CSE 373

Implementing a Stack/Queue as a Linked List

Reading: Weiss Ch. 3; 3.7

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The Stack<E> ADT

- We have now implemented a stack using an array.
  - It is also just fine to implement a stack using a linked list.
  - Let's write a `LinkedStack` class...

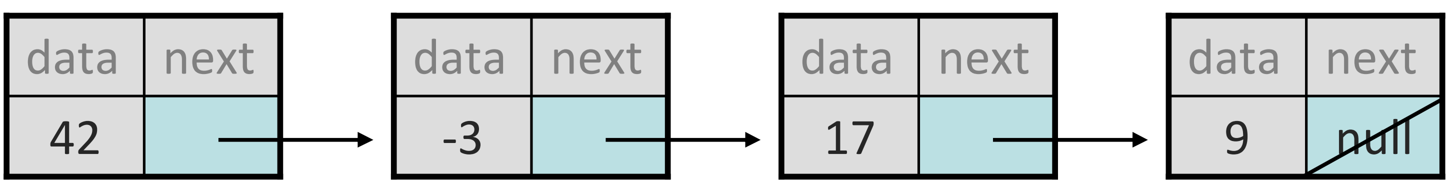
```
public interface Stack<E> {
    void clear();
    boolean isEmpty();
    E peek();
    E pop();
    void push(E value);
    int size();
}

public class LinkedStack<E> implements Stack<E> {
    ...
```

Recall: linked nodes

```
public class Node<E> {
    public E data;
    public Node next;
}
```

- Each node object stores:
  - one piece of data
  - a reference to (at least) one other list node
- Nodes can be "linked" into chains to store a list/stack of values:



Null references

- **`null`** : A value that does not refer to any object.
  - The elements of a new array of objects are initialized to `null`.
  - Objects' fields are also `null` by default until initialized.

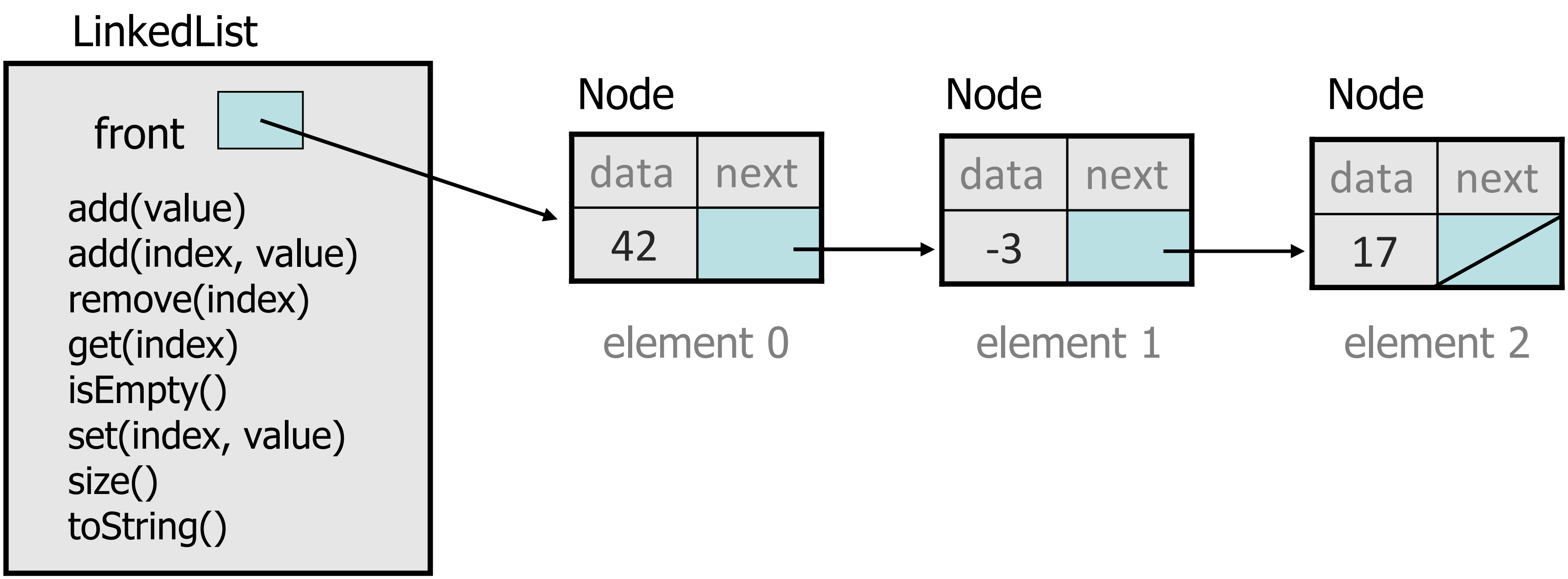
```
String[] words = new String[5];
private Point myLocation;          // null
```

	index	*0*	*1*	*2*	*3*	*4*
`words` →	***value***	`null`	`null`	`null`	`null`	`null`

  - not the same as the empty string `""` or the string `"null"`
  - Why does Java have `null`? What is it used for?
  - You cannot *deference* a `null` variable (use a dot `.` on it).

Recall: Linked list

- Previously you have implemented a linked list.
  - The list is internally implemented as a chain of linked nodes.
    - The `LinkedList` keeps a reference to its `front` as a field
    - `null` is the end of the list; a `null` front signifies an empty list
    - fast O(1) to add/remove at front, slow O(*N*) at back (opposite of array)



Inner classes

```
// outer (enclosing) class
public class name {
    ...

    // inner (nested) class
    private class name {
        ...
    }
}
```

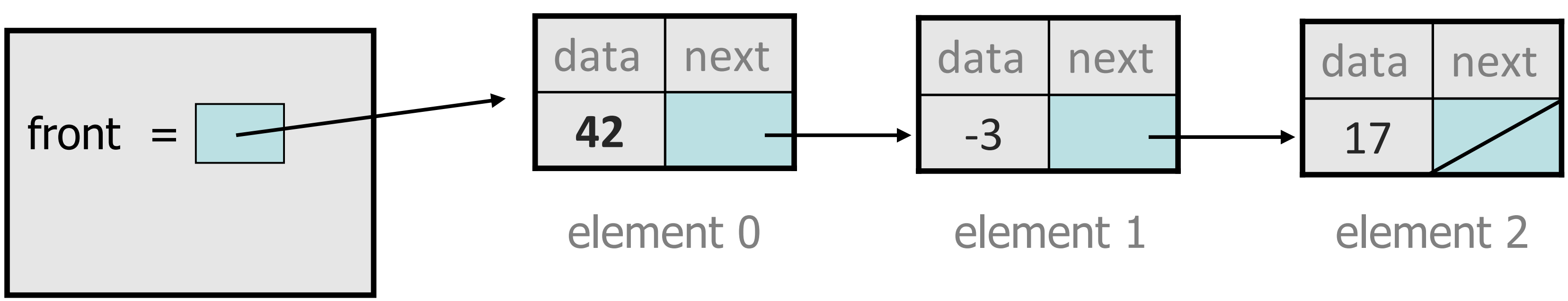
- Only the outer file can see the inner class or make objects of it.
- Each inner object is associated with the outer object that created it, so it can access/modify that outer object's methods/fields.
- Usually it makes sense to make your linked Node into an inner class.
- *An inner class sees the generic type parameters (like* `<E>`*) of its enclosing outer class, so it should not try to re-declare them.*

Implementing push

- How do we push an element onto the end of a stack?

```
public void push(E value) {
    Node newNode = new Node(value);
    newNode.next = front;
    front = newNode;
    size++;
}
```

```
    s.push(42);   // client code
```

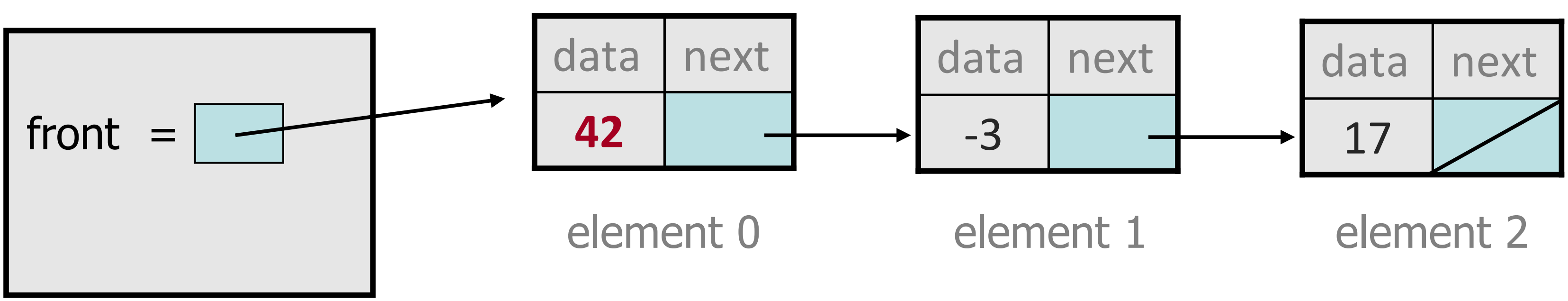


Implementing pop

- How do we pop an element off the end of a stack?

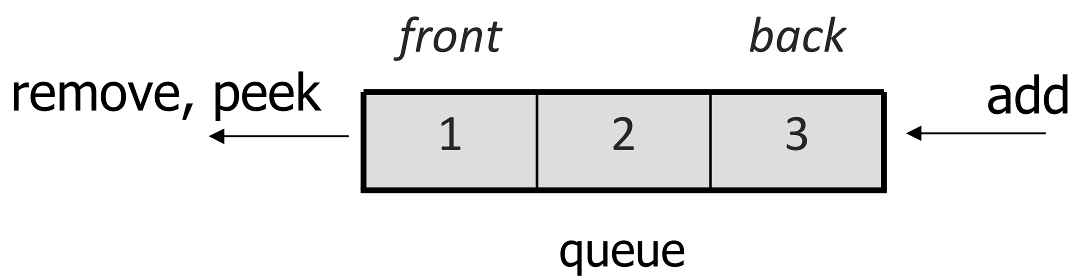
```
public int pop() {
    int top = front.data;
    front = front.next;
    size--;
    return top;
}
```

```
s.pop();      // client code;  returns 42
```



Queues

- **queue**: Retrieves elements in the order they were added.
  - First-In, First-Out ("FIFO")
  - Elements are stored in order of insertion but don't have indexes.
  - Client can only add to the end of the queue, and can only examine/remove the front of the queue.



- basic queue operations:
  - **add** (enqueue): Add an element to the back.
  - **remove** (dequeue): Remove the front element.
  - **peek**: Examine the front element.

Queue ADT interface

- Let's write our own implementation of a queue.
  - As is done in the Java Collection Framework, we will define queues as an ADT by creating a queue interface.

```
public interface Queue<E> {
    void clear();
    boolean isEmpty();
    E peek();
    E remove();              // remove from back
    void add(E value);       // add to front
    int size();
}
```

Implement with array?

```
public class ArrayQueue<E> implements Queue<E> {
    private E[] elements;
    private int size;
    ...
```

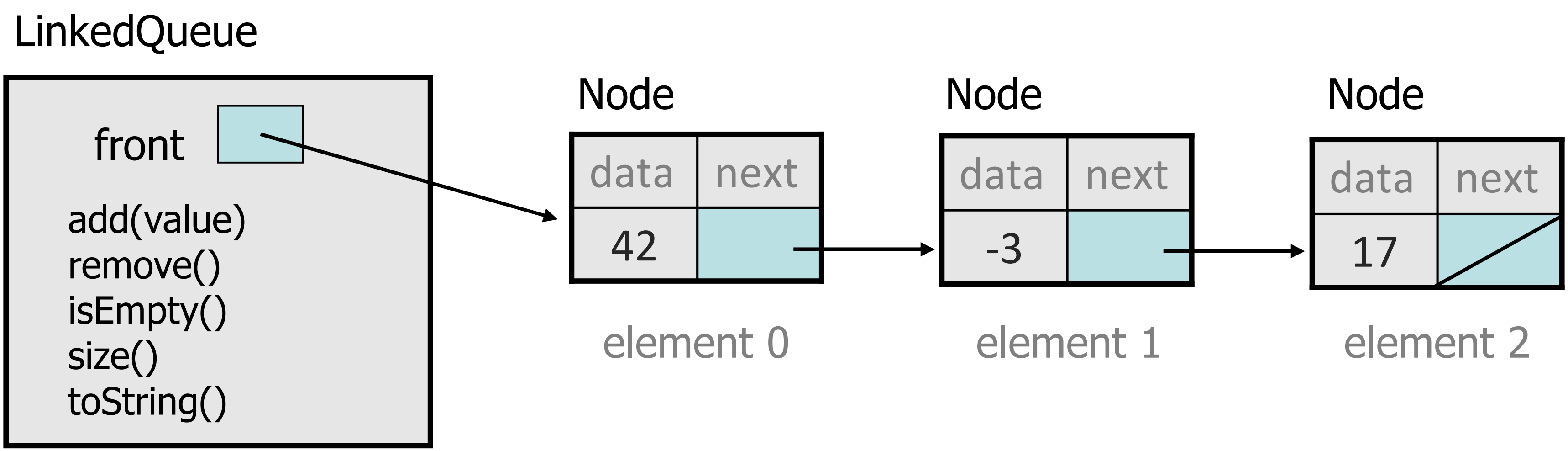
- A queue is tough to implement efficiently with an unfilled array.
  - The array is fast to add/remove at the end, but slow at the front.

```
queue.add(26);    // client code
queue.add(-9);
queue.add(14);
queue.remove();
```

index	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
value	26	-9	14	0	0	0	0	0	0	0
size	3									

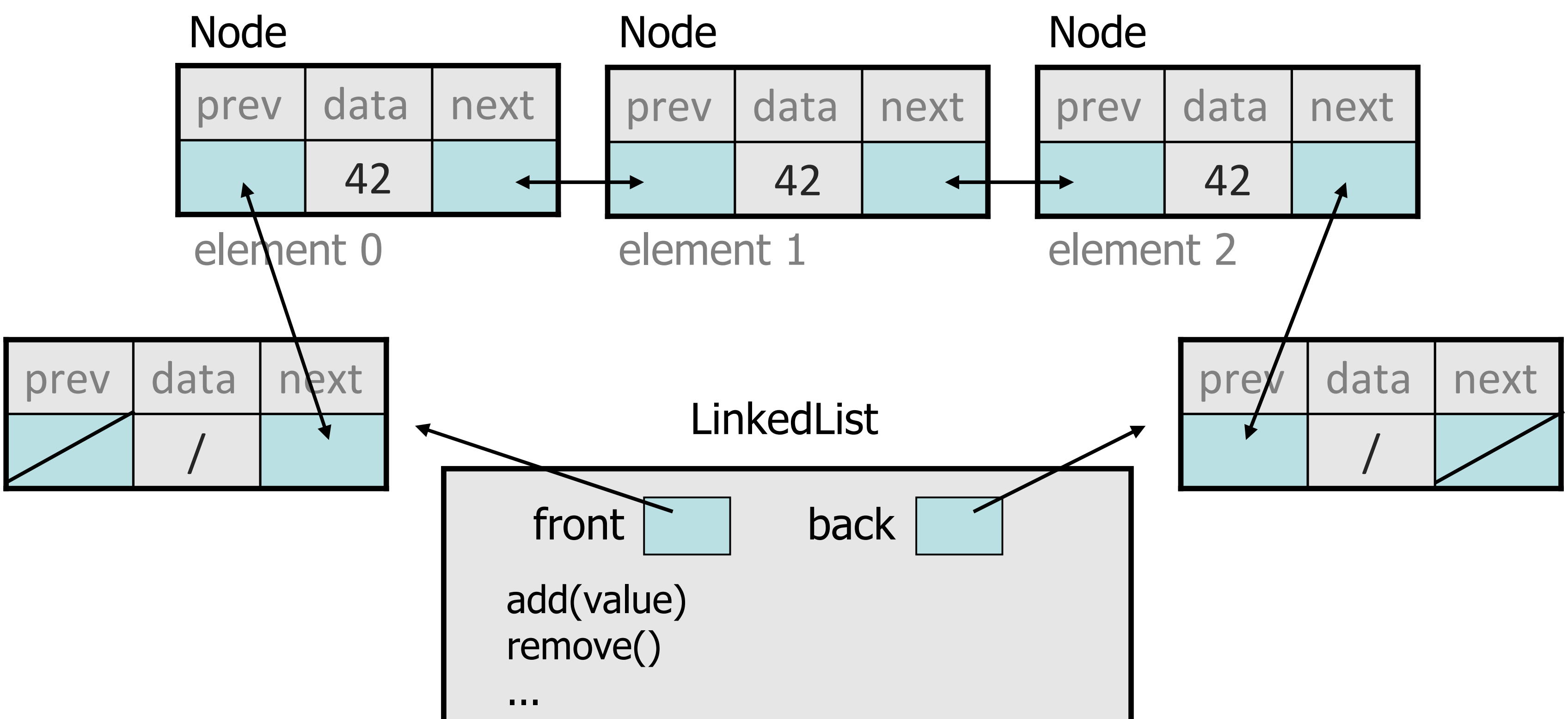
Implement with linked list?

- We could implement a queue as a linked list of nodes. Good idea?
  - *problem:* fast O(1) to add/remove at front, slow O(*N*) at back
  - queue needs fast O(1) access to both ends



Doubly linked list

- Nodes in a *doubly linked list* keep references in two directions.
  - The list itself keeps a front and back reference. Fast at both ends!
  - often implemented with "dummy" nodes at each end to avoid `nulls`



Circular array buffer

- *idea:* when elements are added/removed from front, rather than shifting, array simply alters its definition of the "front" index.

```
queue.add(26);    // client code
queue.add(-9);
queue.add(14);
```

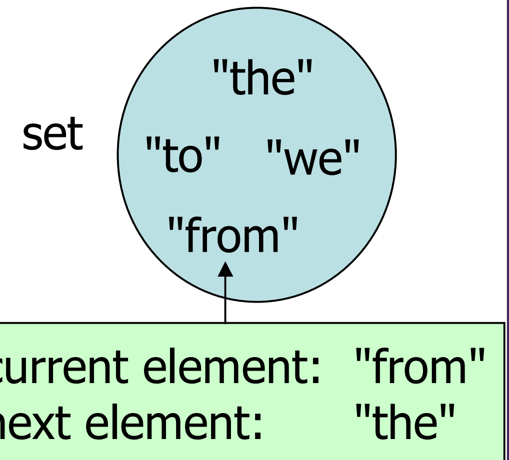
index	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
value	26	-9	14	0	0	0	0	0	0	0
size	3	*front*		**0**						

```
queue.remove();   // returns 26
queue.remove();   // returns -9
queue.add(87);
queue.add(35);
```

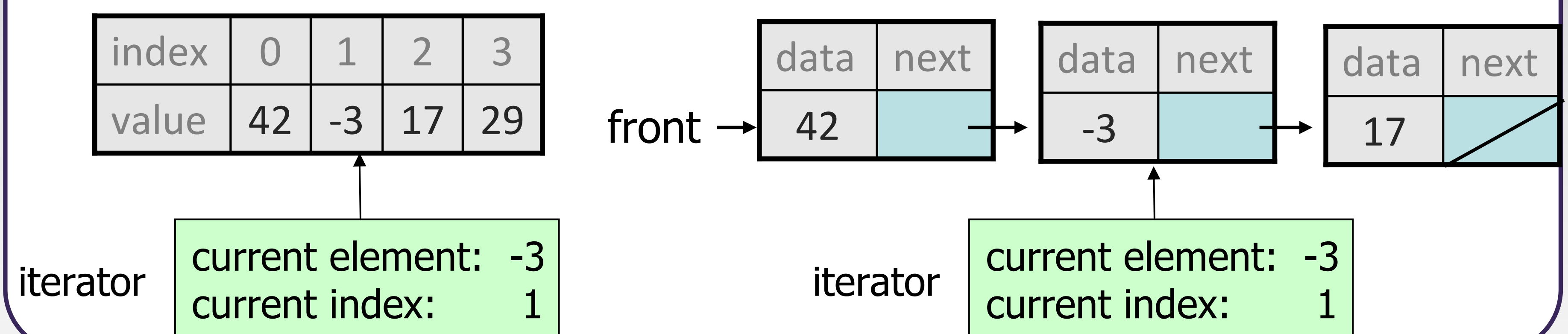
index	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
value	0	0	14	87	35	0	0	0	0	0
size	3	*front*		**2**						

Iterators

- **iterator**: An object that allows a client to traverse the elements of a collection, regardless of its implementation.
  - Remembers a position within a collection, and allows you to:
    - get the element at that position
    - advance to the next position
    - remove the element at that position



  - A common way to examine *any* collection's elements.



Iterator methods

`hasNext()`	returns `true` if there are more elements to examine
`next()`	returns the next element from the collection (throws a `NoSuchElementException` if there are none left to examine)
`remove()`	removes the last value returned by `next()` (throws an `IllegalStateException` if you haven't called `next()` yet)

- `Iterator` interface in `java.util`
  - every collection has an `iterator()` method that returns an iterator over its elements (usually implemented as an inner class)

```
Set<String> set = new HashSet<String>();
...
Iterator<String> itr = set.iterator();
...
```

Iterator example

```
Set<Integer> scores = new TreeSet<Integer>();
scores.add(94);
scores.add(38);   // Jenny
scores.add(87);
scores.add(43);   // Marty
scores.add(72);
…

Iterator<Integer> itr = scores.iterator();
while (itr.hasNext()) {
    int score = itr.next();
    System.out.println("The score is " + score);

    // eliminate any failing grades
    if (score < 60) {
        itr.remove();
    }
}
System.out.println(scores);  // [72, 87, 94]
```

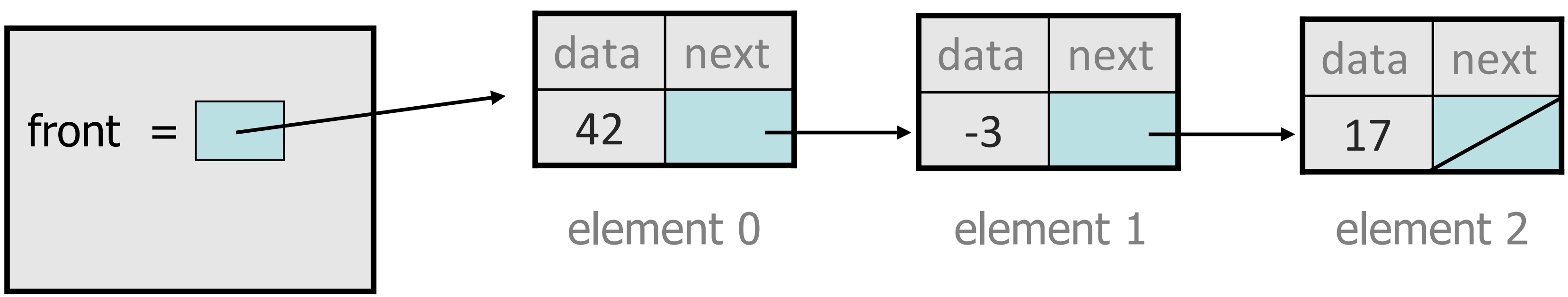
Bad linked list usage

- What's bad about this code?

```
List<Integer> list = new LinkedList<Integer>();
```

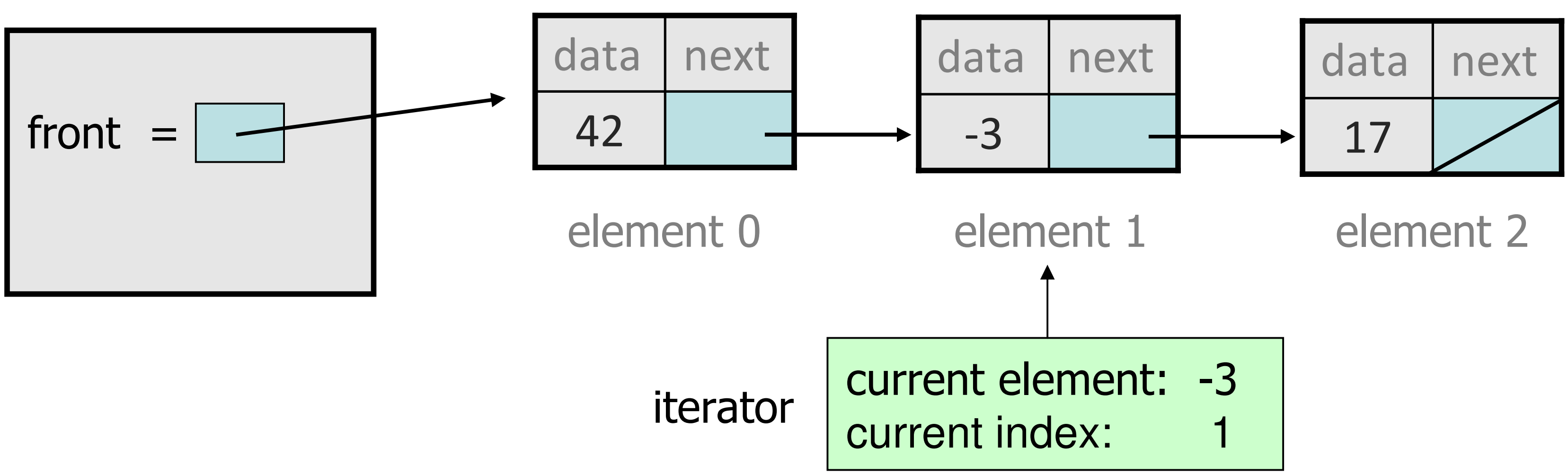
... (add lots of elements) ...

```
for (int i = 0; i < list.size(); i++) {
    int value = list.get(i);
    if (value % 2 == 1) {
        list.remove(i);
    }
}
```



Iterators and linked lists

- Iterators are particularly useful with linked lists.
  - The previous code is O(N^2) because each call on `get` must start from the beginning of the list and walk to index `i`.
  - Using an iterator, the same code is O(N). The iterator remembers its position and doesn't start over each time.



Array stack iterator

```
// Traverses the elements of the stack from top to bottom.
private class ArrayStackIterator implements Iterator<E> {
    private int index;

    public ArrayStackIterator() {
        index = size - 1;
    }

    public boolean hasNext() {
        return index >= 0;
    }

    public E next() {
        E result = elements[index];
        index--;
        return result;
    }

    public void remove() {
        throw new UnsupportedOperationException();
    }
}
```

Linked stack iterator

```
// Traverses the elements of the stack from top to bottom.
private class LinkedStackIterator implements Iterator<E> {
    private Node position;   // current position in list

    public LinkedStackIterator() {
        position = front;
    }

    public boolean hasNext() {
        return position != null;
    }

    public E next() {
        E result = position.data;
        position = position.next;
        return result;
    }

    public void remove() {
        throw new UnsupportedOperationException();
    }
}
```

for-each loop and Iterable

- Java's collections can be iterated using a "for-each" loop:

```
List<String> list = new LinkedList<String>();
...
for (String s : list) {
    System.out.println(s);
}
```

  - Our collections currently do not work in this way.

- To fix this, your list must implement the `Iterable` interface.

```
public interface Iterable<E> {
    public Iterator<E> iterator();
}

public class ArrayStack<E> implements Iterable<E> ...
```

ListIterator

`add(`**value**`)`	inserts an element just after the iterator's position
`hasPrevious()`	`true` if there are more elements *before* the iterator
`nextIndex()`	the index of the element that would be returned the next time `next` is called on the iterator
`previousIndex()`	the index of the element that would be returned the next time `previous` is called on the iterator
`previous()`	returns the element before the iterator (throws a `NoSuchElementException` if there are none)
`set(`**value**`)`	replaces the element last returned by `next` or `previous` with the given value

```
ListIterator<String> li = myList.listIterator();
```

- lists have a more powerful `ListIterator` with more methods
  - can iterate forwards or backwards
  - can add/set element values (efficient for linked lists)