Data Structures
Chapter 4

1. Singly Linked List
2. Doubly Linked List
   - **Revisit – Singly Linked List**
   - **Sentinel Nodes & Basic Operations**
   - Two Key Operations: erase, insert
   - Advanced Operations

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우리가 알거니와 하나님을 사랑하는 자 곧 그의 뜻대로 부르심을 입은 자들에겐 모든 것이 합력하여 선을 이루느니라 (롬8:28)

And we know that in all things God works for the good of those who love him, who have been called according to his purpose. (Rom8:28)

하나님이 우리를 구원하사 거룩하신 소명으로 부르심은 우리의 행위대로 하심이 아니요 오직 자기의 뜻과 영원 전부터 그리스도 예수 안에서 우리에게 주신 은혜대로 하심이라 (딤후1:9)

A Node and List Data Structure with Constructor and Destructor

```
struct Node {
  int     data;
  Node*   prev;
  Node*   next;
};

struct List {
  Node*   head;
  Node*   tail;
  int     size; //optional
};
using pNode = Node*;
using pList = List*;
```

unused in singly linked list

```
struct Node {
  int     data;
  Node*   prev;
  Node*   next;
  Node(int d = 0, Node* p = nullptr,
                  Node* x = nullptr)
      { data = d; prev = p; next = x; }
  ~Node() {}
};

struct List {
  Node* head;
  Node* tail;
  int   size; // optional
  List() { head = new Node{}; tail = new Node{};
           head->next = tail; tail->prev = head;
           size = 0;
  }
  ~List() {}
};

using pNode = Node*;
using pList = List*;
```

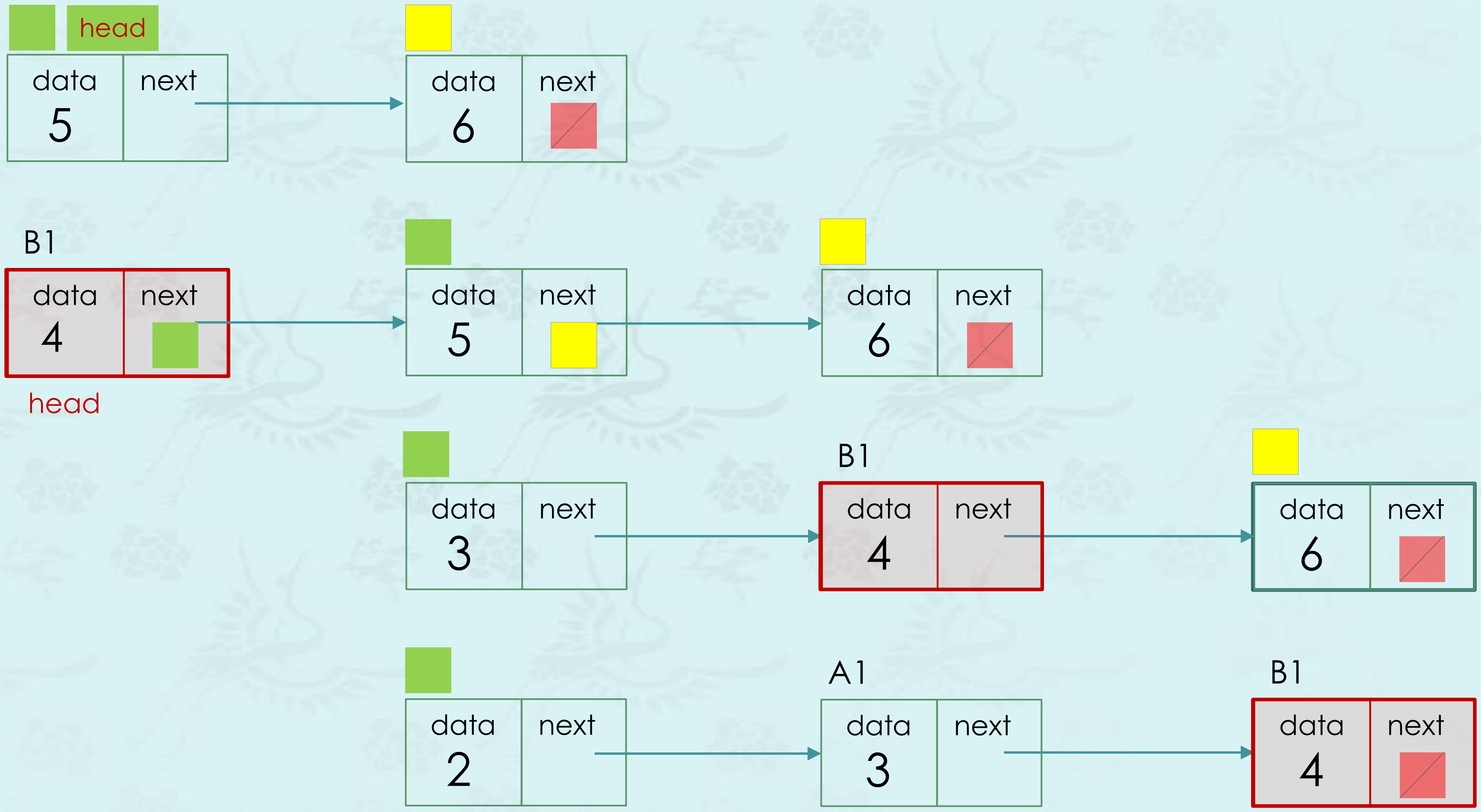
push a node – three different cases

Given: an data(4) to insert as sorted – What was the most difficult part of this coding?

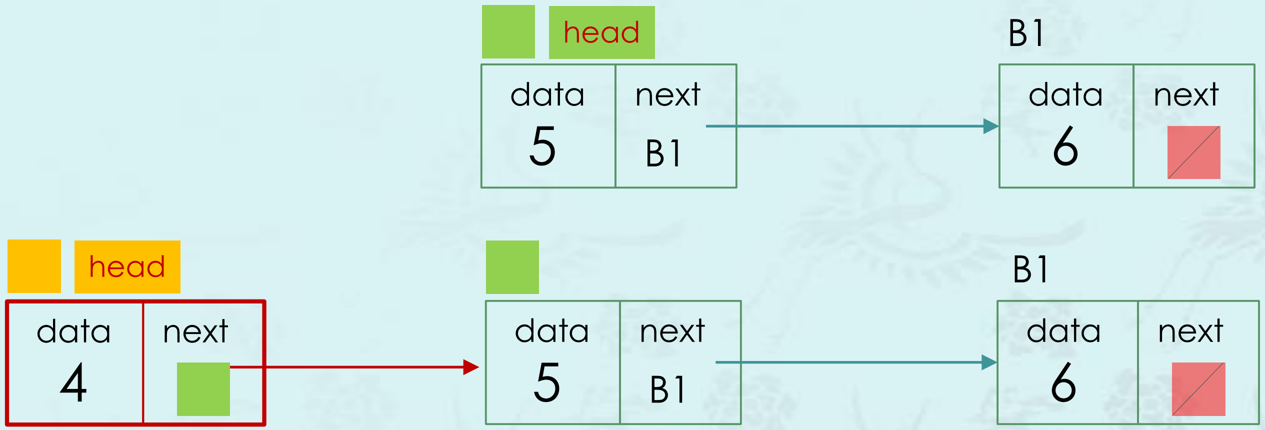
Case 1: in front

Case 2: in middle

Case 3: at end



push a node – **Case 1:** insert in front, head given



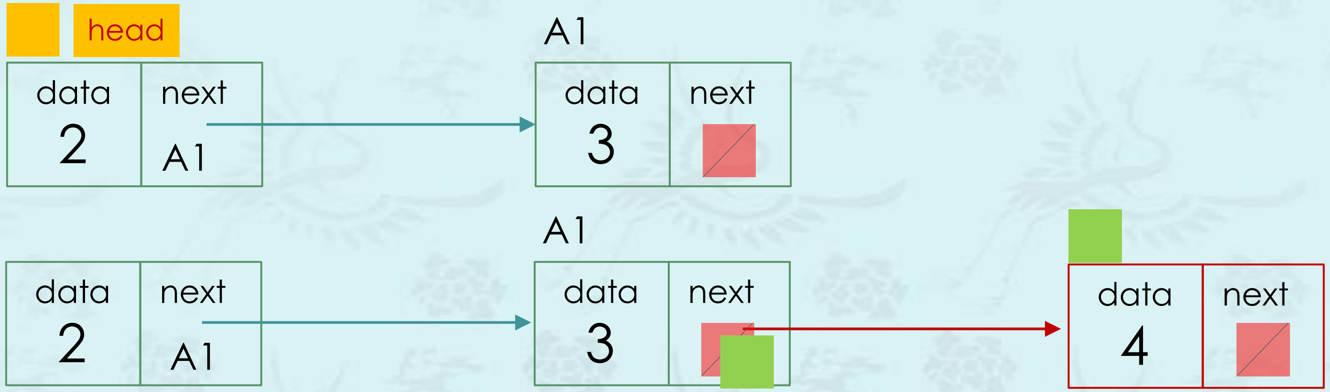

```
void push_front(pList p, int value) {
  p->head = new Node{value, p->head};
}
```

```
struct Node{
  int data;
  Node* next;
  Node(const int d = 0, pNode x = nullptr){
    data = d;        next = x;
  }
  ~Node() {}
};
```

```
struct List {
  Node*  head;
  Node*  tail;
  int    size; //optional
};
using pList = List*;
```

push a node – **Case 3;** insert at end, head given

Append a new Node{4}; then find the last node first to append.

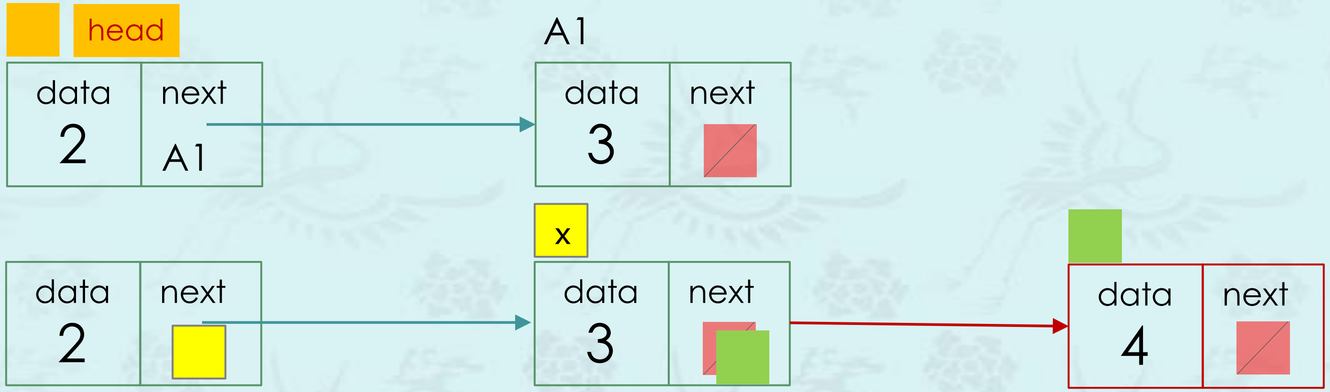



```
void push_back(pList p, int value) {

}
```

push a node – **Case 3;** insert at end, head given

Append a new Node{4}; then find the last node first to append.



O(n)

```
void push_back(pList p, int value) {
  pNode x = last(p->head);
  x->next = new Node{ value, nullptr };
}
```

```
pNode last(pNode head) {
  pNode x = head;
  while (x->next != nullptr)
    x = x->next;
  return x;
}
```

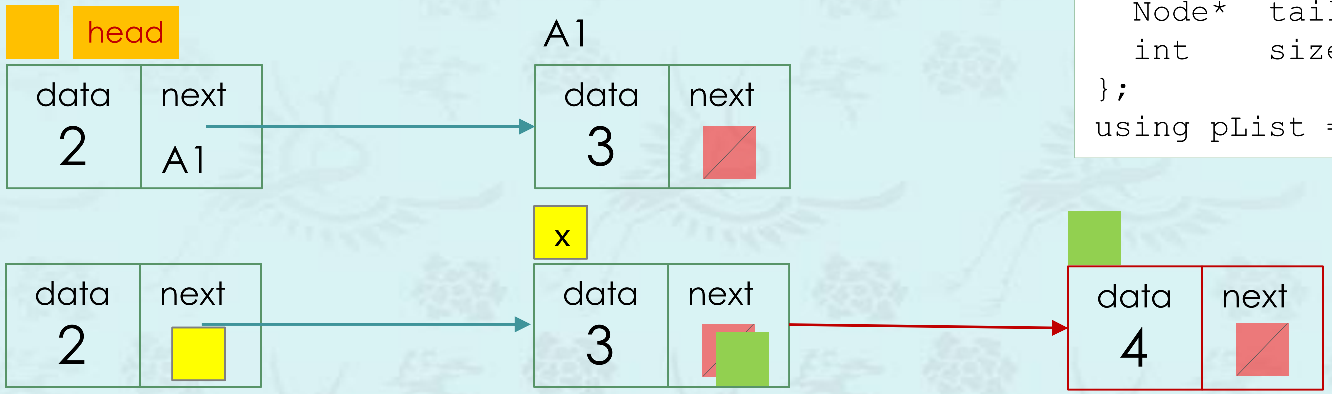
need this or not?

```
  while (head->next != nullptr)
    head = head->next;
  return head;
```

OK

push a node – **Case 3**; insert at end, head given

Append a new Node{4}; then find the last node first to append.




```
struct List {
  Node*  head;
  Node*  tail;
  int    size; //optional
};
using pList = List*;
```

O(n)

```
void push_back(pList p, int value) {
  pNode x = last(p->head);
  x->next = new Node{ value, nullptr };
}
```

```
pNode last(pNode head) {
  while (head->next != nullptr)
    head = head->next;
  return head;
}
```

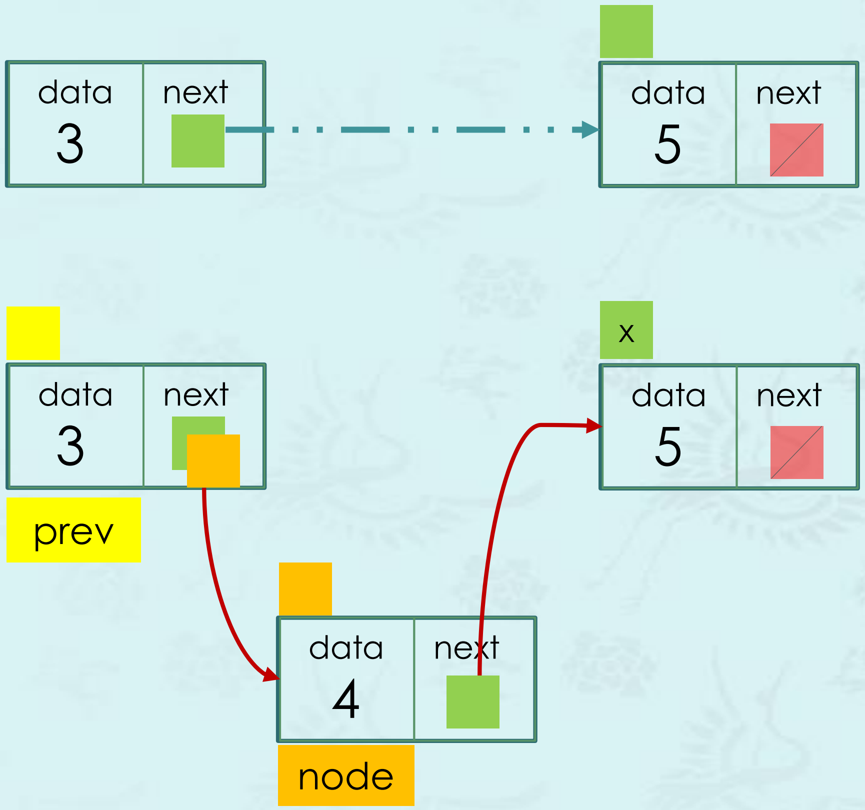
O(1)

```
void push_back(pList p, int value) {
  p->tail->next = new Node{ val };
  p->tail = p->tail->next;
}
```

it can be shortened

```
void push_back(pList p, int value) {
  p->tail = p->tail->next = new Node{ val };
}
```

push a node – **Case 2;** insert in middle, head given

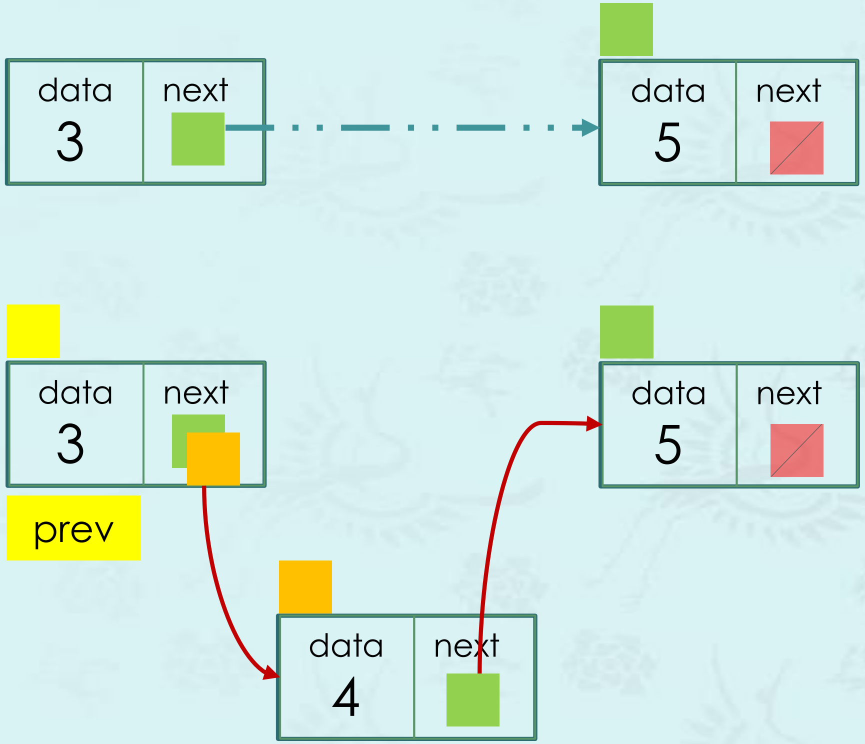



```
// inserts a node value at node z
void push_at(pList p, int value, int z) {
  if (empty(p) || (p->head->data == z) }
    return push_front(p, value);

  pNode x = p->head;
  pNode prev = nullptr;
  while (x != nullptr) {

    prev = x;
    x = x->next;
  }
}
```

push a node – **Case 2**; insert in middle, head given

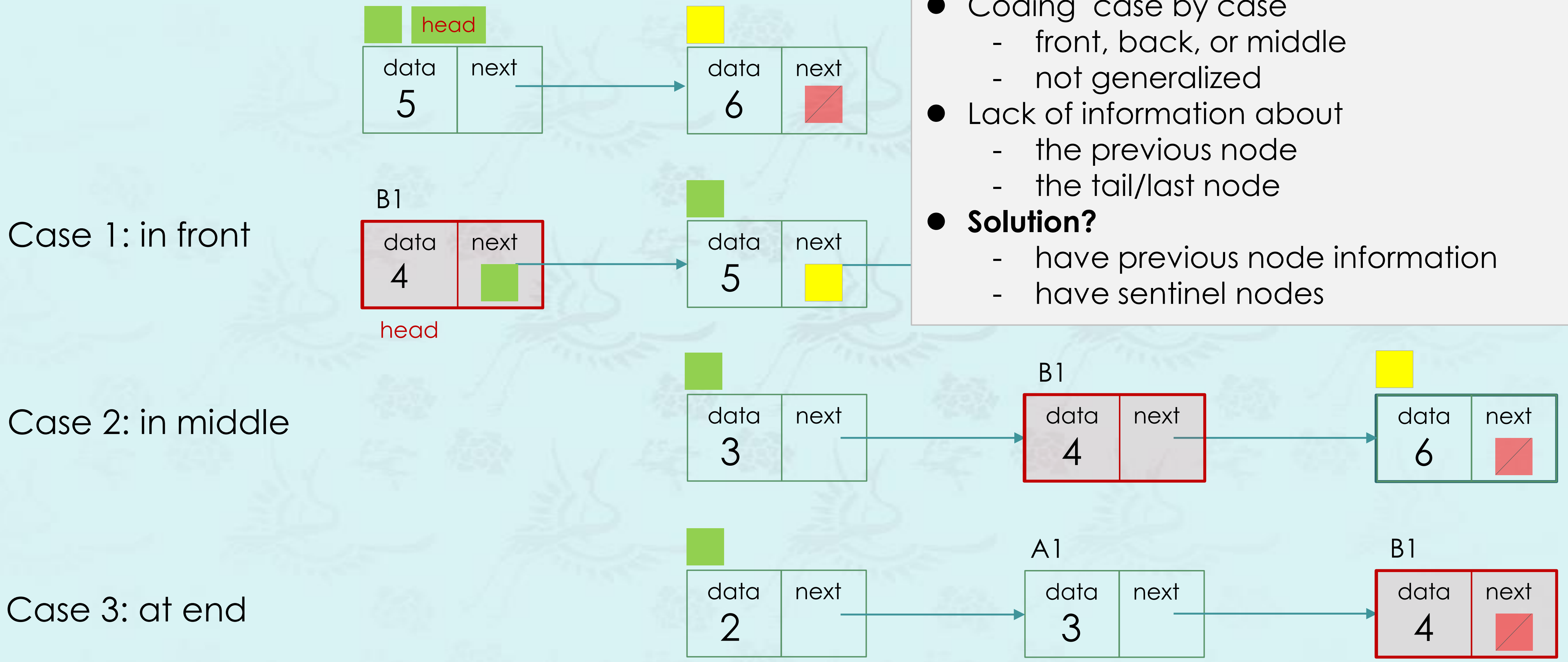



```
// inserts a node value at node z
void push_at(pList p, int value, int z) {
  if (empty(p) || (p->head->data == z) }
    return push_front(p, value);

  pNode x = p->head;
  pNode prev = nullptr;
  while (x != nullptr) {
    if (x->data == z) {
      prev->next = new Node{value, prev->next};
      return;
    }
    prev = x;
    x = x->next;
  }
}
```

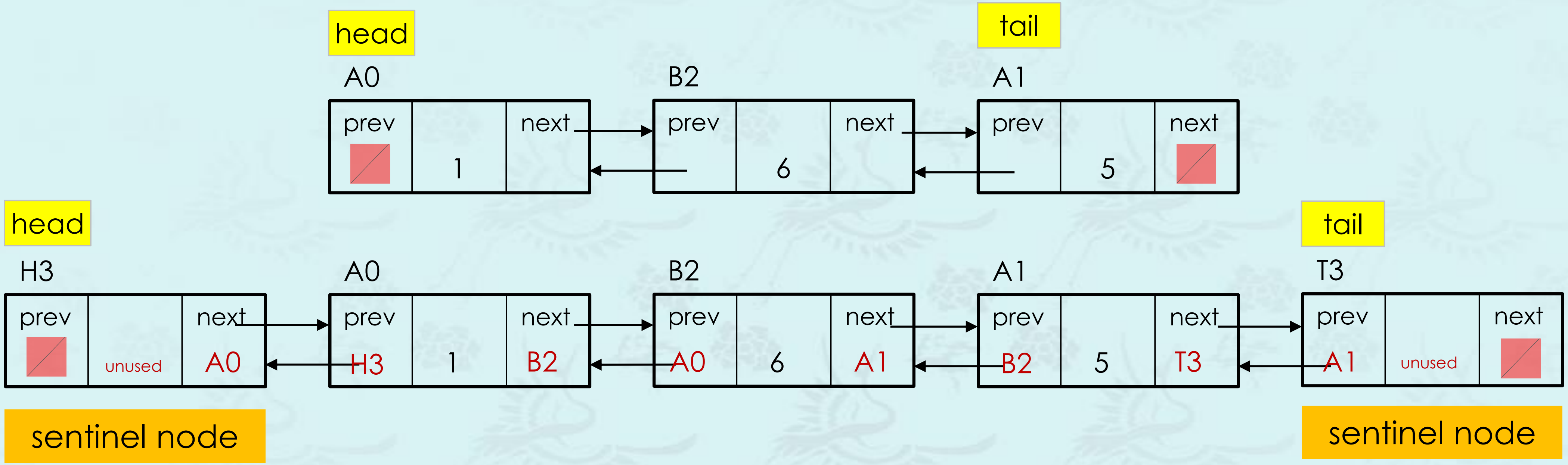
push a node – **Three different cases**

Given: an data(4) to insert – **What was the most difficult part of this coding?**



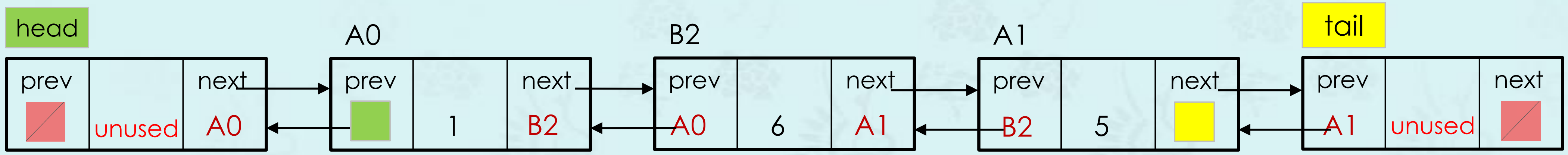
- Coding case by case
  - front, back, or middle
  - not generalized
- Lack of information about
  - the previous node
  - the tail/last node
- **Solution?**
  - have previous node information
  - have sentinel nodes

doubly linked list with sentinel nodes



- **Solution**
  - **doubly linked list with two sentinel nodes**
  - Each node carries the pointer to the previous node.
  - There is only one case (middle) with two sentinel nodes.

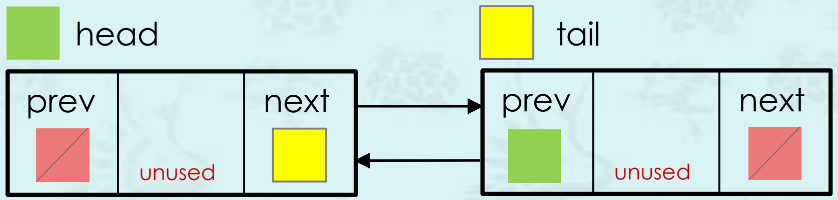
doubly linked list with sentinel nodes



- These extra nodes are known as **sentinel nodes.** The node at the front is known as **head node**, and the node at the end as a **tail node**. The head and tail nodes are created when the doubly linked list is initialized. The purpose of these nodes is to simply the insert, push/pop front and back, remove methods by eliminating all need for special-case code when the list empty, or when we insert at the head or tail of the list. This would **greatly** simplify the coding **unbelievably**.

- For instance, if we do not use a head node, then removing the first node becomes a special case, because we must reset the list's link to **the first node** during the remove and because the remove algorithm in general needs to access the node prior to the node being removed (and without a head node, the first node does not have a node prior to it).

doubly linked list with sentinel nodes



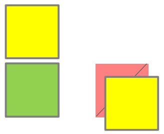
An **empty** doubly linked list with sentinel nodes

Initializing doubly linked list with sentinel nodes

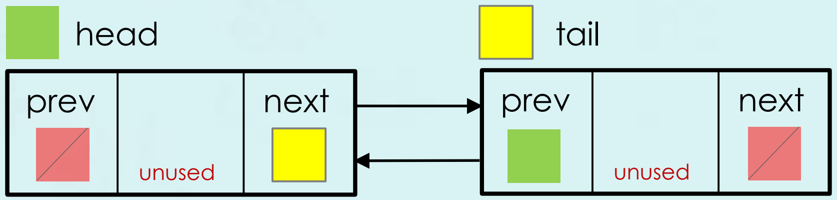
```
struct Node {
  int     data;
  Node*   prev;
  Node*   next;
};

struct List {
  Node*   head;  //sentinel
  Node*   tail;  //sentinel
  int     size;  //size of list, optional
  List() {

  }
  ~List() {}
};
using pNode = Node*;
using pList = List*;
```



An **empty** doubly-linked list with sentinel nodes



Initializing doubly linked list with sentinel nodes

```
struct Node {
  int     data;
  Node*   prev;
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};

struct List {
  Node*   head;  //sentinel
  Node*   tail;  //sentinel
  int     size;  //size of list, optional
  List() {
       tail = new Node{};

  }
  ~List() {}
};
using pNode = Node*;
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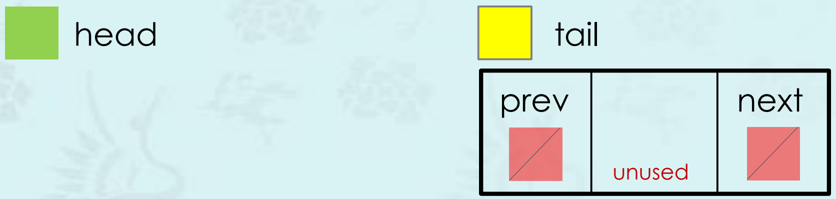

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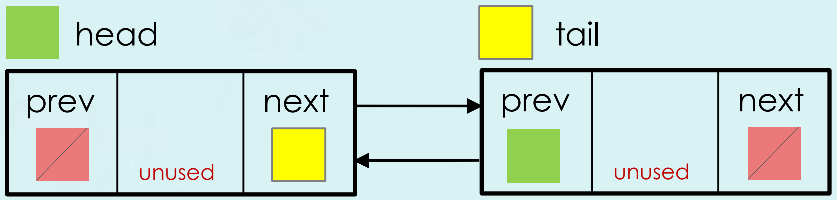

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};

struct List {
  Node*   head;  //sentinel
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  int     size;  //size of list, optional
  List() {
       tail = new Node{};
       head = new Node{0, nullptr, tail};

  }
  ~List() {}
};
using pNode = Node*;
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```

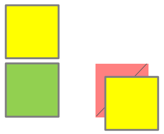

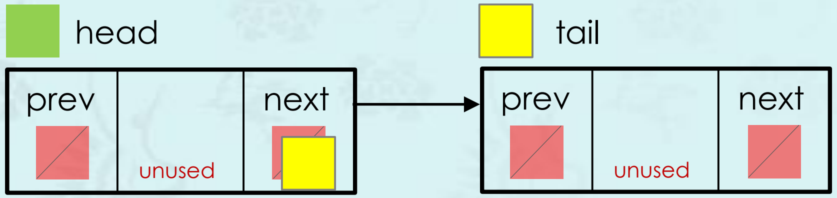

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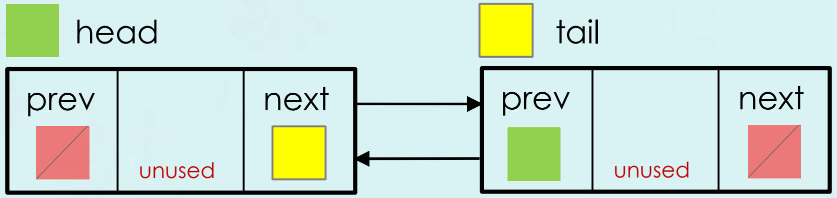

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  List() {
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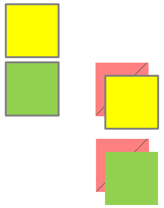
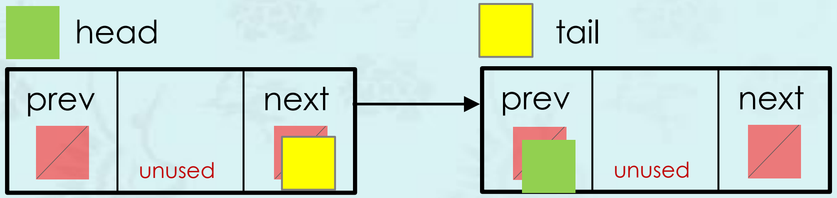
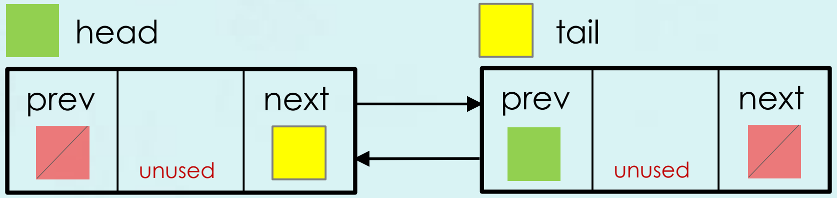




An **empty** doubly-linked list with sentinel nodes



Initializing doubly linked list with sentinel nodes

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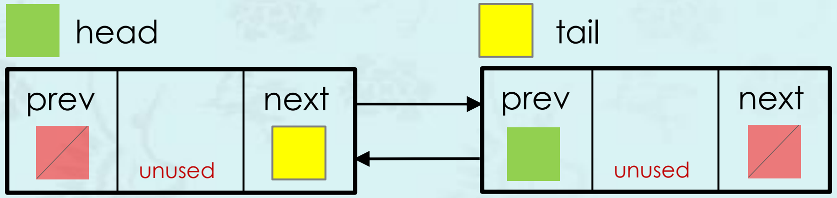
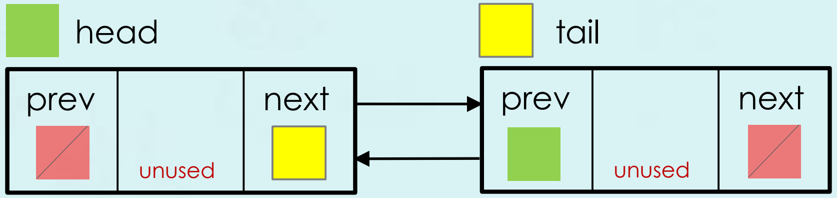
struct List {
  Node*   head;  //sentinel
  Node*   tail;  //sentinel
  int     size;  //size of list, optional
  List() {
       tail = new Node{};
       head = new Node{0, nullptr, tail};
       tail->prev = head;

  }
  ~List() {}
};
using pNode = Node*;
using pList = List*;
```



An **empty** doubly-linked list with sentinel nodes



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       tail = new Node{};
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       tail->prev = head;
       size = 0;
  }
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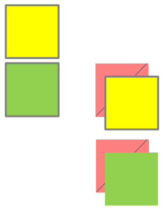
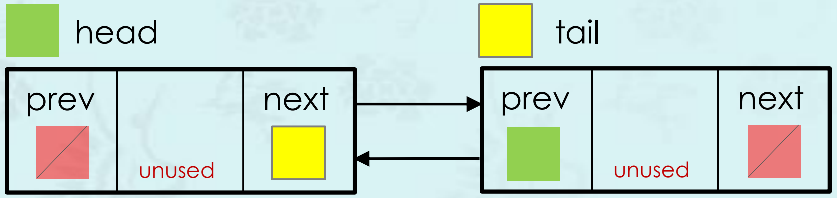
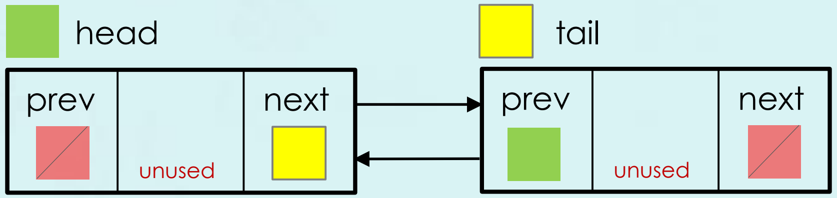




An **empty** doubly-linked list with sentinel nodes



Initializing doubly linked list with sentinel nodes

```
struct Node {
  int     data;
  Node*   prev;
  Node*   next;
  Node(const int d = 0, Node* p = nullptr, Node* x = nullptr) {
    data = d; prev = p; next = x;
  }
  ~Node() {}
};

struct List {
  Node* head;
  Node* tail;
  int   size; //size of list, optional
  List() {


  }
  ~List() {}
};

using pNode = Node*;
using pList = List*;
```

another way of doubly linked list initialization

head

tail

An **empty** doubly-linked list with sentinel nodes

Initializing doubly linked list with sentinel nodes

```
struct Node {
  int     data;
  Node*   prev;
  Node*   next;
  Node(const int d = 0, Node* p = nullptr, Node* x = nullptr) {
    data = d; prev = p; next = x;
  }
  ~Node() {}
};

struct List {
  Node* head;
  Node* tail;
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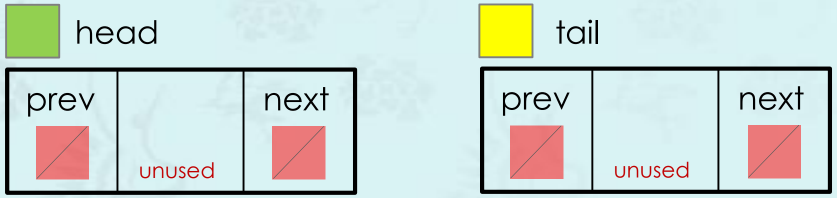
another way of doubly linked list initialization



An **empty** doubly-linked list with sentinel nodes

Initializing doubly linked list with sentinel nodes

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    data = d; prev = p; next = x;
  }
  ~Node() {}
};

struct List {
  Node* head;
  Node* tail;
  int   size; //size of list, optional
  List() { head = new Node{};    tail = new Node{};


  }
  ~List() {}
};

using pNode = Node*;
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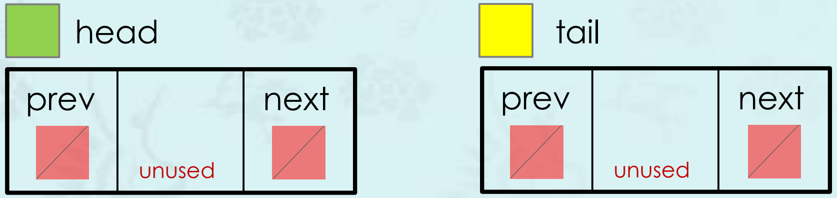
```

another way of doubly linked list initialization



An **empty** doubly-linked list with sentinel nodes

Initializing doubly linked list with sentinel nodes

```
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};

struct List {
  Node* head;
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  List() { head = new Node{};    tail = new Node{};

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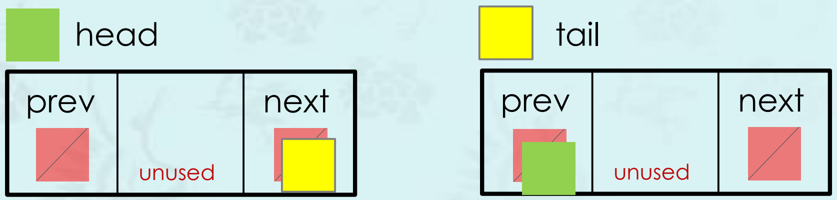
another way of doubly linked list initialization



An **empty** doubly-linked list with sentinel nodes

Initializing doubly linked list with sentinel nodes

```
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  Node(const int d = 0, Node* p = nullptr, Node* x = nullptr) {
    data = d; prev = p; next = x;
  }
  ~Node() {}
};

struct List {
  Node* head;
  Node* tail;
  int   size; //size of list, optional
  List() { head = new Node{};    tail = new Node{};
           head->next = tail;    tail->prev = head;

  }
  ~List() {}
};

using pNode = Node*;
using pList = List*;
```
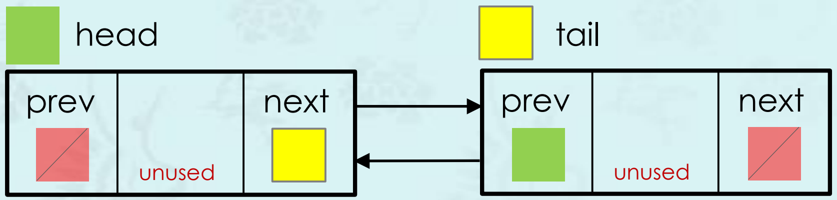

another way of doubly linked list initialization



An **empty** doubly-linked list with sentinel nodes

Initializing doubly linked list with sentinel nodes

```
struct Node {
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    data = d; prev = p; next = x;
  }
  ~Node() {}
};

struct List {
  Node* head;
  Node* tail;
  int   size; //size of list, optional
  List() { head = new Node{};    tail = new Node{};
           head->next = tail;    tail->prev = head;
           size = 0;
  }
  ~List() {}
};

using pNode = Node*;
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```
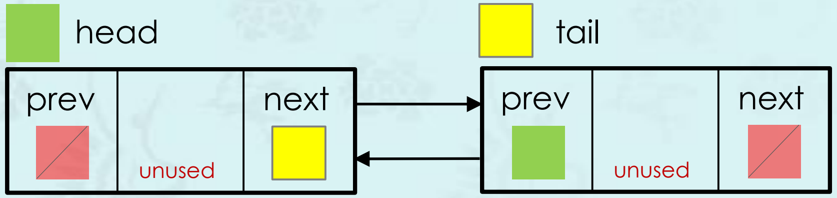
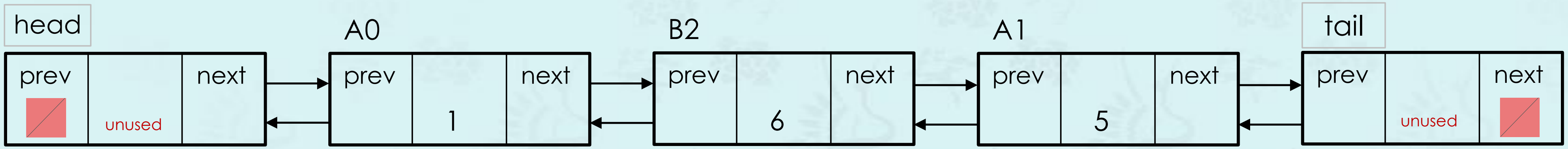

another way of doubly linked list initialization



An **empty** doubly-linked list with sentinel nodes

Basic Operations:




```
pNode begin(pList p) {
  return p->head->next;
}
```

What is the name of this function?

```
pNode end(pList p) {
  return p->tail;
}
```

What is the name of this function?

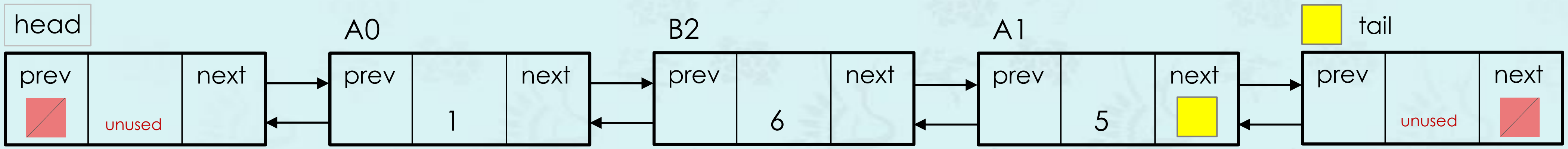
Basic Operations: begin() and end()

```
// returns the first node which list::head points to in the container.
pNode begin(pList p) {
  return p->head->next;
}
```

```
// returns the tail node referring to the past -the last- node in the list.
// The past -the last- node is the sentinel node which is used only as a sentinel that would
// follow the last node. It does not point to any node next, and thus shall not be dereferenced.
// Because the way we are going use during the iteration, we don't want to include the node
// pointed by this. This function is often used in combination with List::begin to specify a
// range including all the nodes in the list. This is a kind of simulated used in STL. If the
// container is empty, this function returns the same as List::begin.

pNode end(pList p) {
  return p->tail;
}
```

```
With the container given below,
what does begin(p) and end(p) return
in mnemonic code, respectively?
```

Basic Operations:




```
pNode begin(pList p) {
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}
```
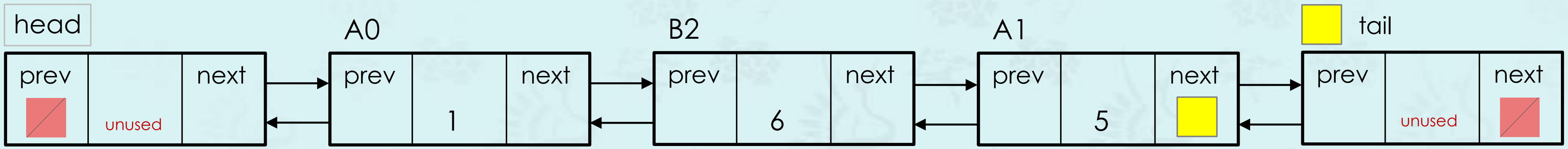

What is the return value of begin() in mnemonic shown above?

```
pNode end(pList p) {
  return p->tail;
}
```

What is the return value of begin() in mnemonic shown above?

Basic Operations:

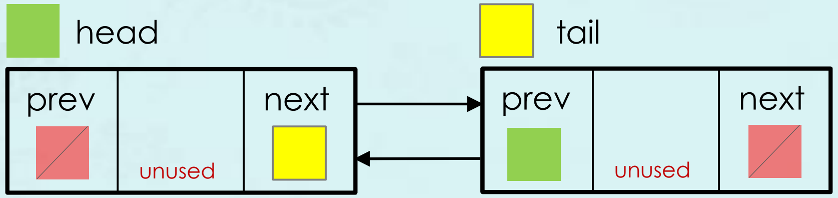



```
pNode begin(pList p) {
  return p->head->next;
}
```

```
bool empty(pList p) {
  return begin(p) == end(p);
}
```

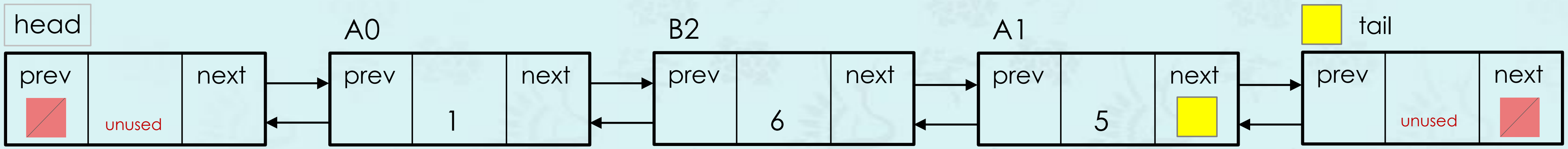
```
pNode end(pList p) {
  return p->tail;
}
```

```
pNode last(pList p) {
  return end(p)->prev;
}
```



An **empty** doubly-linked list with sentinel nodes

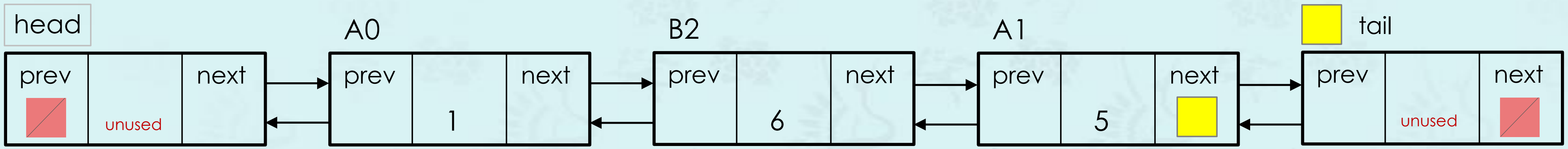
Basic Operations:




```
int size(pList p) {
  int count = 0;


  return count;
}
```

```
int size(pList p) {
  int count = 0;
  pNode x = begin(p);
  while(x != end(p)) {
    count++;
    x = x->next;
  }
  return count;
}
```

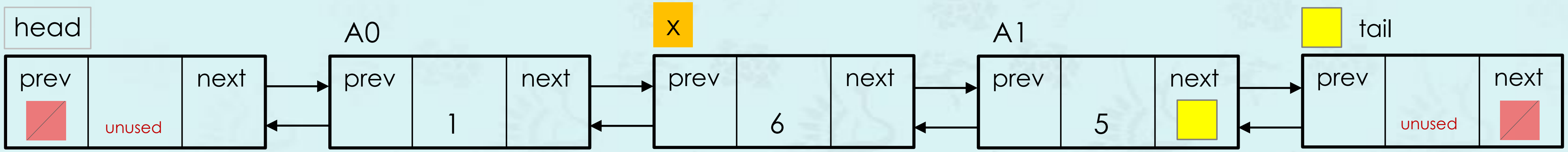
Basic Operations:




```c
int size(pList p) {
  int count = 0;
  for (pNode x = begin(p); x != end(p); x = x->next)
    count++;
  return count;
}
```

```c
int size(pList p) {
  int count = 0;
  pNode x = begin(p);
  while(x != end(p)) {
    count++;
    x = x->next;
  }
  return count;
}
```

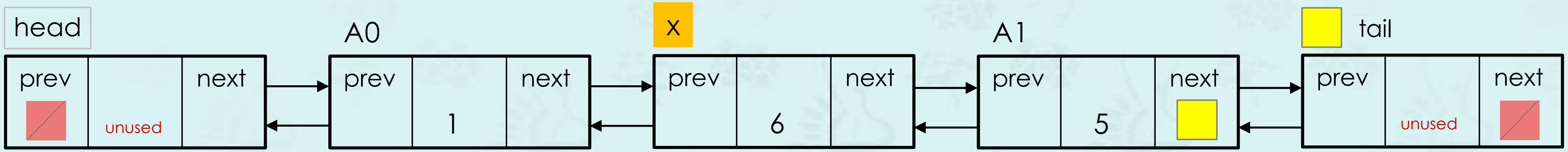
Exercise 1: What does it return if not found?



- What does it return if not found?
  (1) A1, (2) tail, (3) nullptr.

```
pNode find(pList p, int value){
  pNode x = begin(p);
  while(x != end(p)) {
    if (x->data == value) return x;
    x = x->next;
  }
  return x;
}
```

Exercise 2: Rewrite find() using a for-loop

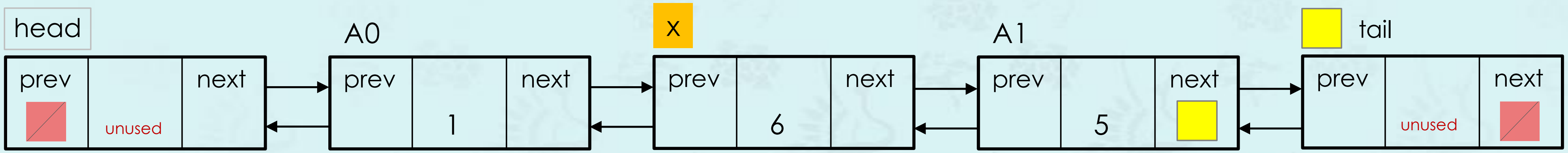



```
int find(pList p, int value) {
  for (pNode x = begin(p); x != end(p); x = x->next)
    if (x->data == value) return x;
  return x;
} // there is a bug.
```

```
int find(pList p, int value) {



  return x;
}
```

```
pNode find(pList p, int value){
  pNode x = begin(p);
  while(x != end(p)) {
    if (x->data == value) return x;
    x = x->next;
  }
  return x;
}
```

Exercise 3: Reduce the while-loop in two lines




```
pNode find(pList p, int value){
  pNode x = begin(p);


  return x;
}
```

```
pNode find(pList p, int value){
  pNode x = begin(p);
  while(x != end(p)) {
    if (x->data == value) return x;
    x = x->next;
  }
  return x;
}
```

Data Structures
Chapter 4

1. Singly Linked List
2. Doubly Linked List
   - Revisit – Singly Linked List
   - Sentinel Nodes & Basic Operations
   - **Two Key Operations: erase, insert**
   - Advanced Operations

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