CS 261-020
Data Structures

Lecture 7

Stack, Queue, Deque (cont.)

Encapsulation and Iterators

2/6/24, Tuesday

Oregon State University

Odds and Ends

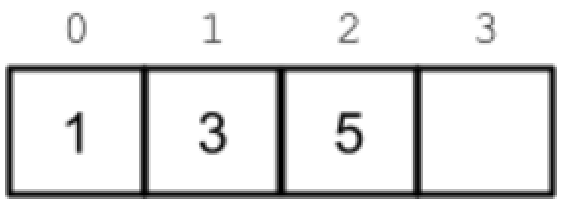
- Recitation 5 posted
- Assignment 2 due Sunday midnight
- Assignment 1 demo due Friday (2/9)
- Midterm:
  - Tuesday (2/13) during lecture time
  - Same classroom
  - Review on Thursday

Lecture Topics:

- Stacks, Queues, and Deques
  - Linear ADTs
- Encapsulation and Iterators

Implement Queue using Dynamic Array

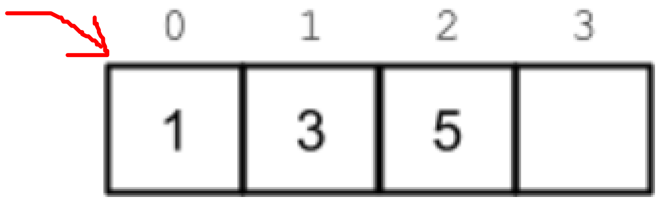
- Using a dynamic array,
  - Front of the queue = front of the array
  - Back of the queue = back of the array
- Ex. A queue with 3 values (1 at the front, 5 at the back)

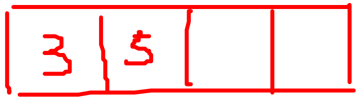


- Enqueue a new value → insert it at the end of the array

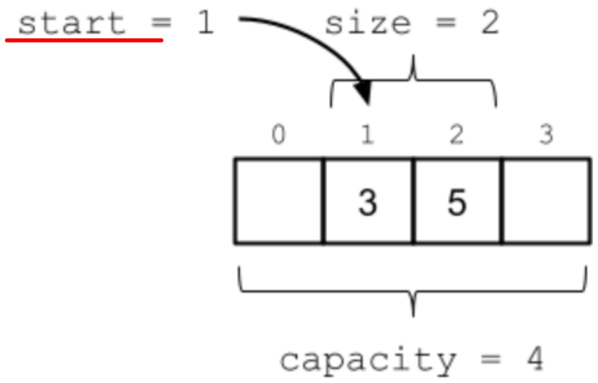
- What about dequeue?

Implement Queue using Dynamic Array

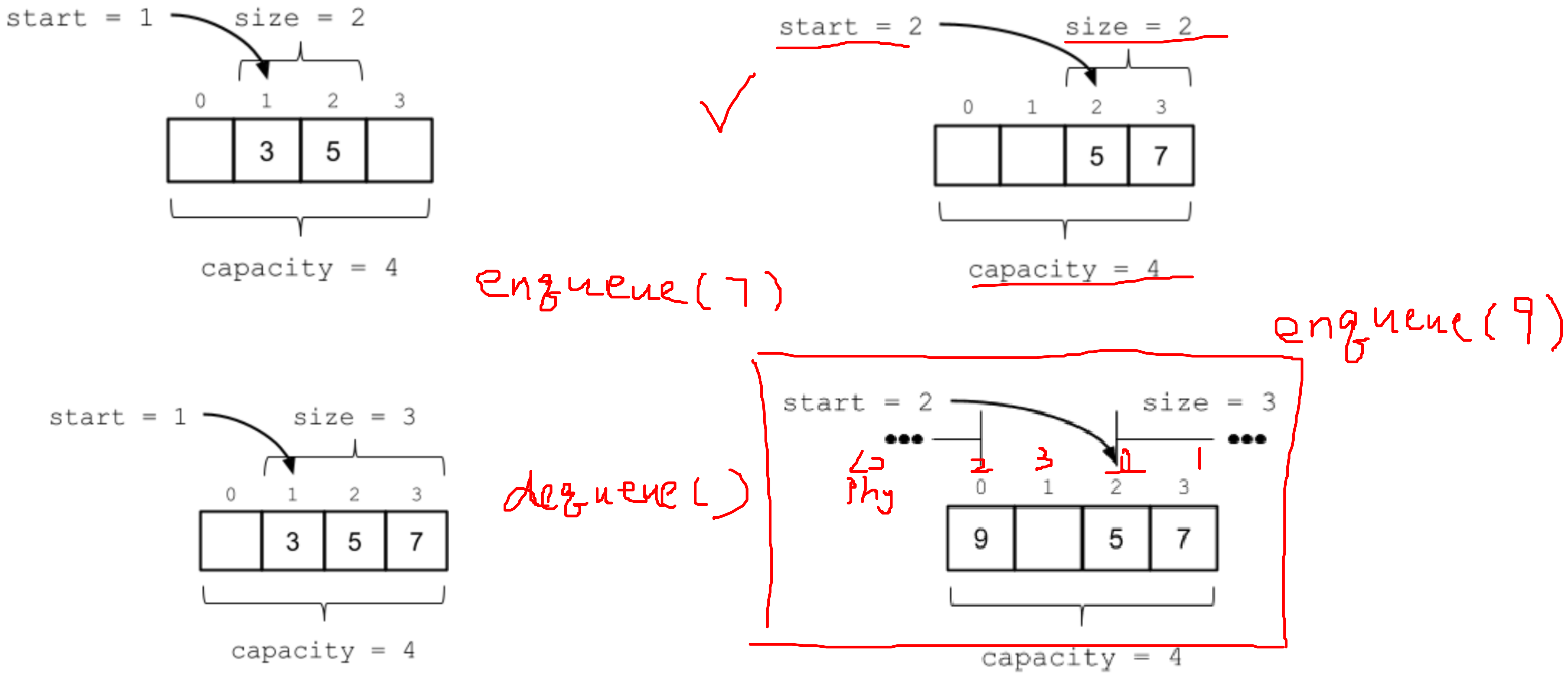




- Dequeue:
  - Option 1: remove the front, and shift all the remaining to left
    - Drawback: O(n) runtime complexity for each dequeue → NOT GOOD!!!
  - Option 2: allow the front of the queue to *"float" back* into the middle of the array.
    - Need to keep track of the start of the data



Implement Queue using Dynamic Array



Implement Queue using Dynamic Array

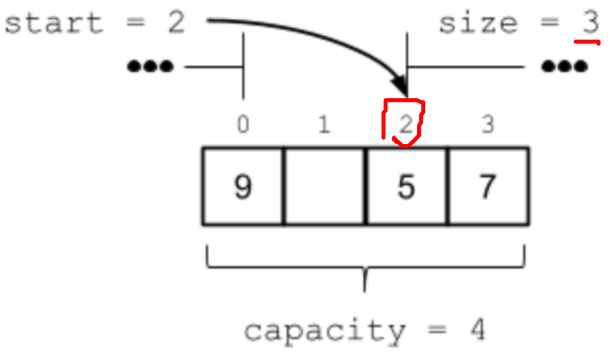
- An array that allows data to wrap around from the back to the front is known as a circular buffer

- Q: How do we know which index corresponds to the back of the queue?
  - By computing a mapping between the array's *logical indices* and its *physical indices*
- Logical indices – the indices relative to the start of the data
- Physical indices – the indices relative to the start of the physical array

Implement Queue using Dynamic Array

- Mapping formula: `physical = start + logical;`
- Since it is circular, add the following to check:

```
if (physical >= capacity) {
    physical -= capacity;
}
```



- OR: **`physical = (start + logical) % capacity;`**

- Index at which the next element will be inserted:
  - Previously: array[size] – when the data starts at physical index 0
  - Now: array[physical] – where physical = (start + size) % capacity

Implement Queue using Dynamic Array

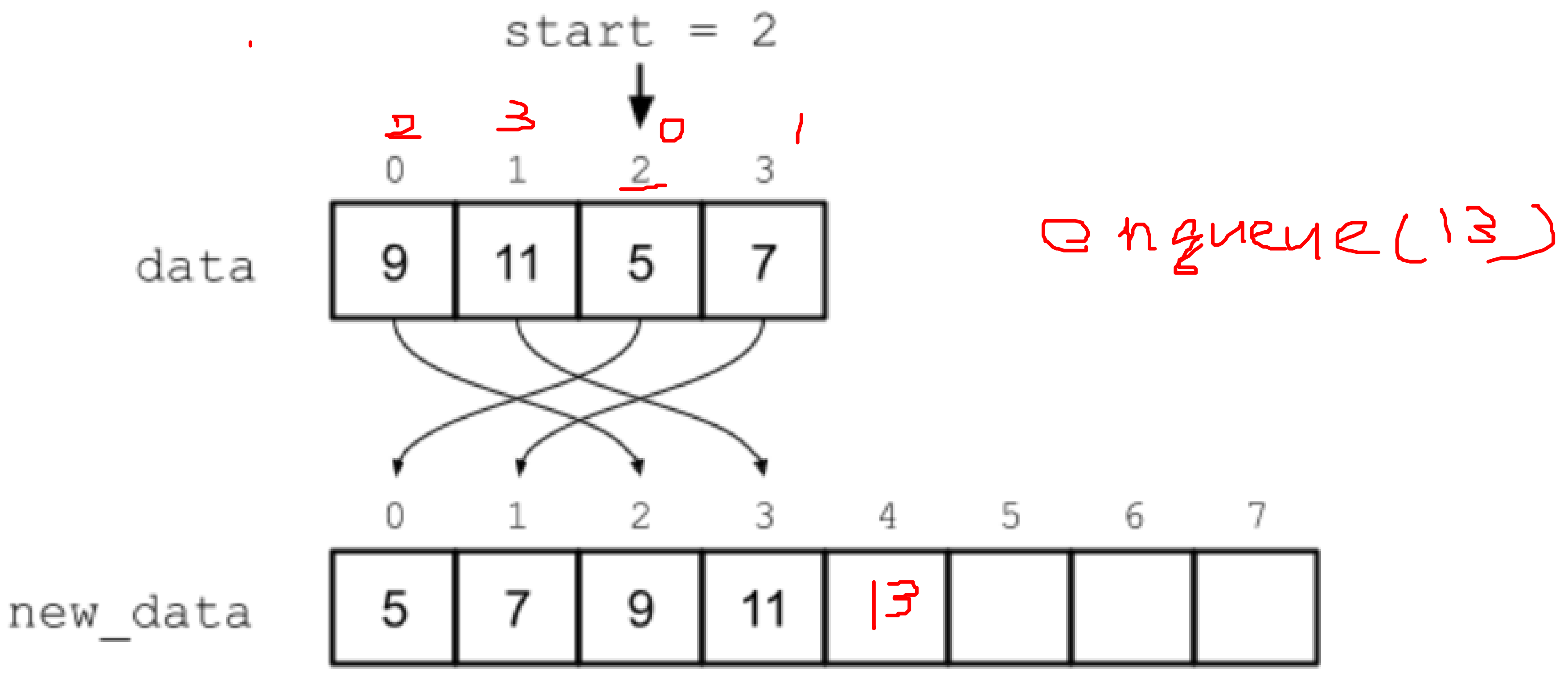
- Dynamic Array resizing for the queue implementation
- When do we need to resize?
  - size >= capacity
- When resize, reindex!
  - Logical index 0 ←→ Physical index 0

- How?
  - Loop through the logical indices from 0 to size – 1
  - Copy elements at each logical index in the old array to the equivalent physical index in the new array

Implement Queue using Dynamic Array

- Visually, look like this:

```
physical = (start + logical) % capacity;
```



Implement Queue using Dynamic Array

- Complexity:
  - Dequeue – O(1) for all best-case, worst-case, and average case

  - Enqueue
    - O(1) for best-case and average case
    - O(n) for worst-case, when resize is needed

Deques

- A deque (double-ended queue) is a linear ADT that supports insertion and removal at both ends
- Examples: multi-processor job scheduling
- Four primary operations:
  - Add to front
  - Add to back
  - Remove from front
  - Remove from back

*Implement Deque using Dynamic Array

- Very similar to dynamic array-based queue implementation
  - Using circular buffer

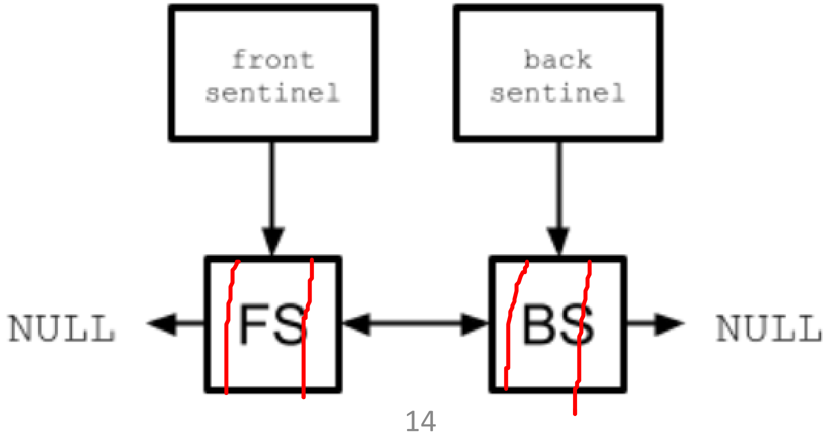
- Not covered in this class

- FYI: https://www.geeksforgeeks.org/implementation-deque-using-circular-array/

Implement Deque using Linked List

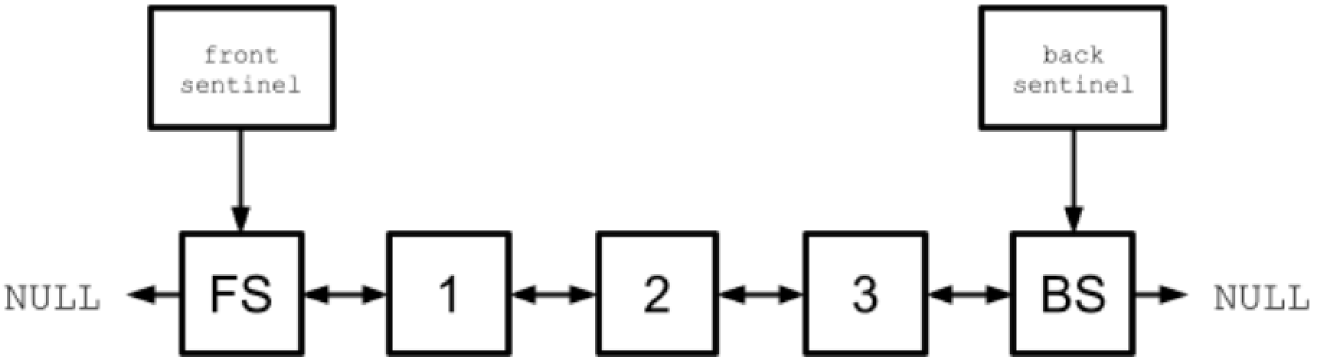
- Since a deque supports removal from both front and back, we need to use a doubly linked list
  - Allows to remove from the back and find the new back

- Use front and back sentinel in the list
  - Sentinel: a special node that is never removed from the list (doesn't store a value)



Implement Deque using Linked List

- Values are inserted into the list in nodes that live between the sentinels. For example:



- Add front: insert a new node after the front sentinel
- Add back: insert a new node before the back sentinel
- Remove front: remove the node after the front sentinel
- Remove back: remove the node before the back sentinel

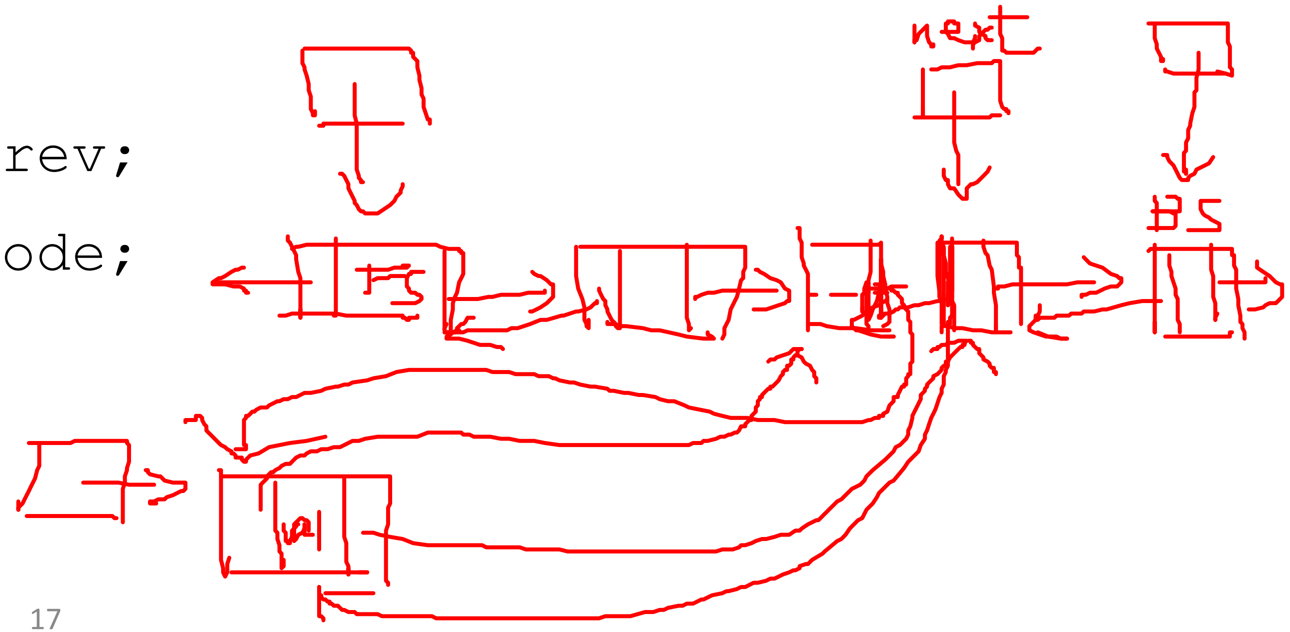
Implement Deque using Linked List

- Why do we use sentinels?
  - w/o sentinels, each operation would have to implemented differently, i.e.:
    - Add to the front w/o sentinels → update the head pointer upon each insertion
    - Add to the back w/o sentinels → update the tail pointer upon each insertion
  - w/ sentinels, both insertions (add to front and add to back) can use the exact same mechanics
    - So can both of the removal operations

Implement Deque using Linked List

- add_before() – insert a new node with a given value before a specified node already in the list, i.e.:

```
void add_before(void* value, struct node* next) {
      struct node* new_node = malloc(sizeof(struct node));
      new_node->value = value;
      new_node->prev = next->prev;
      next->prev->next = new_node;
      new_node->next = next;
      next->prev = new_node;
}
```



Implement Deque using Linked List

- Since our list uses sentinels, then our add_to_front() becomes:

```
void add_to_front(void* value) {
      add_before(value, front_sentinel->next);
}
```

- Our add_to_back() becomes:

```
void add_to_back(void* value) {
      add_before(value, back_sentinel);
}
```

Implement Deque using Linked List

- Similarly, assuming our list has a `remove_node()` function, then our remove_front() becomes:

```
void remove_front() {
    remove_node(front_sentinel->next);
}
```

- Our remove_back() becomes:

```
void remove_back() {
    remove_node(back_sentinel->prev);
}
```

- To check if the list is empty:

```
if (front_sentinel->next == back_sentinel)
```

Implement Deque using Linked List

- Complexity:
  - Add to front – O(1)
  - Add to back – O(1)
  - Remove front – O(1)
  - Remove back – O(1)

*For all best case, worst case, and average case

Lecture Topics:

- Stacks, Queues, and Deques
  - Linear ADTs

- Encapsulation and Iterators

Have you seen this error before?

dereferencing a pointer of incomplete type

Encapsulation

- Encapsulation – hide the internal details of a data type from the user of that data type, instead exposing only a simplified interface through which the user interacts with the data type
  - User – another developer who will be using the code we've written

- For example, linked list implementation has hidden the details of the list implementation behind a simplified interface.
  - Only the name of linked list data type was exposed to the user (i.e., `struct list`)
  - If the user tried to access internal fields (`list->head`) → error
    - "dereferencing a pointer of incomplete type"

Why Encapsulation?

- Reduces the cognitive overhead to understand
- Cannot misuse (and possibly break) the data type
  - Cannot set `list->head` to `NULL` (could cause a memory leak)
- Easier to implement the data type
  - Avoid tedious error checking

- Potential challenges:
  - What if our user wants to ***iterate*** through each element in the collection within a loop?
    - Problem: cannot access the internals, i.e., for linked list, cannot access the `head`

Iterator

- Iterator – a data type acts as a companion to a collection and provides a mechanism to iterate through that collection
  - Implemented to have access to the internals of the collection

- Each specific kind of collection will have its own iterator data type

- Two common functions:
  - next () – returns the current value, and moves the iterator to the next element
  - has_next () – returns true or false to indicate whether or not there is another element afterwards

To use an Iterator

- Assuming we have an iterator `iter` over a collection:

```
while (has_next(iter)) {
   value = next(iter);
  ... /* Do something with value. */
}
```

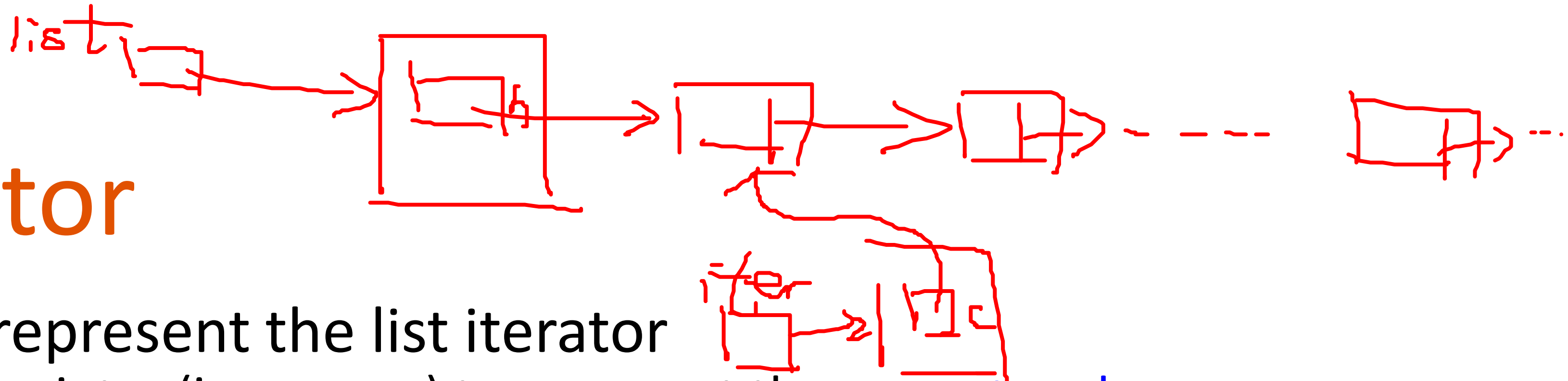
Linked list Iterator

- Implement an iterator for a linked list:
  - In C: defined within the same file
  - In C++: using nested classes or friend

- Our linked list iterator must have access to the internals of the linked list:

```
struct node {
  void* value;
  struct node* next;
};

struct list {
  struct node* head;
};
```



Linked list Iterator

- 1. define a structure to represent the list iterator
  - How to iterate? Using a pointer (i.e., `curr`) to represent the current node
  - Initially points to the head, and moves to the next (i.e., `curr = curr -> next;`)

```
struct list_iterator {
    struct node* curr;
};
```

- 2. implement a function to create a new iterator and associate it with a list to iterate:

```
struct list_iterator* list_iterator_create(struct list* list) {
    struct list_iterator* iter = malloc(sizeof(struct list_iterator));
    iter->curr = list->head;
    return iter;
}
```

Linked list Iterator

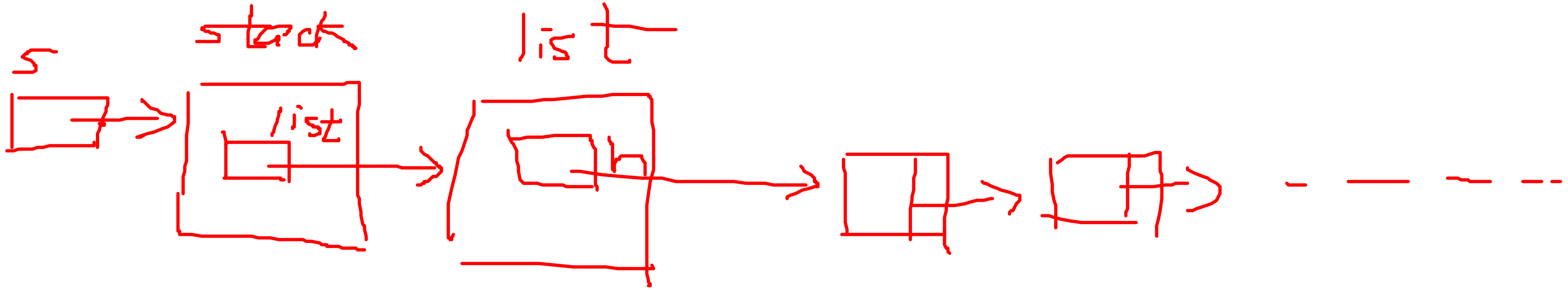
- 3. Implement has_next()

```
int has_next(struct list_iterator* iter) {
  return iter->curr != NULL;
}
```

- 4. Implement next()

```
void* next(struct list_iterator* iter) {
  void* value = iter->curr->value;
  iter->curr = iter->curr->next;
  return value;
}
```

- *5. Polish (i.e., add error checking)



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Next Lecture

- Binary Search
- Midterm Review