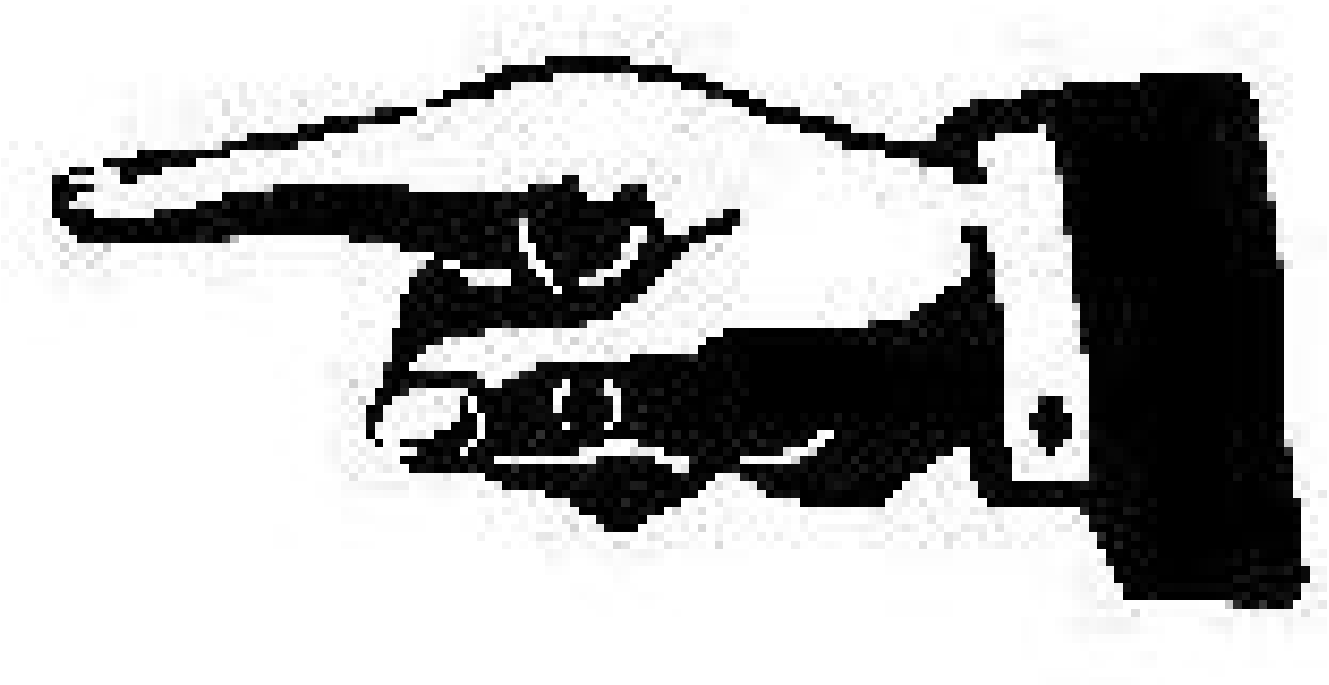
Algorithms and Analysis

Lesson 6: *Point to where you are going: links*



Linked lists

Outline

1. **References**
2. Singly Linked List
3. Stacks and Queues
4. Doubly Linked List
5. Using Linked Lists
6. Skip Lists

Non-Contiguous Data

- So far we have considered arrays where the data is stored in a contiguous chunk of memory
- This has the great advantage of allowing random access
- It has the disadvantage that it is expensive to add or remove data from the middle of the list or to rearrange the data
- A different approach is to use units of data that point to other units

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Non-Contiguous Data Structures

- There are a lot of important data structures using non-contiguous memory
  - ⋆ Binary trees
  - ⋆ Graphs
- In this lecture we consider **linked-lists**
- This is a classic data structure
- However, it serves as a good introduction to much more useful data structures

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Self-Referential Classes

- The building block for a linked list is a node class

```
struct Node<T>
{
  Node(U value, Node<U> *node): value(value), next(node) {}
  T element;
  Node<T> *next;
}
```

- We create new nodes

```
Node<int> *node = new Node<int>(10, pt_to_next)
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- Note that `node` is the address of this node
- I make it a `struct` as this is a class where I want public access to the element and next
- I can make this class a private class of my linked list

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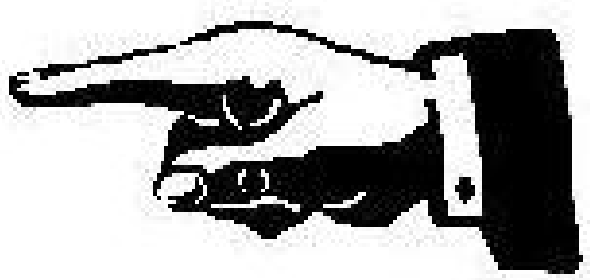
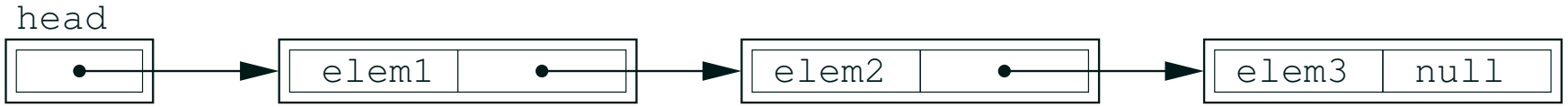


Singly Linked List

- We can build a linked list by stringing nodes together



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- A singly linked list has a single "pointer" to the next element
- A doubly linked list has "pointers" to the next and previous element—we will see this later
- We should be able to create a linked list, add elements, remove elements, see if an element exists, etc.

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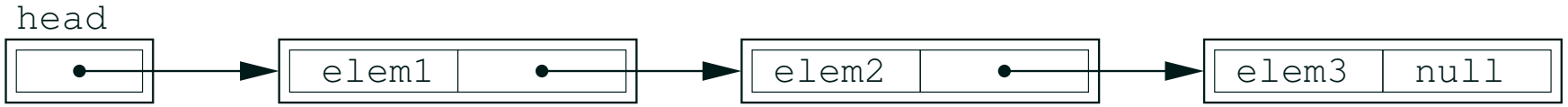

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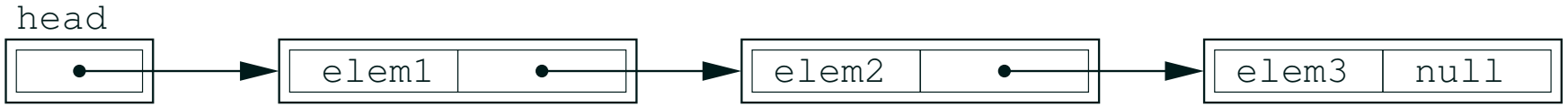

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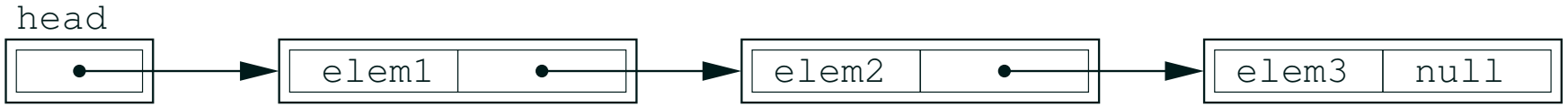

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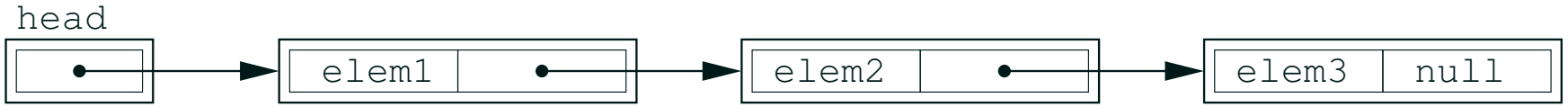

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Implementation

- We consider a lightweight implementation
- The class will have a head, a size counter and have a `Node` as a nested class

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class MyList {
private:
  template <typename U>
  struct Node{
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Simple Methods

- The constructor is simple (and not strictly necessary)

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- Other simple methods are

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unsigned size() const {return noElements;}

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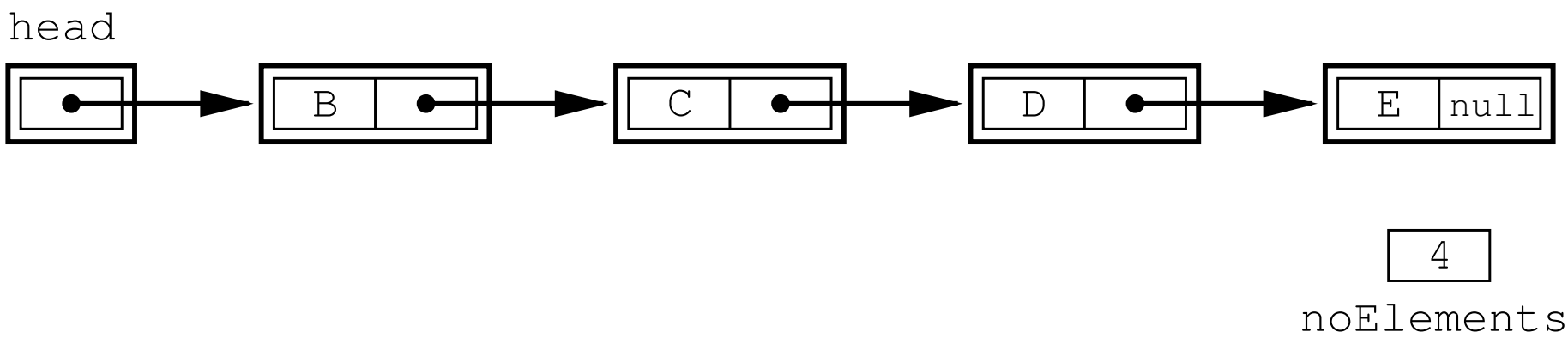

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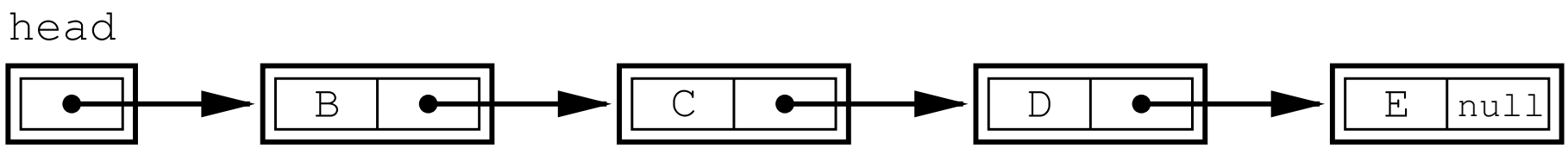

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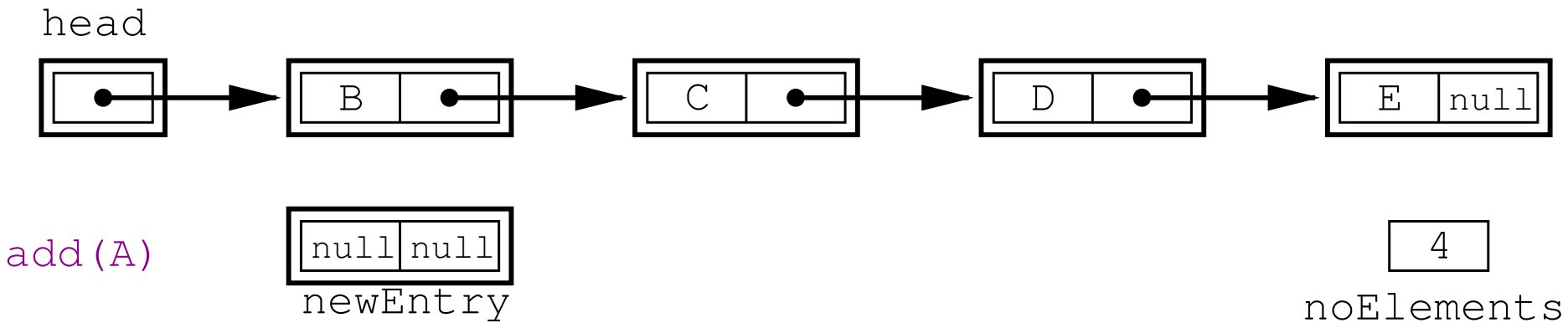

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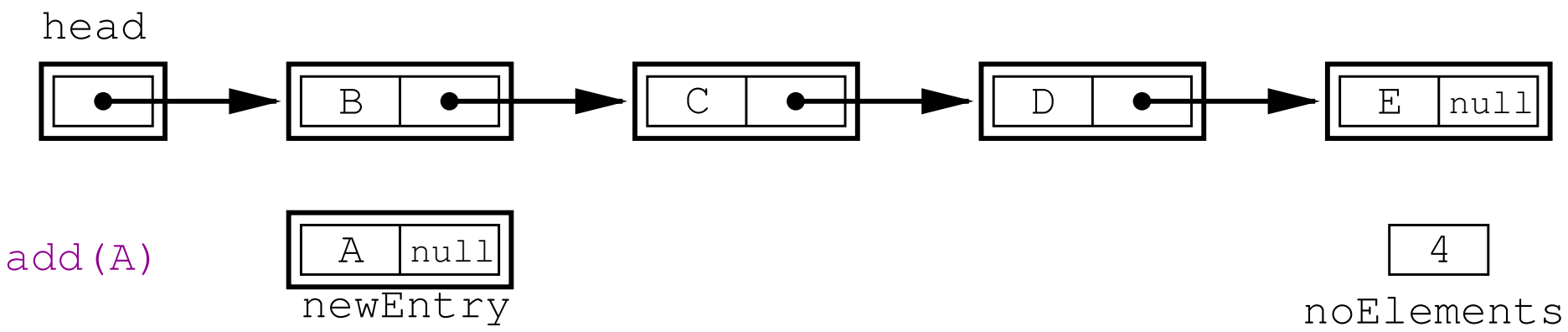

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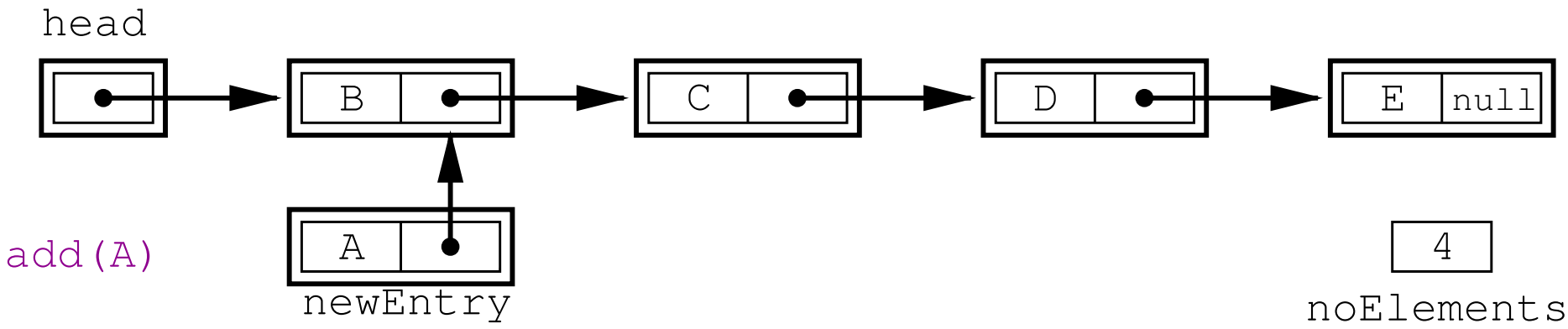

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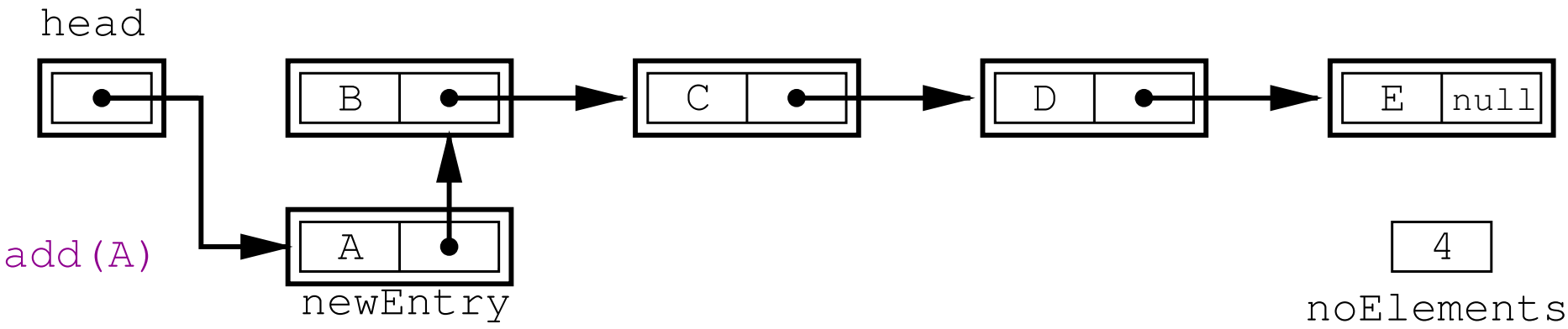

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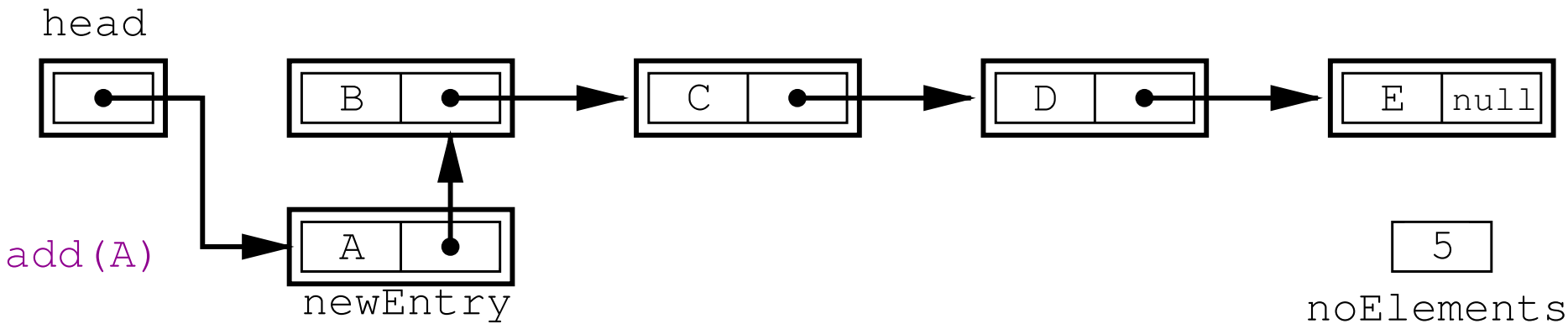

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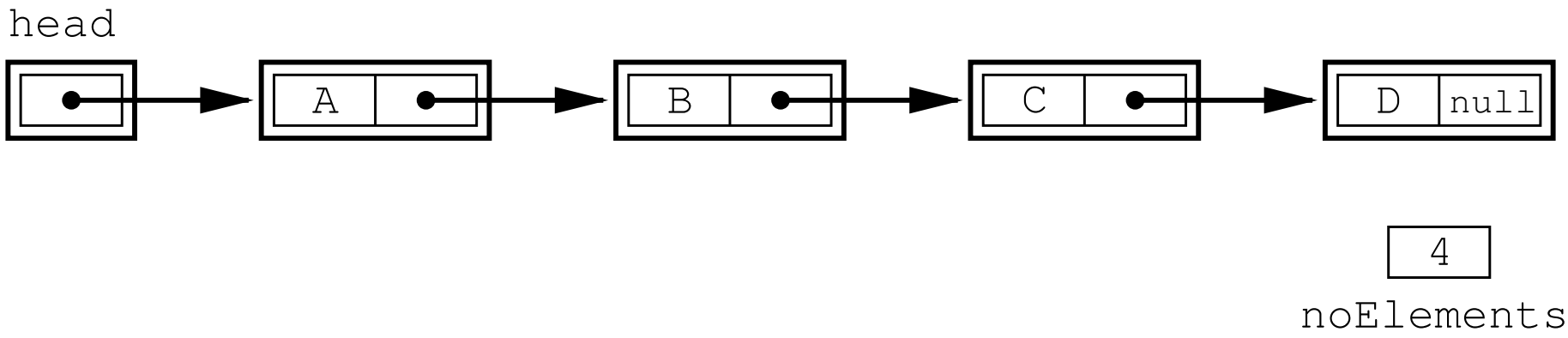

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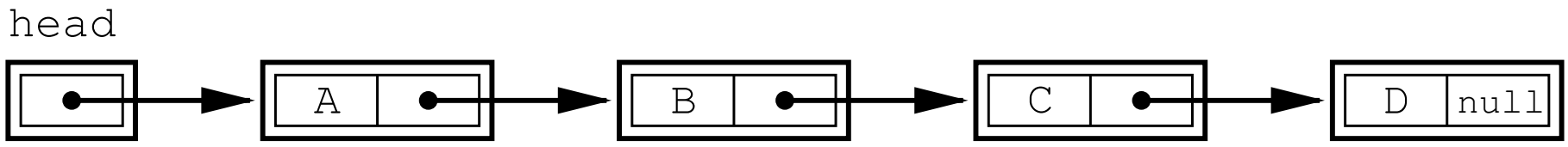

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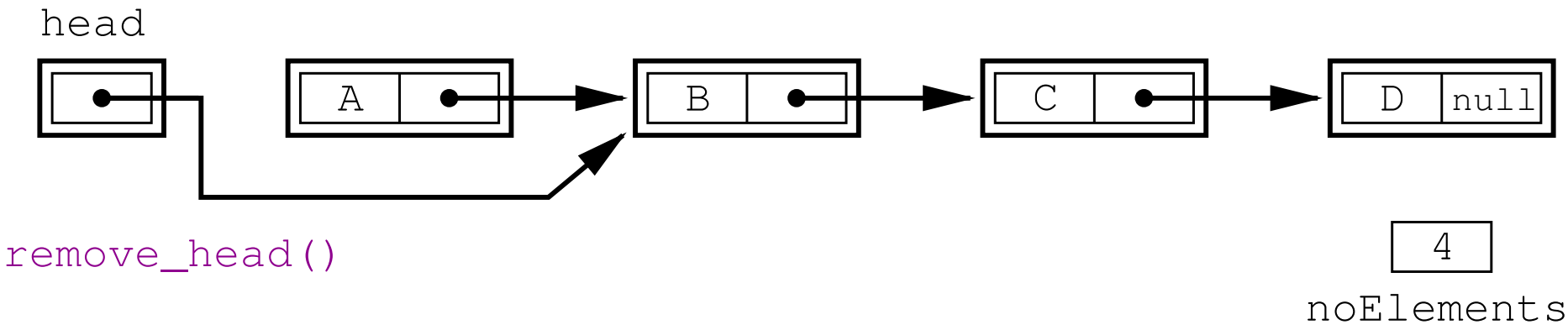

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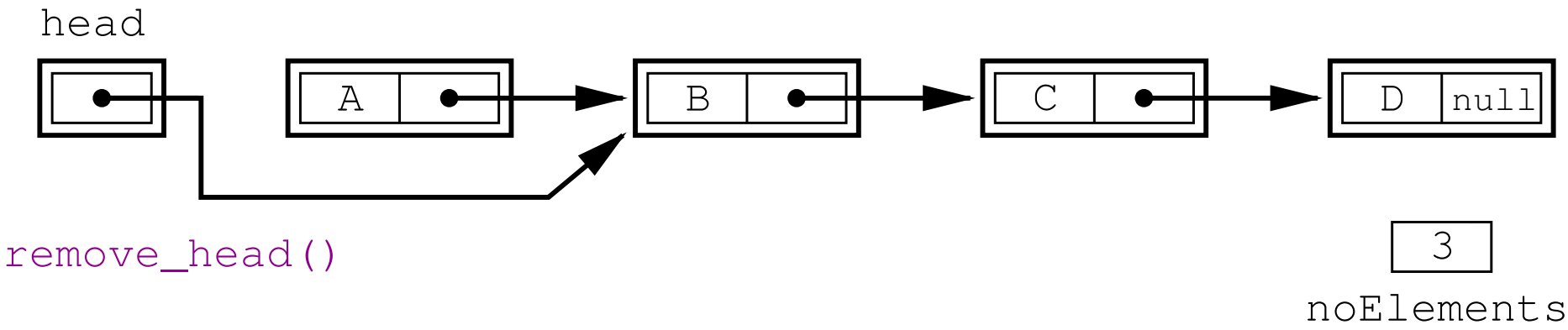

Other Methods

- We can easily implement many other methods
  - ⋆ `get(int i)`—return i^{th} item in list
  - ⋆ `remove(T obj)`-remove `obj` from list
  - ⋆ `insert(int position, element)`
- Note that `get(int i)` requires moving down the list so is $O(n)$ (i.e. not random access)

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Stack

- It is easy to implement a stack using a linked list

```
template <typename T>
class Stack<E>
{
  private Mylist<T> list = new mylist<T>();

  boolean push(E obj) {list.add(obj);}

  E top() {return list.get_head();} // throw exception

  E pop() {
    T tmp = list.get_head();
    list.remove_head();
    return tmp;
  }

  boolean empty() {return list.empty();}
}
```

Complexity of Stack

- All operations of the stack is constant time, i.e. $O(1)$
- This is the same time complexity as an array implementation
- Memory requirement is approximately $2 \times n$ reference and n objects—same as worst case for an array
- However, hidden cost of creating and destroying `Node` objects
- The array implementation is therefore slightly faster

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Point to the Back

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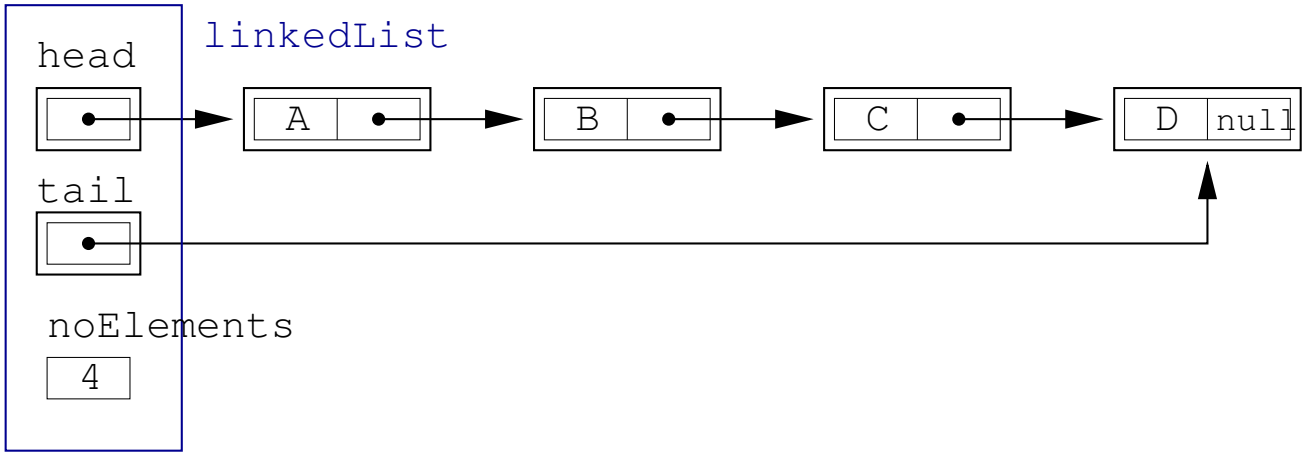
- Thus our linked list isn't the right data structure to implement a queue
- However, we could include a pointer to the end of the queue



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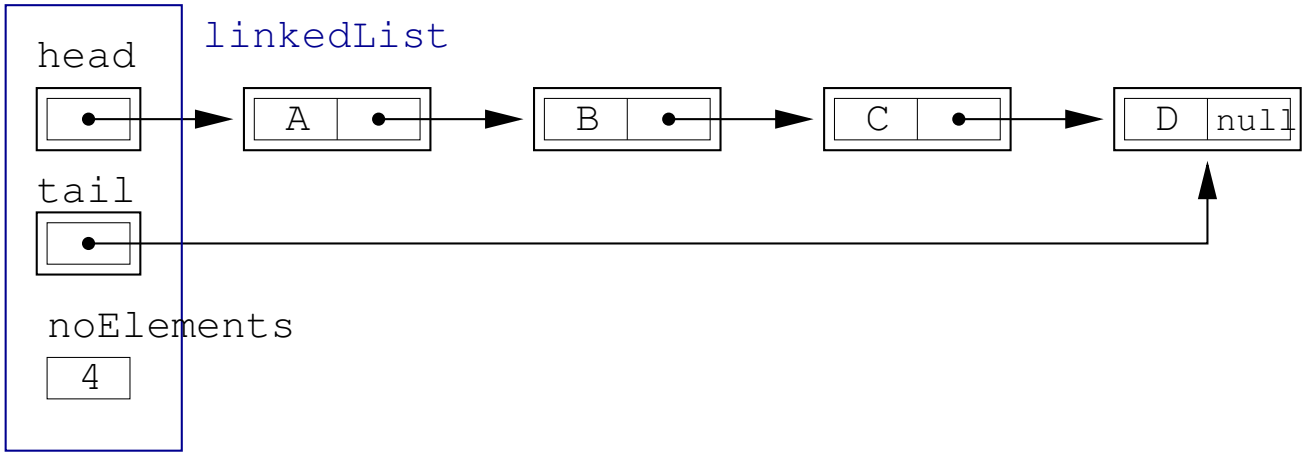

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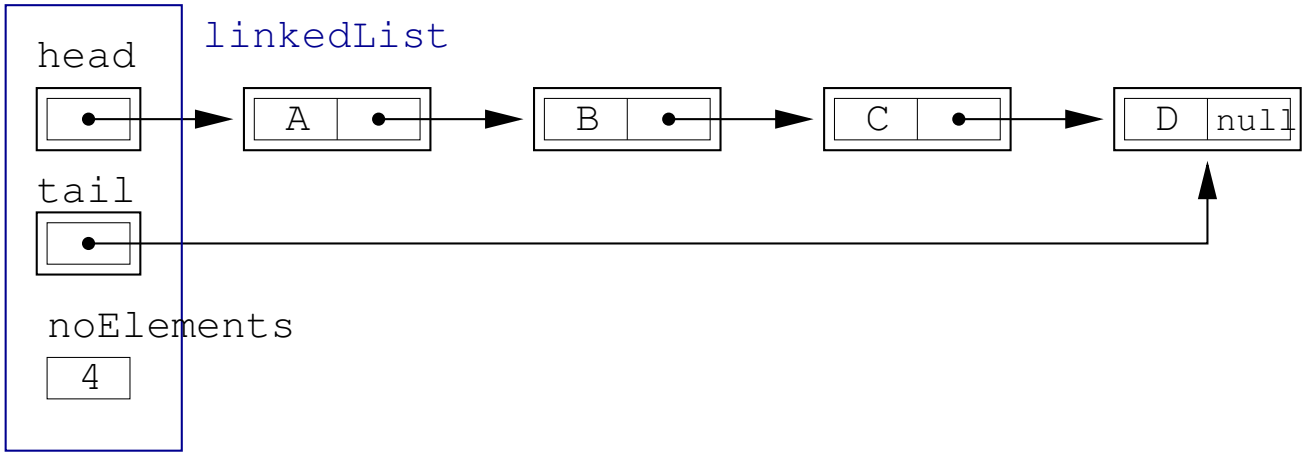

Implementing a Queue

- We can then add elements to the tail in constant time
- We can the implement a queue in $O(1)$ time by
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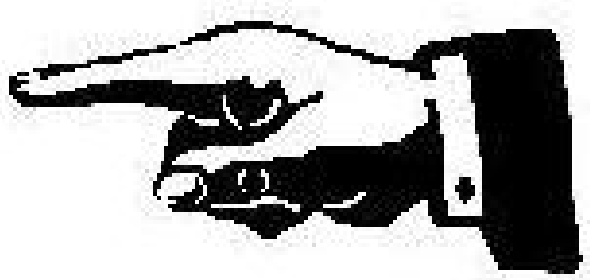
3. Stacks and Queues
4. **Doubly Linked List**
5. Using Linked Lists
6. Skip Lists



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- To achieve this it uses a doubly-linked lists with elements to next and previous

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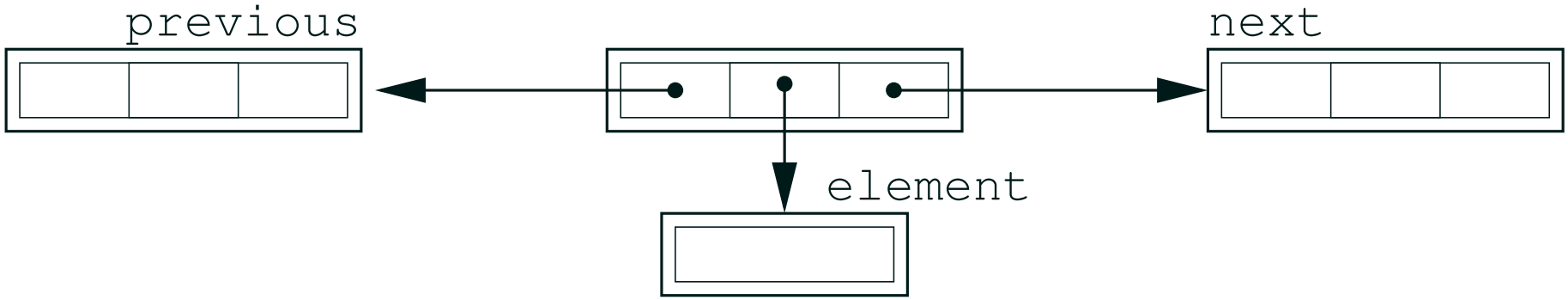

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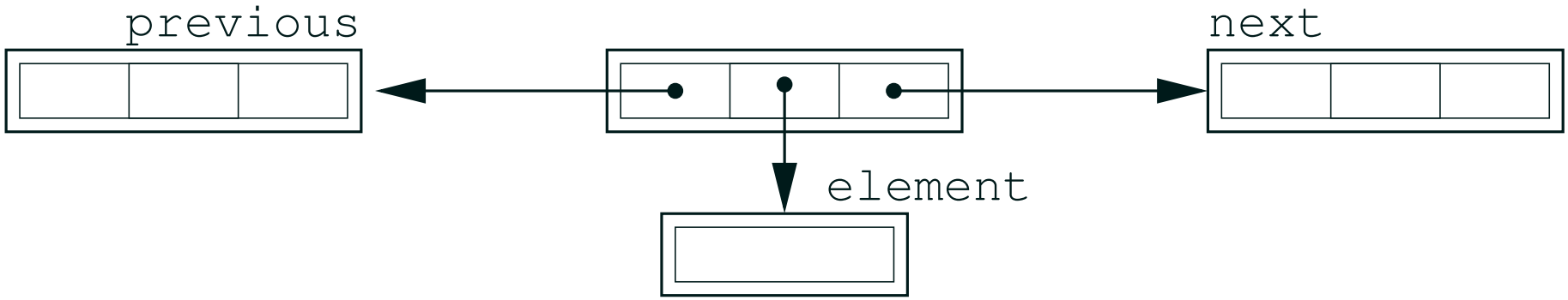

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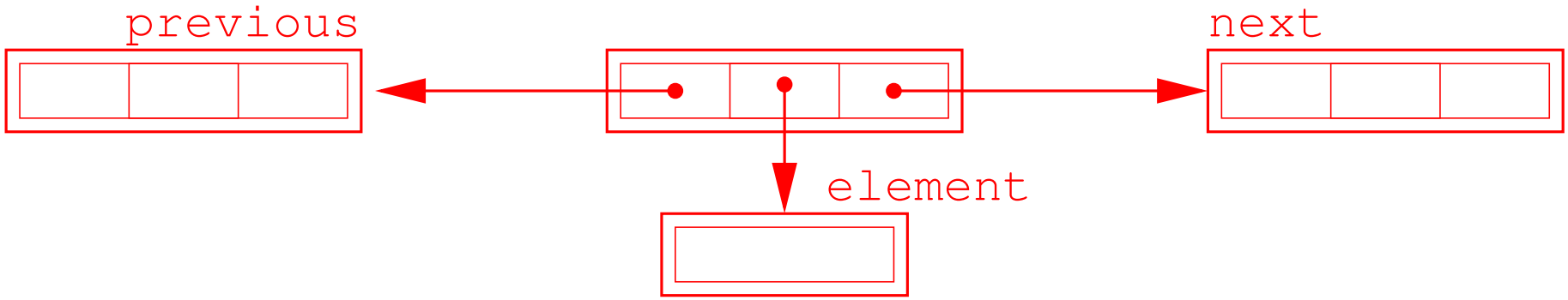

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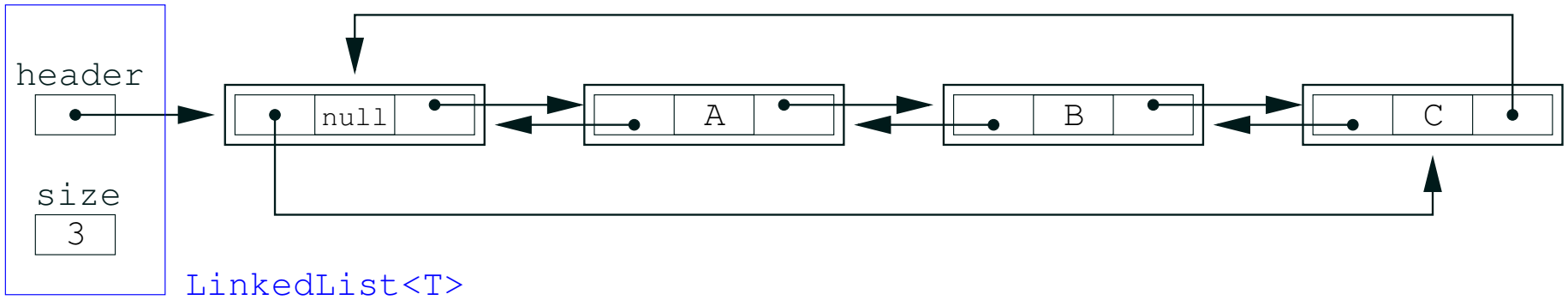

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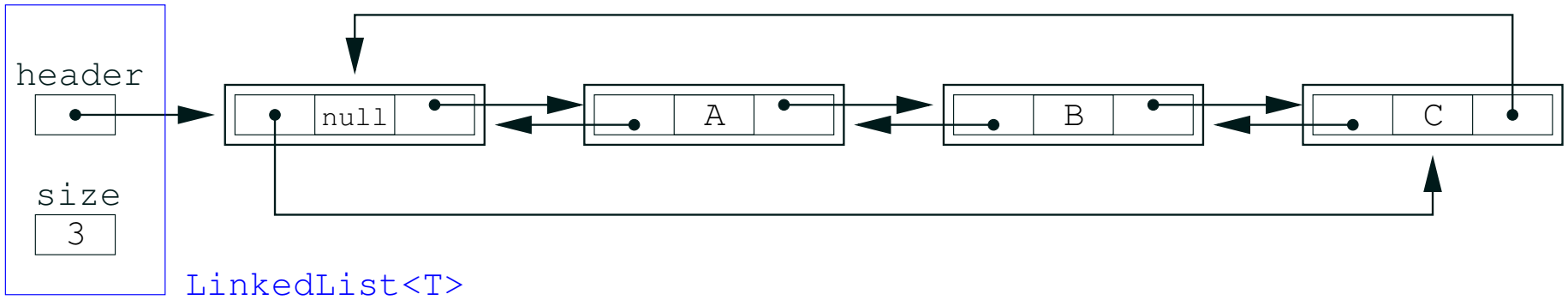

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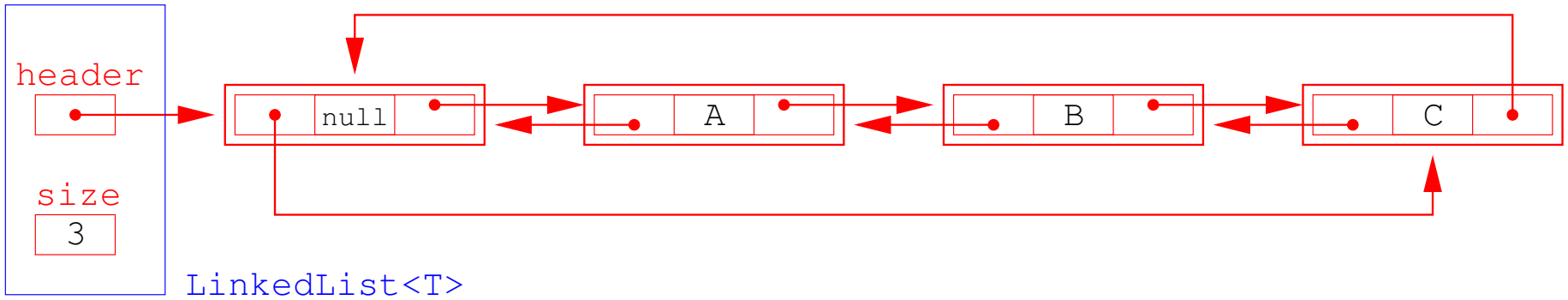

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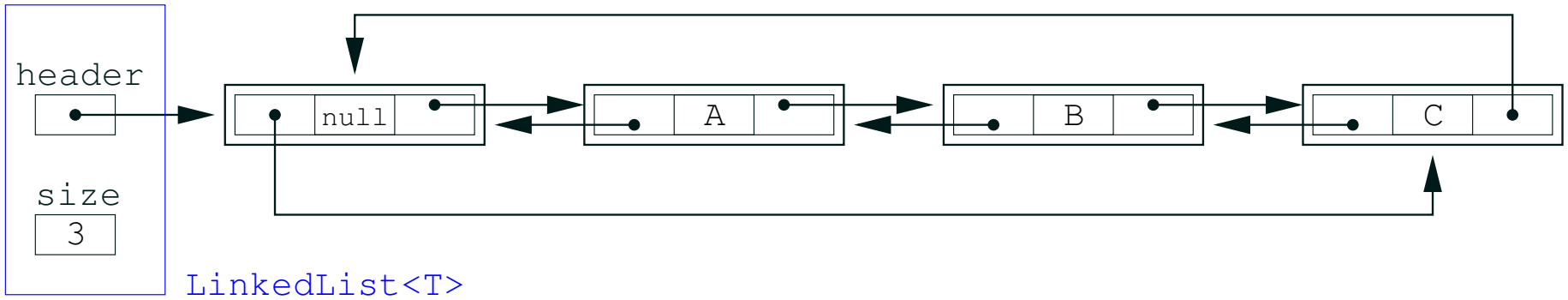

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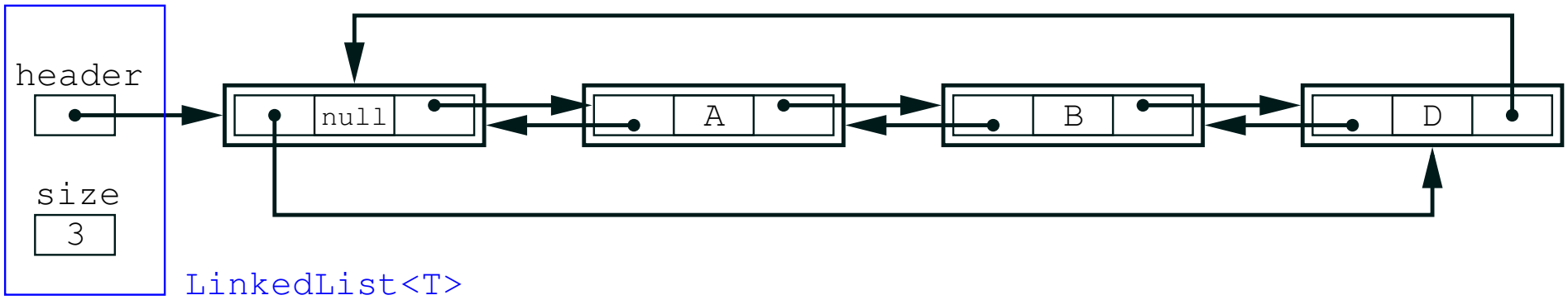

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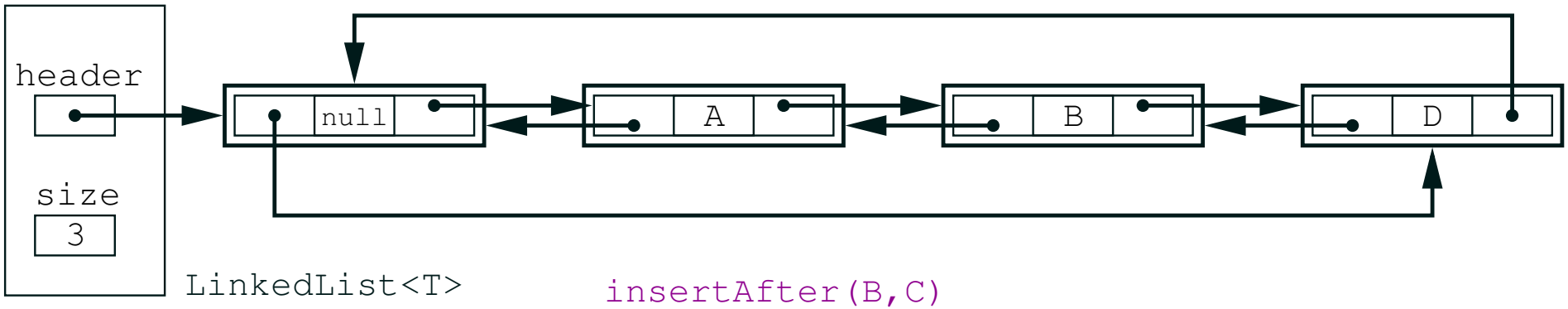

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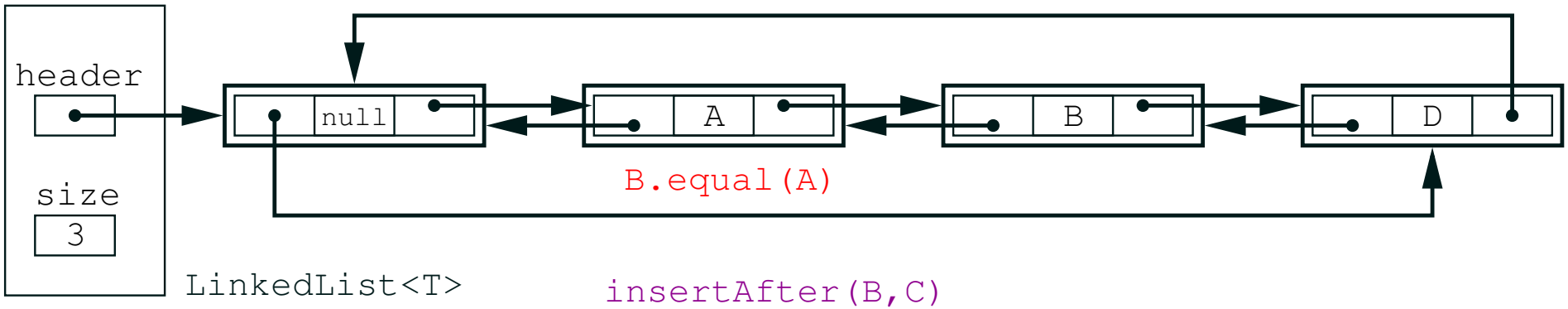

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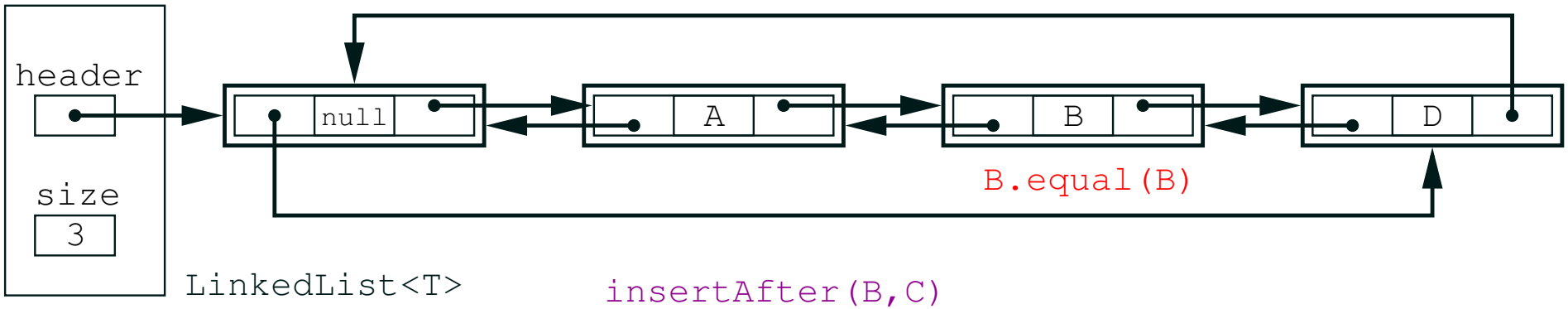

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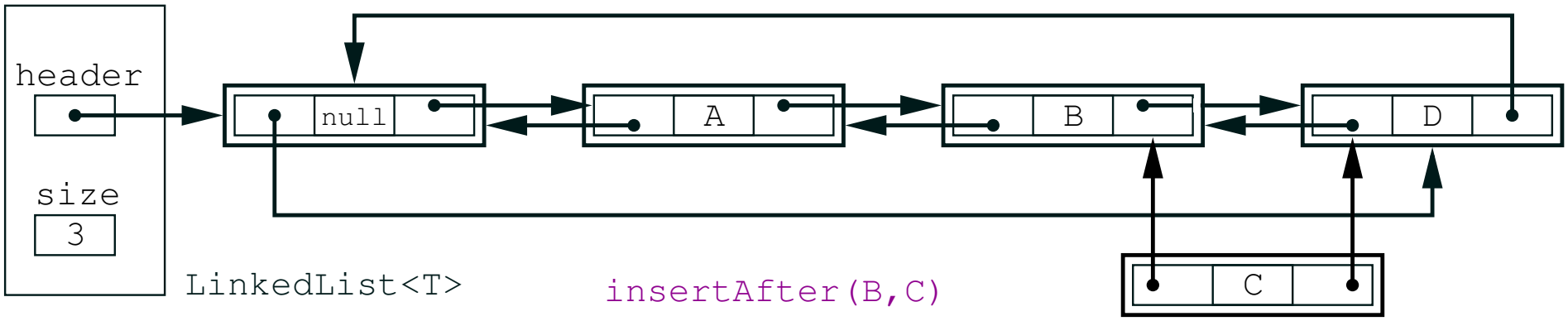

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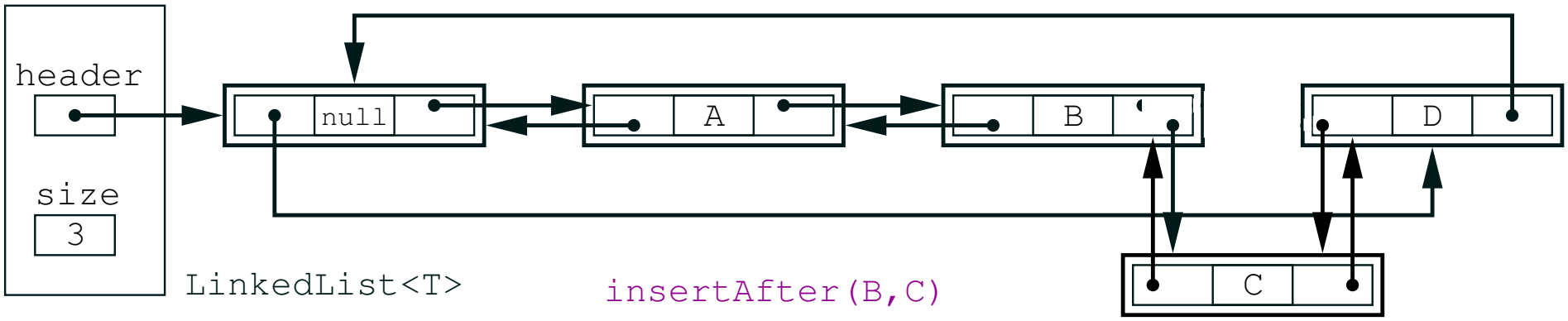

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When To Use Linked Lists

- It is difficult to think of applications where linked lists are the best data structure
- lists—variable length arrays are usually better
- queues—linked list OK, but circular arrays are probably better
- sorted lists—binary trees much better
- linked lists have efficient insertion and deletion but it is difficult to think of an application where this matters

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- We are usually working at a particular location in the text
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Skip Lists

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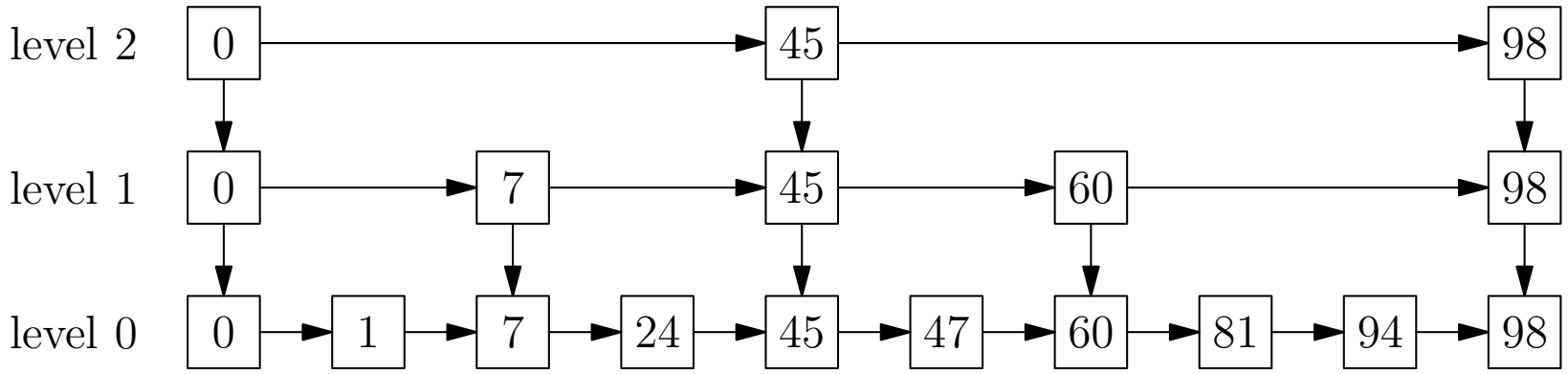
- Even if you kept an ordered list you still need to traverse it
- Skip lists are hierarchies of linked lists which allow binary search



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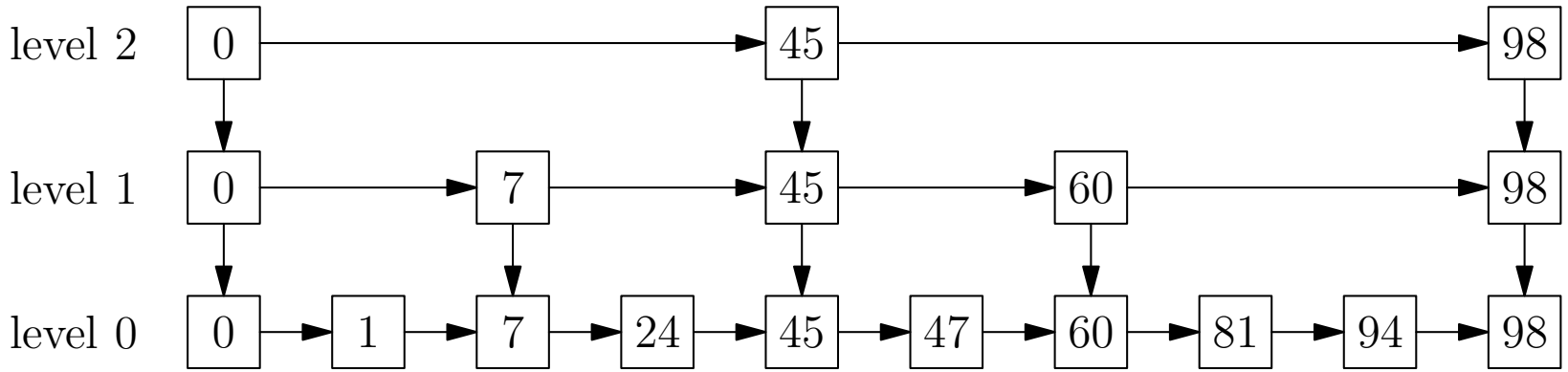

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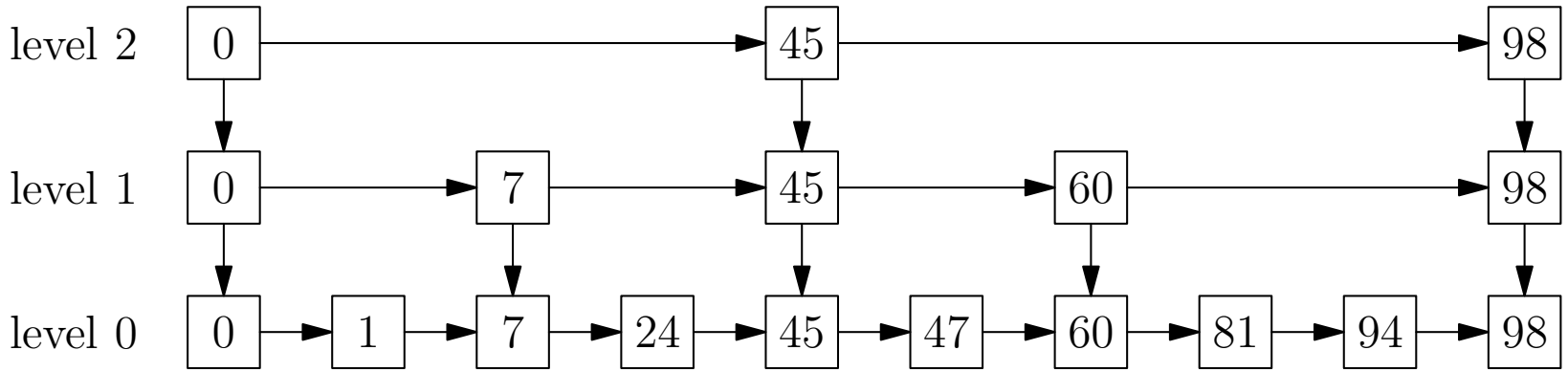

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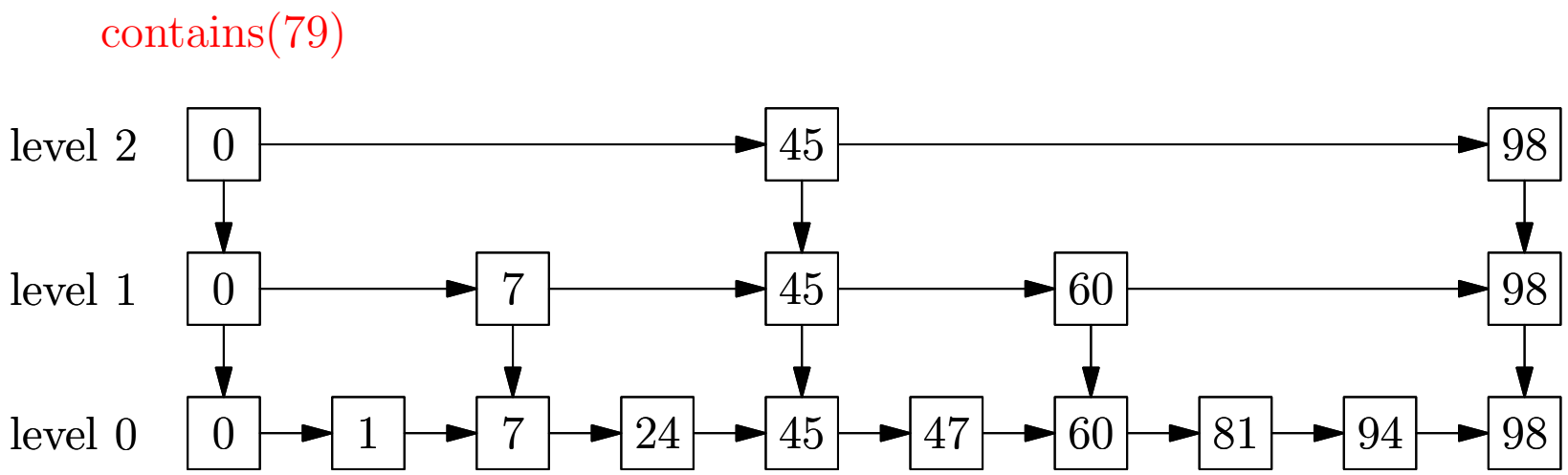

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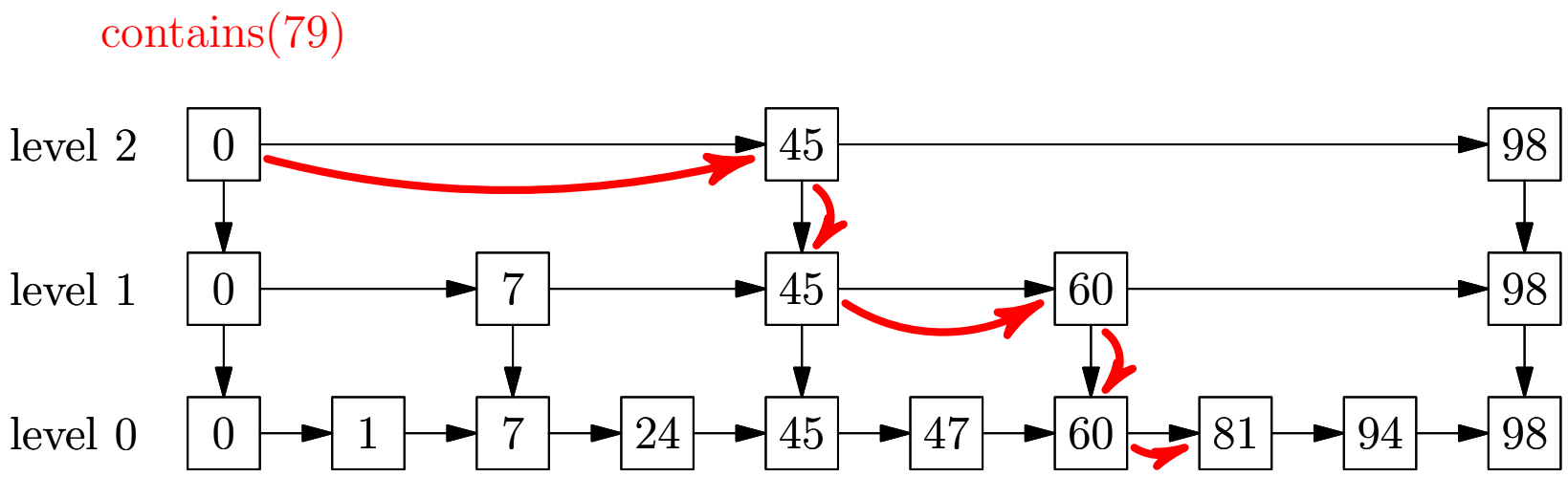

Efficiency of Skip Lists

- Skip lists provide $\Theta(\log_2(n))$ search as opposed to $\Theta(n)$
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