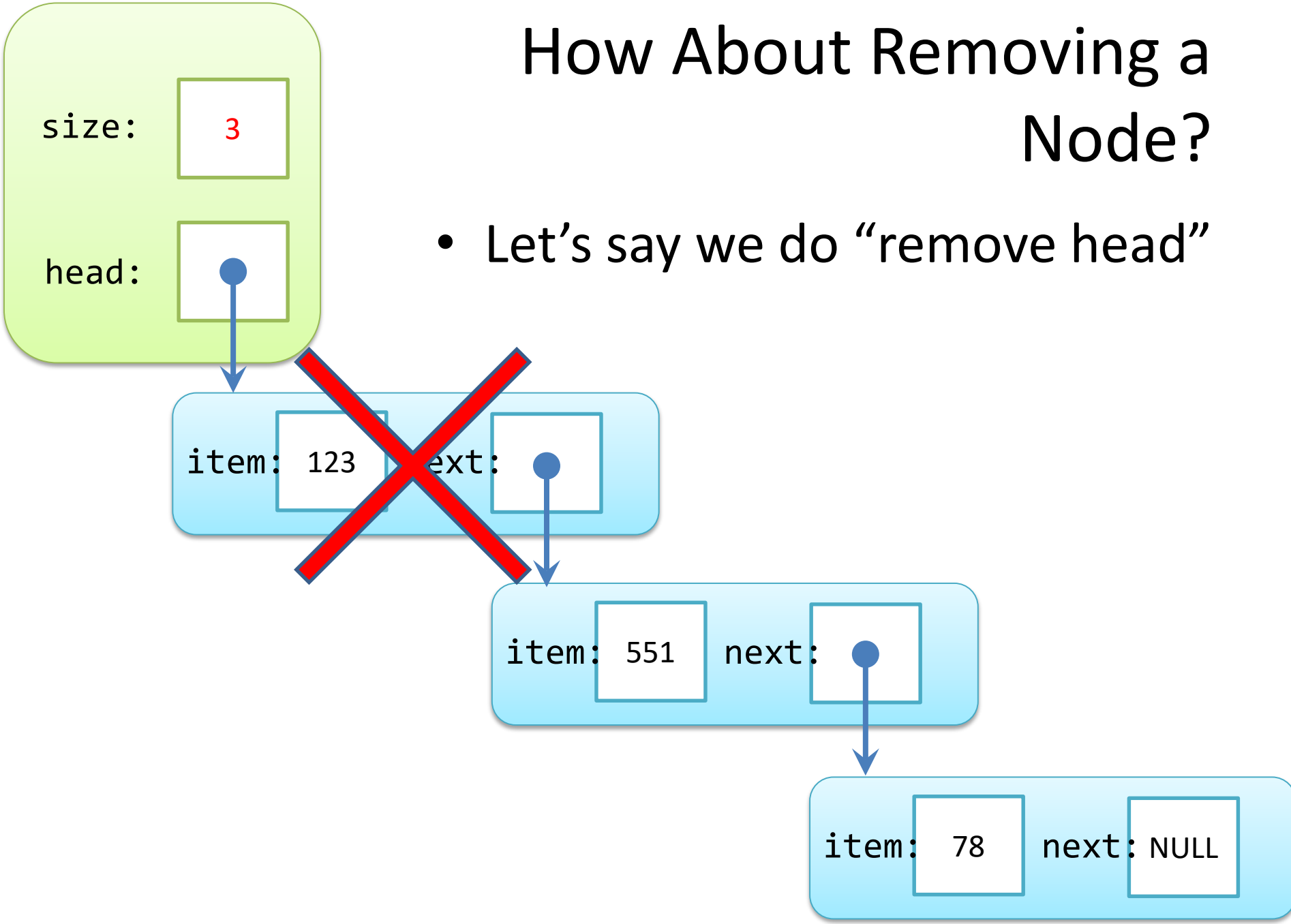
Other Insertions

- The insertion that we have covered is actually:
  - `insertAtHead()`
- There are other varieties
  - `insertAtTail()`
  - `insertAtPos(int)`
  - `insertAtAfter(int)`



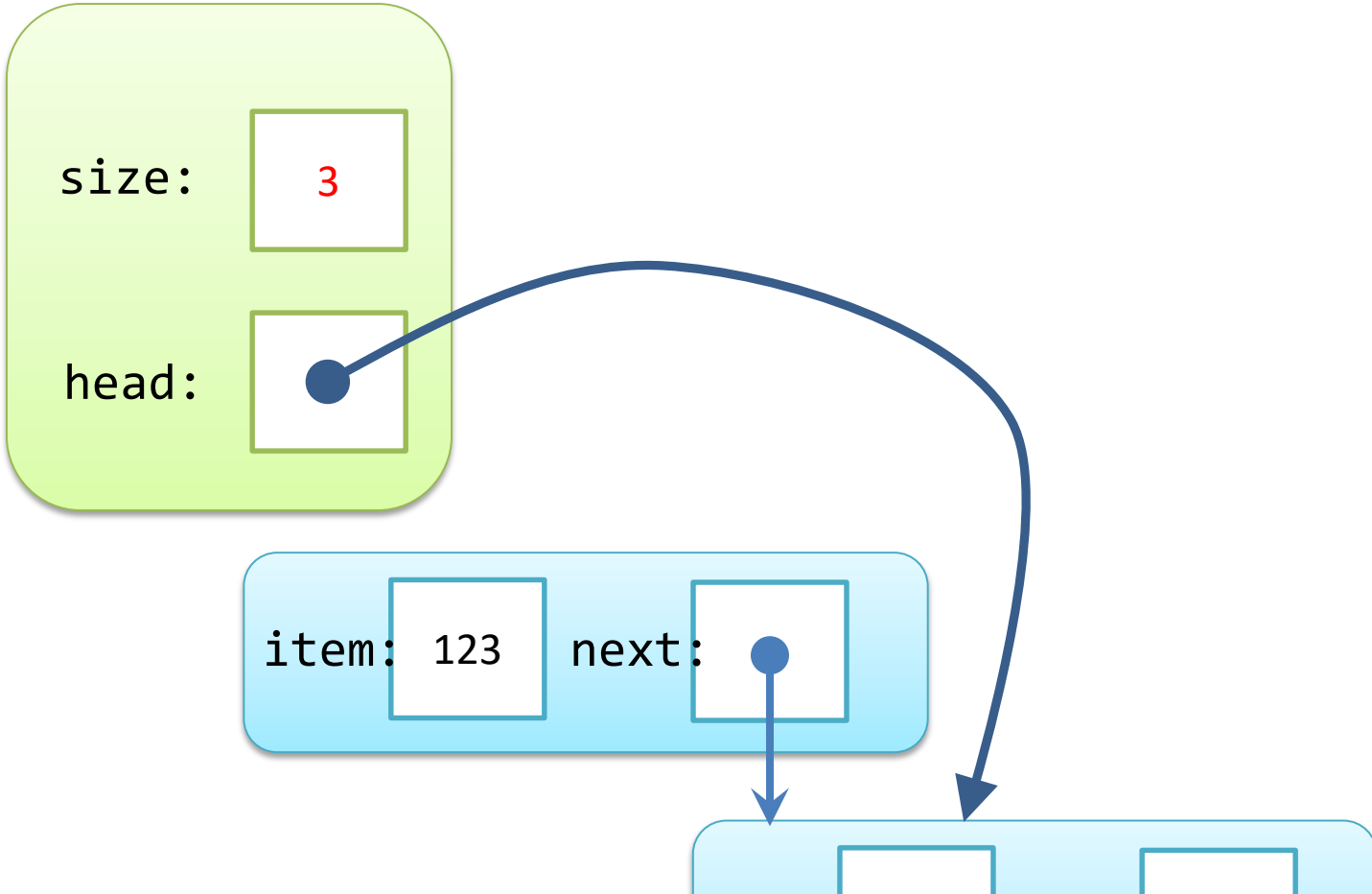
How About Removing a Node?

- Let's say we do "remove head"



Remove Head

- How about: `head = head->next;`

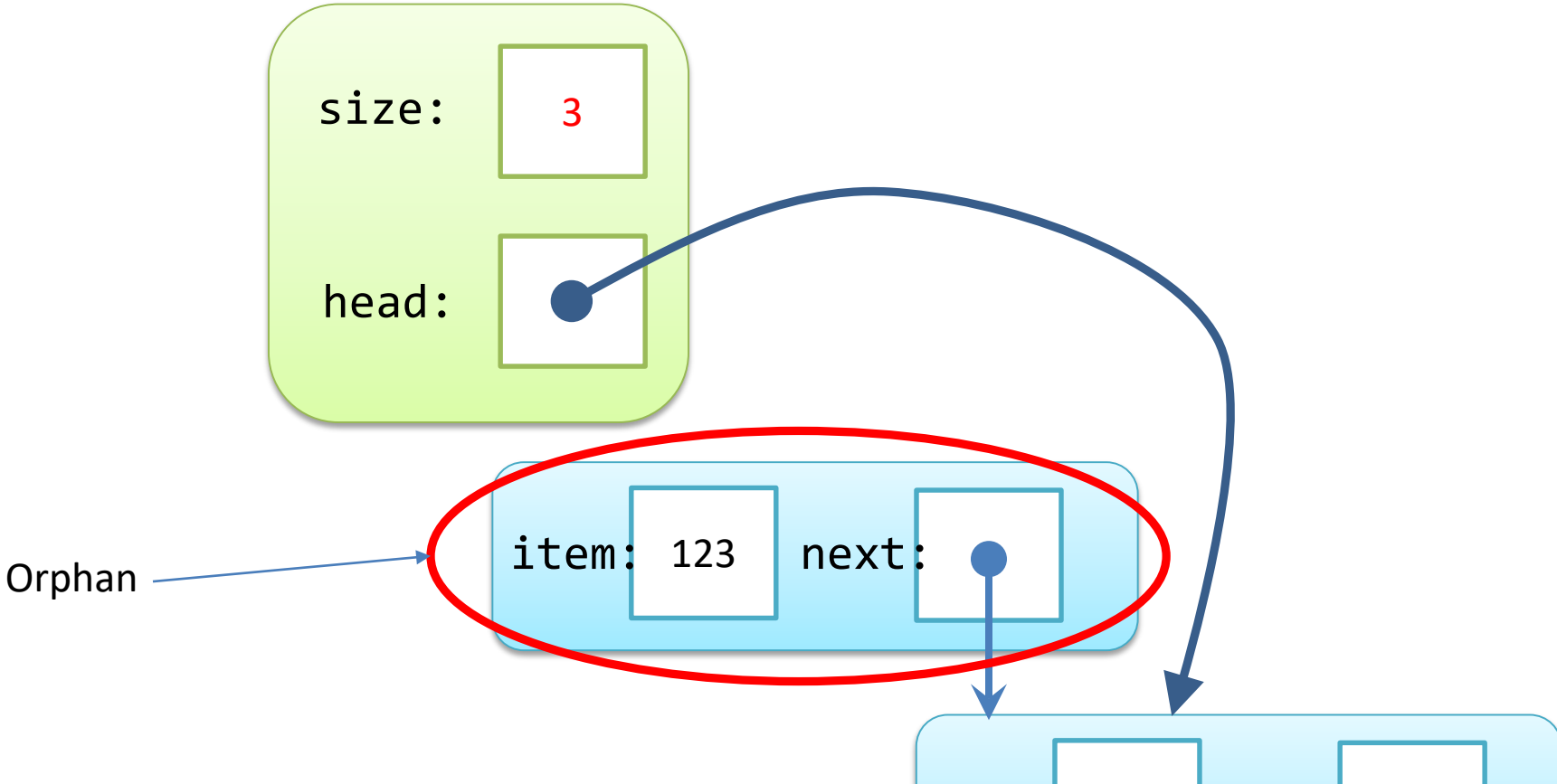


Remove Head

- How about: `head = head->next;`
- Problem?
  - What if the list is empty and we called “remove”?
  - Even if it’s not empty, what happens to the first node?

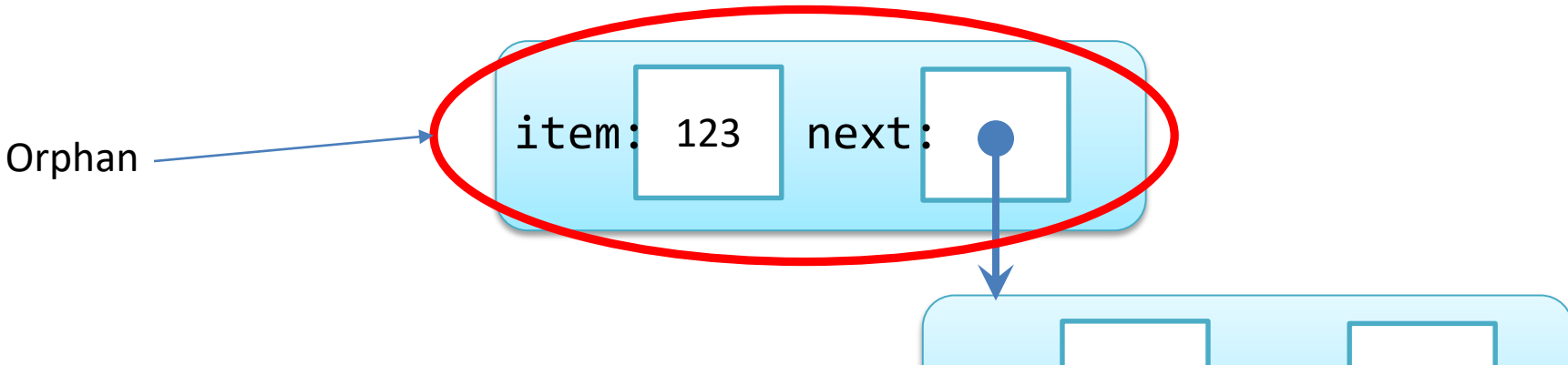
Orphan

- An object created by new, is only accessible when there is a pointer pointing to it



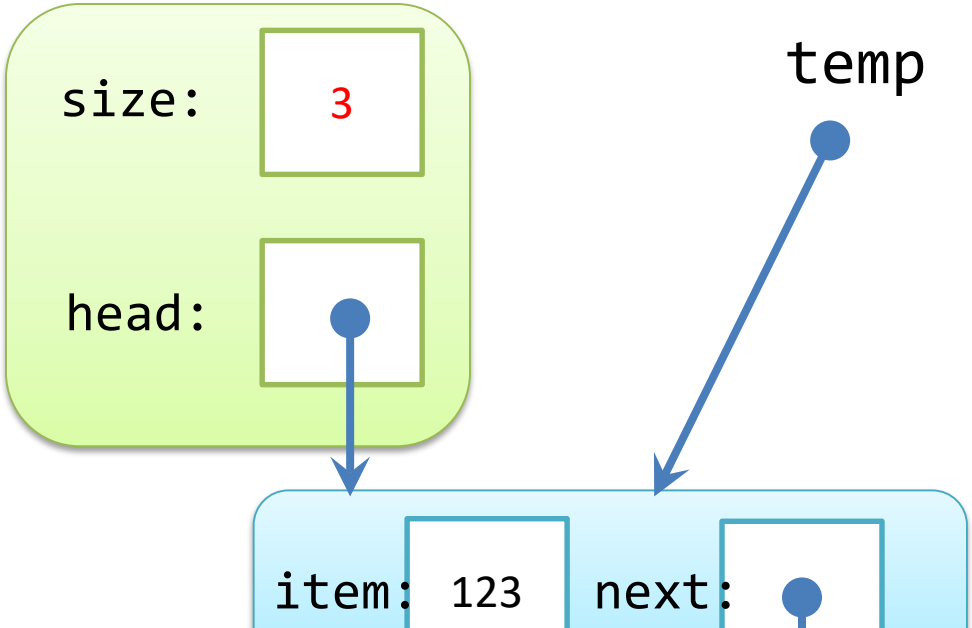
Orphan

- An object created by new, is only accessible when there is a pointer pointing to it
- And even it will not be used anymore, you should delete it
  - Otherwise: Memory Leak



Remove Head

- So, BEFORE: `head = head->next;`
- Create a temporary pointer pointing to the first node
  - `ListNode *temp = head;`



Remove Head Node

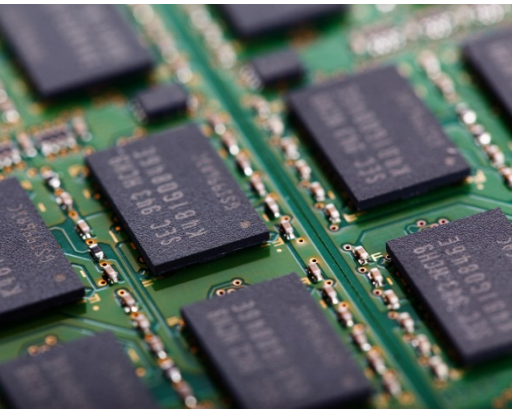
```
void List::removeHead() {
   if(size > 0) {
      ListNode *temp = head;
      head = head->next;
      delete temp;
      size--;
   } else
     // what should we do?
}
```

How

When you use “new”, you “chop” a place in the memory by yourself, instead of automatically, e.g

```
new int;
```

Address	Content
ffbff7db	
ffbff7dc	?
ffbff7dd	
ffbff7de	
ffbff7df	
ffbff7e0	
ffbff7e1	
ffbff7e2	

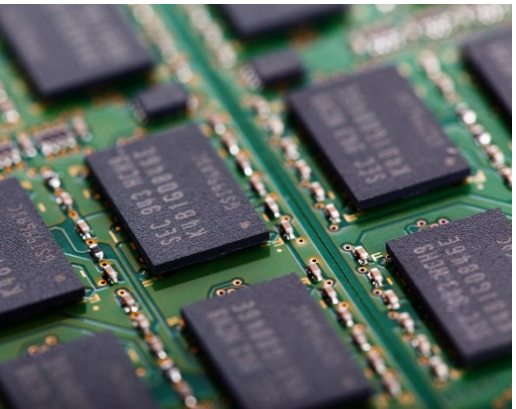


How

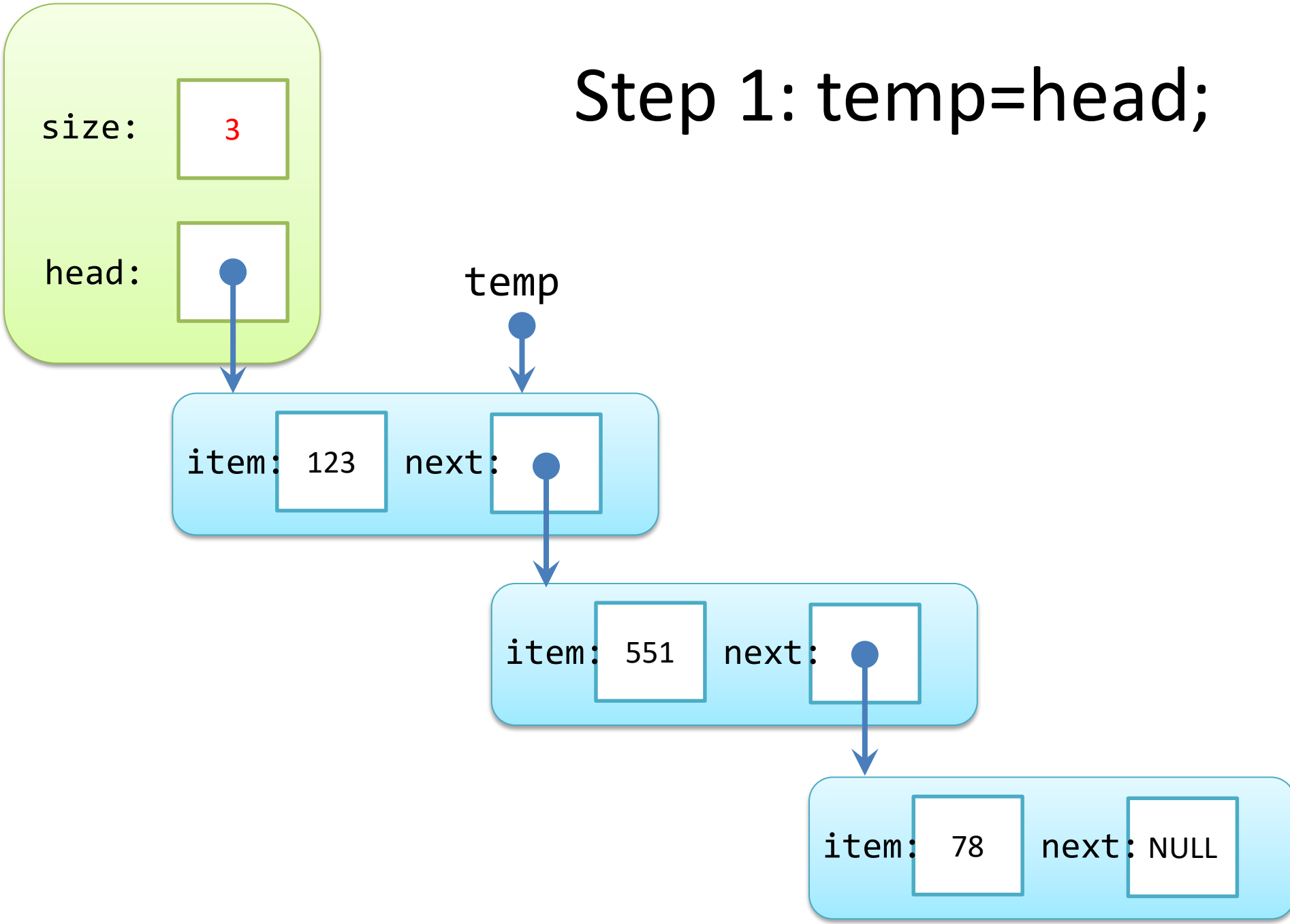
When you use “delete”, you “free” a place in the memory by yourself, instead of automatically, e.g

```
delete temp;
```

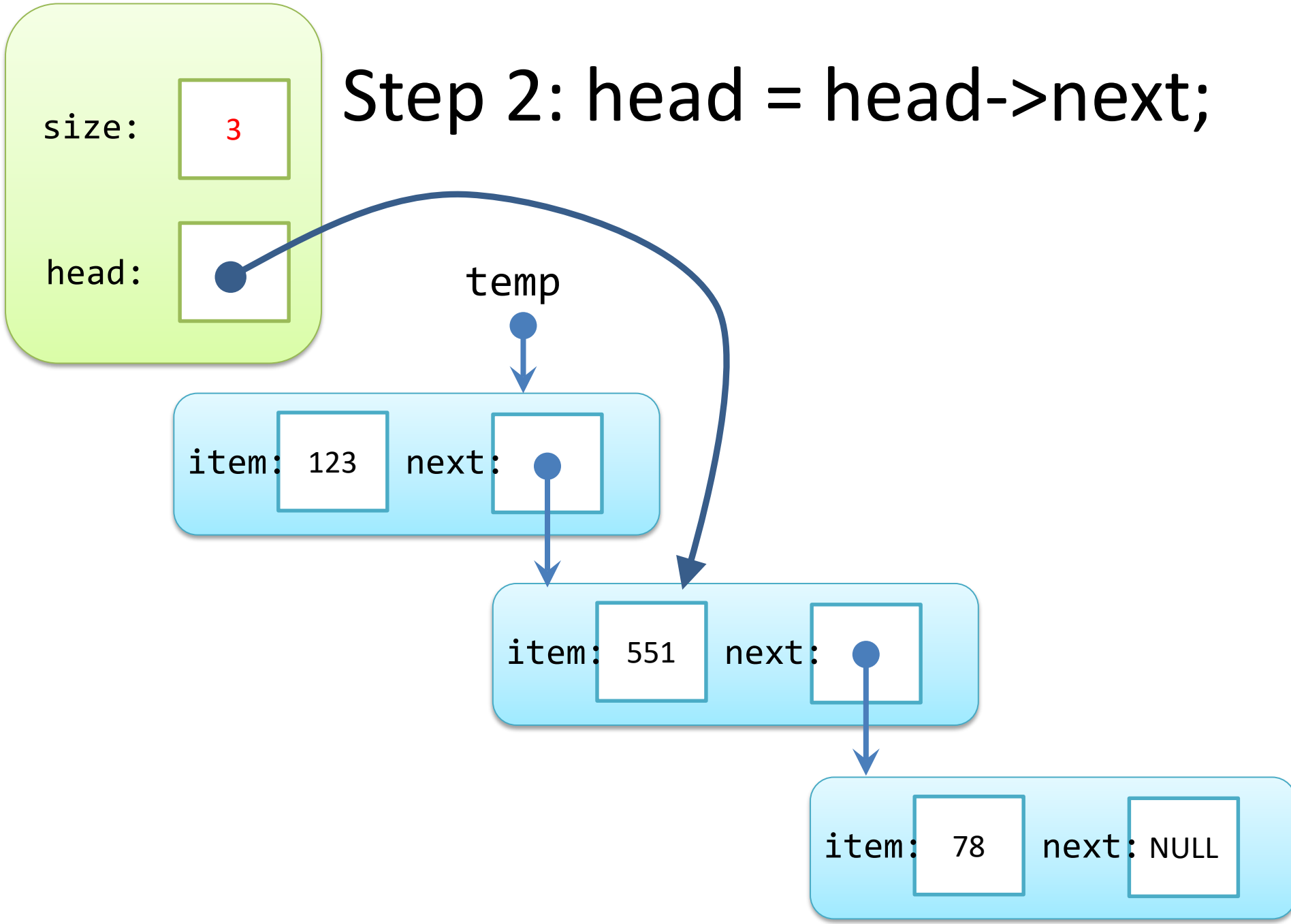
Address	Content
ffbff7db	
ffbff7dc	?
ffbff7dd	
ffbff7de	
ffbff7df	
ffbff7e0	
ffbff7e1	
ffbff7e2	



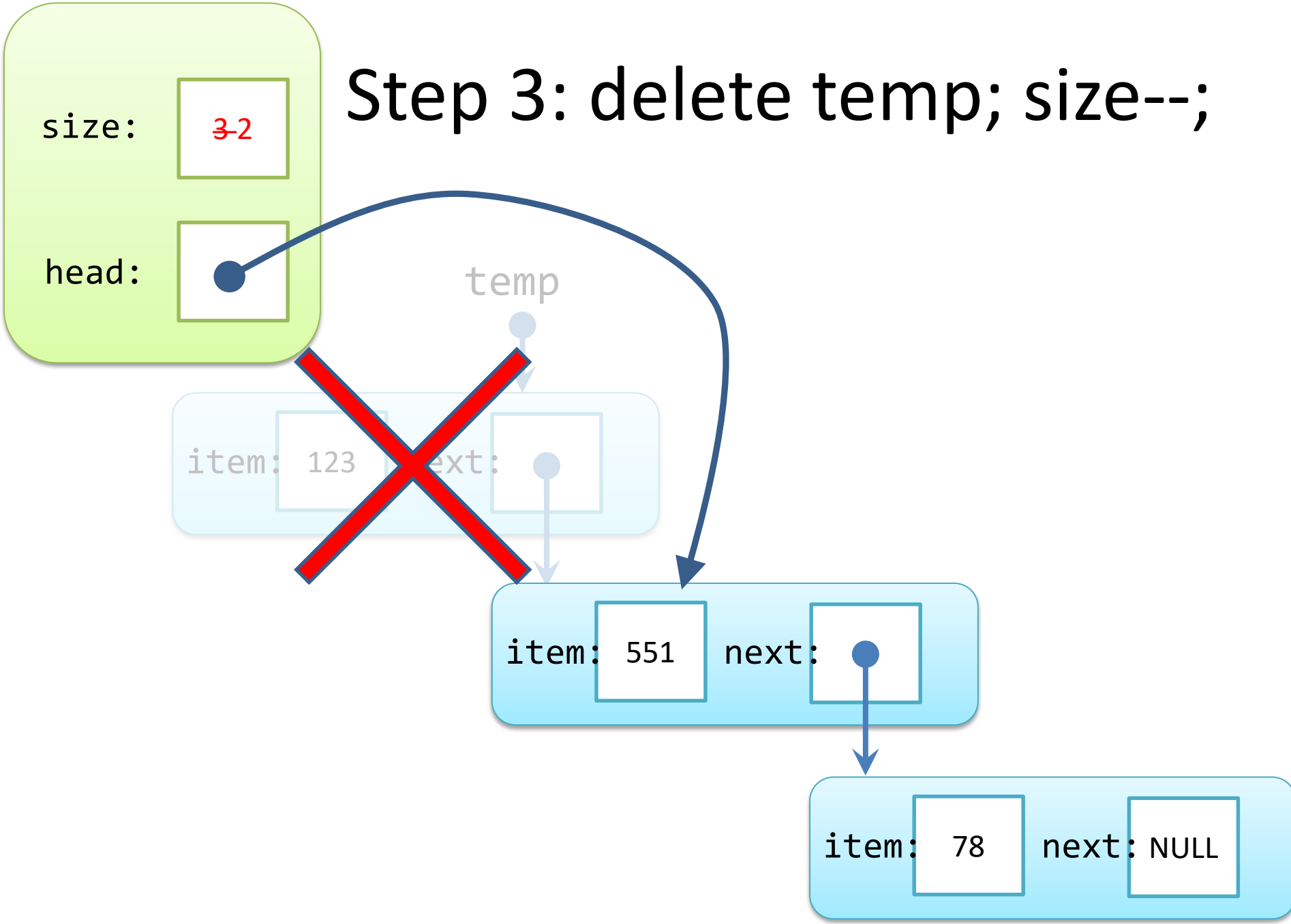
Step 1: temp=head;



Step 2: head = head->next;



Step 3: delete temp; size--;



What If size==0 When We Remove?

- Terminate program

- Print an error message

- Handle the error

Garbage Collection

- Because the node are created (new) by the class List
- When the instance is destroyed, the nodes created will not be deleted automatically
  - Thus, a lot of orphans
- We should delete them when an instance of List is delete
  - By Destructor

Destructor

- The Constructor of a class is called when an instance of the class is created
- The Destructor will be called when an instance of the class is deleted

Destructor

```
class List {
private:
  int size;
  ListNode *head;
public:
  List();
  ~List();
  void insert(int);
  void removeHead();
};
```

```
List::~List() {
  while(size!=0)
    removeHead();
}
```

Other Variations of Removal

- `removeAtTail`
- `removePos(int)`
- `removeItem(int)`

Why We Use Linked List?

- We can store arbitrarily many elements dynamically
  - Just the right amount of memory we need
- Each insertion is fast!
  - No matter how many items you stored already
- There are other issues we haven't talked about yet, e.g. how to search/access the data

Admin

- You should be able to access
  - Coursemology
  - Archipalego
- Homework 1 starts next week
- Tutorials will start at Week 4