Linked Data Structures I: Singly-Linked Lists

What's Wrong With Arrays?

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  - Similarly for the Java ***collections framework***

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Any type whose abstract mathematical model involves a ***`string`*** or ***`set`*** or ***`multiset`*** (or ***`tree`*** or ***`binary tree`***?) is a "collection" type.

What's Wrong With Arrays?

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  - Similarly for the Java ***collectio ramework***

Examples are `Queue`, `Stack`, `Sequence`, `Set`, `Map`, `SortingMachine`, ...

What's Wrong With Arrays?

- A Java array is not ideally suited as a data representation of the various ***collection types***
  - Similarly for the Java ***collections framework***

This is part of the package `java.util`, and includes many types similar to the OSU CSE components.

Collection Terminology

- ***Fixed size*** means the size/length of a collection is “inflexible”, i.e., it is determined at initialization of the collection and cannot be incrementally adjusted
  - A classical synonym is ***static***; this term unfortunately means other things in Java
- ***Dynamic*** means the size/length of a collection is “flexible”, i.e., it can be incrementally adjusted by “adding” and “removing” entries, even from the middle

Collection Terminology

- ***Direct access*** means the entries of a collection (typically with a **`string`** model) may be accessed by providing an **`int`** position/index of any entry in the collection
  - A classical but unfortunate synonym is ***random access***; nothing random about it!
- ***Sequential access*** means the entries of a collection (with a **`string`** model) may be accessed in increasing order of position by accessing the "next" entry in the collection

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We might say any collection with an iterator allows sequential access, but this is about the *other* methods for access.

Key Pros and Cons of Arrays

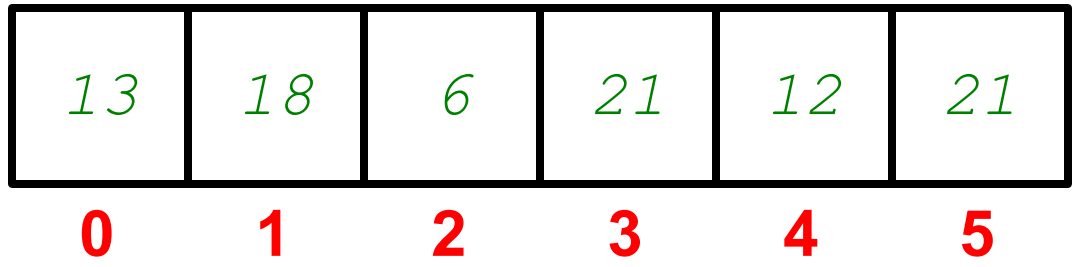
- Pros:
  - Direct access is fast, i.e., it takes ***constant time*** independent of the length of the array
- Cons:
  - Its fixed size limits array utility where dynamic size is important: it can run out of room
  - Adding and removing entries in the middle requires moving array entries, which is slow
  - Initialization may be expensive, especially if many entries are not subsequently used

Fixed Size Can Support Fast Direct Access

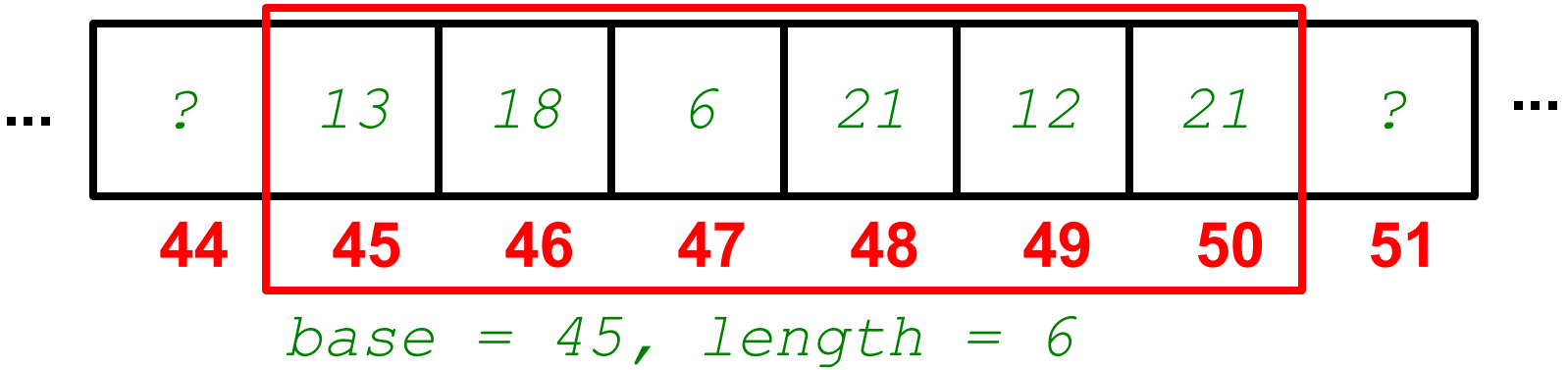
- A Java array is represented in a ***contiguous block*** of memory locations with consecutive memory addresses (IDs), so the memory address of the entry at index `i` can be ***directly calculated*** from the memory address of the first entry, by using simple arithmetic

Example

Client's view of an array (*entries = <13, 18, 6, 21, 12, 21>*):



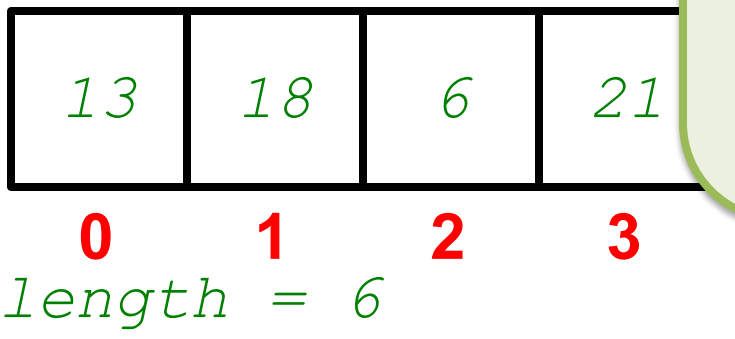
Implementer's view of an array in memory:



Exampl

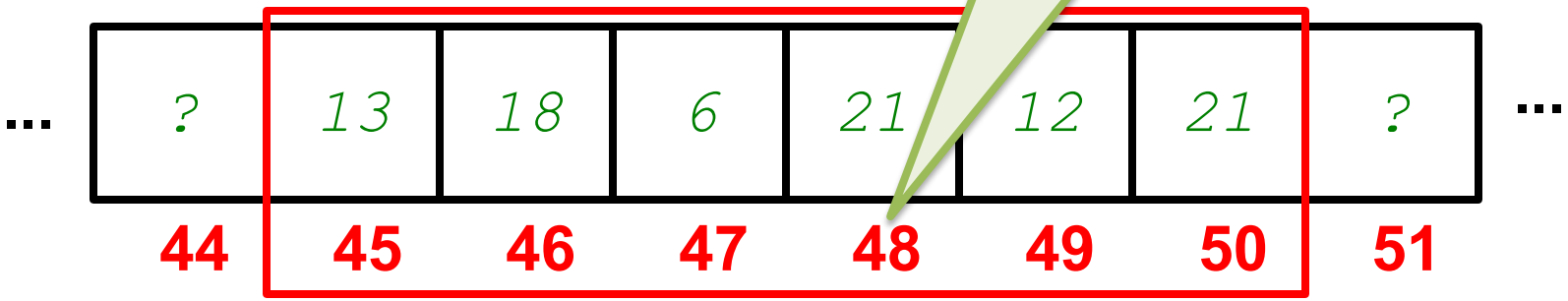
Client's view of an array

(*entries = <13, 18,*



If client wants to access the entry at position *3* of the array, how does implementer compute its memory address/ID?

Implementer's view of an array in memory:



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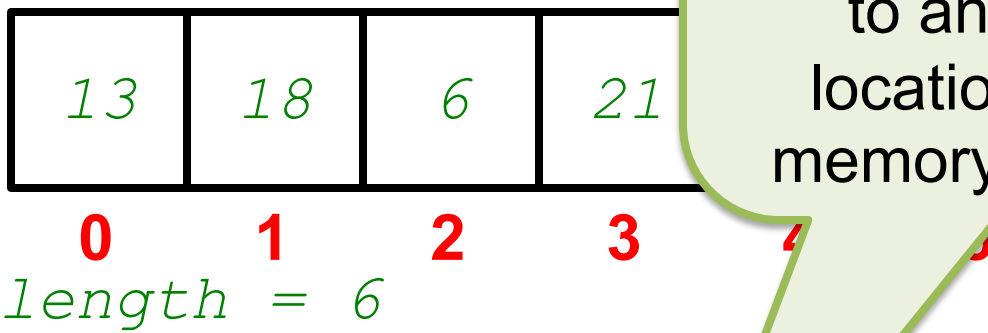

Every modern computer the JVM runs on provides constant-time access to any memory location given the memory address/ID.

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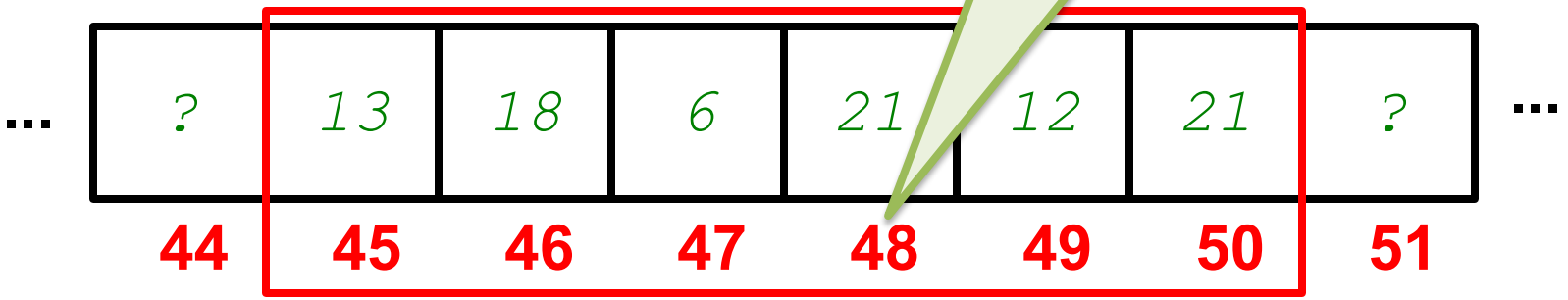


Notice the Array Mismatches

Collection	Fixed Size?	Dynamic?	Direct Access?	Seq Access?
array	✔		✔	
`Queue`		✔		✔
`Stack`		✔		✔
`Sequence`		✔	✔	
`Set`		✔		
`Map`		✔		
`Sorting-Machine`		✔		

What Can Be Done?

- To represent collections that are ***dynamic*** with ***sequential access***, a different approach is needed: not arrays
  - Note: It is an open problem to represent a `Sequence`, which is ***dynamic*** and offers ***direct access***, in a way that is efficient in both execution time of access operations (i.e., constant time) and memory "footprint" (i.e., constant factor overhead)

Dynamic Can Support Fast Sequential Access

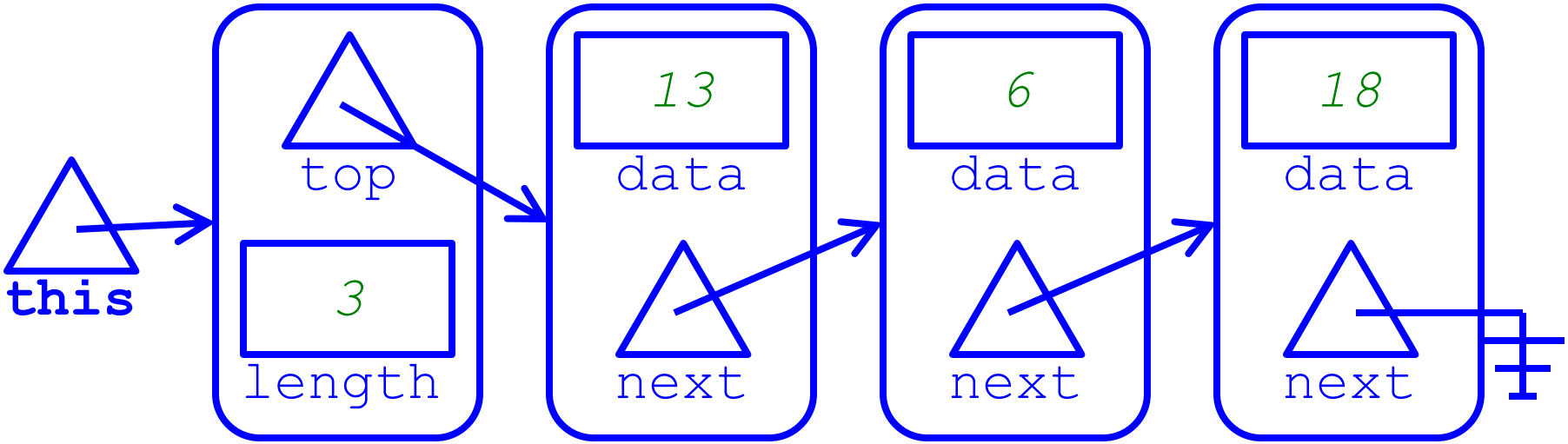
- If we want a ***dynamic*** collection, then we should give up on storing all entries of the collection in contiguous memory locations
- If we want fast ***sequential access***, then we should give up on fast direct access
  - Instead, for every entry in the collection, wherever it is in memory, simply keep a ***reference*** to (i.e., memory location of) the "next" entry

Example: `Stack2`

Client's view of a `Stack`:

this = *<13, 6, 18>*

Implementer's view of a `Stack2`:



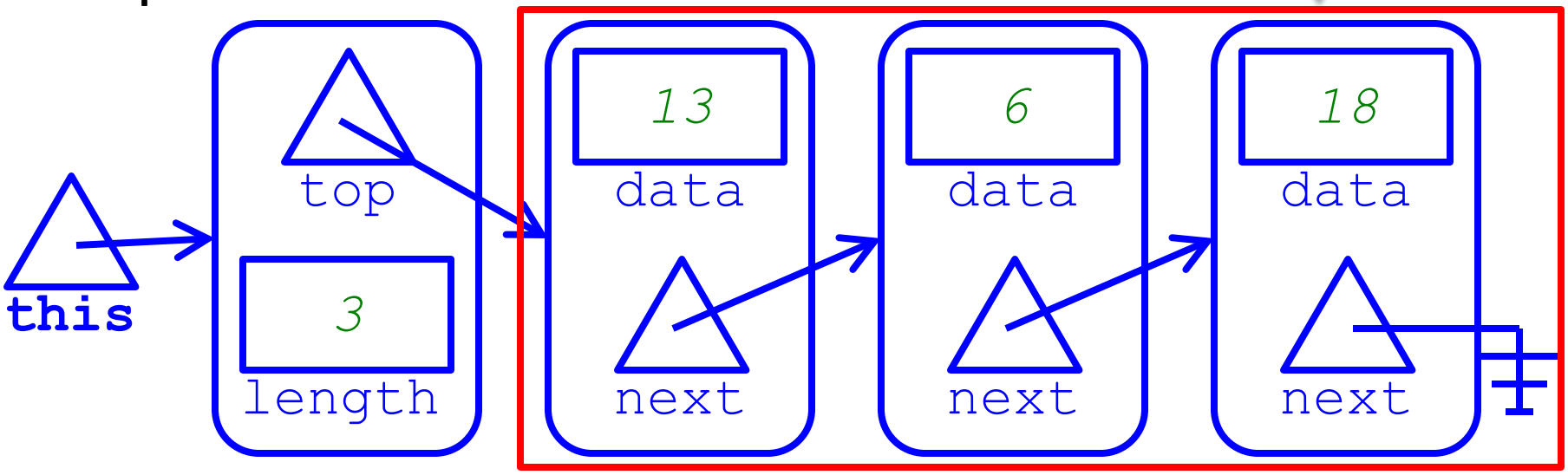
Example:

Client's view of a `Stack`:

this = <13, 6, 18>

This is called a ***singly-linked-list*** data structure.

Implementer's view of a `Stack2`:



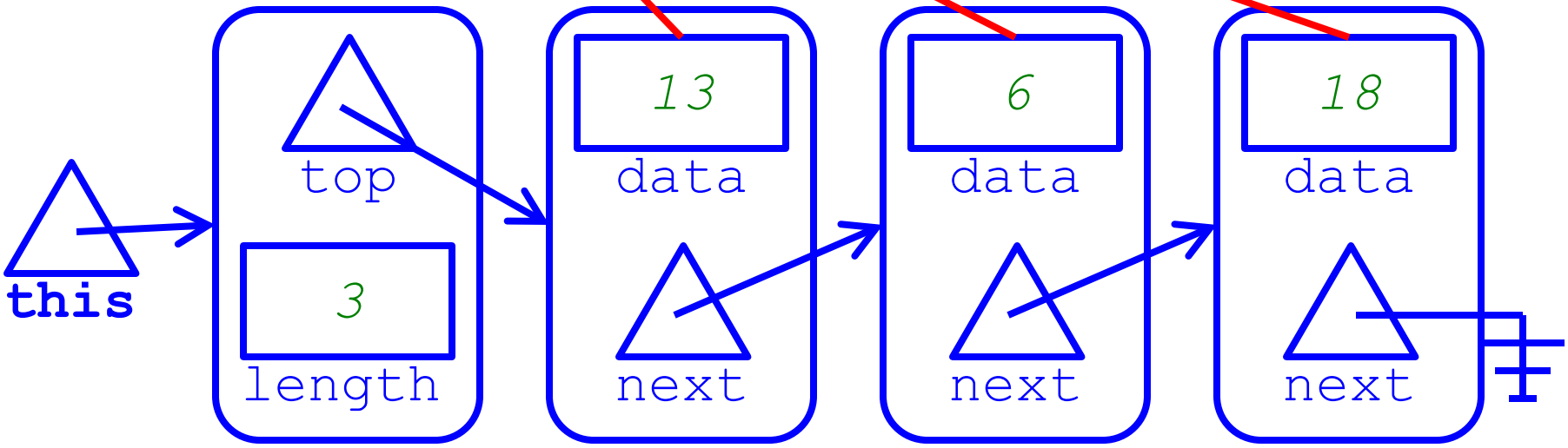
Example:

The abstraction function (correspondence) ...

Client's view of a `Stack`:

this = <13, 6, 18>

Implementer's view of a `Stack2`:



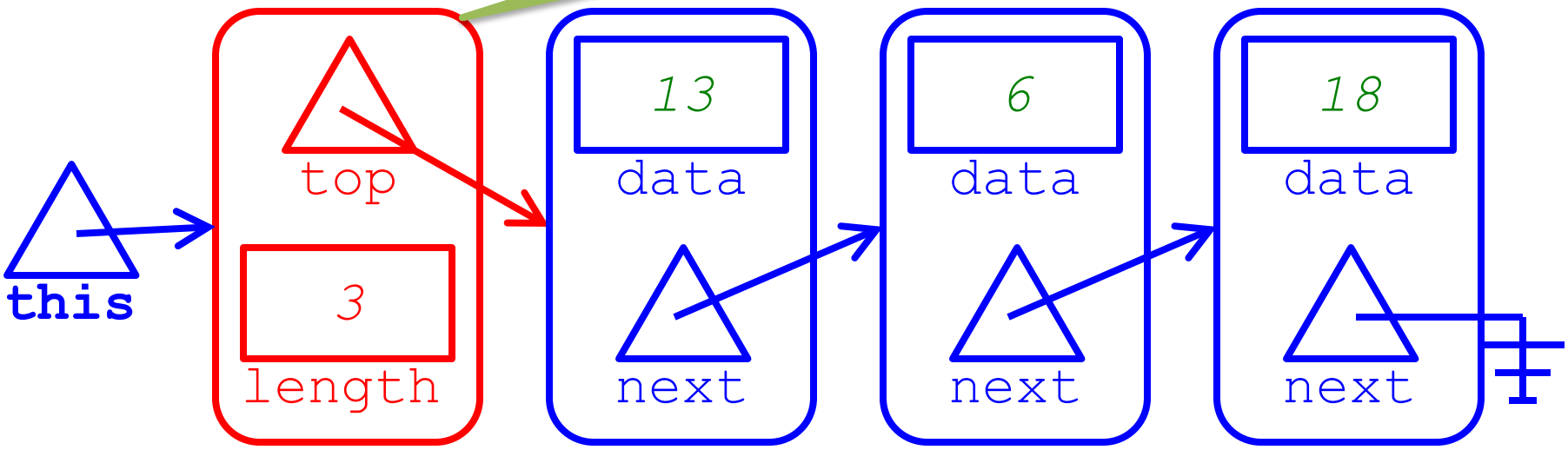
Example

Client's view of a `Stack`

this = <13, 6, ...

The ***instance variables (fields)*** of the data representation for `Stack2` are shown here.

Implementer's view of a `Stack2`:



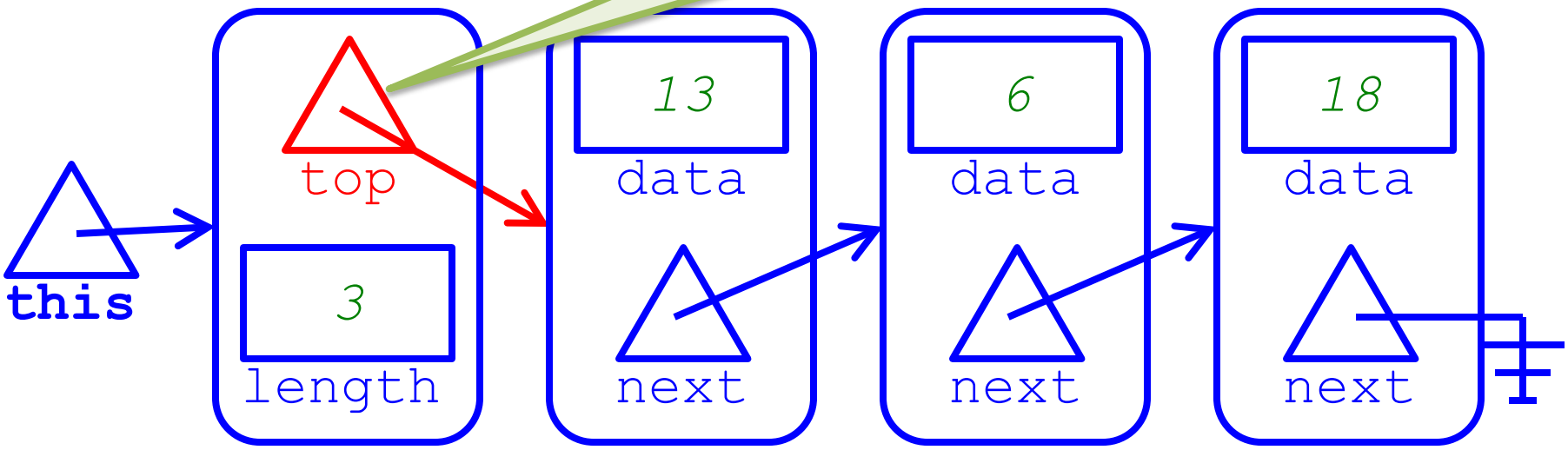
Example

Client's view of a `Stack`

this = <13, 6, 18>

The `Stack` methods only require access to the first entry, i.e., the top, so we keep a reference to its node.

Implementer's view of `LinkedStack2`:



Exampl

Client's view of a Sta

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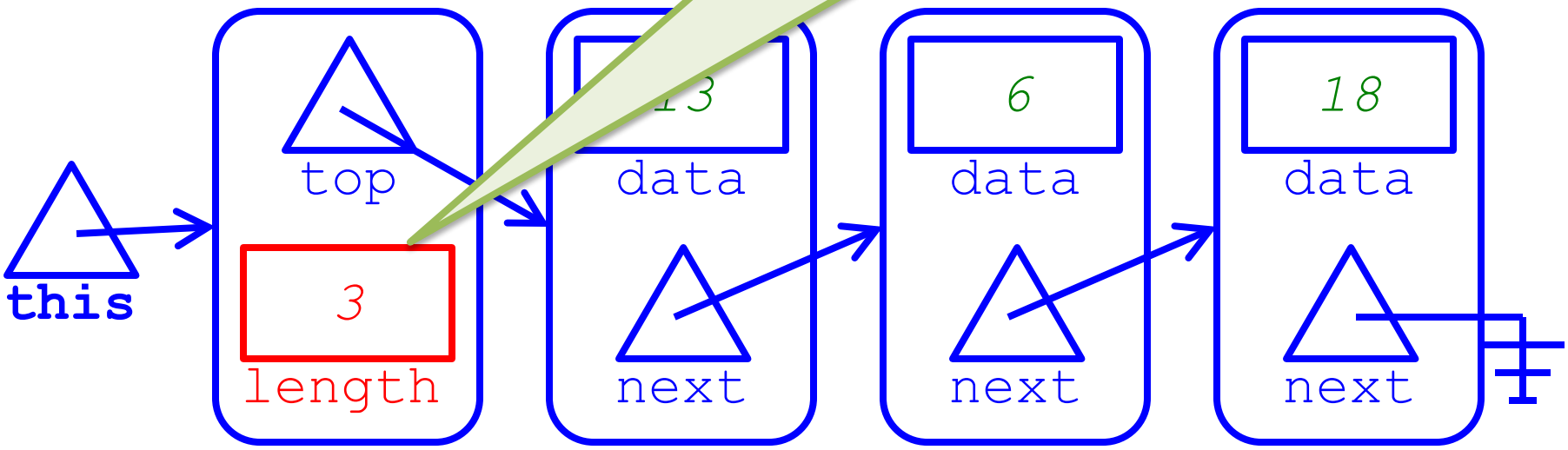
Implementer's view of a ck2:

The Stack methods include length, so we keep this direct count of the number of nodes in the linked list.



Exam

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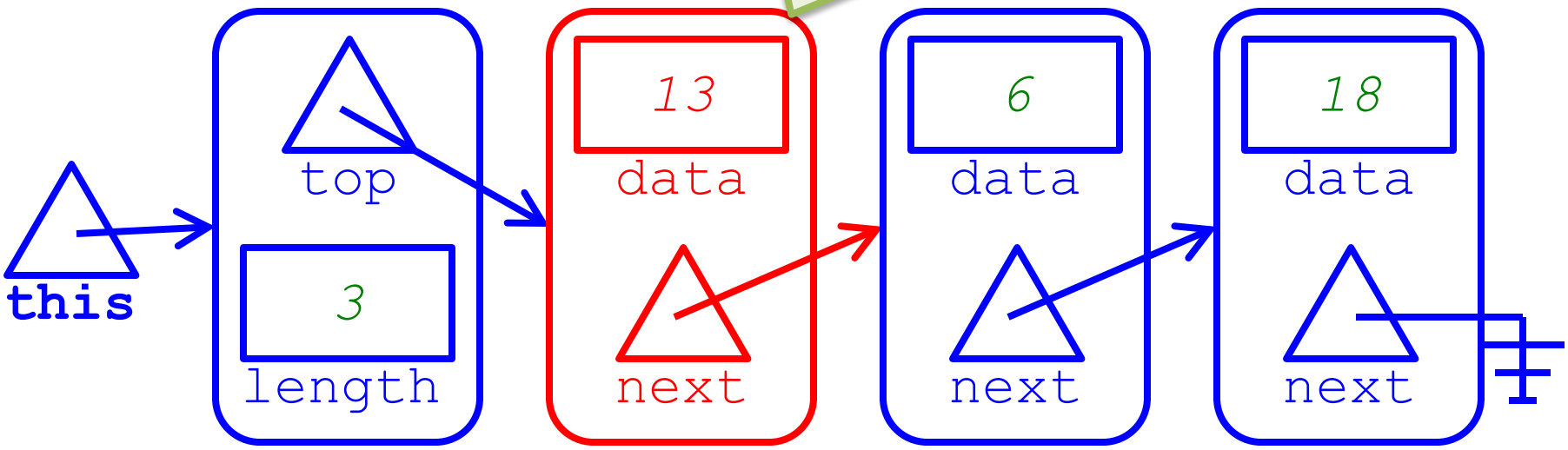
Each of these objects (a pair of variables) is called a ***node*** in this ***singly-linked-list data structure***: a variable of type `T`, and a reference to the "next" node.

Implementer's view of a k2:



Declaration of `Node` Class

- A `Node` class is declared as a ***nested class*** inside the kernel implementation that uses it in a data representation (e.g., `Stack2`, `Queue2`, and similar classes)

```
private final class Node {
  private T data;
  private Node next;
}
```

Declaratio

This declaration is recursive, and may seem circular!
One of the instance variables of a `Node` is of type `Node`.
How can this work?

- A `Node` class is ***class*** inside the … that uses it in a data … sentation (e.g., `Stack2`, `Queue2`, an… similar classes)

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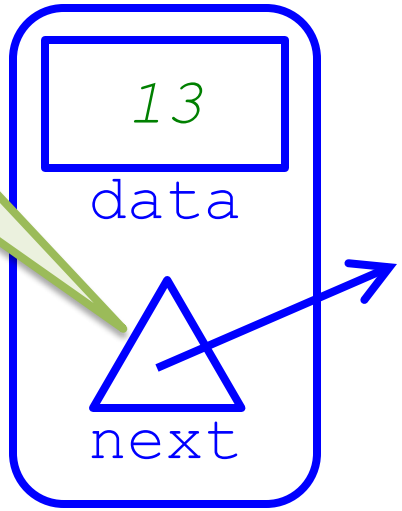
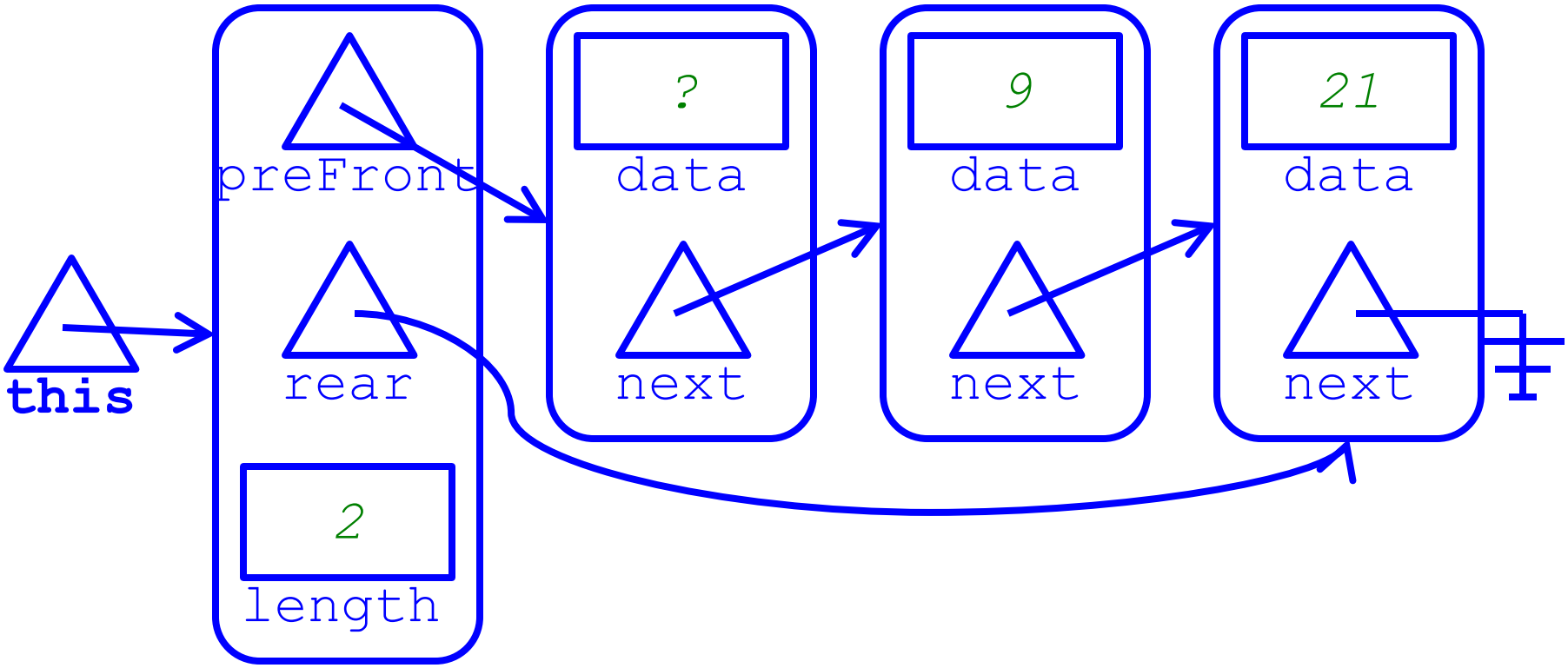


It works because the instance variable `next` is a ***reference variable***, hence is a ***reference*** to a `Node` object rather than a "nested" object.

Example: `Queue2`

this = *<9, 21>*



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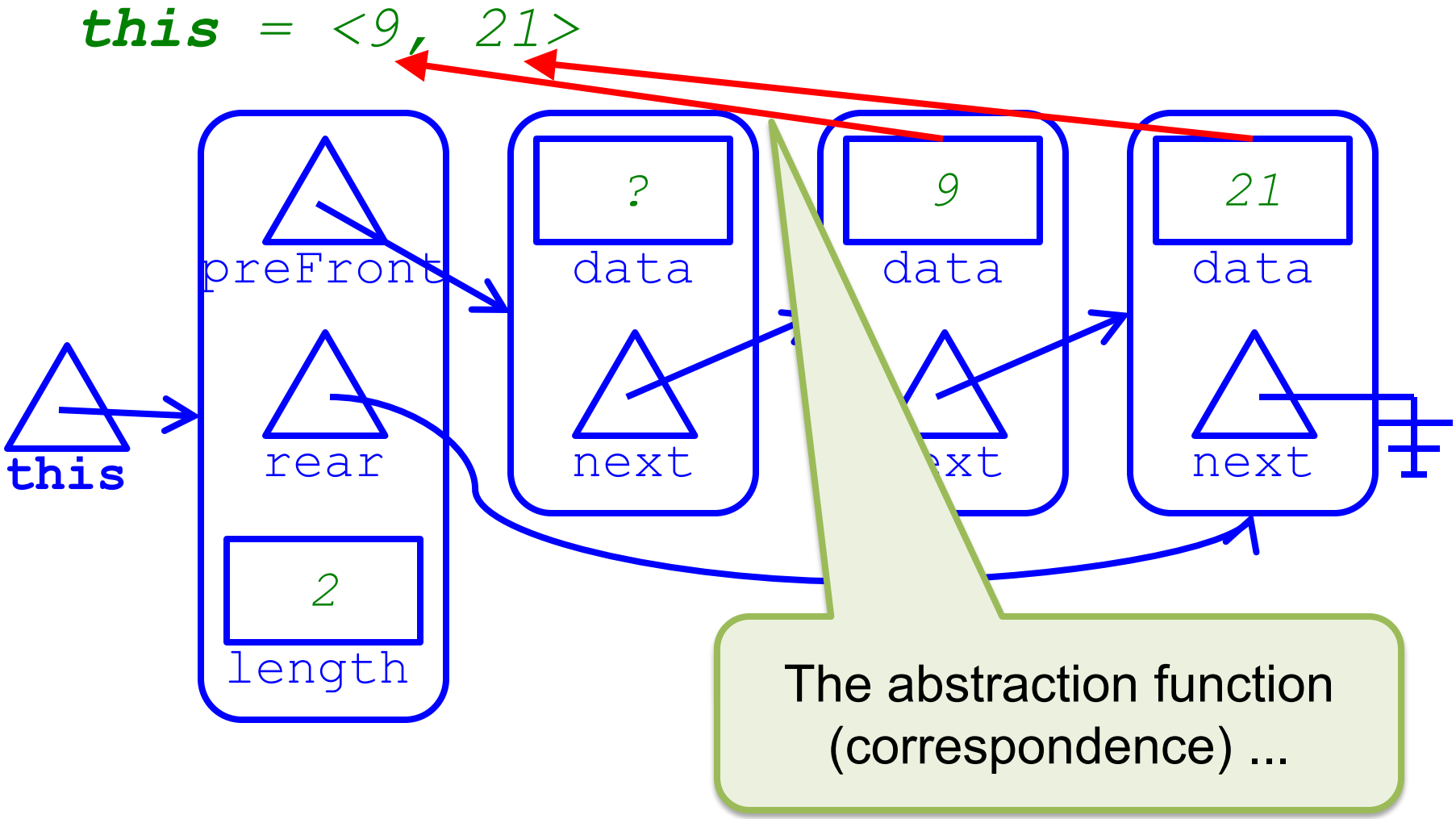

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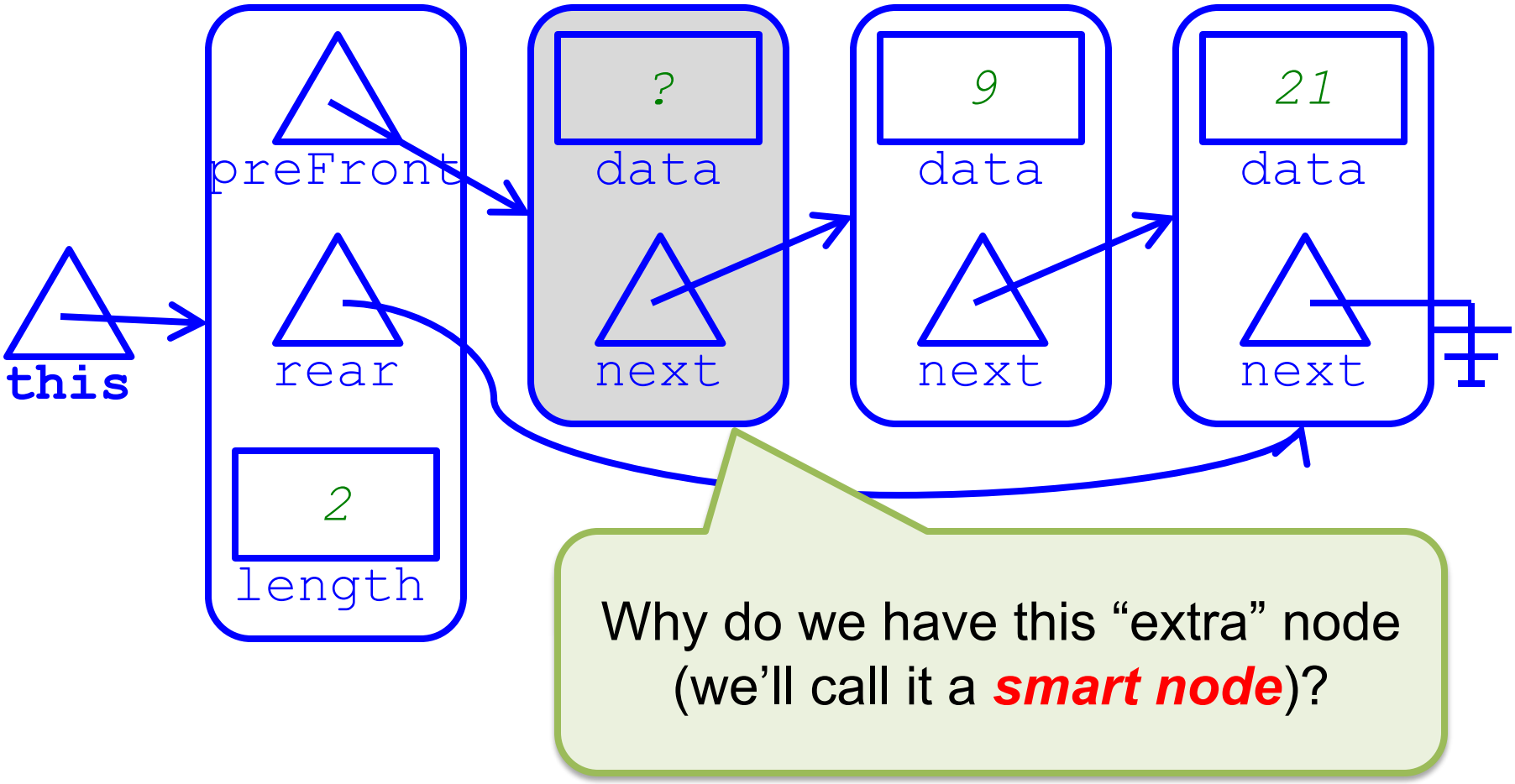

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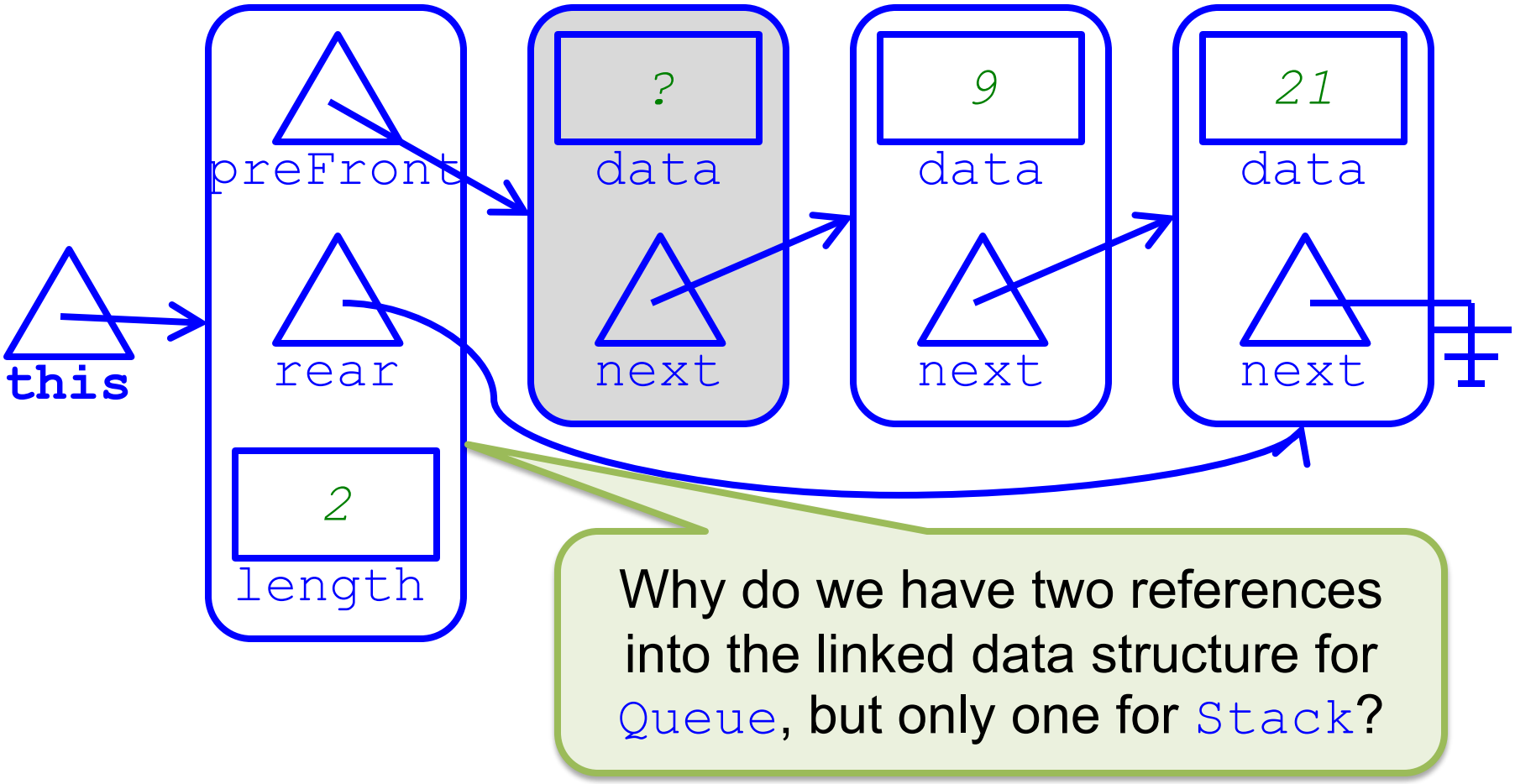

Why do we have two references into the linked data structure for `Queue`, but only one for `Stack`?

Example: `dequeue` for `Queue2`

```
public final T dequeue() {
   Node p = this.preFront;
   Node q = p.next;
   T result = q.data;
   this.preFront = q;
   this.length--;
   return result;
}
```

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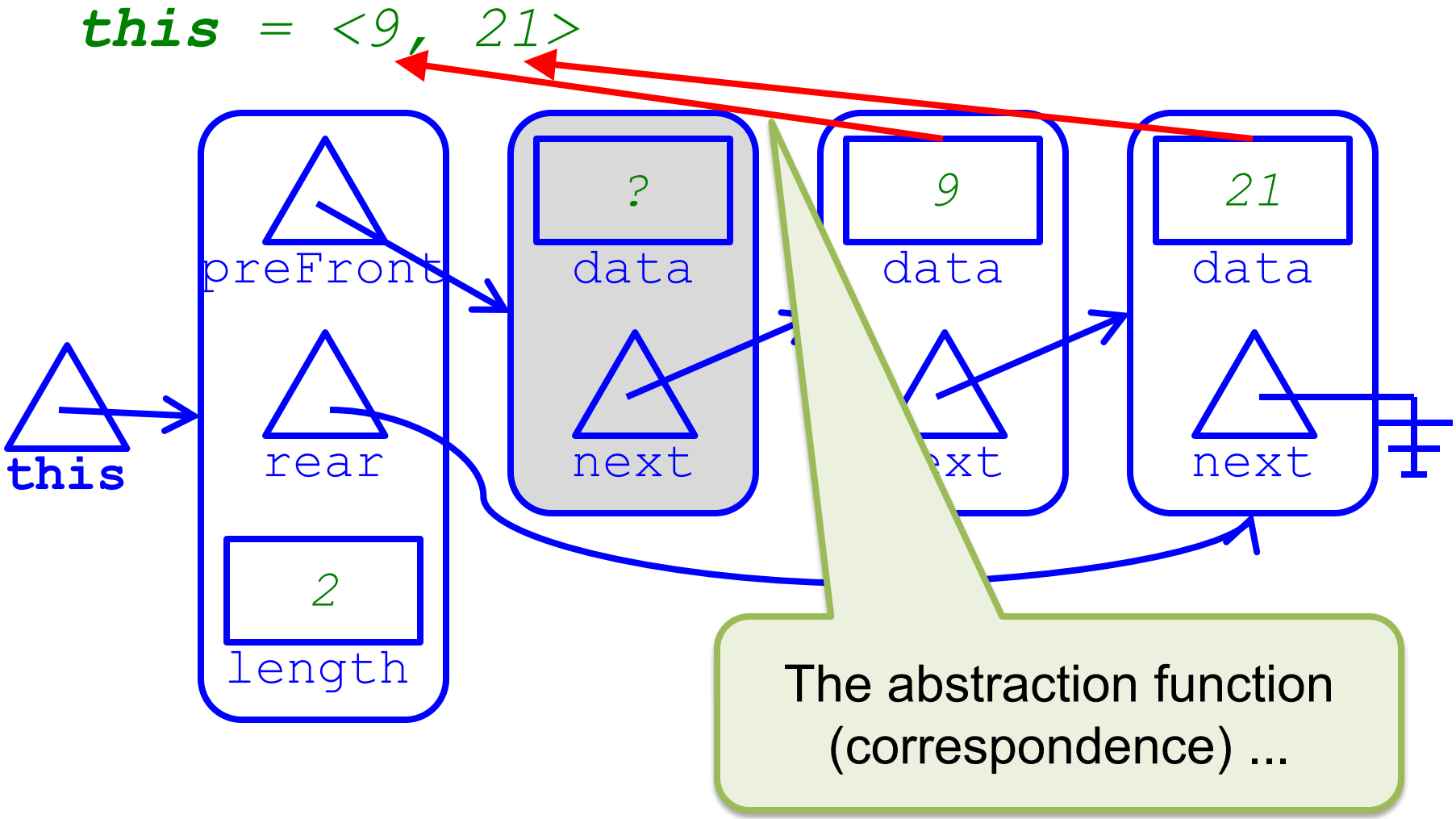

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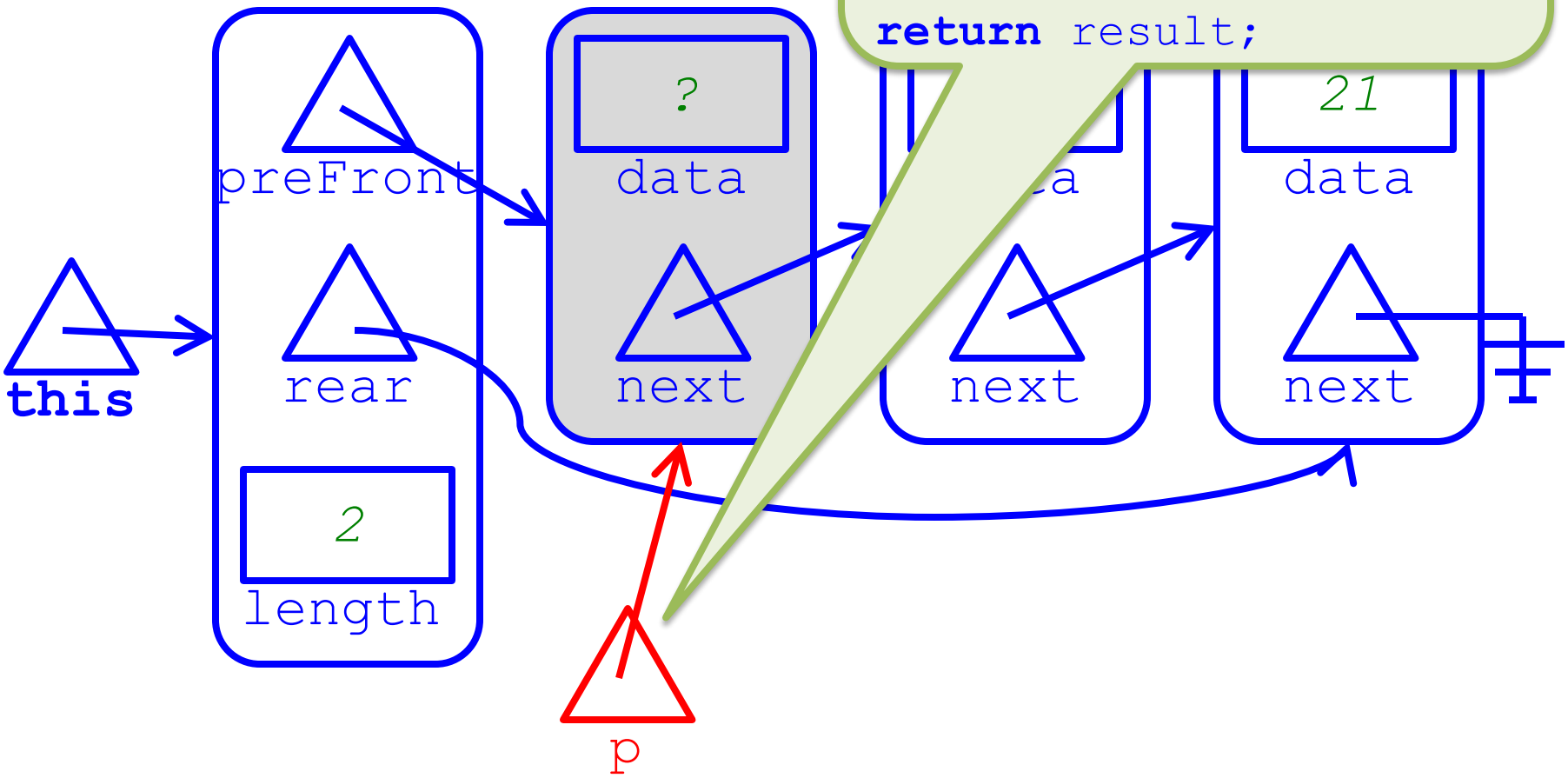

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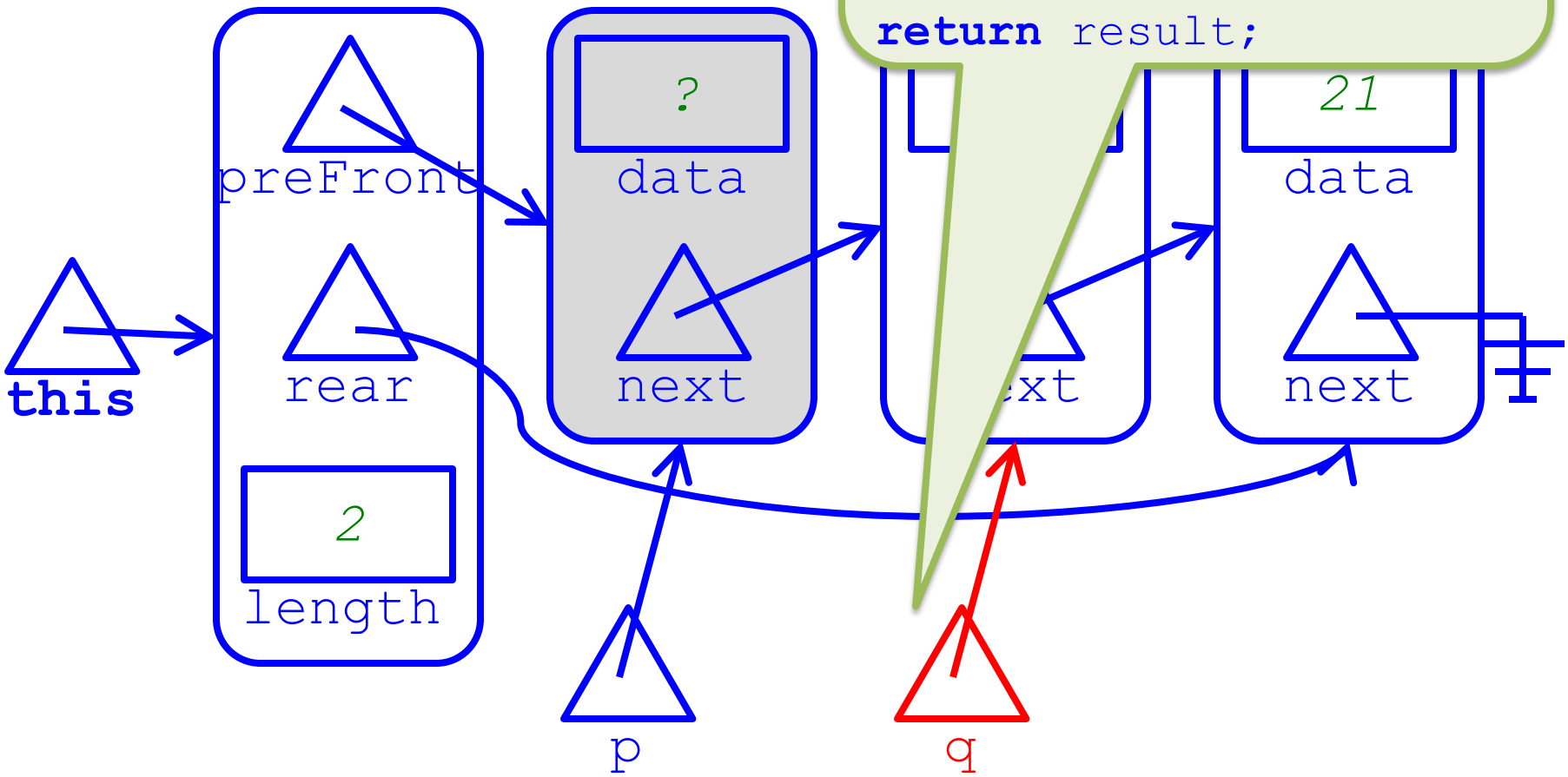

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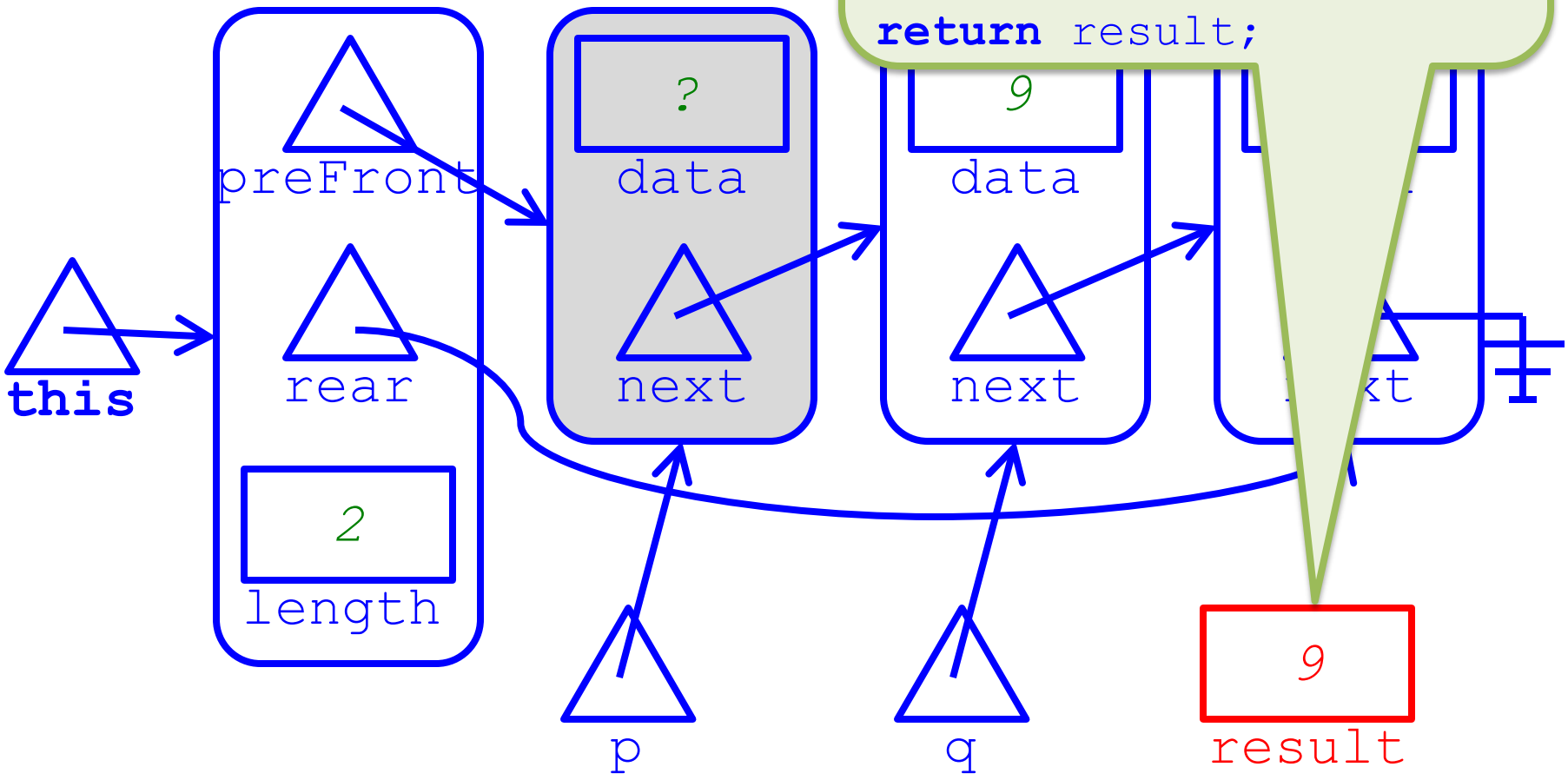

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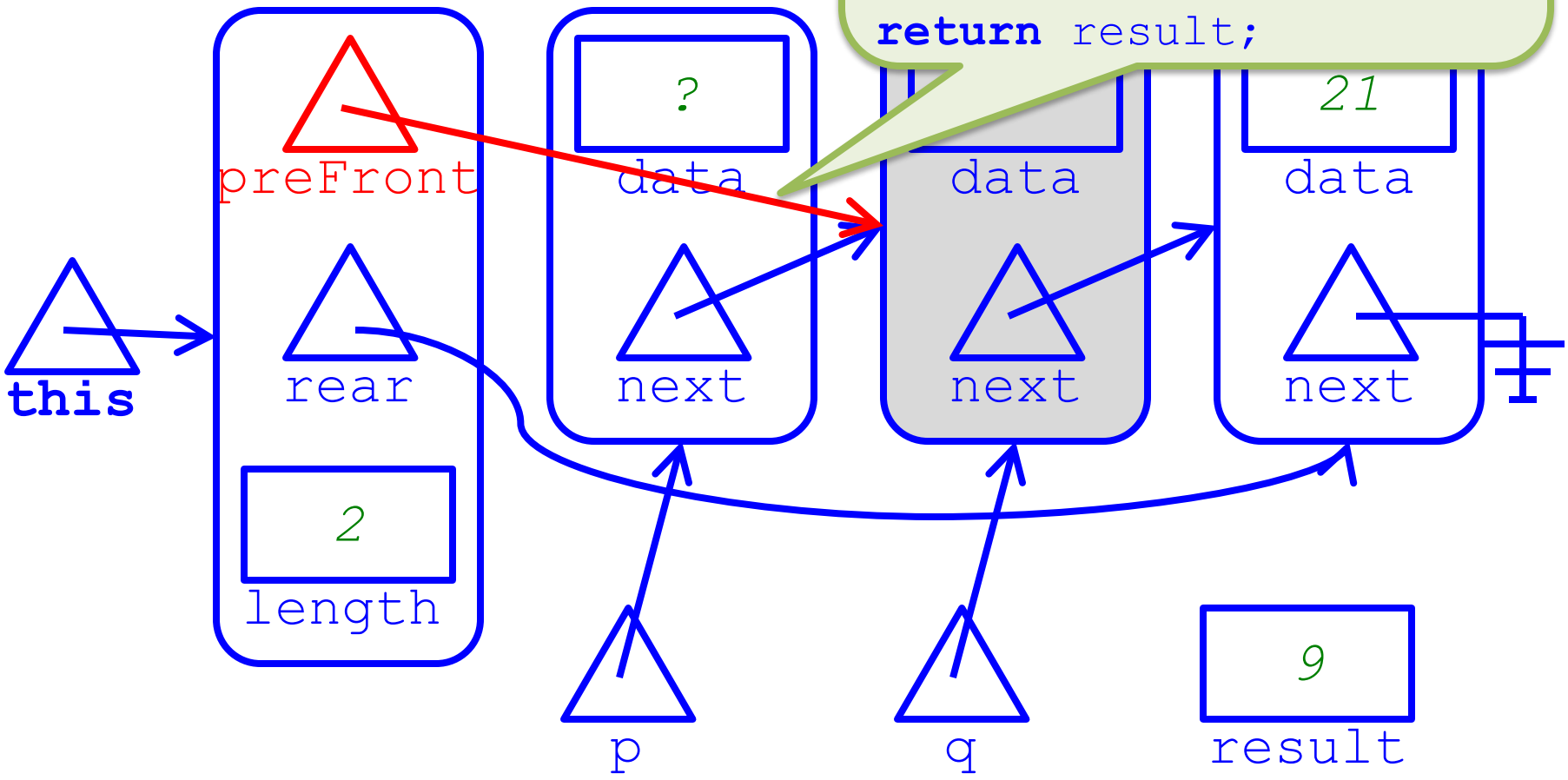

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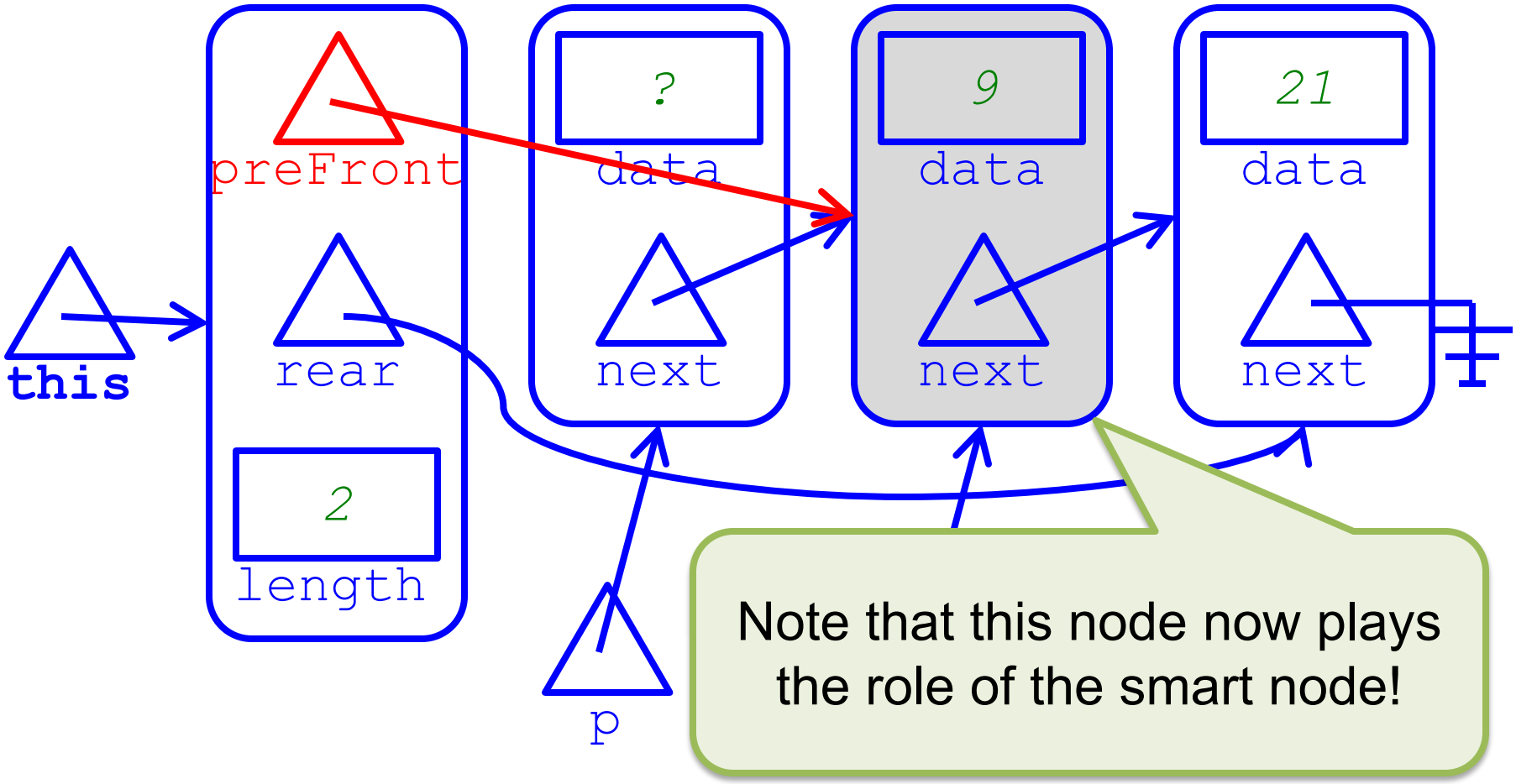

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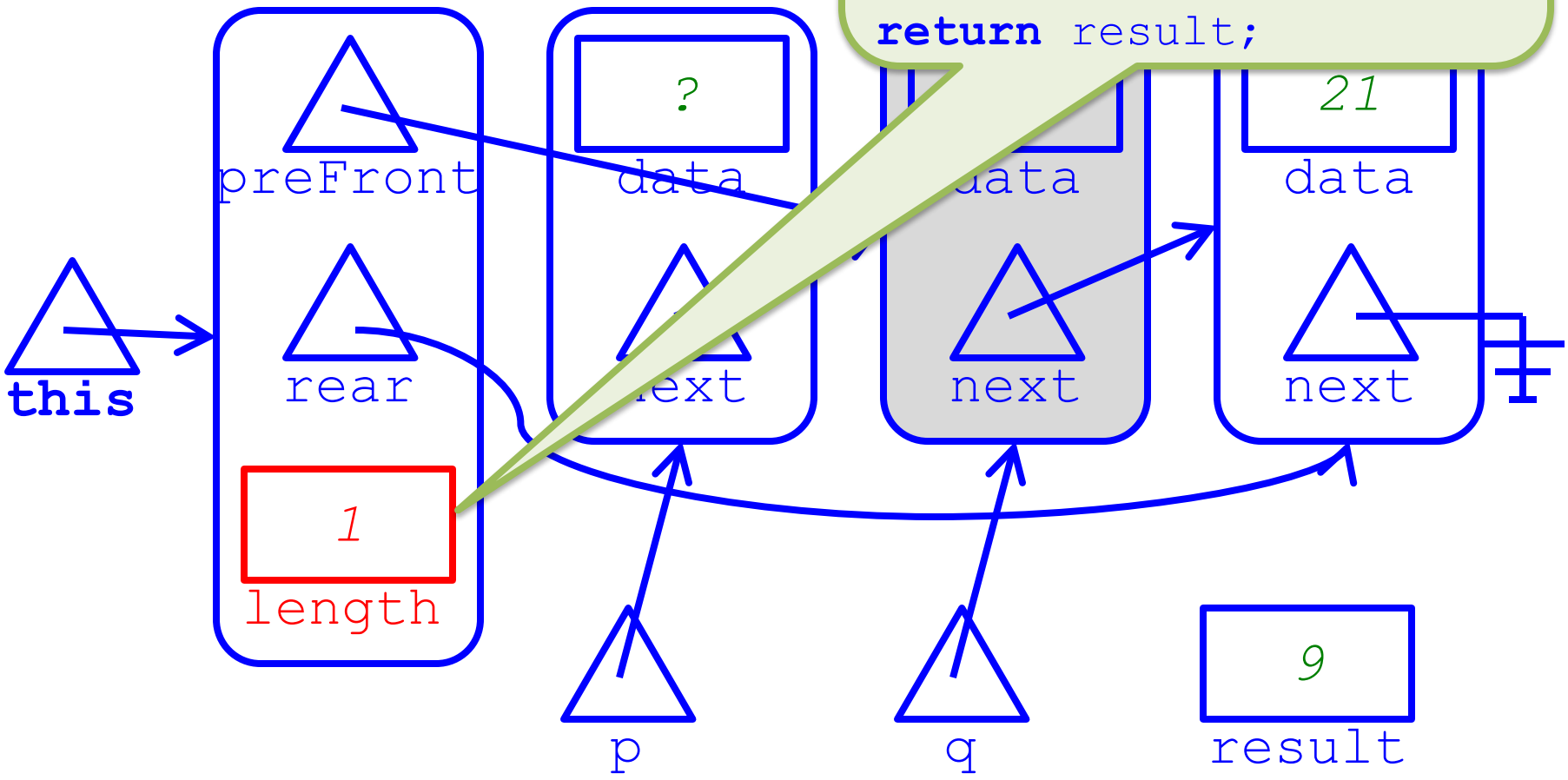

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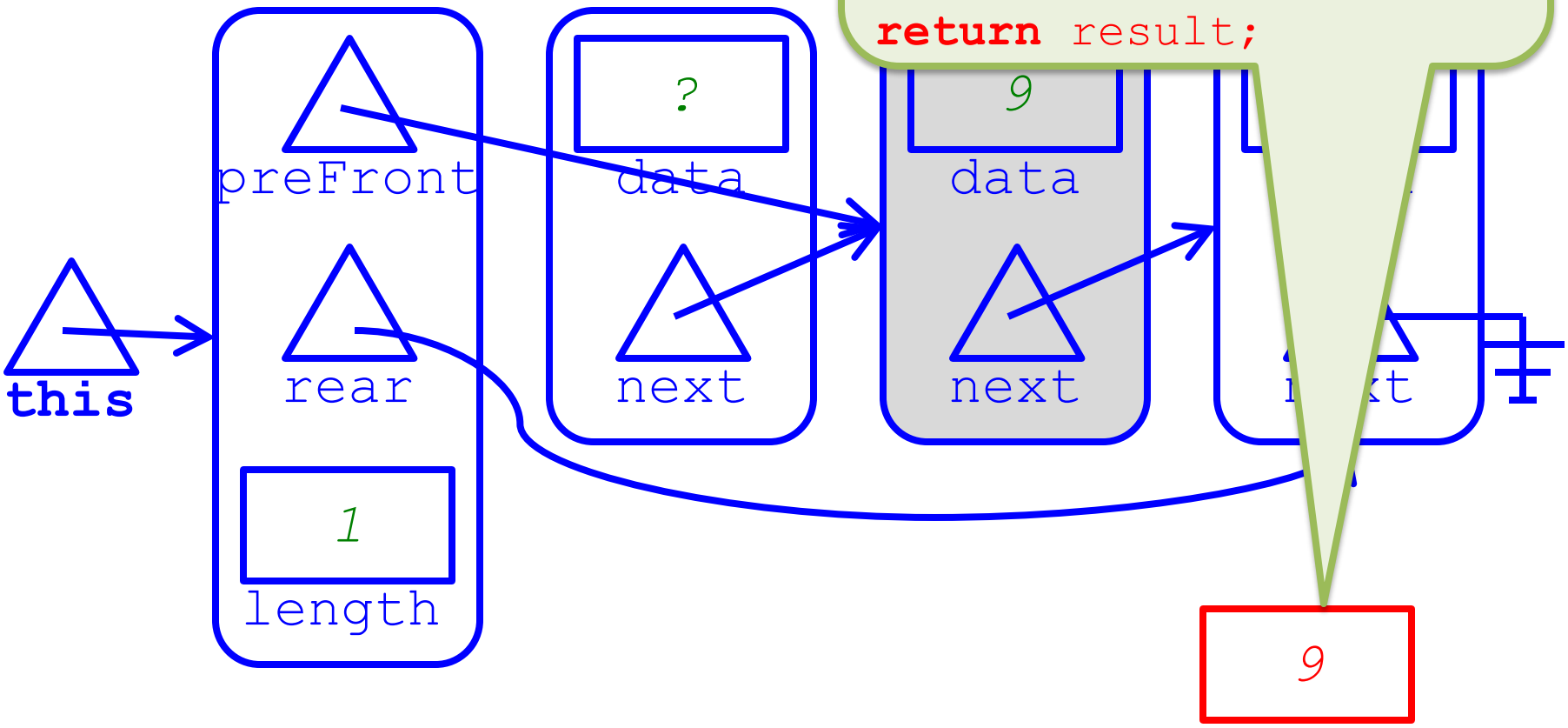

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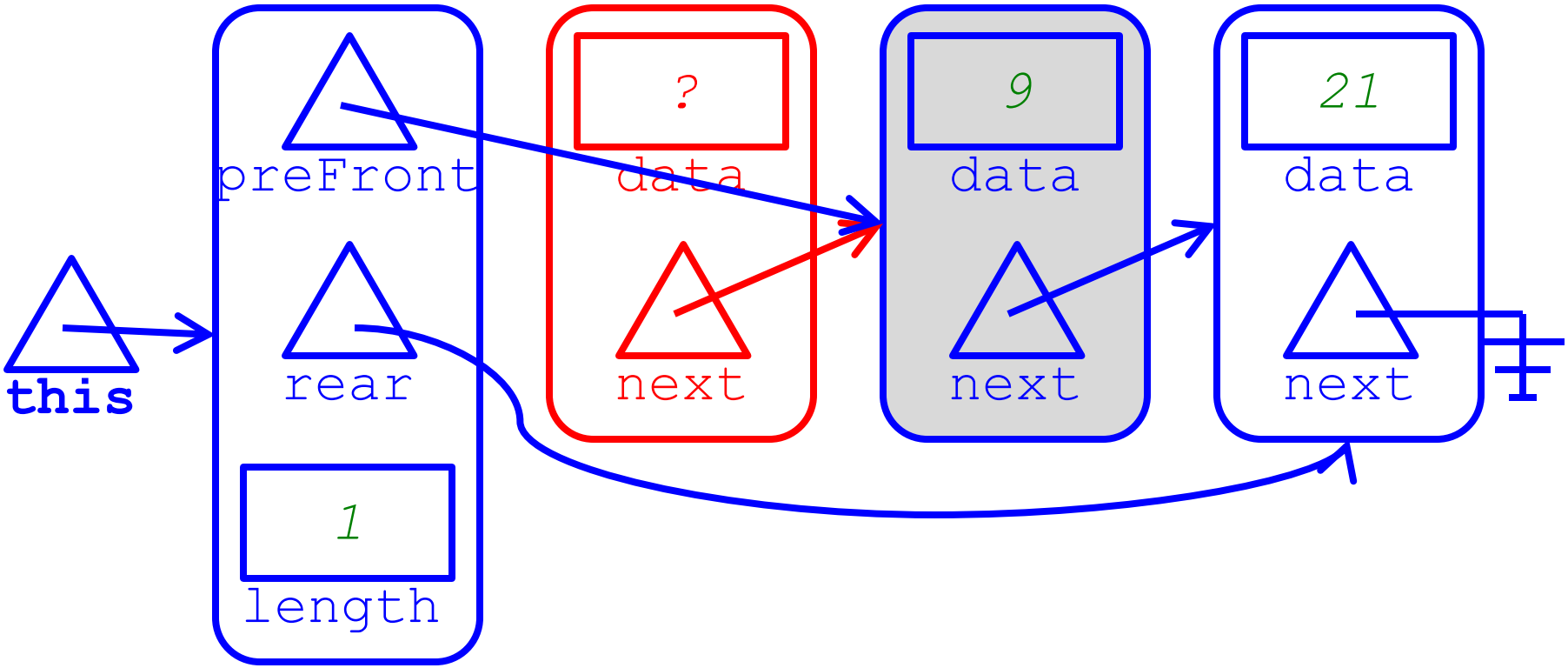

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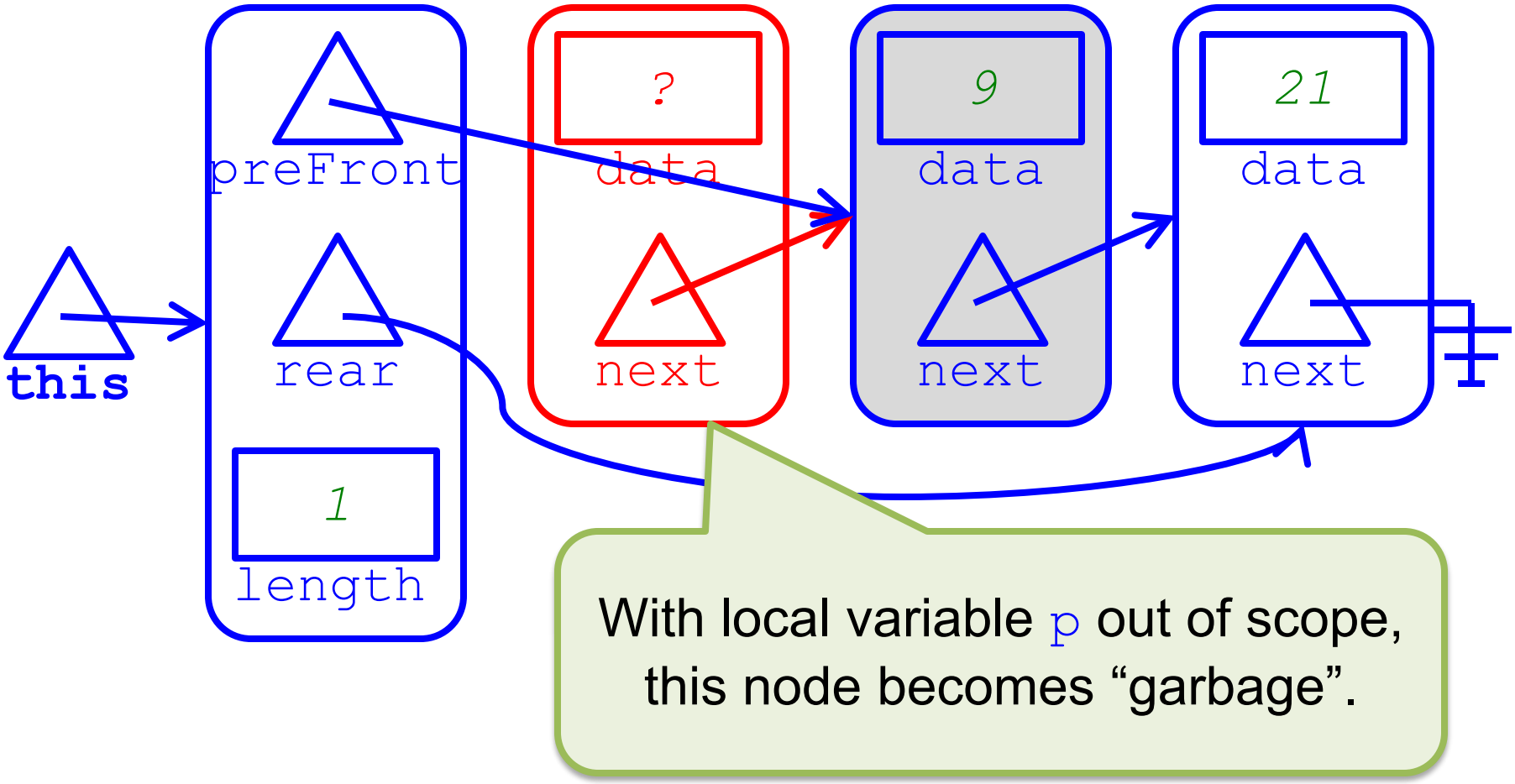

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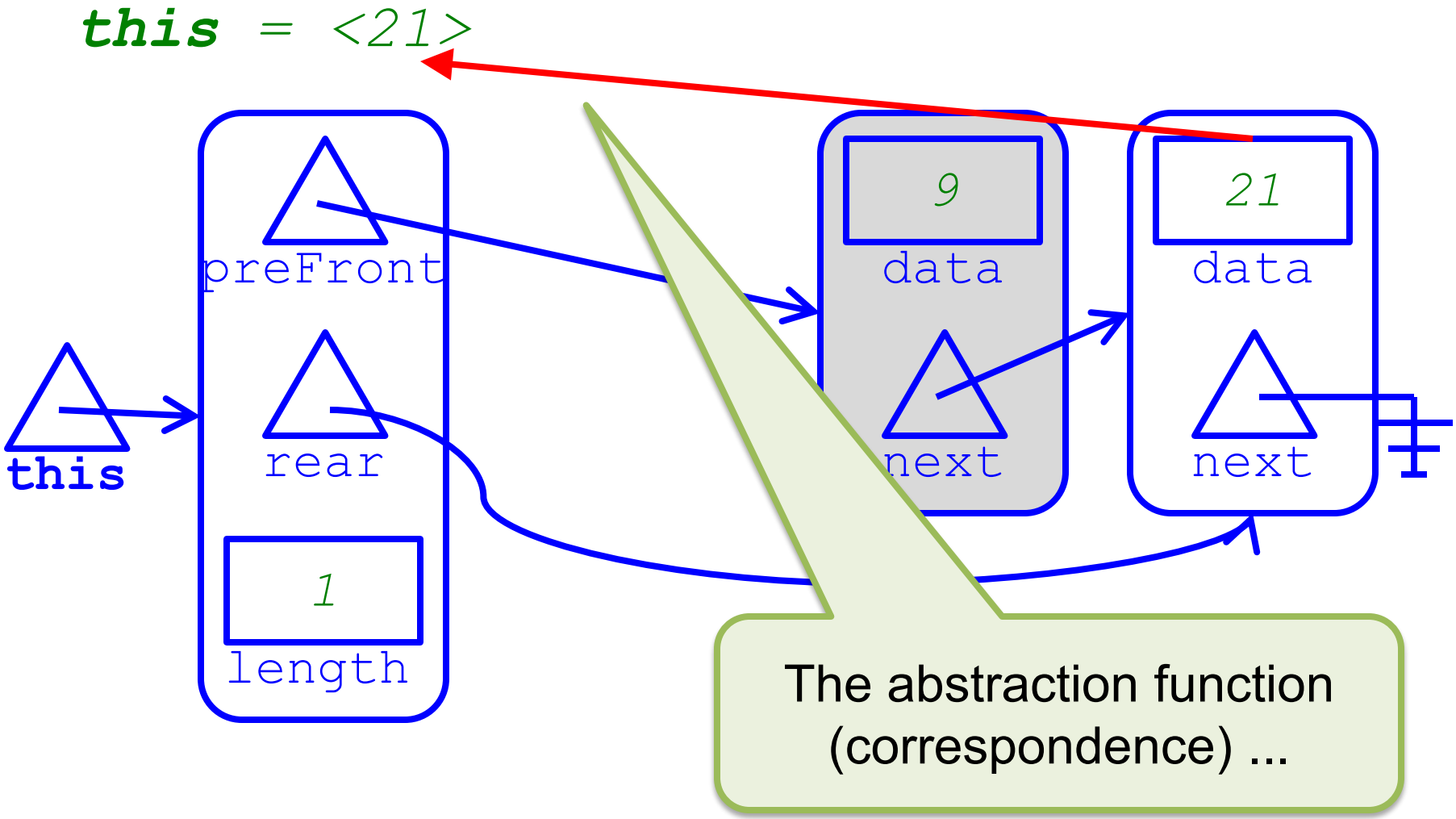
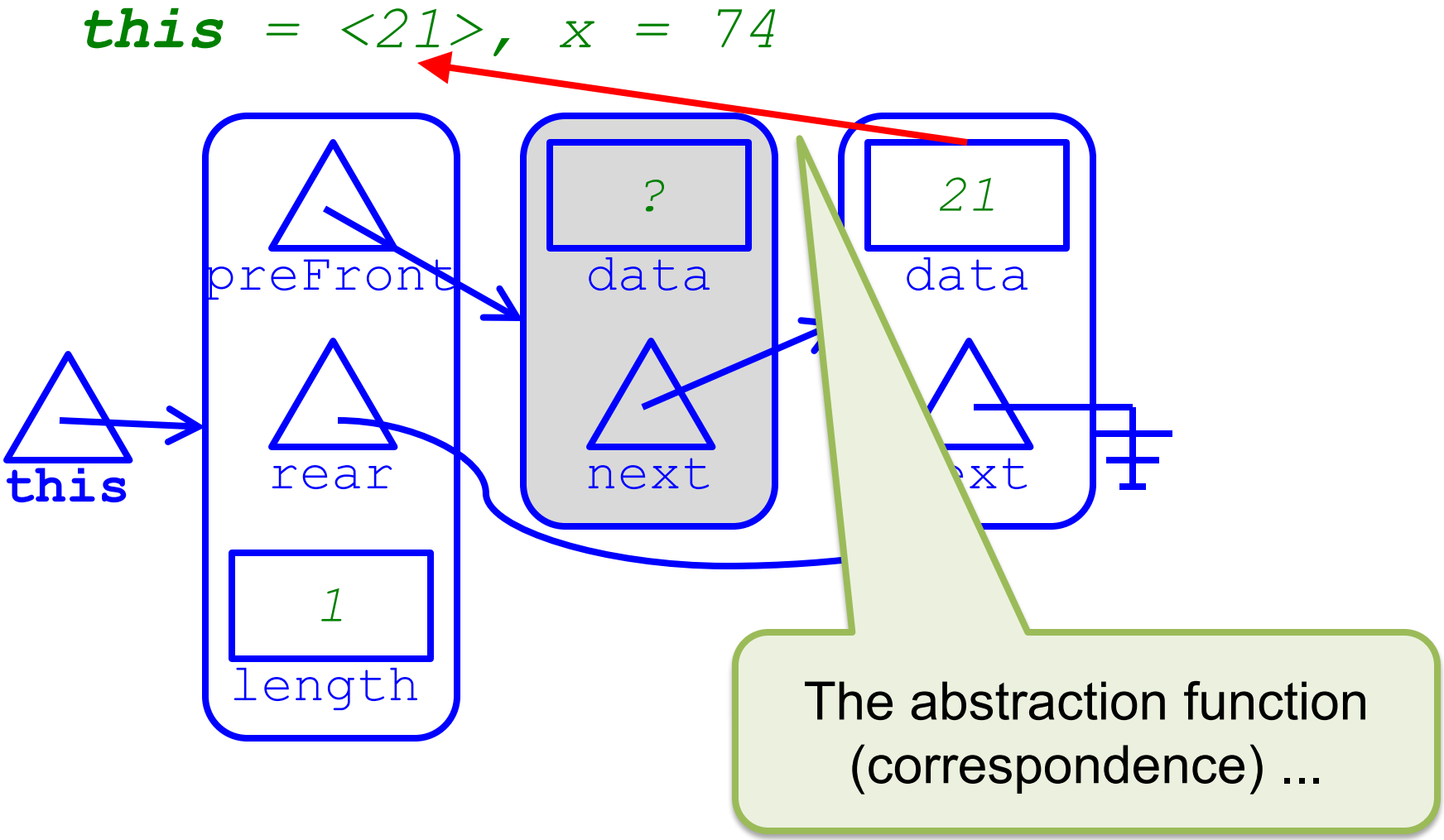


Example: `enqueue` for `Queue2`

```
public final void enqueue(T x) {
   Node p = new Node();
   Node q = this.rear;
   p.data = x;
   p.next = null;
   q.next = p;
   this.rear = p;
   this.length++;
}
```

Example: `enqueue` for `Queue2`



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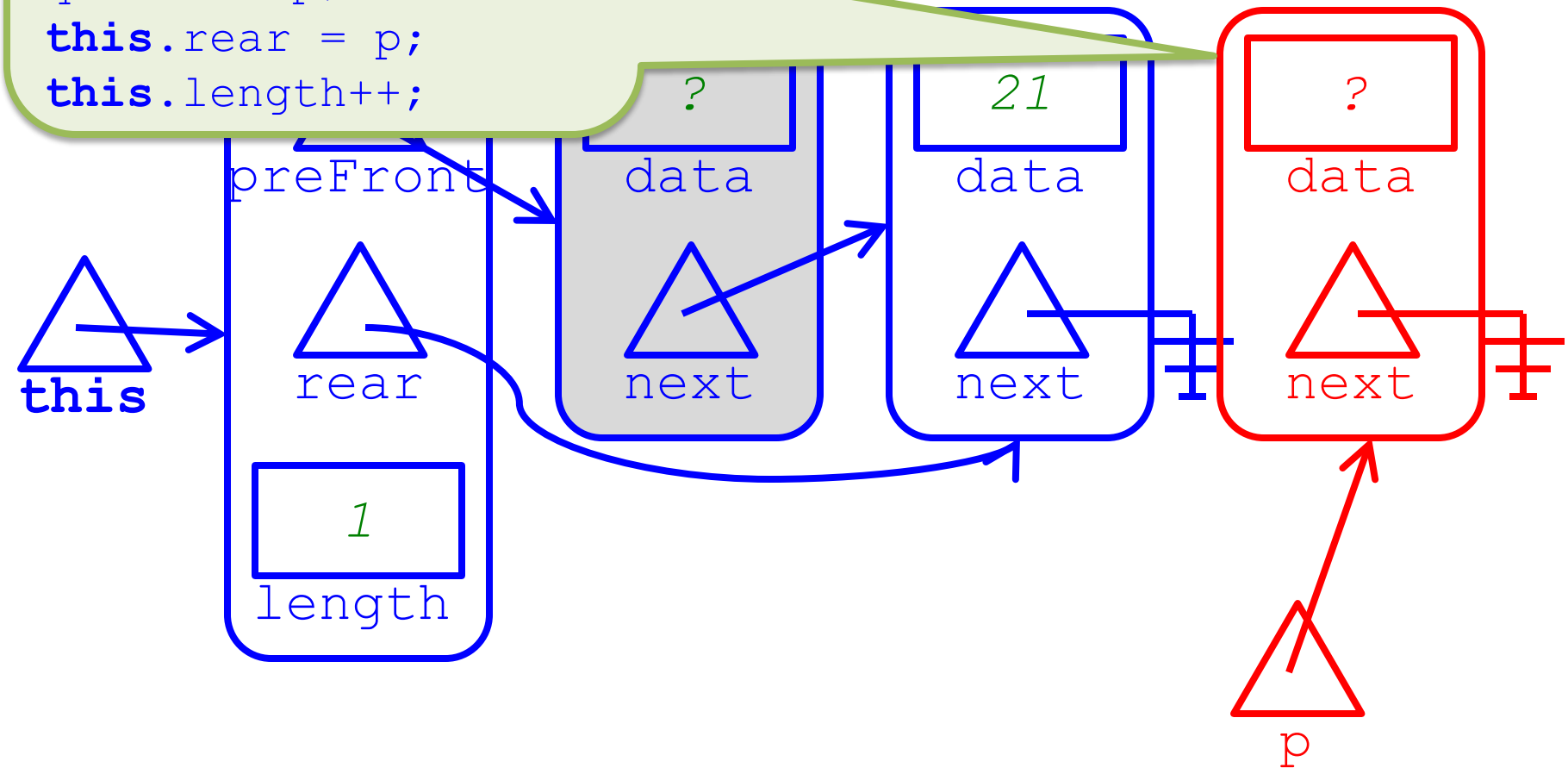
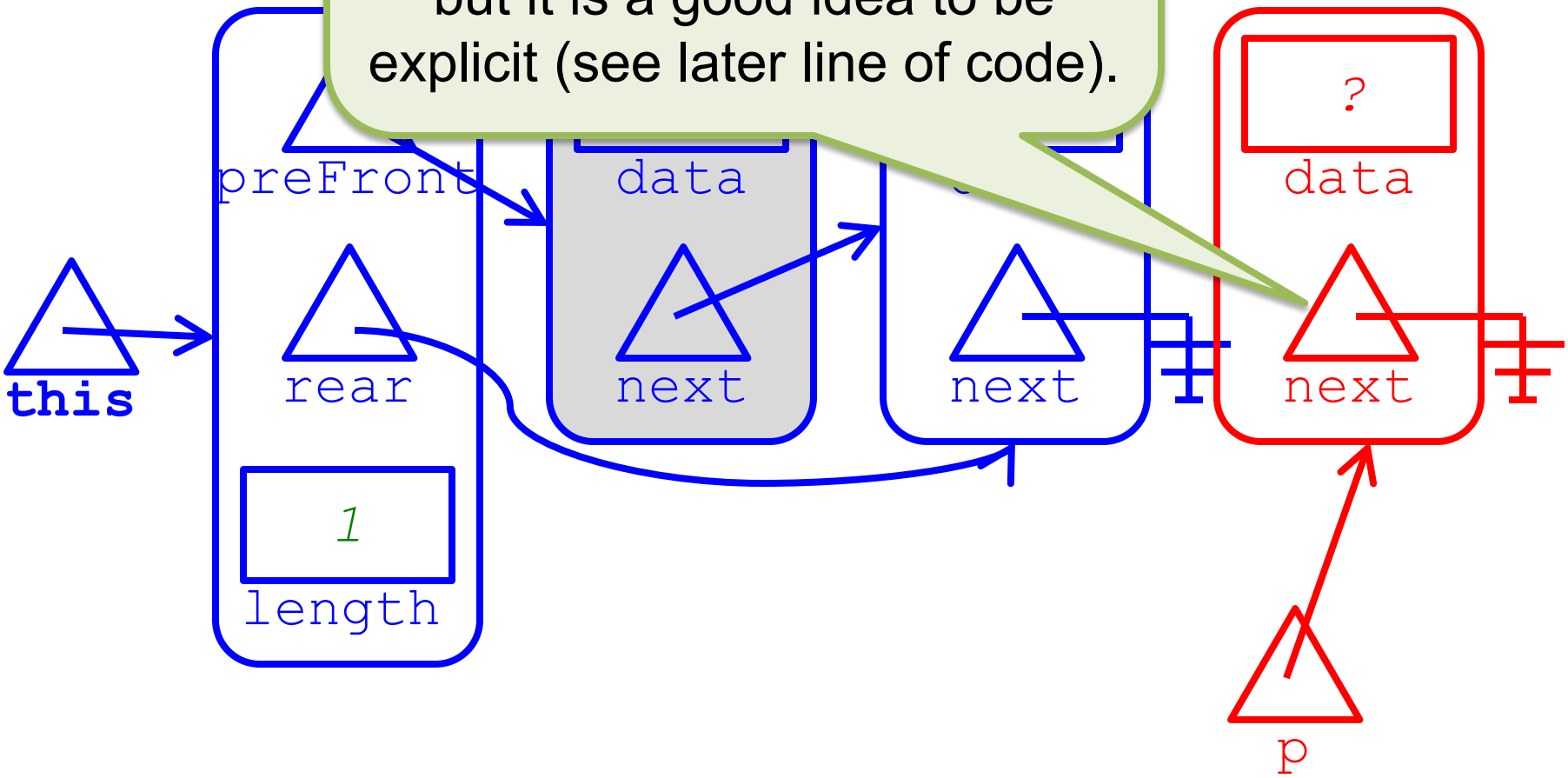
x = 74



Exam ueue2

this =

An instance variable of a reference type in Java is always initialized to **`null`**; but it is a good idea to be explicit (see later line of code).



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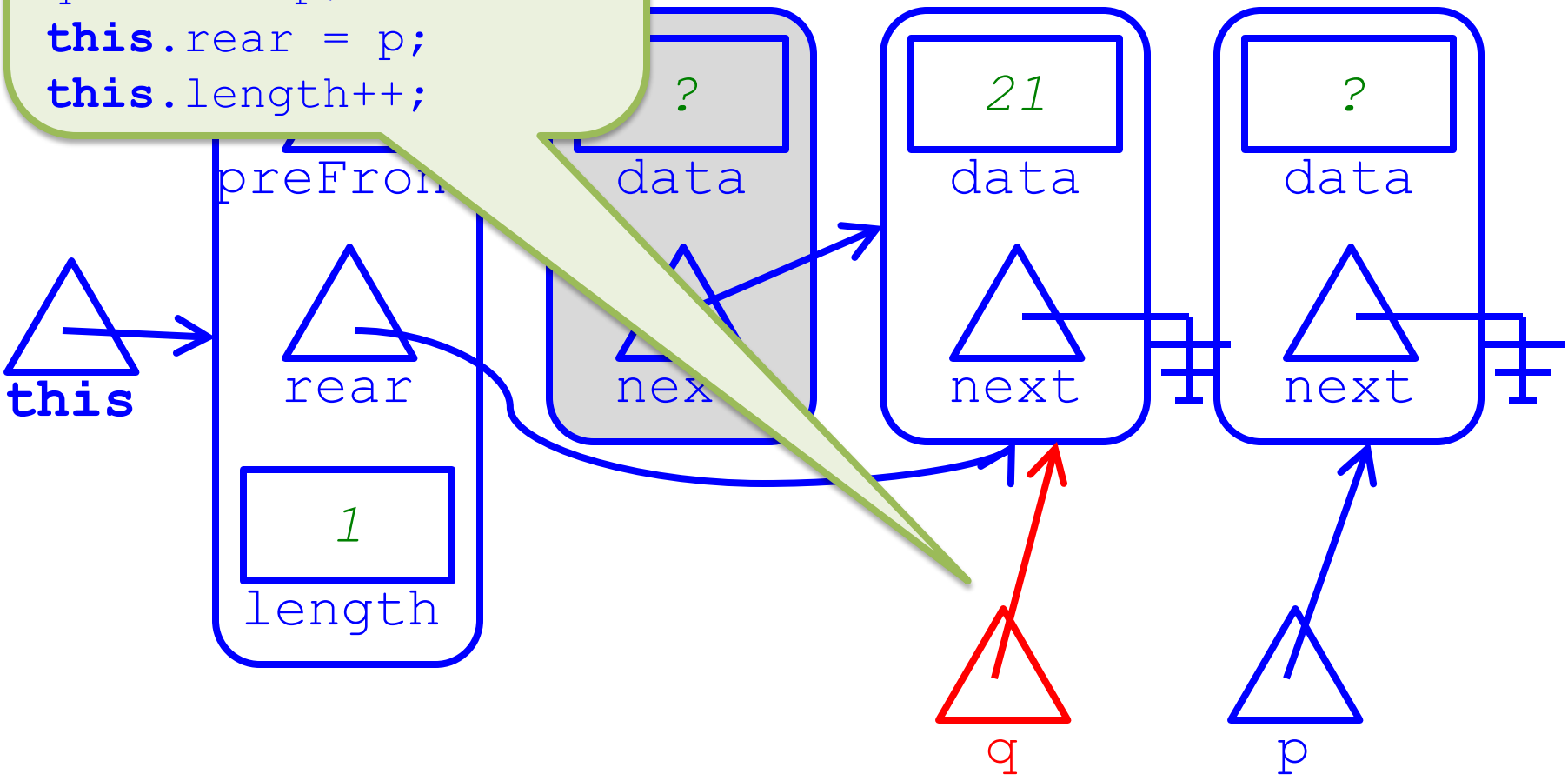

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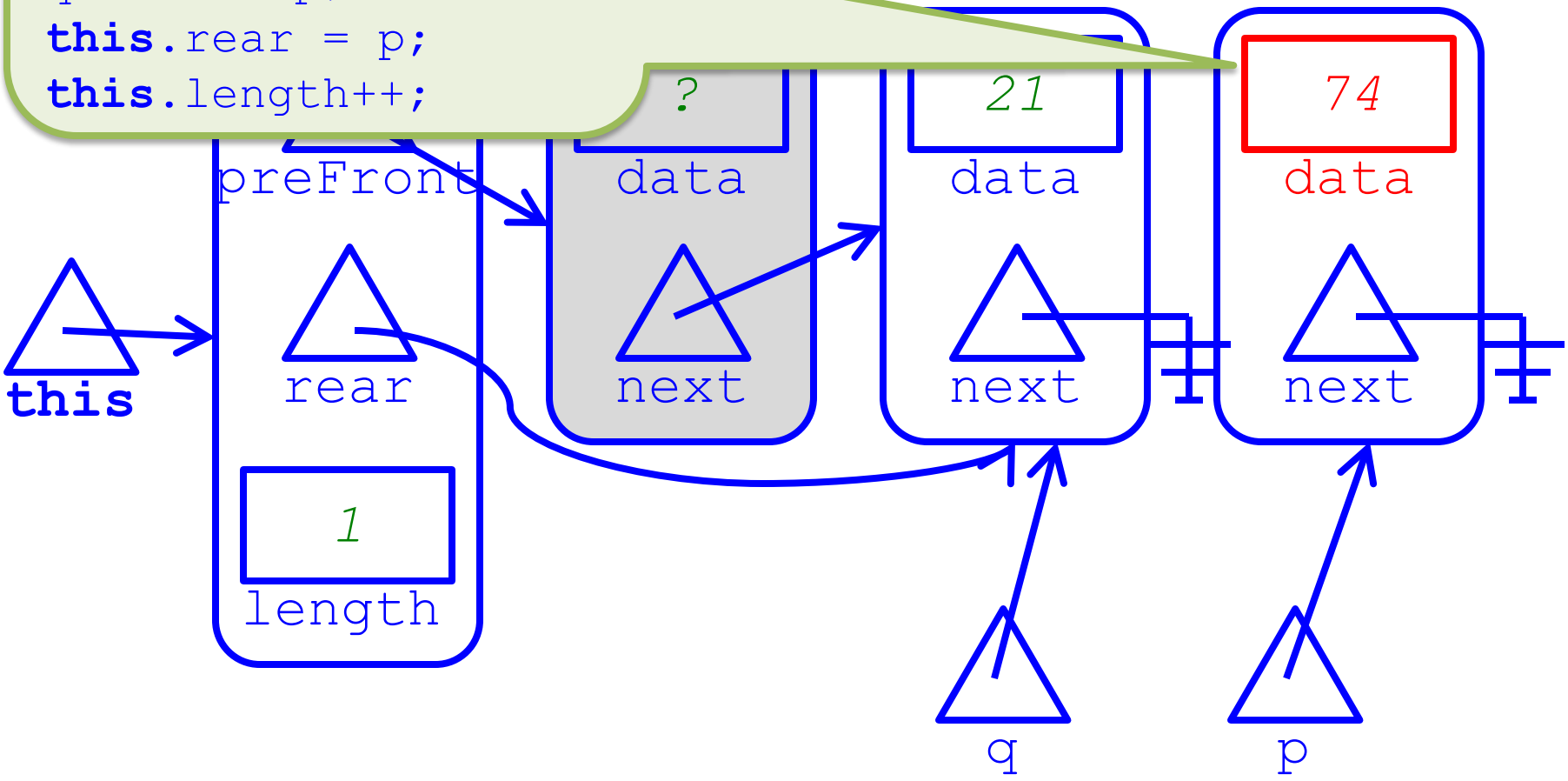

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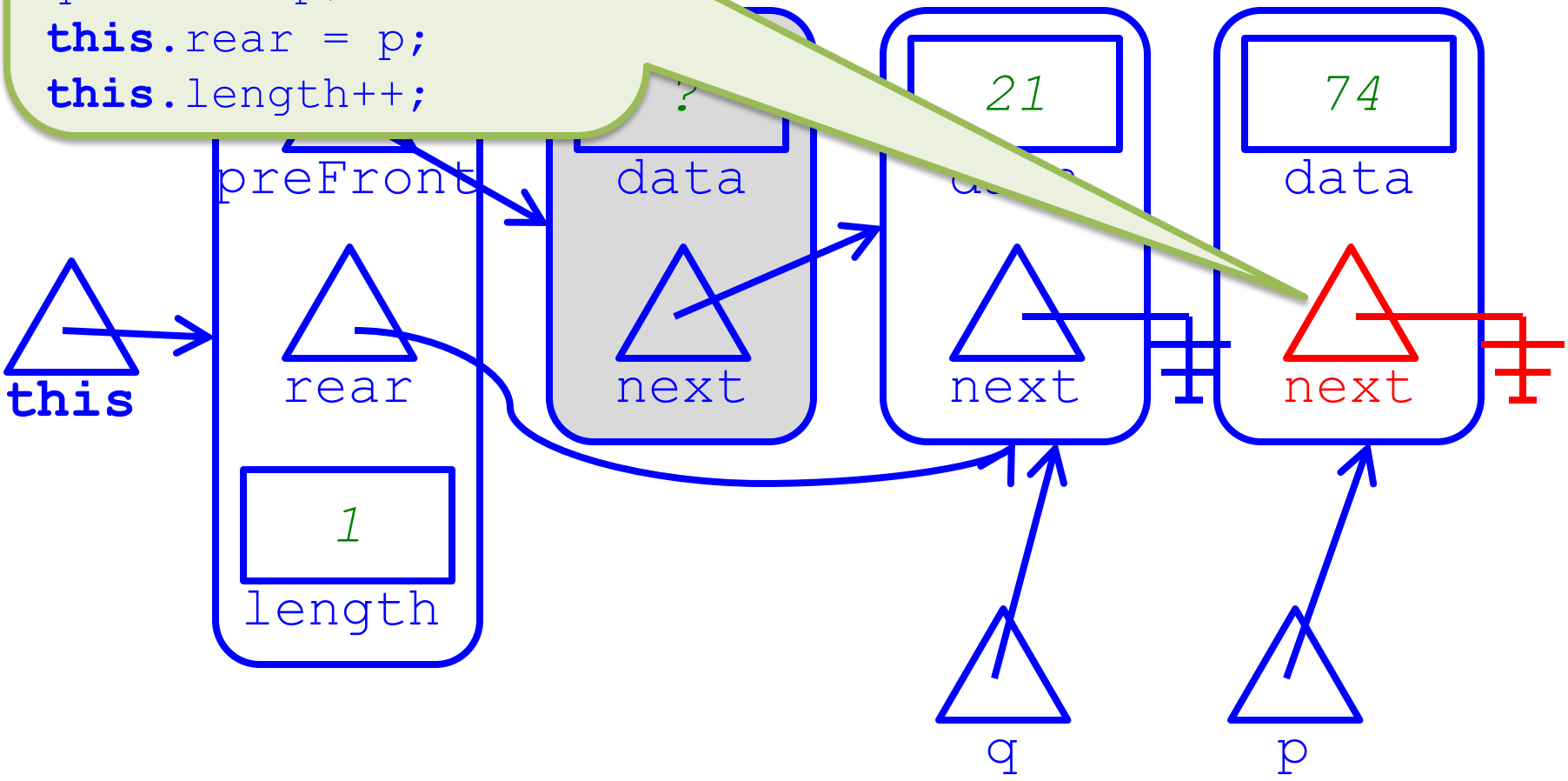

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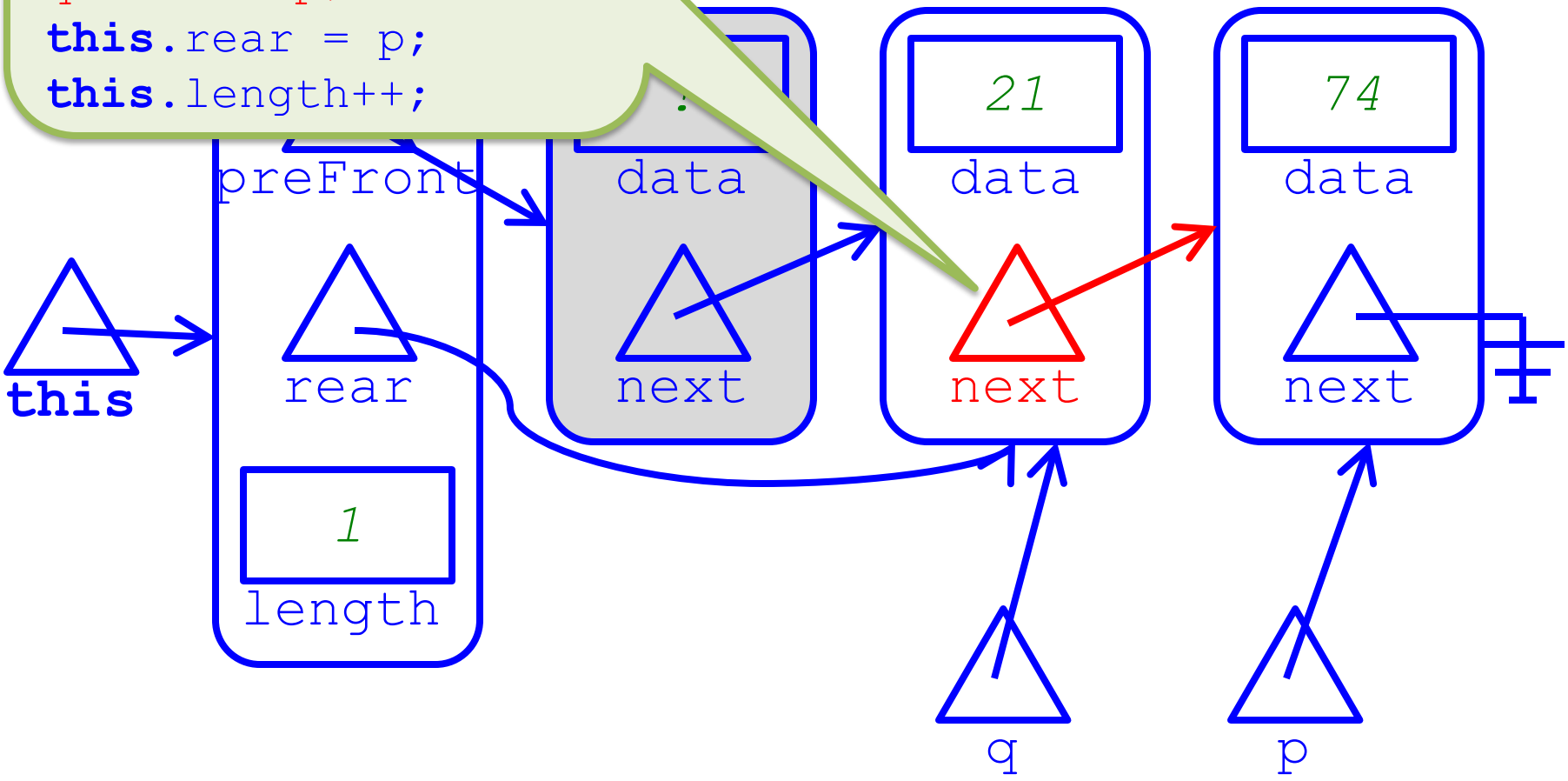

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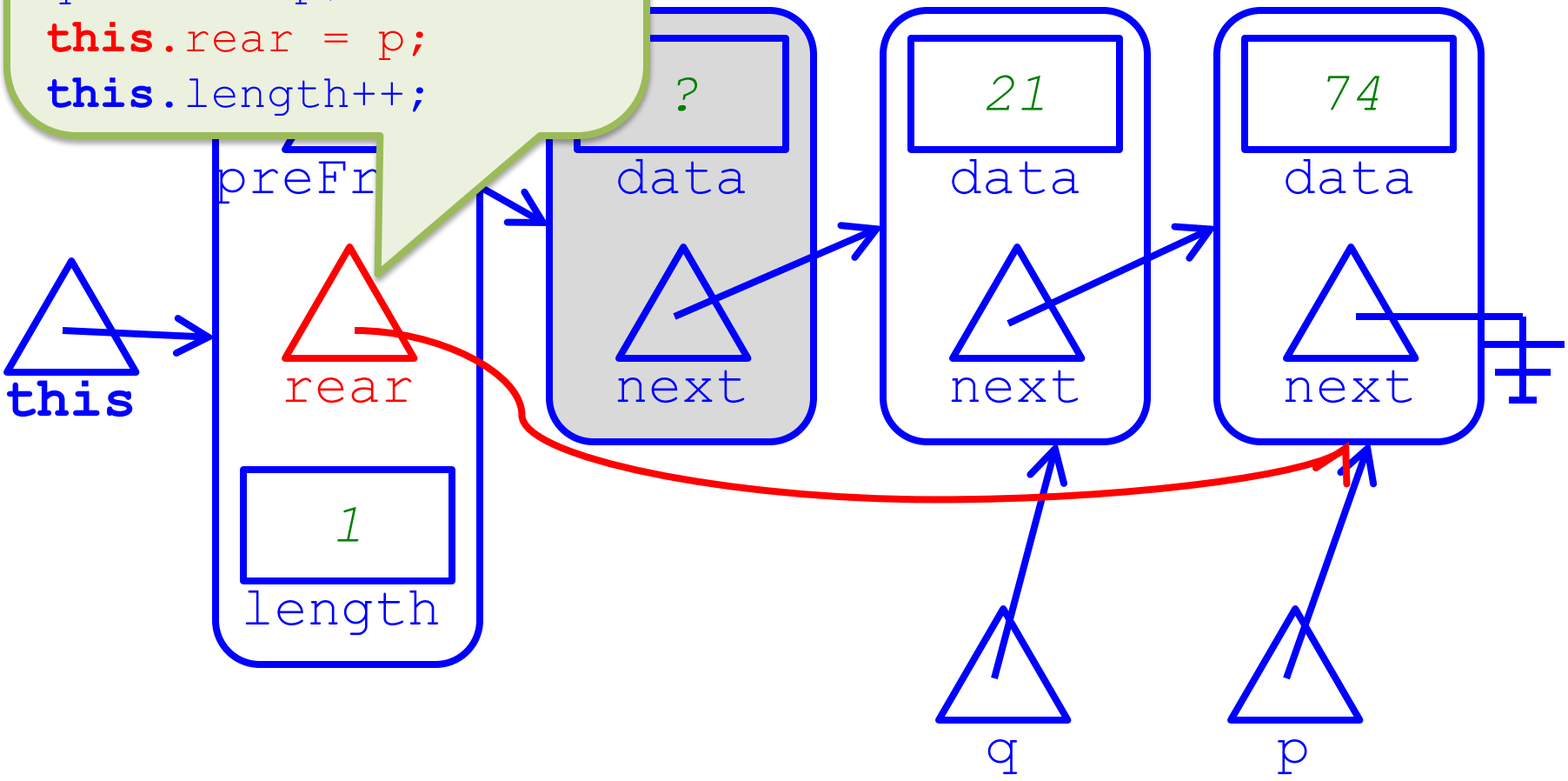

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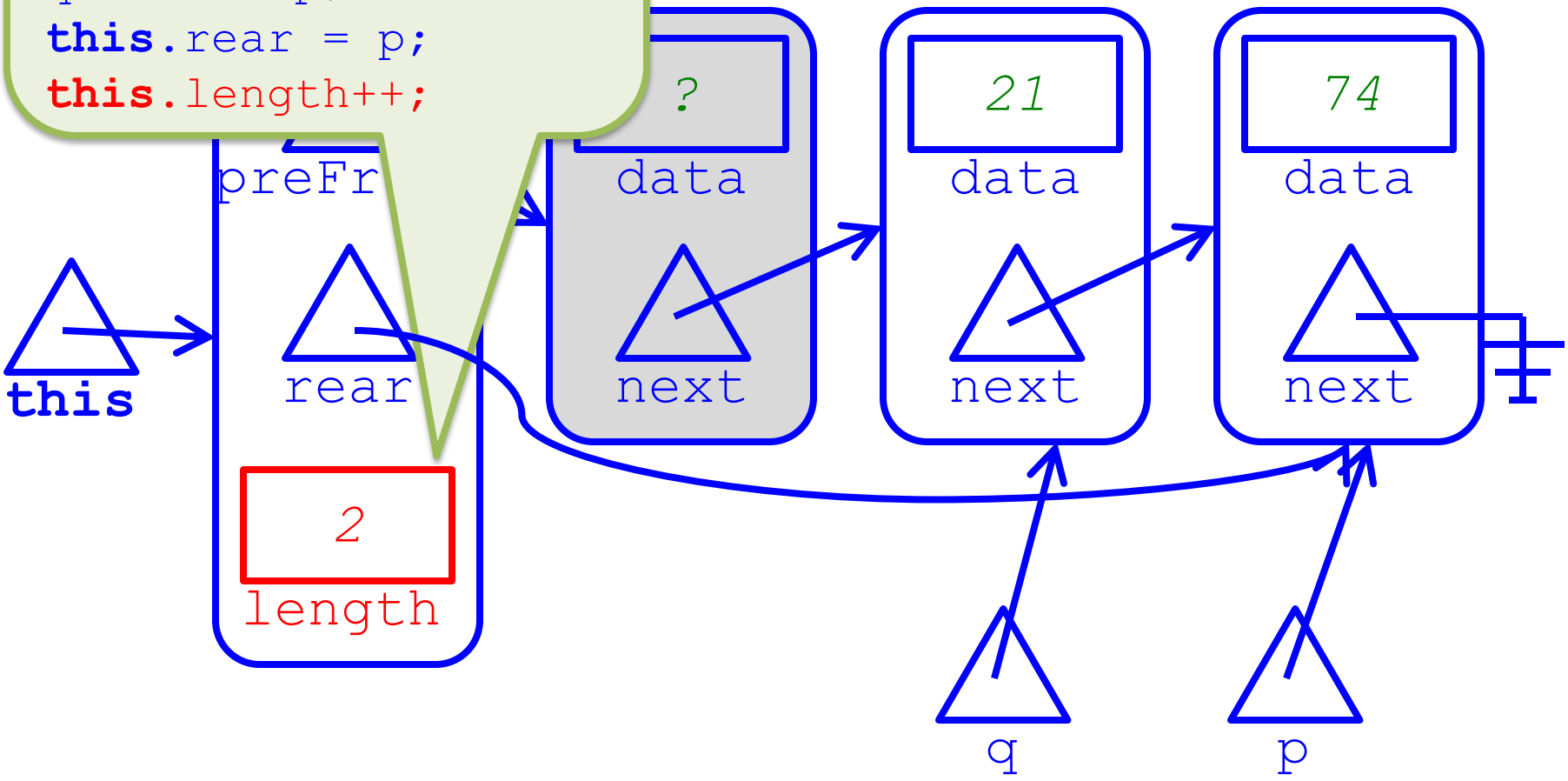
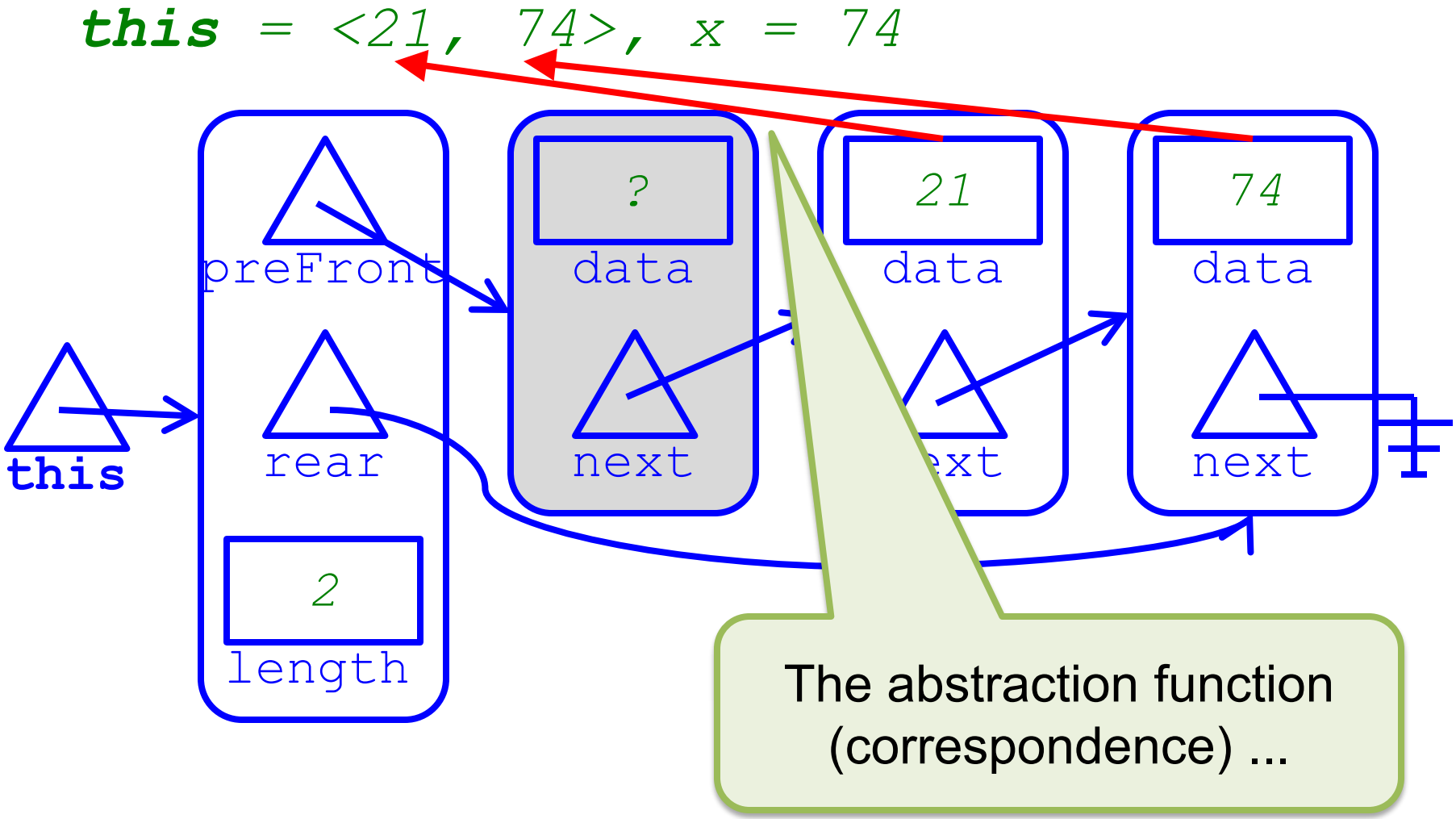
this.length++;
```



Example: `enqueue` for `Queue2`



The “Smart” Node

- To see why we want the extra node at the beginning of the linked list, write the code for `enqueue` without it (but be careful)
  - You should be able to see why it’s a ***smart node*** rather than a ***dummy node*** 😄
- Why is the smart node helpful in the representation of a `Queue`, but not of a `Stack`?

Resources

- Wikipedia: Linked Data Structure
  - http://en.wikipedia.org/wiki/Linked_data_structure
- *Big Java (4th ed)*, Sections 15.1, 15.2 (but not the part about iterators)
  - https://library.ohio-state.edu/record=b8540788~S7