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Information Technology

Linked Stacks & Queues

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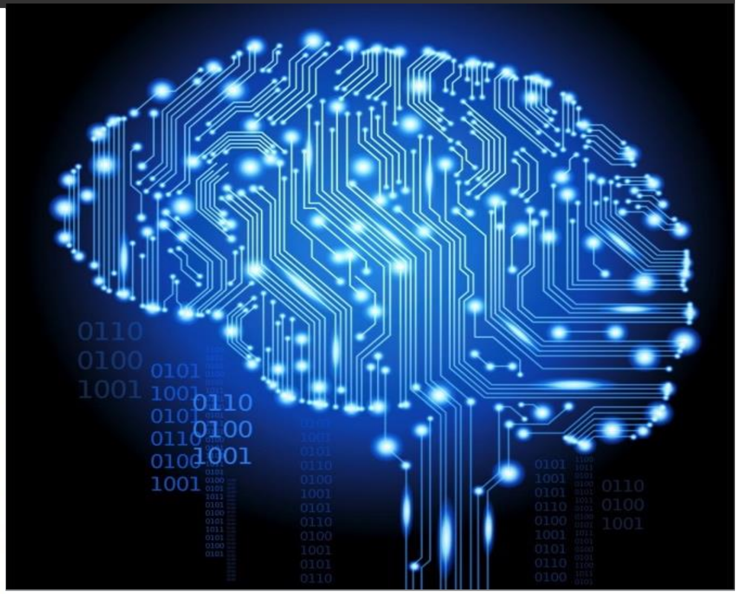
Updated by Brendon Taylor



Objectives for this lesson

- **To understand the use of linked data structures in implementing**
  - Stacks
  - Queues
- **To be able to:**
  - Implement, use and modify linked stacks and linked queues
  - Decide when it is appropriate to use them (rather than arrays)

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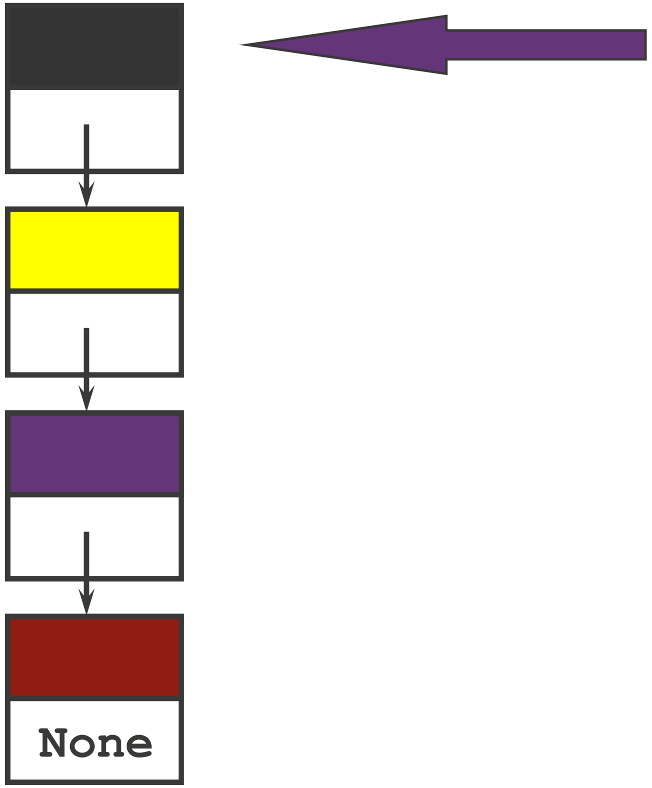
Linked Stacks

Remember:
Abstract base Stack class

```
from abc import ABC, abstractmethod
from typing import TypeVar, Generic
T = TypeVar('T’)


class Stack(ABC, Generic[T]):
    def __init__(self) -> None:
        self.length = 0

    @abstractmethod
    def push(self, item: T) -> None:
        pass

    @abstractmethod
    def pop(self) -> None:
        pass

    @abstractmethod
    def peek(self) -> T:
        pass

    def __len__(self) -> int:
        return self.length

    def clear(self):
        self.length = 0
```

```
def is_empty(self) -> bool:
    return len(self) == 0

@abstractmethod
def is_full(self) -> bool:
    pass

@abstractmethod
def __toString__(self) -> str:
    pass
```

Linked Stack implementation



Top of the Stack

For an array implementation we needed one thing in addition to the length:

- `the_array`

What do we need for a linked implementation?

Nodes!

Class for a Linked Stack

```
from typing import TypeVar
from abstract_stack import Stack
from node import Node
T = TypeVar('T’)

class LinkStack(Stack[T]):
    def __init__(self):
        Stack.__init__(self)
        self.top = None

    def is_full(self):
        return False

    def clear(self):
        Stack.clear()
        self.top = None
```

No need for **`size`** when initialising the object

Big O?

O(1)

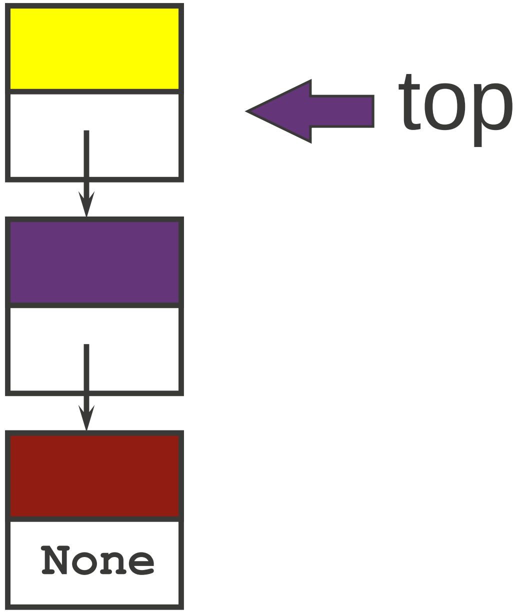
Did not do that for LinkLists,
but it is good to free memory

Push method for Linked Stacks

Push: algorithm

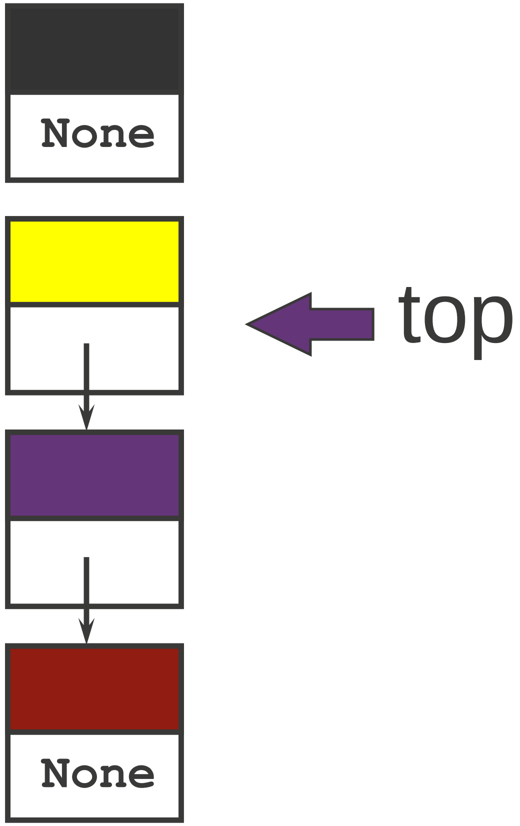
- **In the array implementation:**
  - If the array is full: raise exception (or resize, if we wanted to do that)
  - Else
    - Add the item in the position marked by top (was the same as the length of the list)
    - Increase top
- **In a linked data structure:**
  - Create a new node that contains the item
  - We link it to the current top
  - Make the new node the new top
- **No need for `is_full` check**
- **If no more memory can be allocated:**
  - The system will raise an exception

Push: algorithm



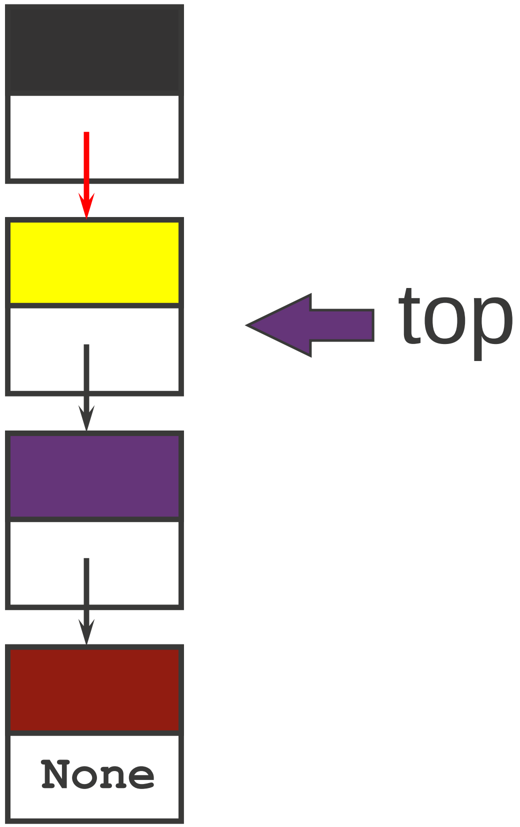
Push: algorithm

- Create a new node for item ⬛



Push: algorithm

- Create a new node for item ⬛
- Link it to the current top node



Push: algorithm

- Create a new node for item ■
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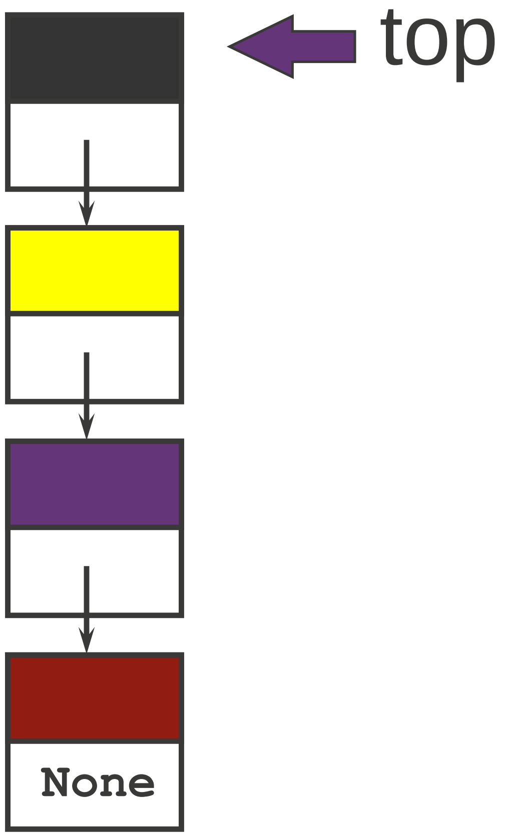
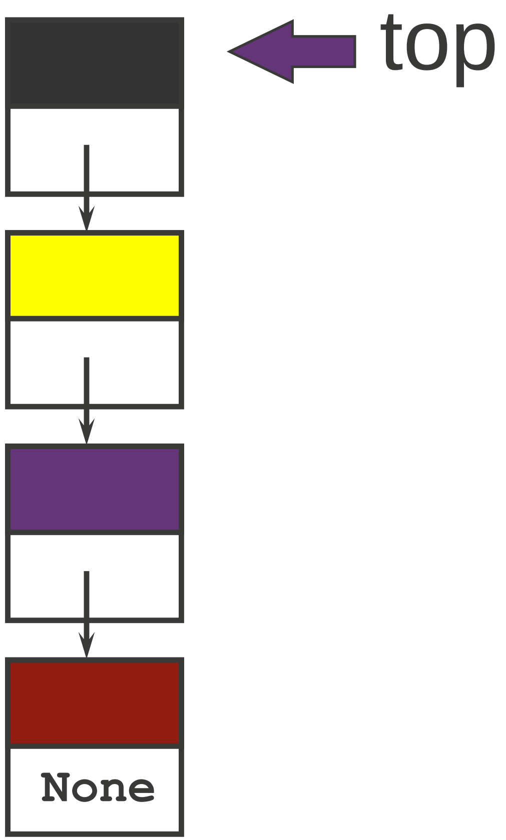


Push: algorithm

- Create a new node for item ■
- Link it to the current top node
- Make the new node the new top

```
def push(self, item: T):
    new_node = Node(item)
    new_node.link = self.top
    self.top = new_node
    self.length += 1
```



Consider a **stack** with a node whose item is **7**

Lets see the memory diagram for **stack.push(41)**

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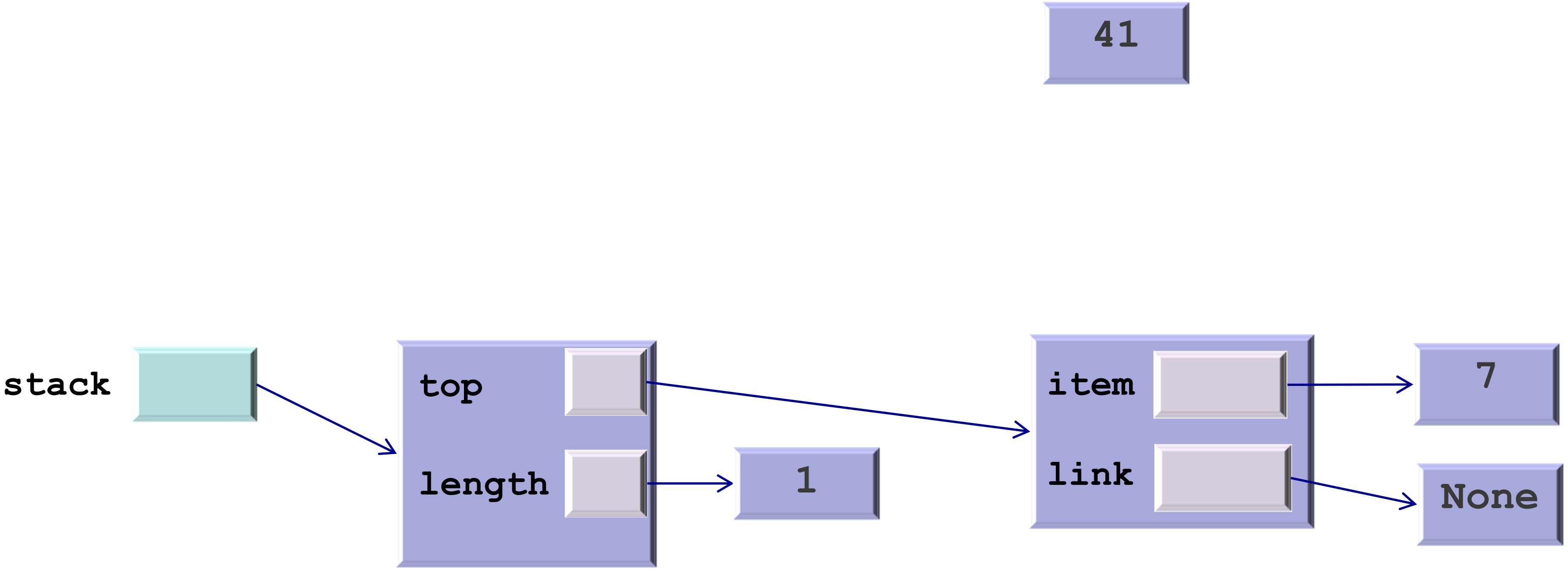

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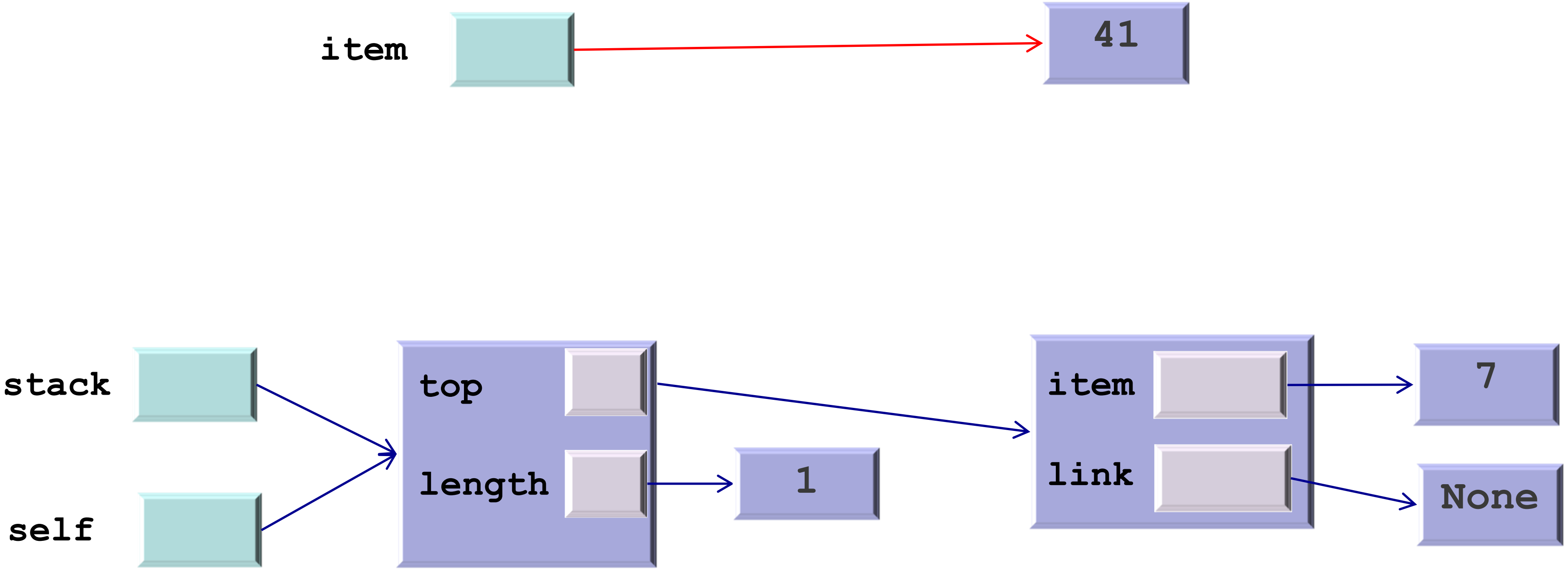

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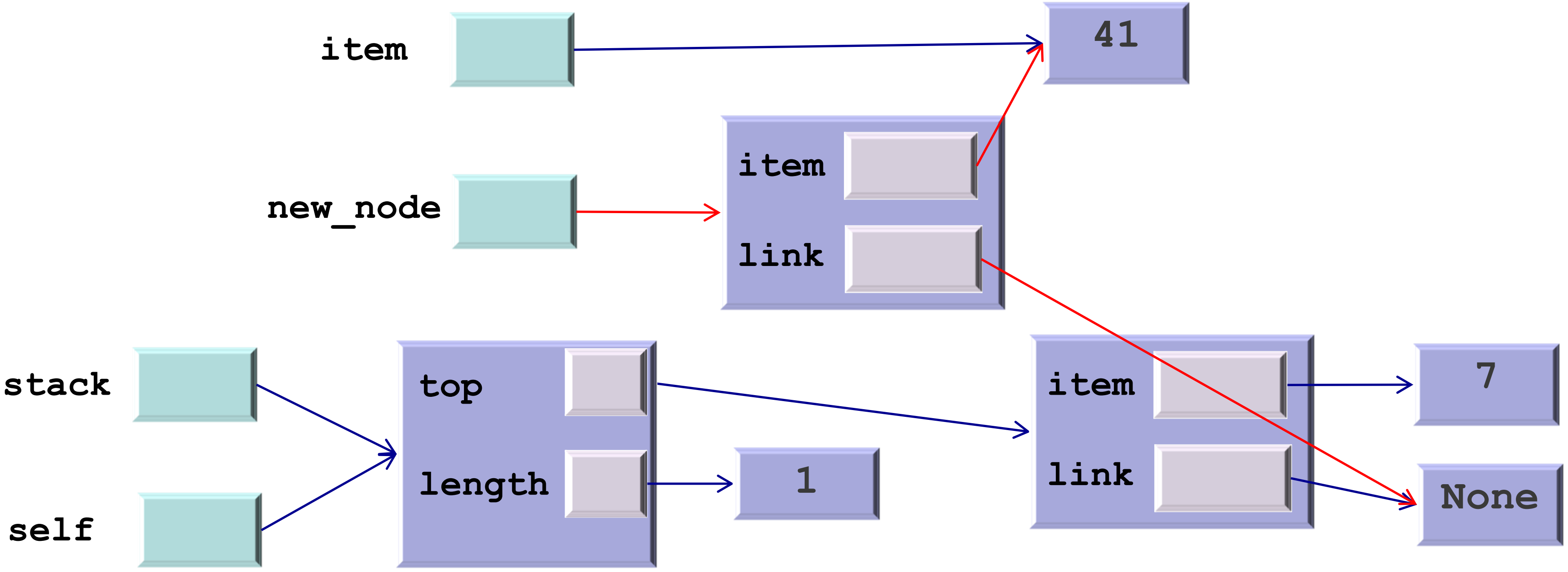

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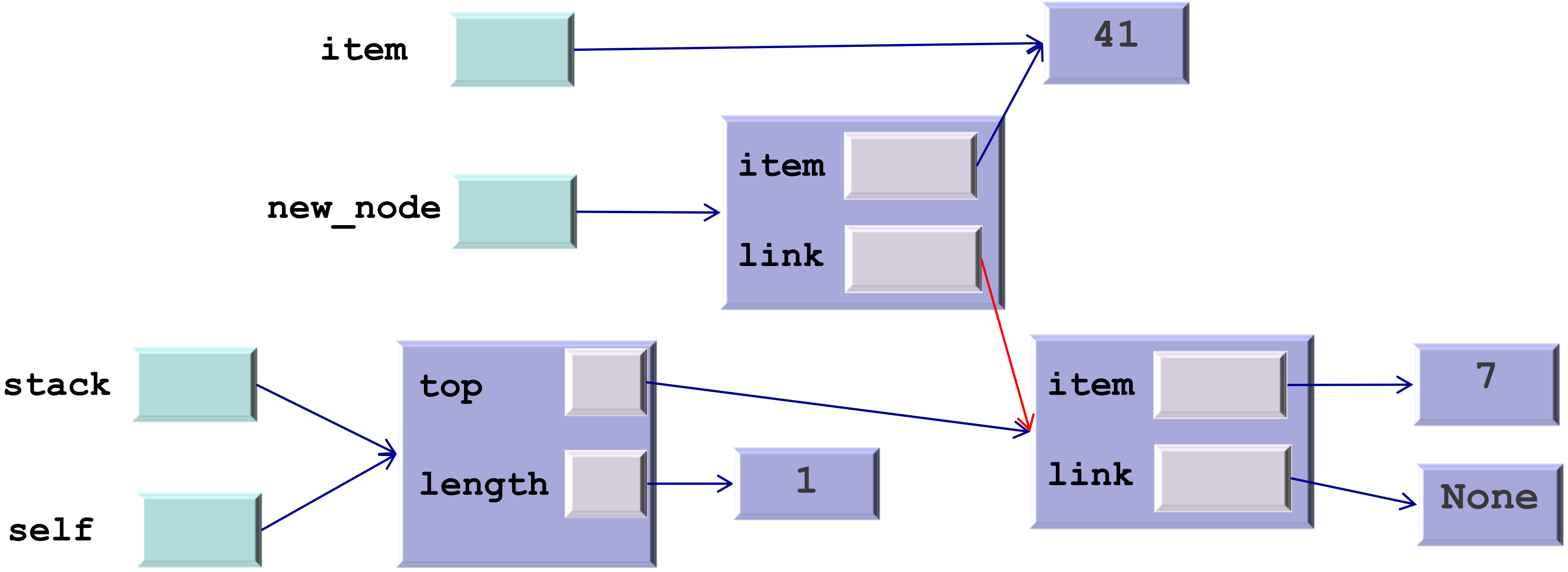

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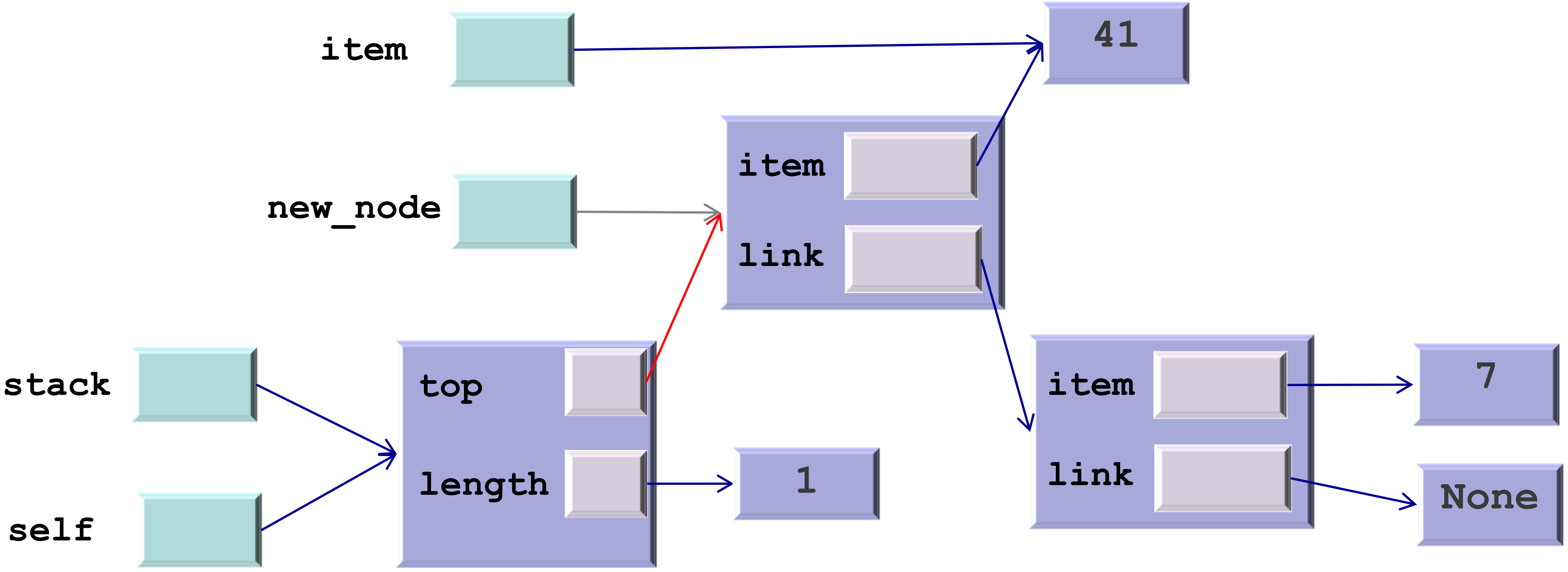

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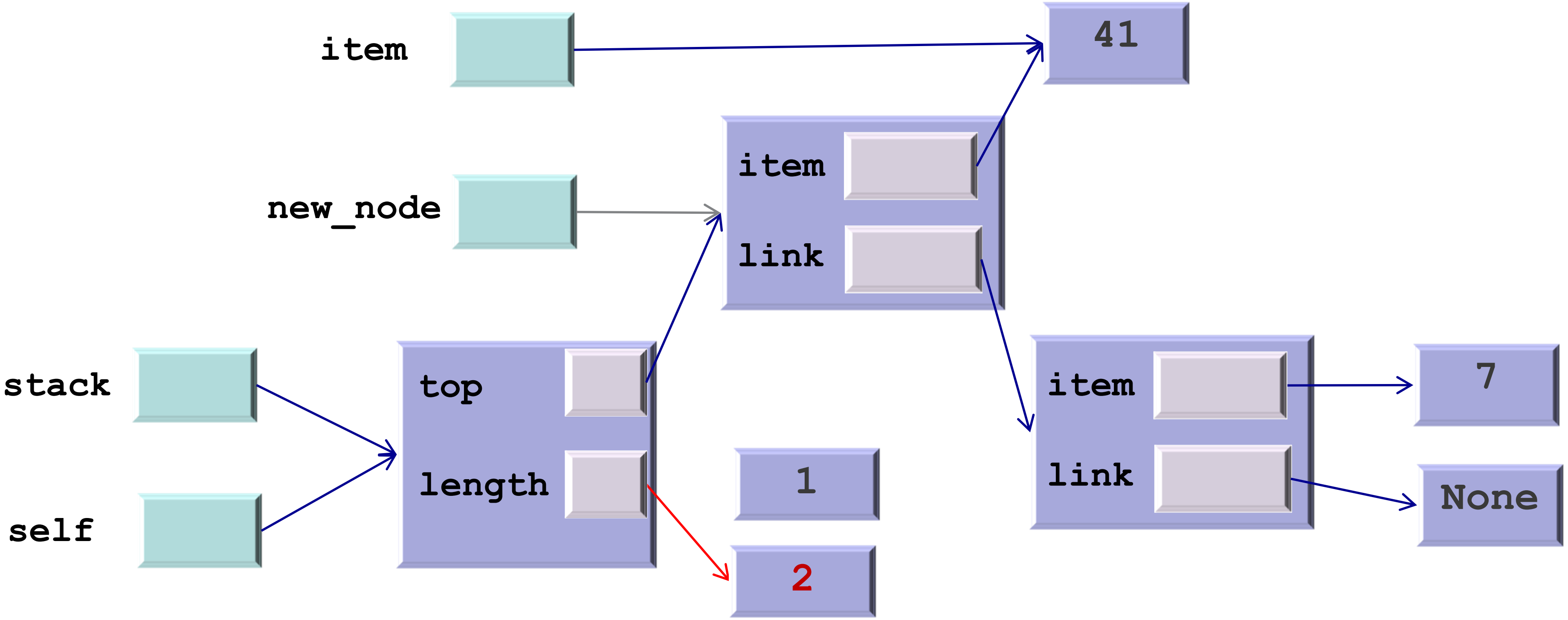
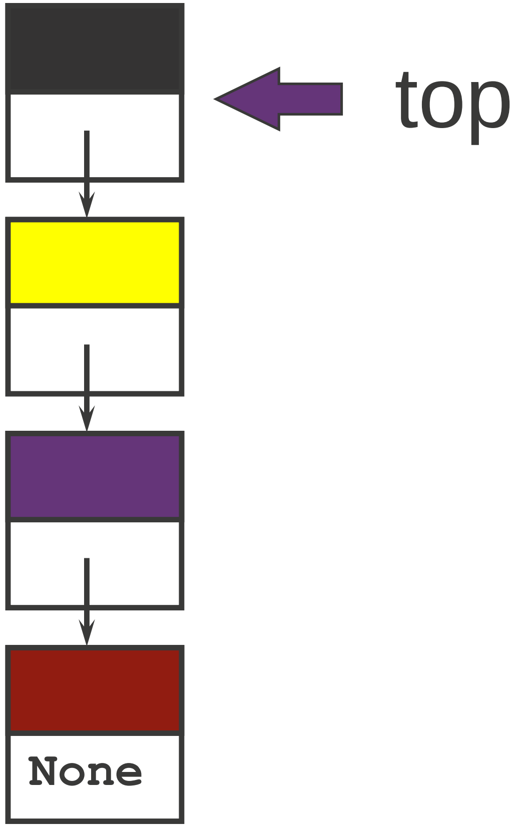


Pop method for Linked Stacks

Pop algorithm

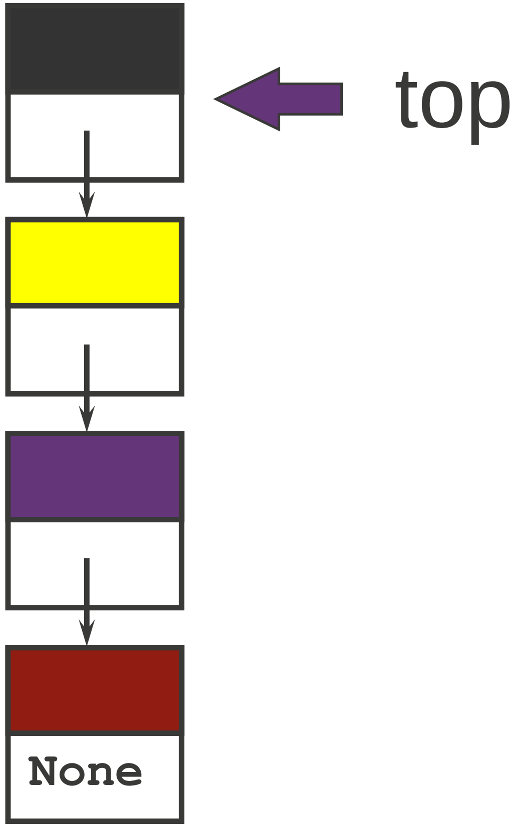
- **Array implementation:**
  - If it is empty: raise exception
  - Else:
    - Remember the top item
    - Decrease top
    - Return the item
- **Linked nodes:**
  - Almost identical
  - We simply move top along, rather than increase it

Pop: algorithm



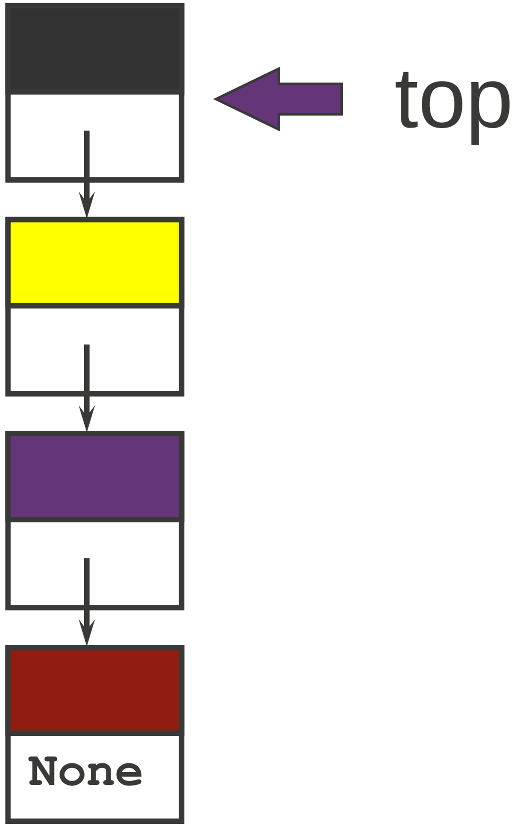
Pop: algorithm

- Check if the stack is empty



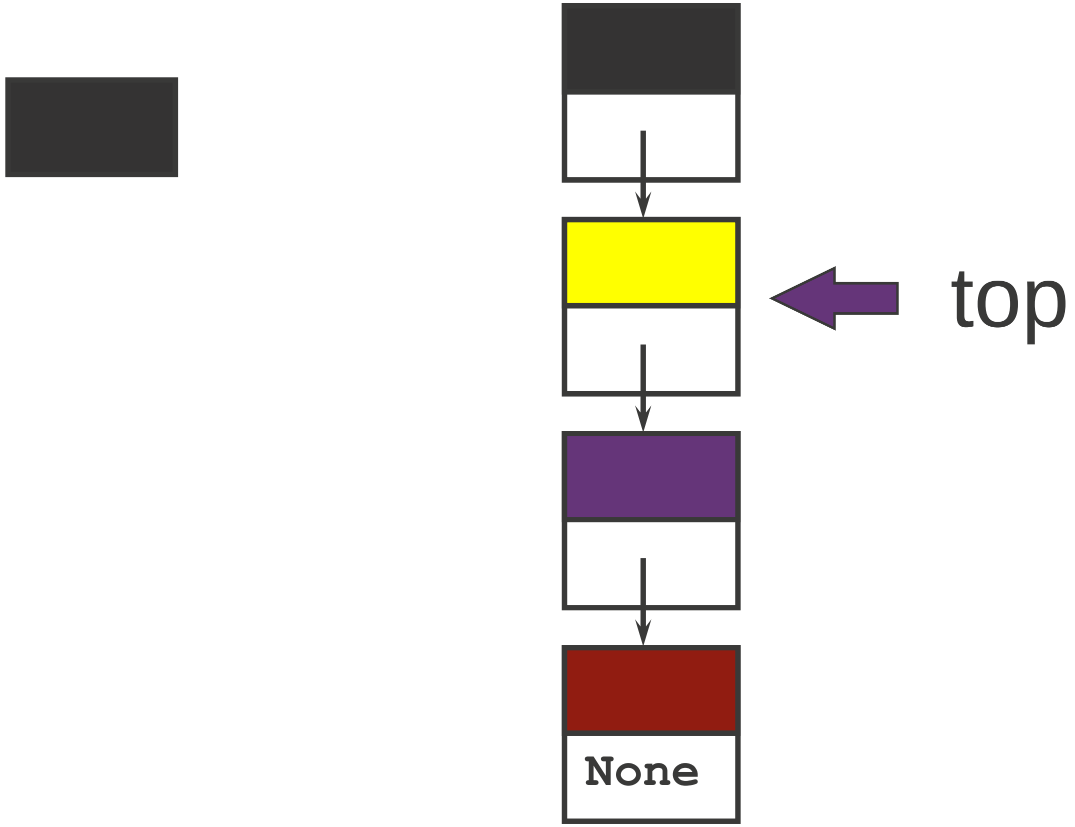
Pop: algorithm

- Check if the stack is empty
- Remember the item in the top node



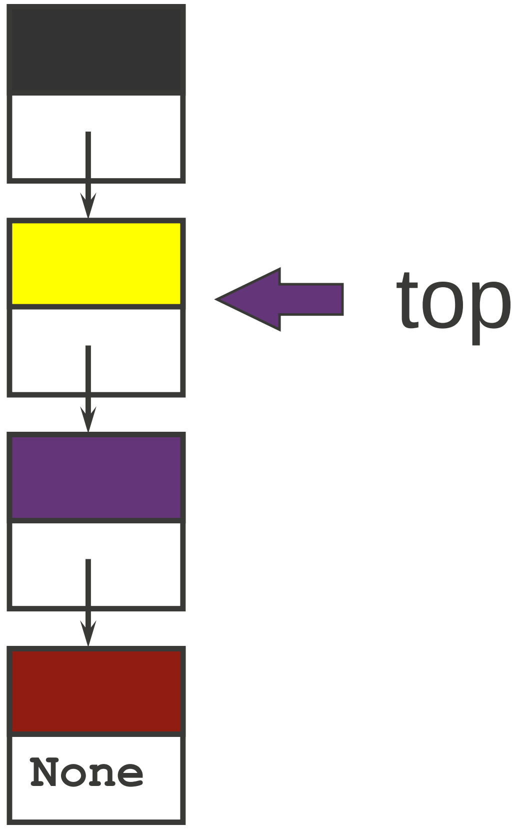
Pop: algorithm

- Check if the stack is empty
- Remember the item in the top node
- Make the next node the new top



Pop: algorithm

- Check if the stack is empty
- Remember the item in the top node ■
- Make the next node the new top
- Return the item



As usual, no need to do anything about this. Python will automatically free the memory

Pop: algorithm and method

```
def pop(self) -> T:
    if not self.is_empty():
        item = self.top.item
        self.top = self.top.link
        self.length -= 1
        return item
    else:
        raise ValueError("Stack is empty")
```

Complexity? **O(1)**

Consider a stack with two nodes whose items are 41 and 7

Lets see the memory diagram for stack.pop()

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def pop(self) -> T:
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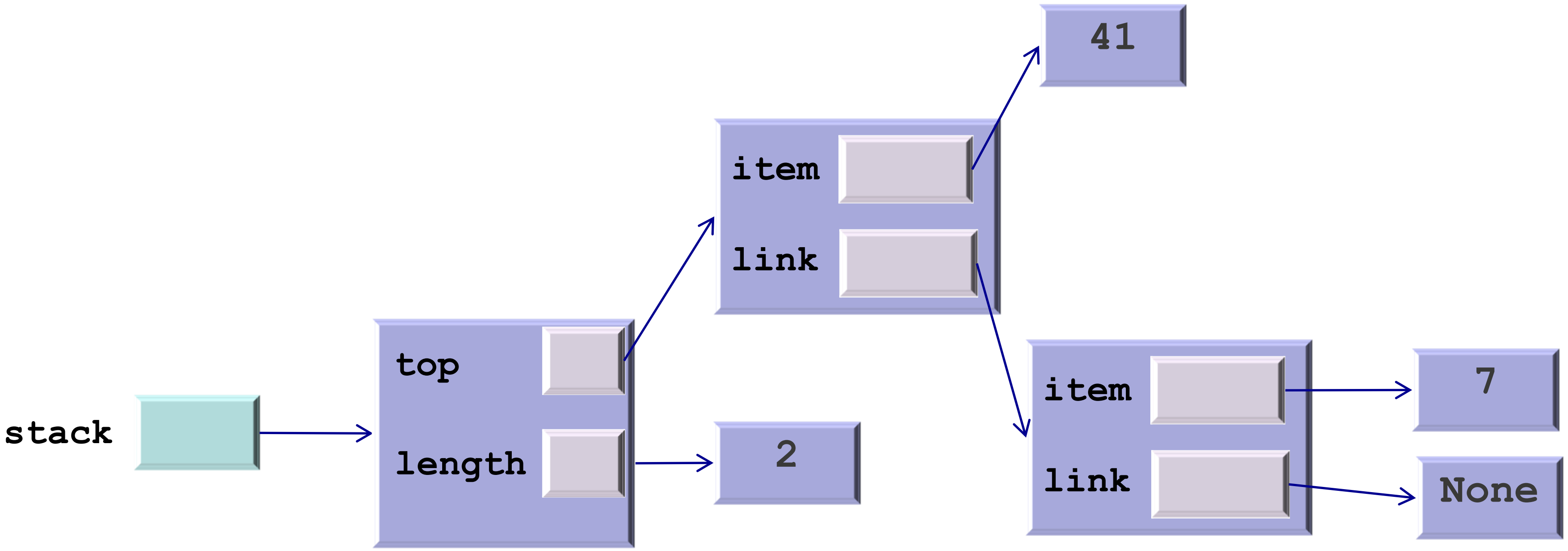

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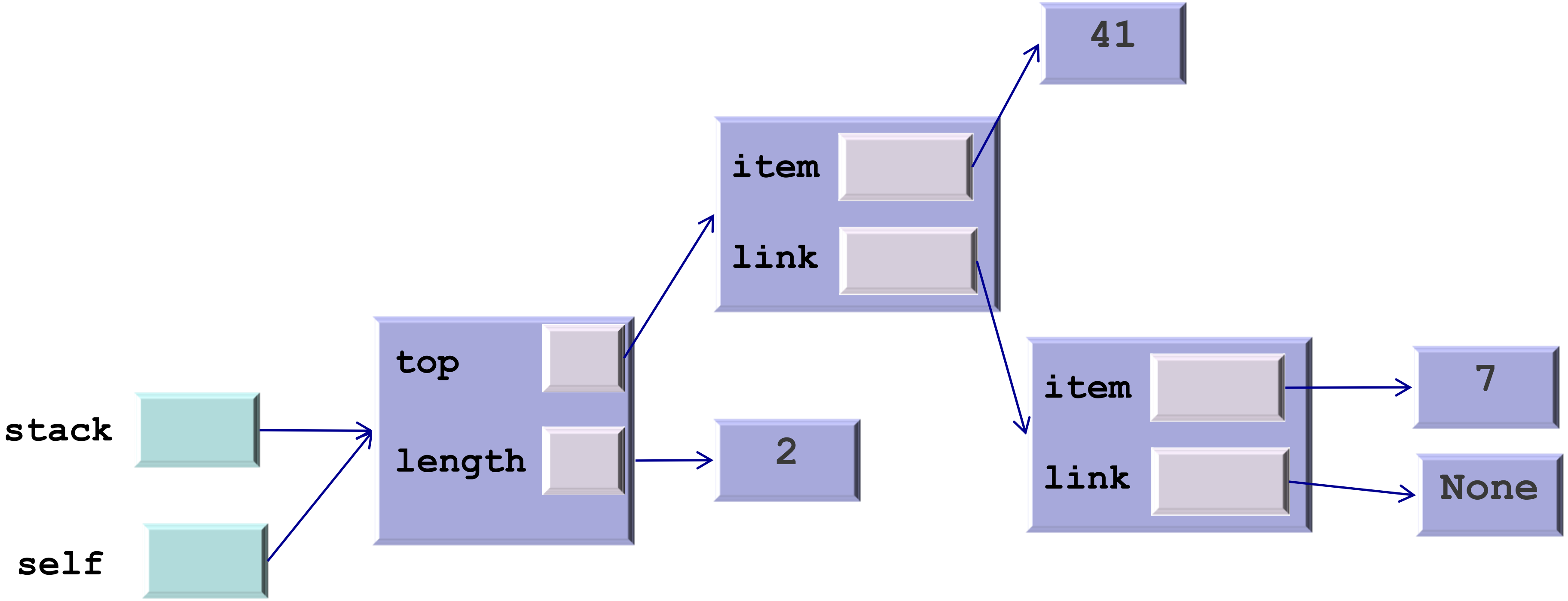

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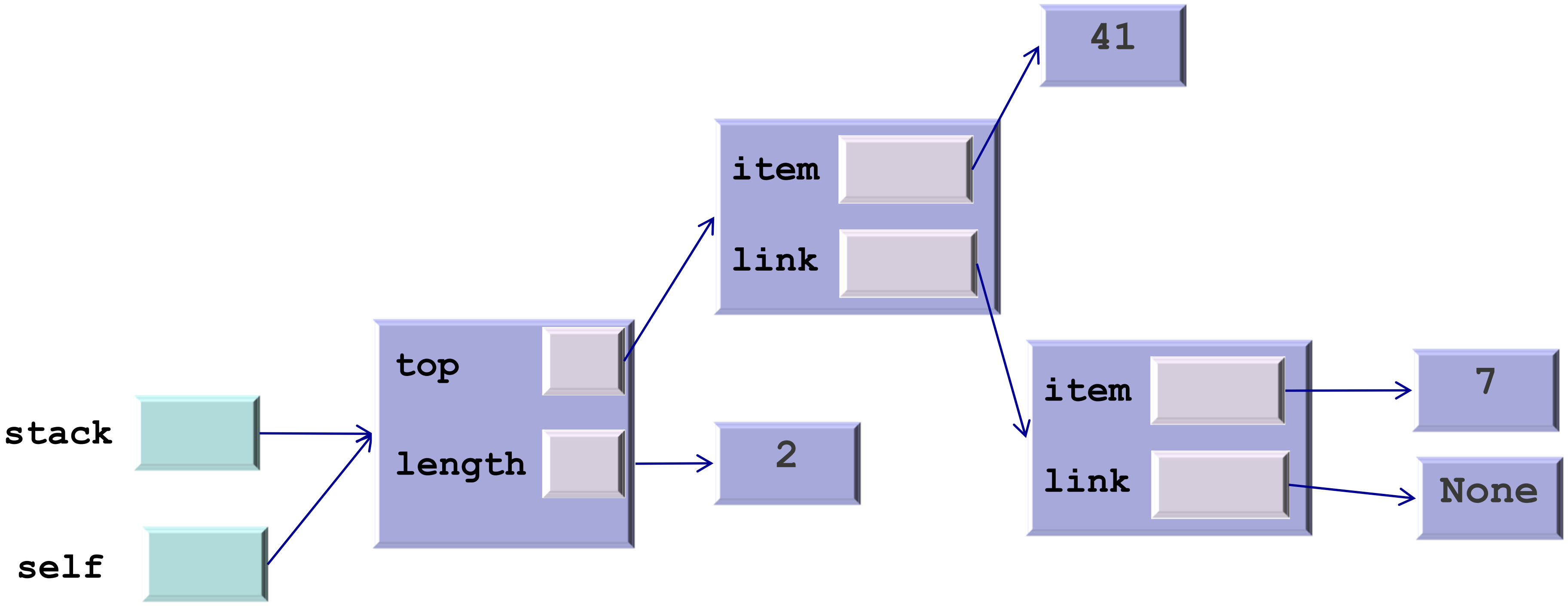

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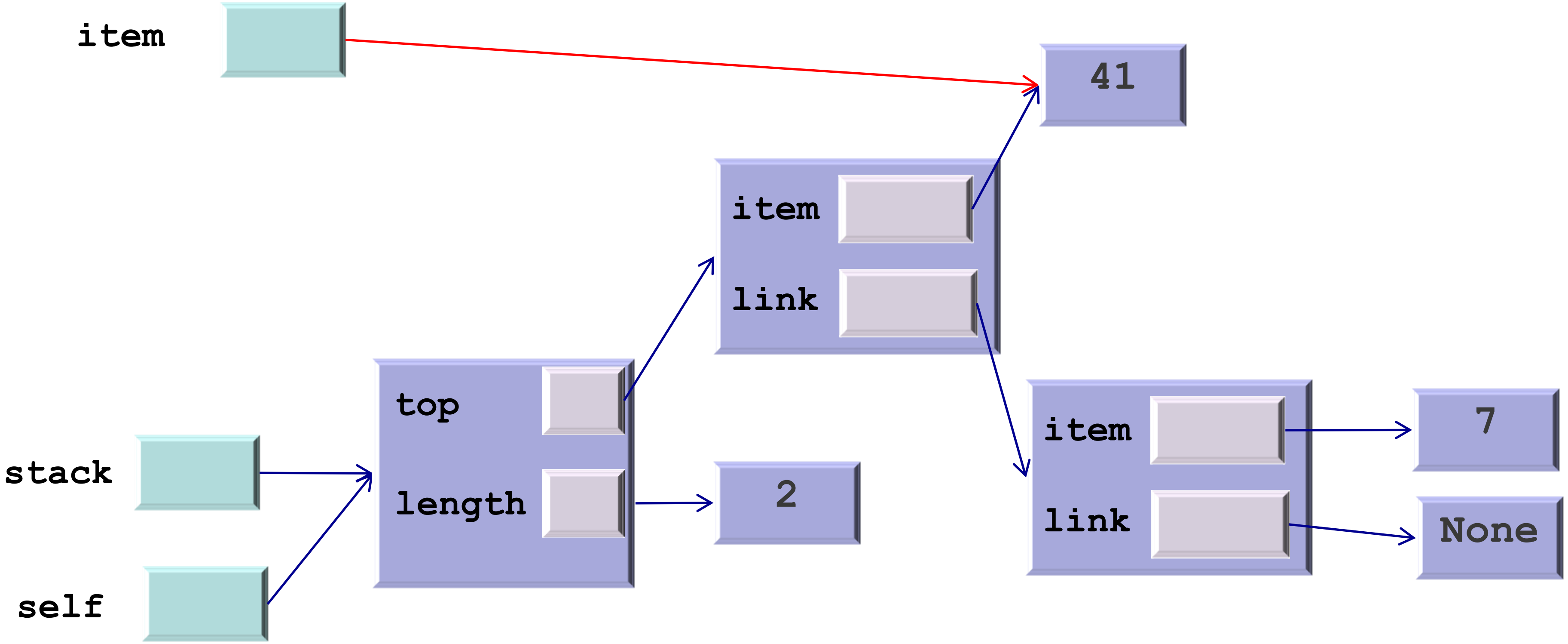

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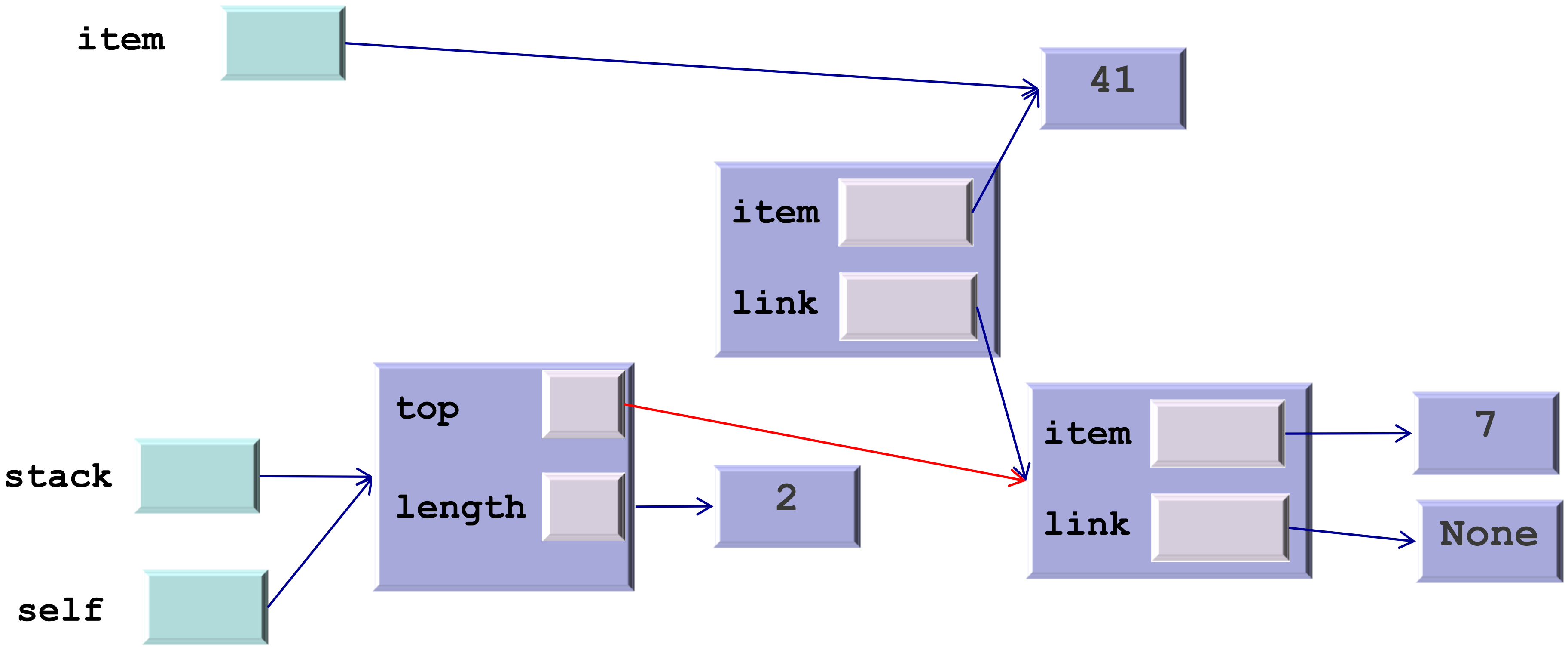

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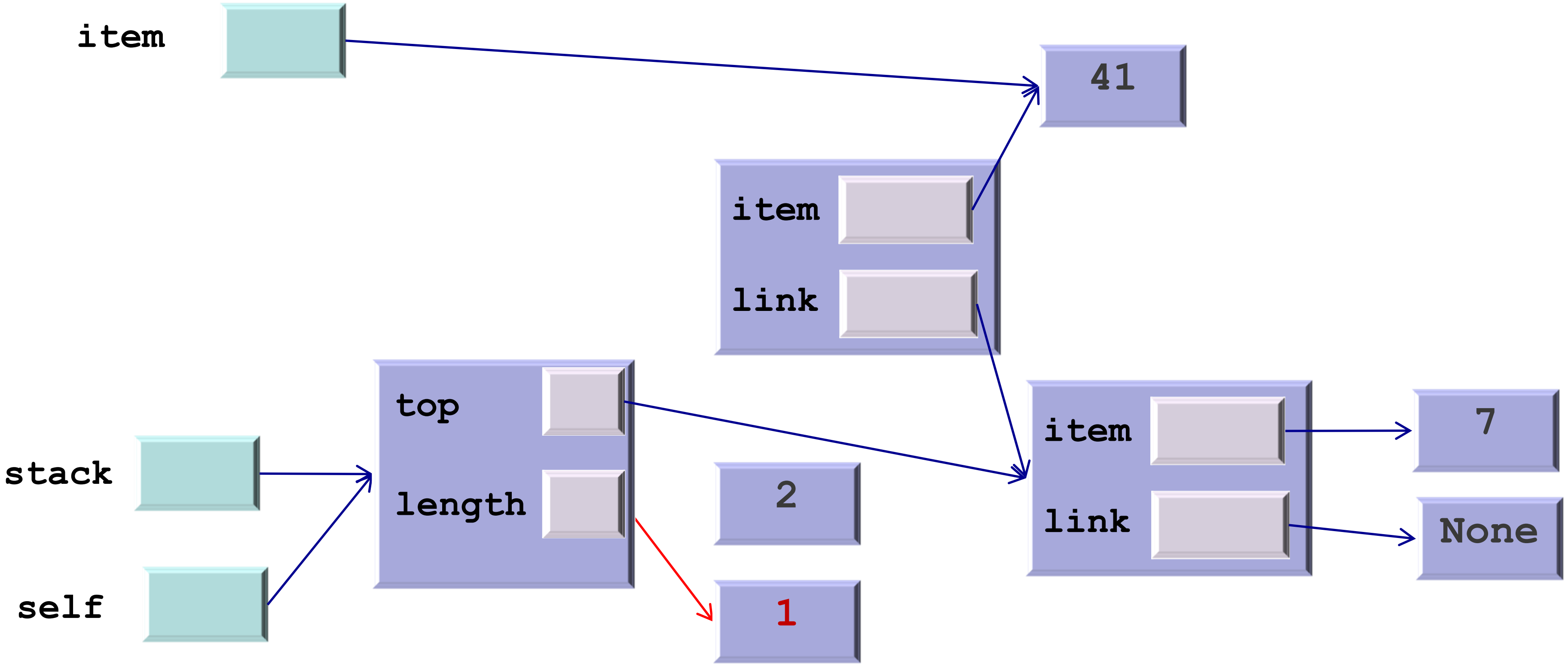

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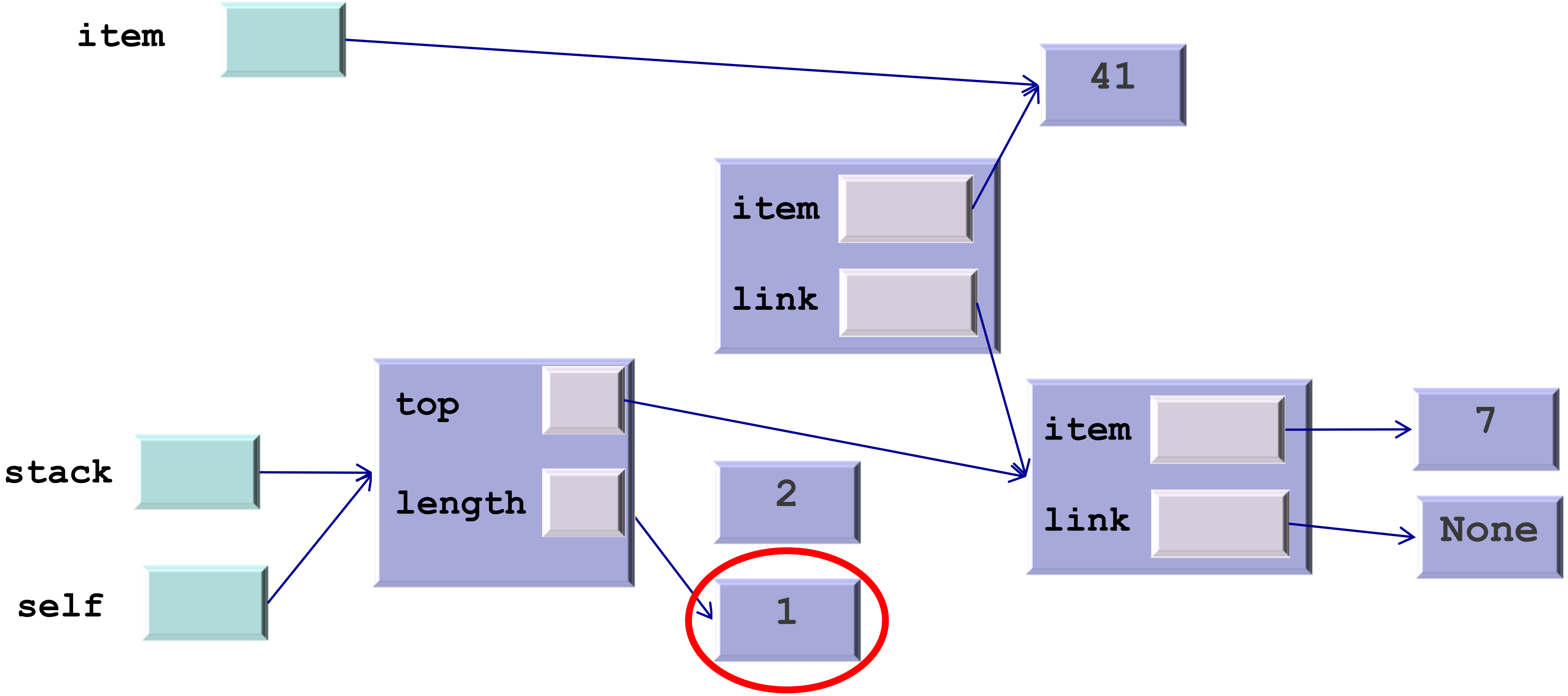

Example: modify for using linked stacks

```
def reverse(string: str) -> str:
    my_stack = ArrayStack(len(string))

    for char in string:
        my_stack.push(char)

    output = ""

    while not my_stack.is_empty():
        char = my_stack.pop()
        output += char

    return output
```

What needs to change?

Only the class name for instantiating the object

That is the point of ADTs!

Advantages/Disadvantages for Stacks

- **Main advantages:**
  - Good to resize:
    - Push: never full so no need to copy, just add element at top
    - Pop: uses less memory when elements are popped
  - Needs less space than the array, if the array is relatively empty (less than half)
- **Main disadvantage:**
  - Needs more space (for the links) than the array, if the array is relatively full
- **Other disadvantages:**
  - A bit slower
    - Still constant time but a bigger constant (create nodes, etc)

Note: Lack of random access is not a problem for a stack: its operations do not need this!

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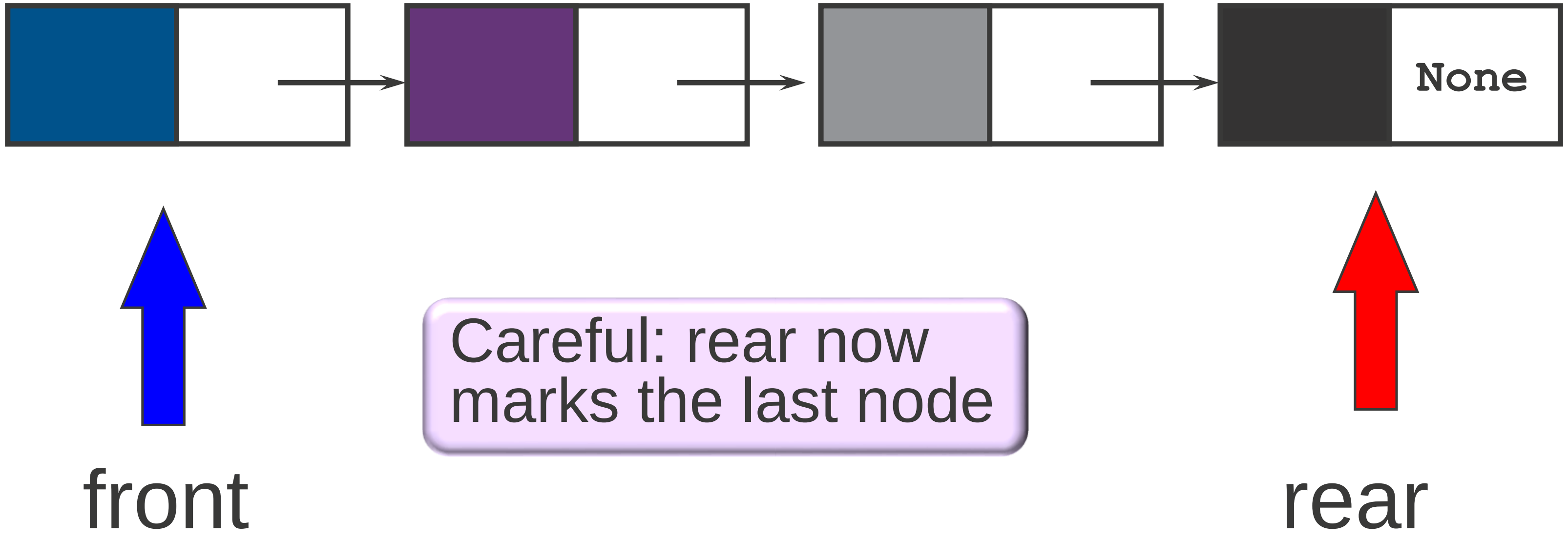
Linked Queues

Remember: Abstract base Queue class

```
from abc import ABC, abstractmethod
from typing import TypeVar, Generic
T = TypeVar('T’)


class Queue(ABC, Generic[T]):
    def __init__(self) -> None:
        self.length = 0

    @abstractmethod
    def append(self, item: T) -> None:
        pass

    @abstractmethod
    def serve(self) -> None:
        pass

    def __len__(self) -> int:
        return self.length

    def clear(self):
        self.length = 0
```

```
    def is_empty(self) -> bool:
        return len(self) == 0

    @abstractmethod
    def is_full(self) -> bool:
        pass
```

Linked Queue



Careful: rear now marks the last node

No need for circularity

What do we need in the class?

Class for Linked Queue

```
from typing import TypeVar
from abstract_queue import Queue
from node import Node
T = TypeVar('T’)

class LinkQueue(Queue[T]):
    def __init__(self):
        Queue.__init__(self)
        self.front = None
        self.rear = None

    def is_empty(self) -> bool:
        return self.front is None

    def is_full(self) -> bool:
        return False
```

The code must ensure that when **`front`** is **`None`**, **`rear`** is also **`None`**

```
def clear(self) -> None:
    Queue.clear()
    self.front = None
    self.rear = None
```

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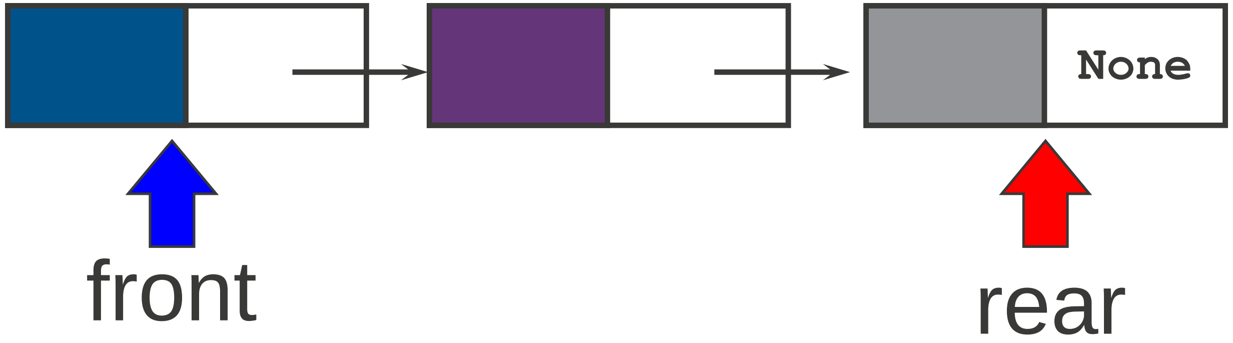
Linked Queues
Append

Append: algorithm

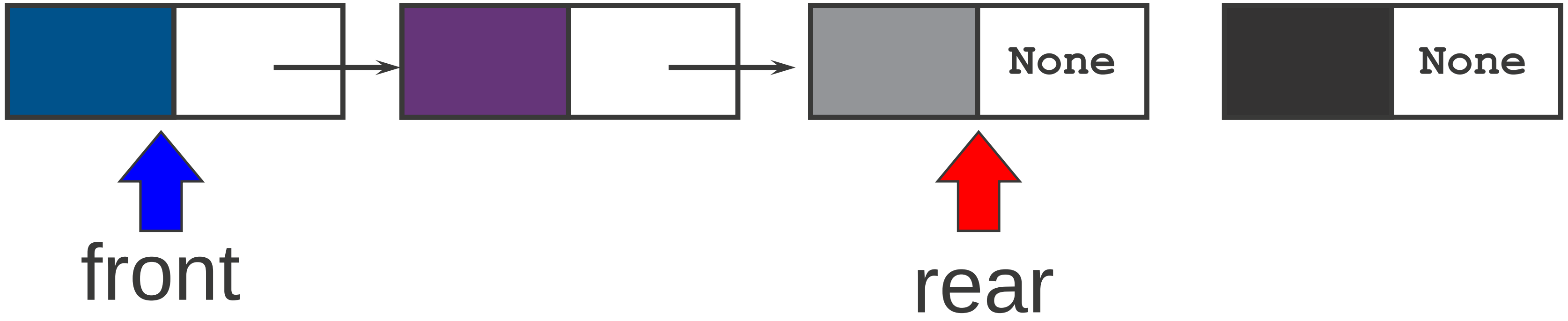
- **Linear array implementation:**
  - If it is full: raise exception
  - Else:
    - Increase rear
    - Add item at position marked by rear
- **In a linked list:**
  - Create a new node that contains item and points to **`None`**
  - Link the current rear to it
  - Make the new node the new rear
- **Again, no need for `is_full` check**

Append: algorithm



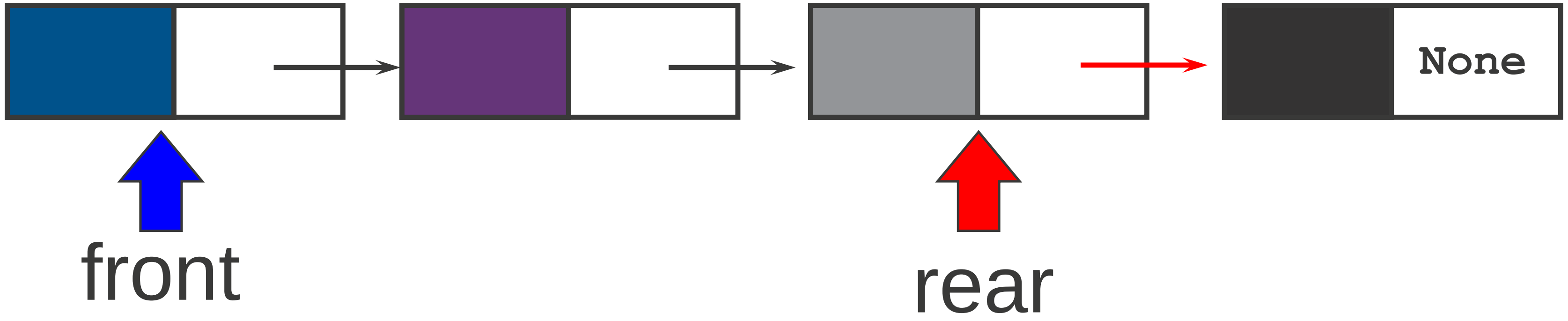
Append: algorithm

- Create a new node for item



Append: algorithm

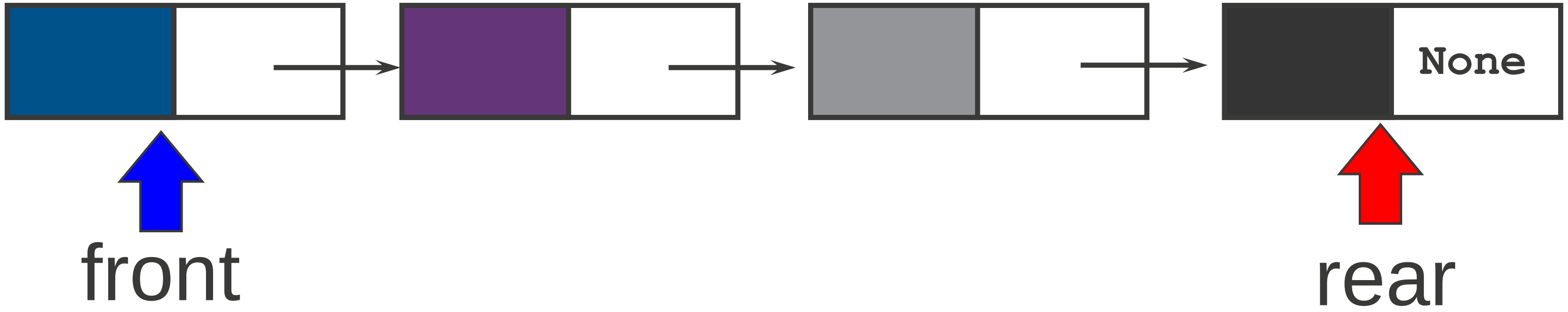
- Create a new node for item ■
- Make a link from the current rear to the new node



Append: algorithm

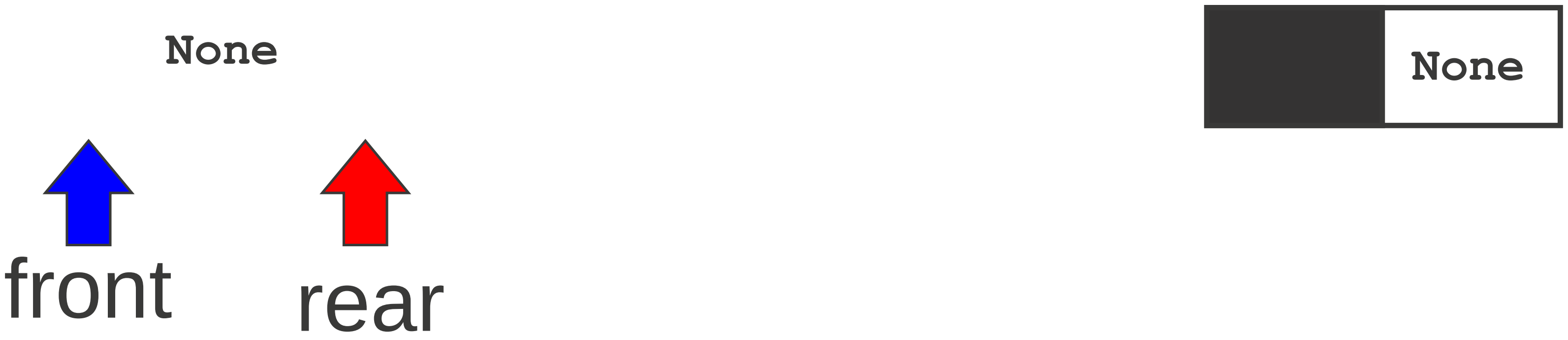
- Create a new node for item ■
- Make a link from the current rear to the new node
- The new node becomes the new rear

Does this general algorithm always work?



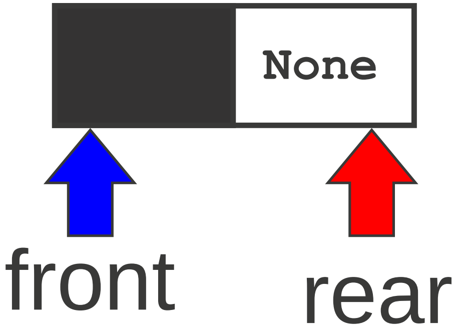
Append: algorithm

- **No, if the queue is empty, we must modify front too**
- **How?**
  - Create a new node for item



Append: algorithm

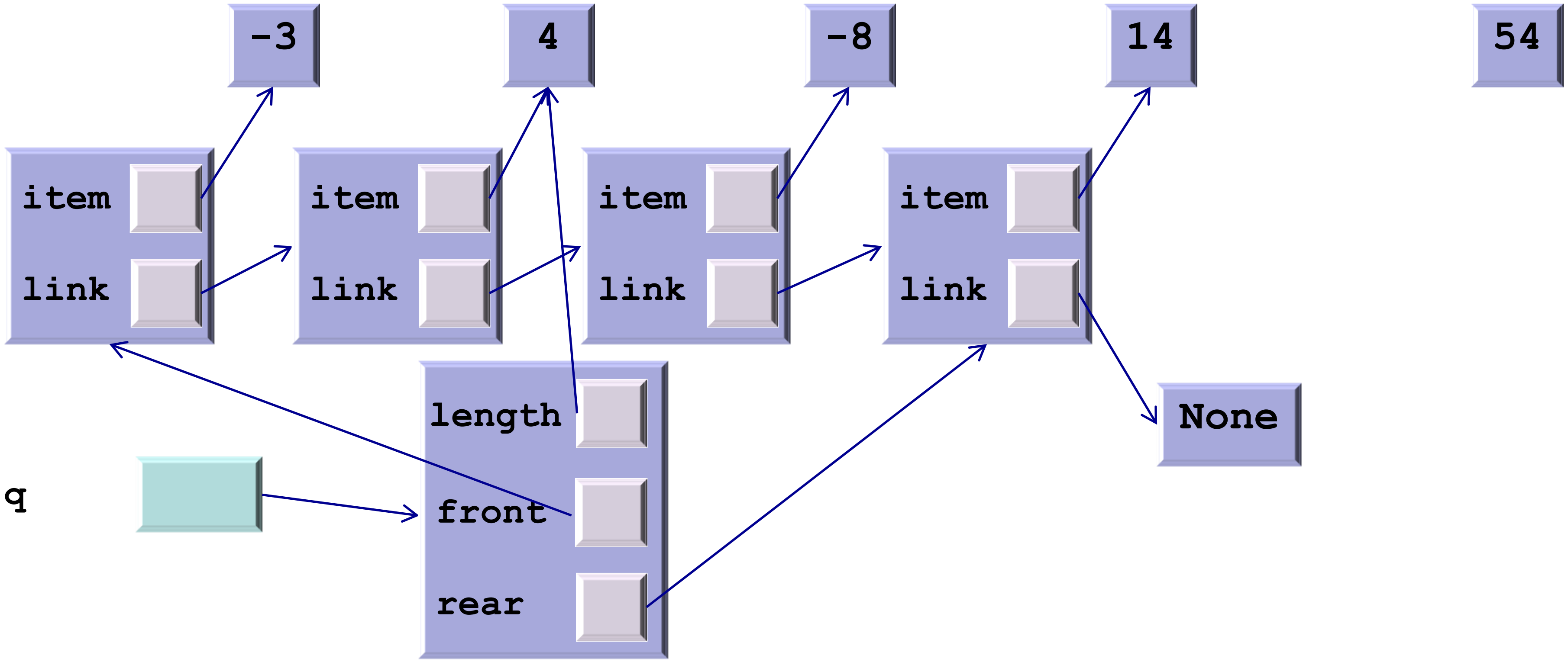
- **No, if the queue is empty, we must modify front too**
- **How?**
  - Create a new node for item ■
- **The new node become the new front and rear**



Append method

```
…
    def append(self, item: T) -> None:
        new_node = Node(item) # create new node
        if self.is_empty():
            self.front = new_node # move head
        else:
            self.rear.link = new_node #link it in
        self.rear = new_node # move rear to new node
        self.length += 1
```

Complexity?   O(1)



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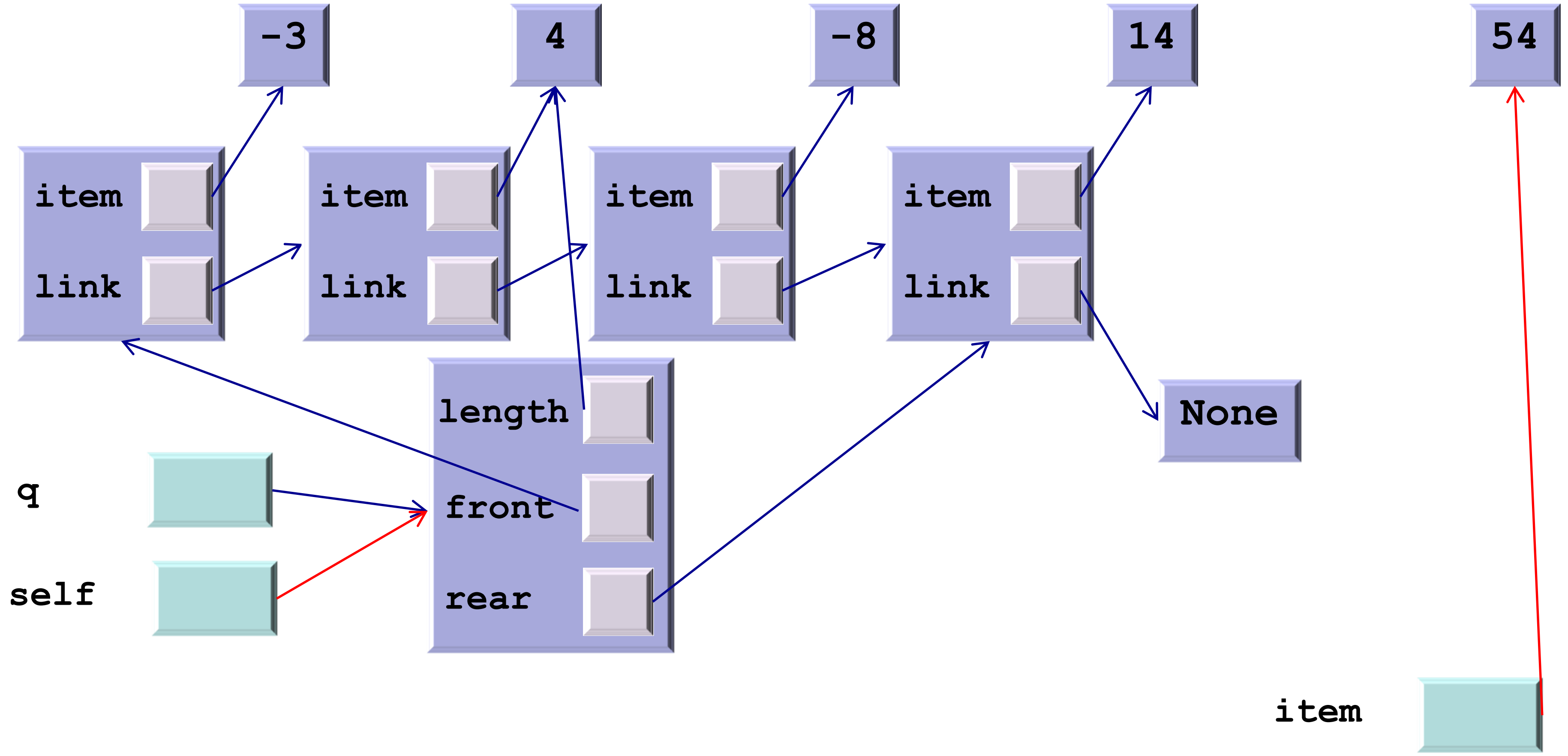
```

q.append(54)



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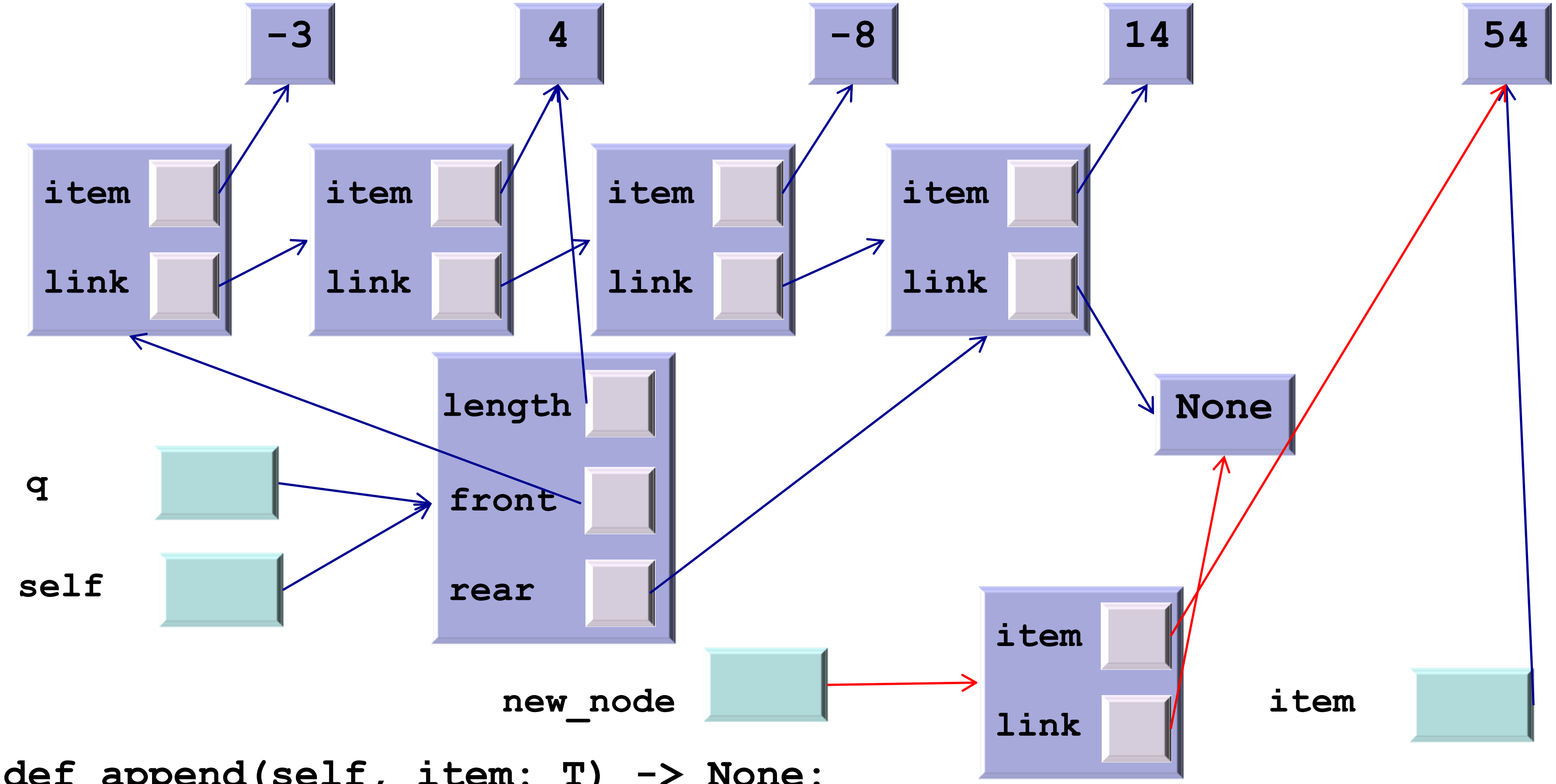

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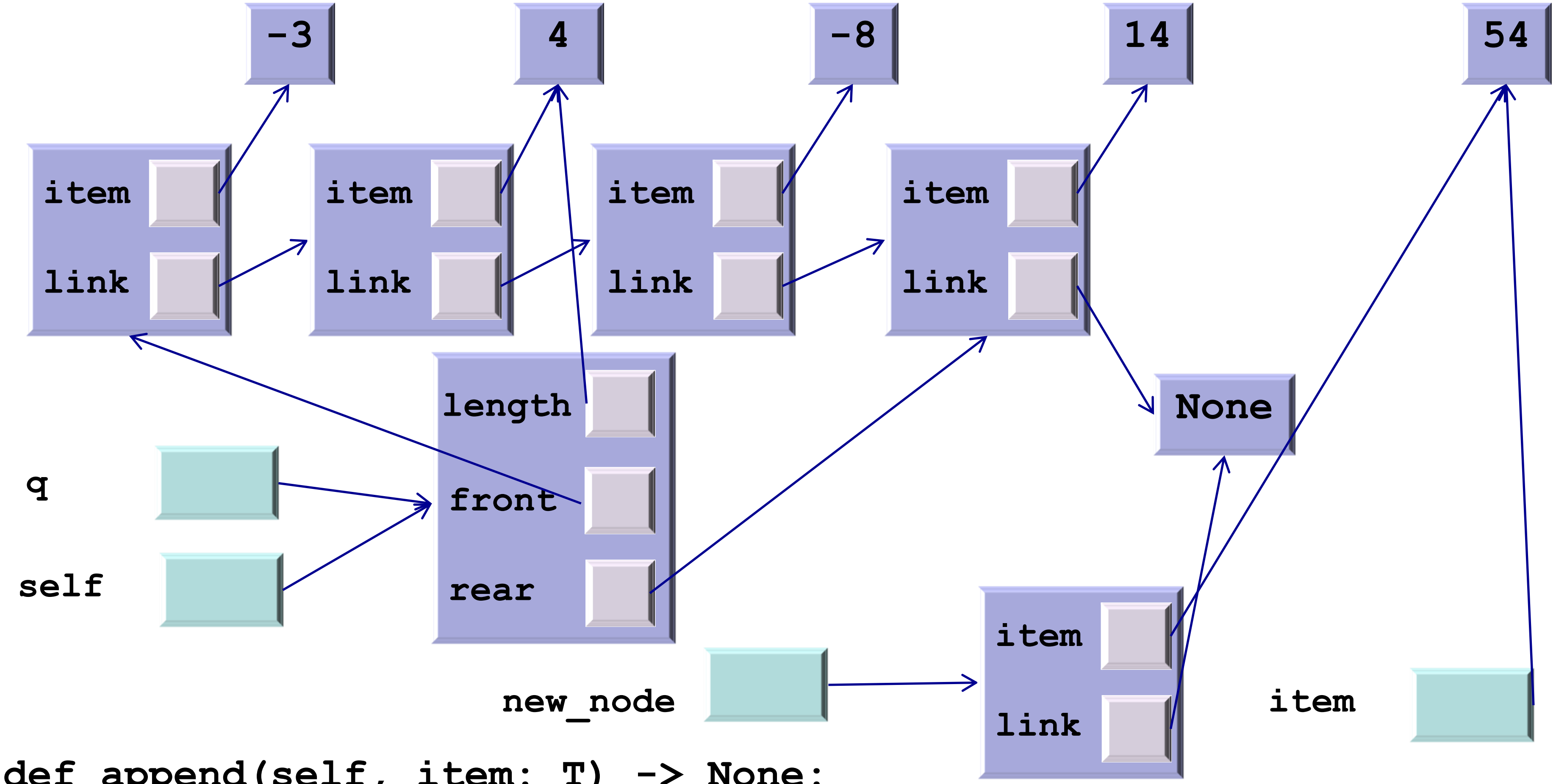

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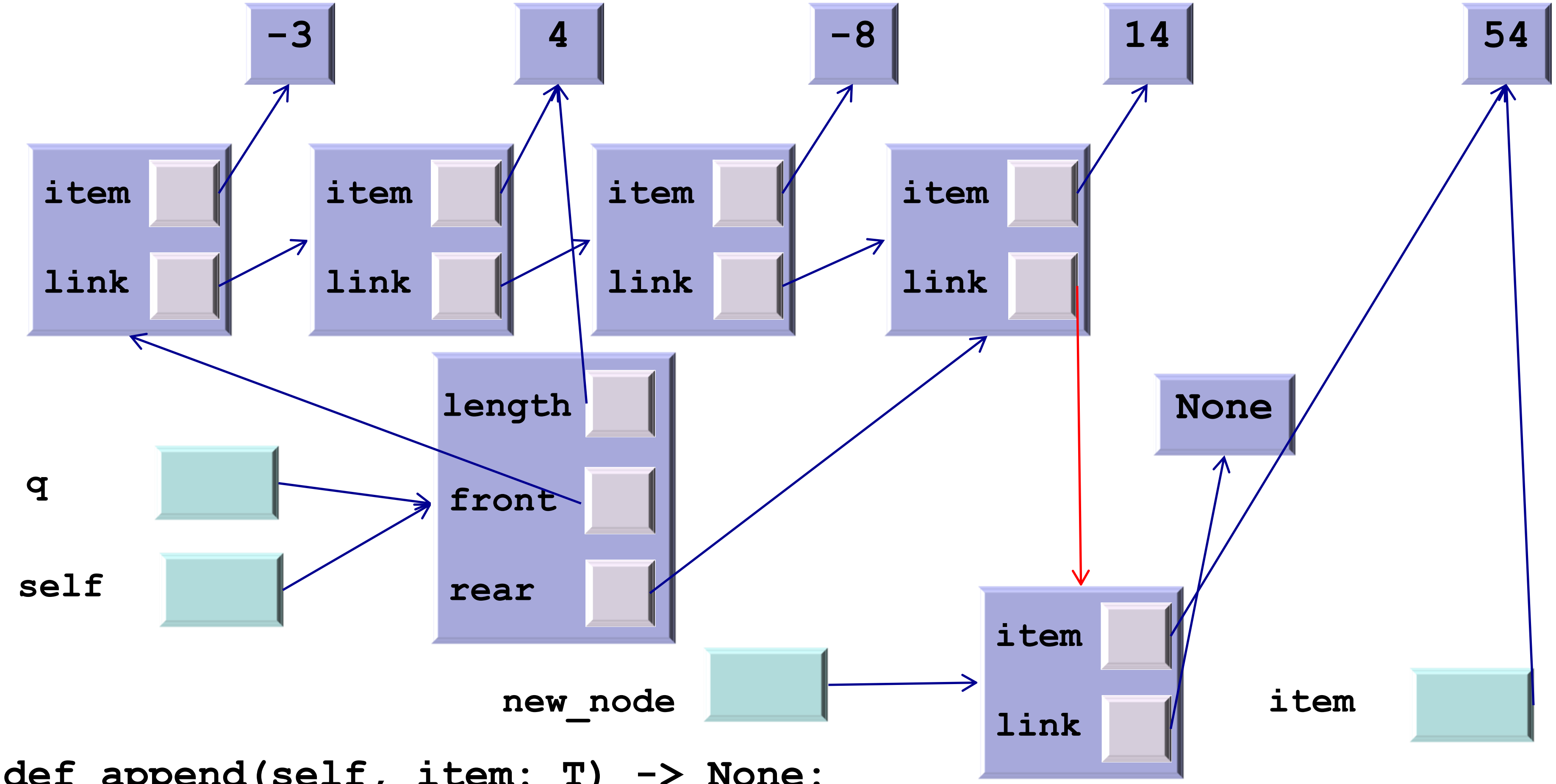

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```
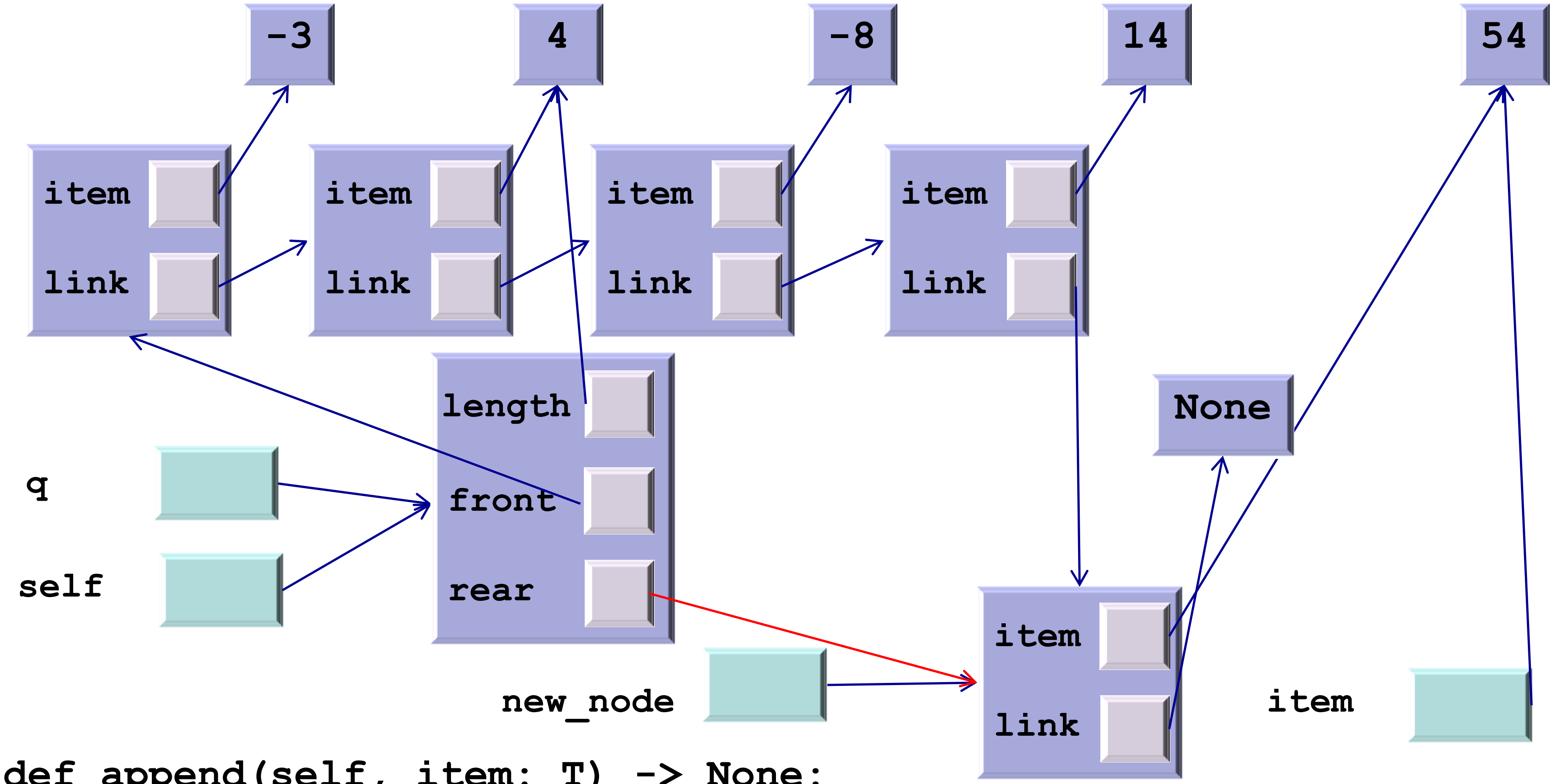
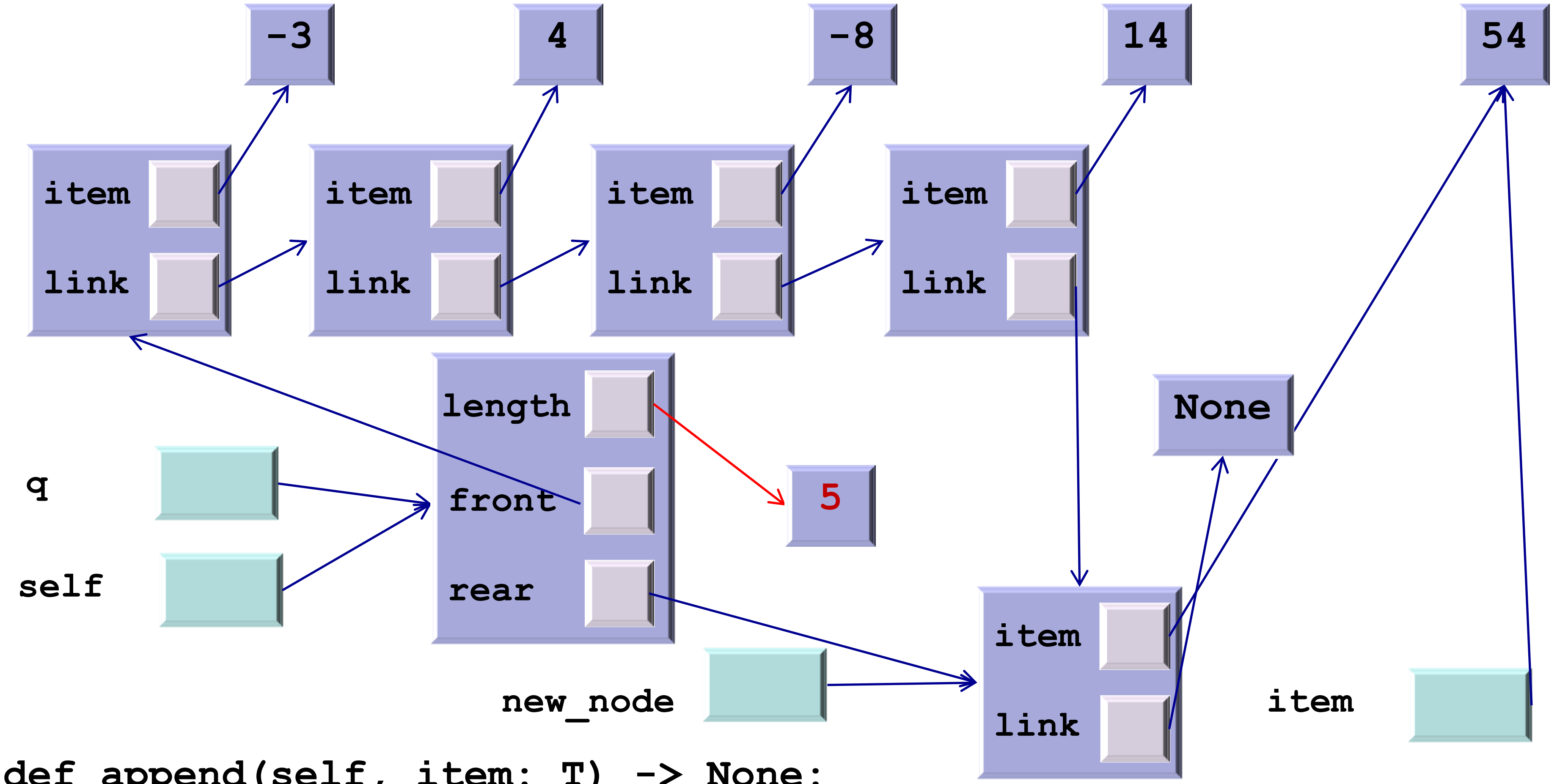

q.append(54)



```
def append(self, item: T) -> None:
    new_node = Node(item)
    if self.is_empty():
        self.front = new_node
    else:
        self.rear.link = new_node
    self.rear = new_node
    self.length += 1
```

q.append(54)



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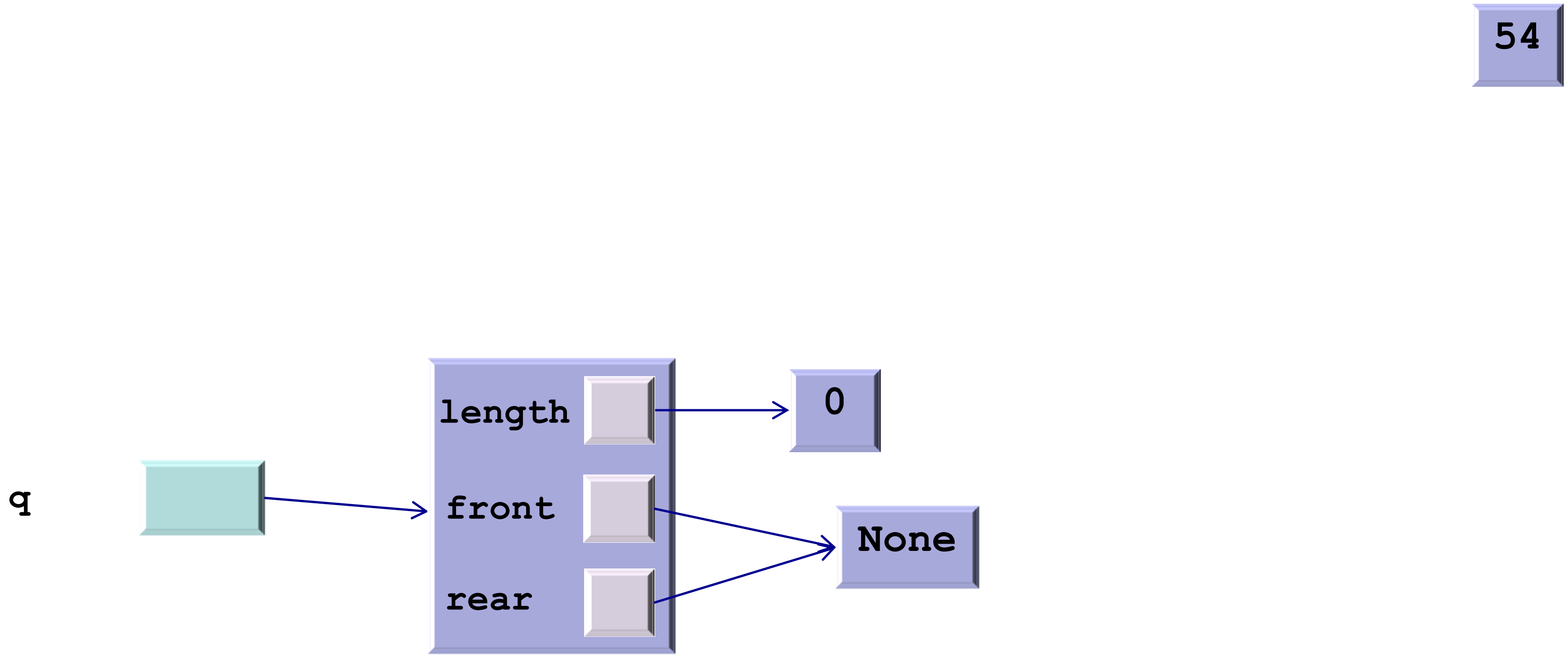
```

q.append(54)



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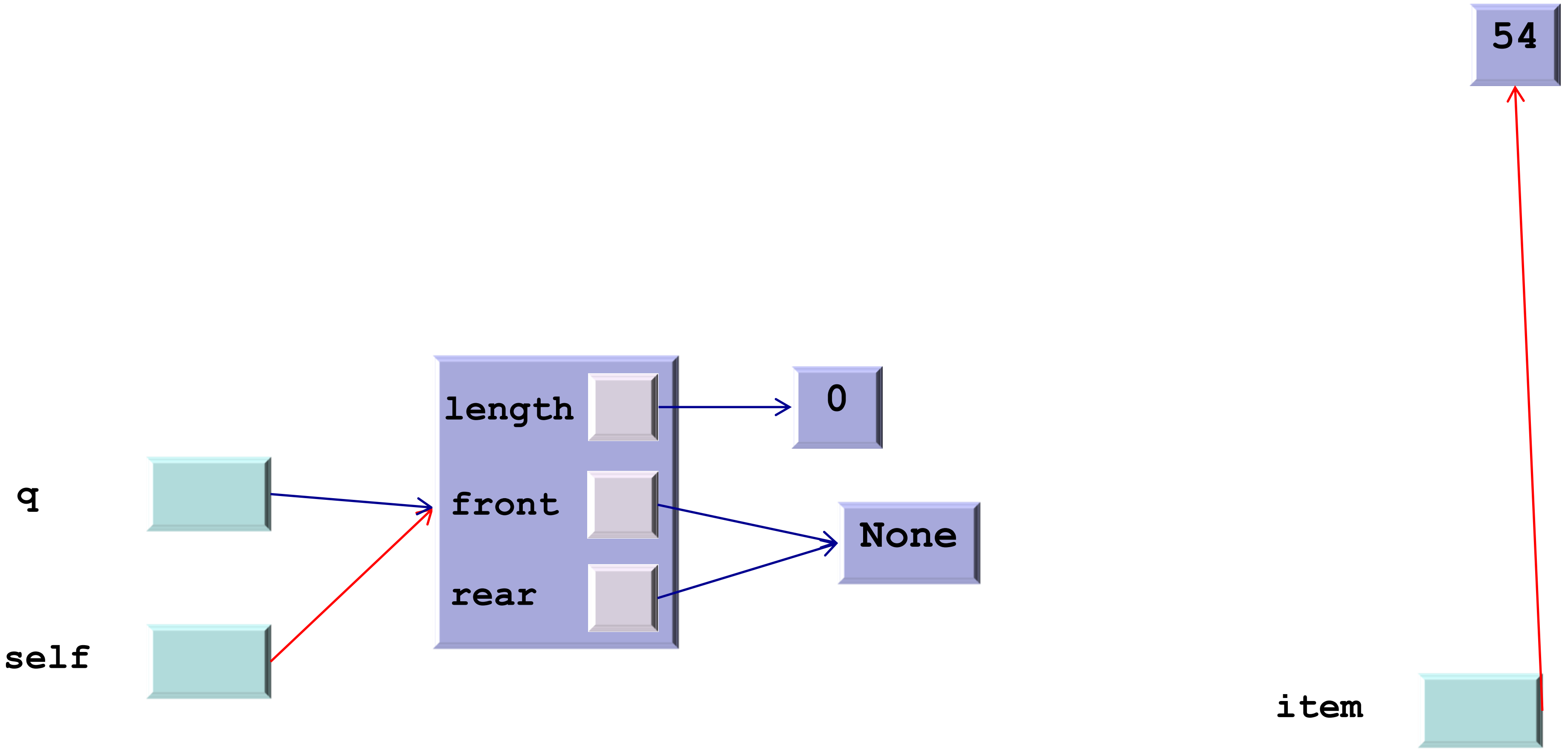

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```

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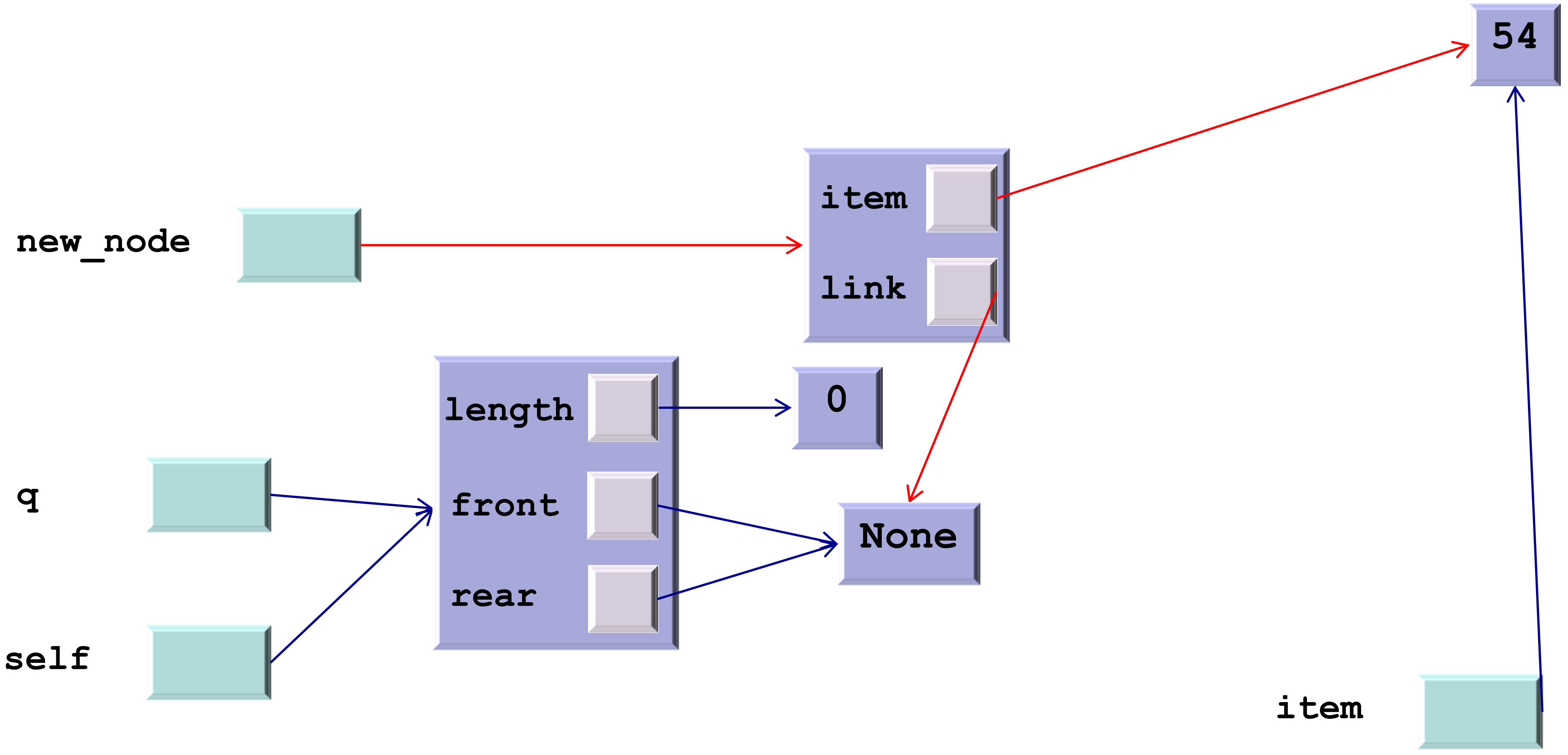

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```

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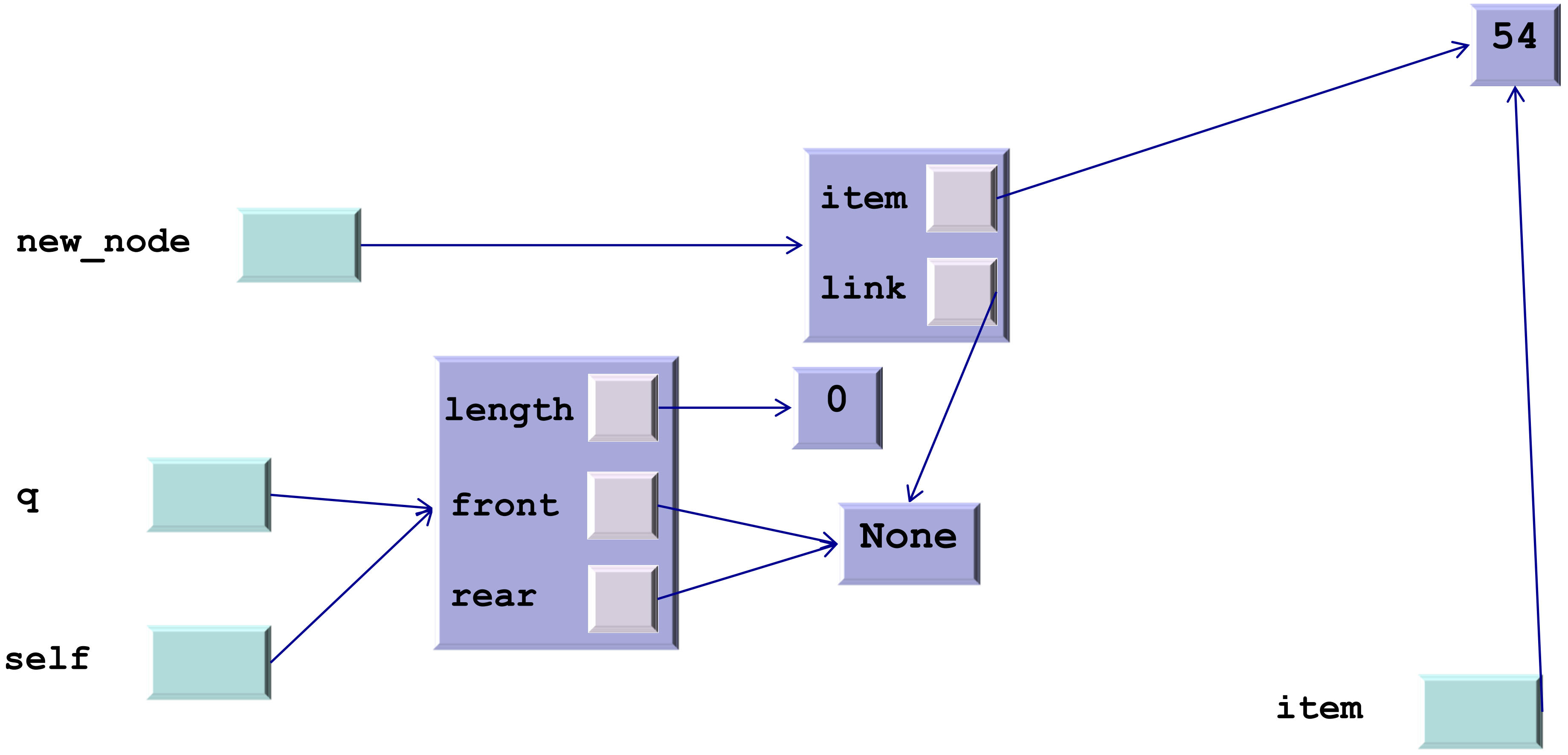

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```

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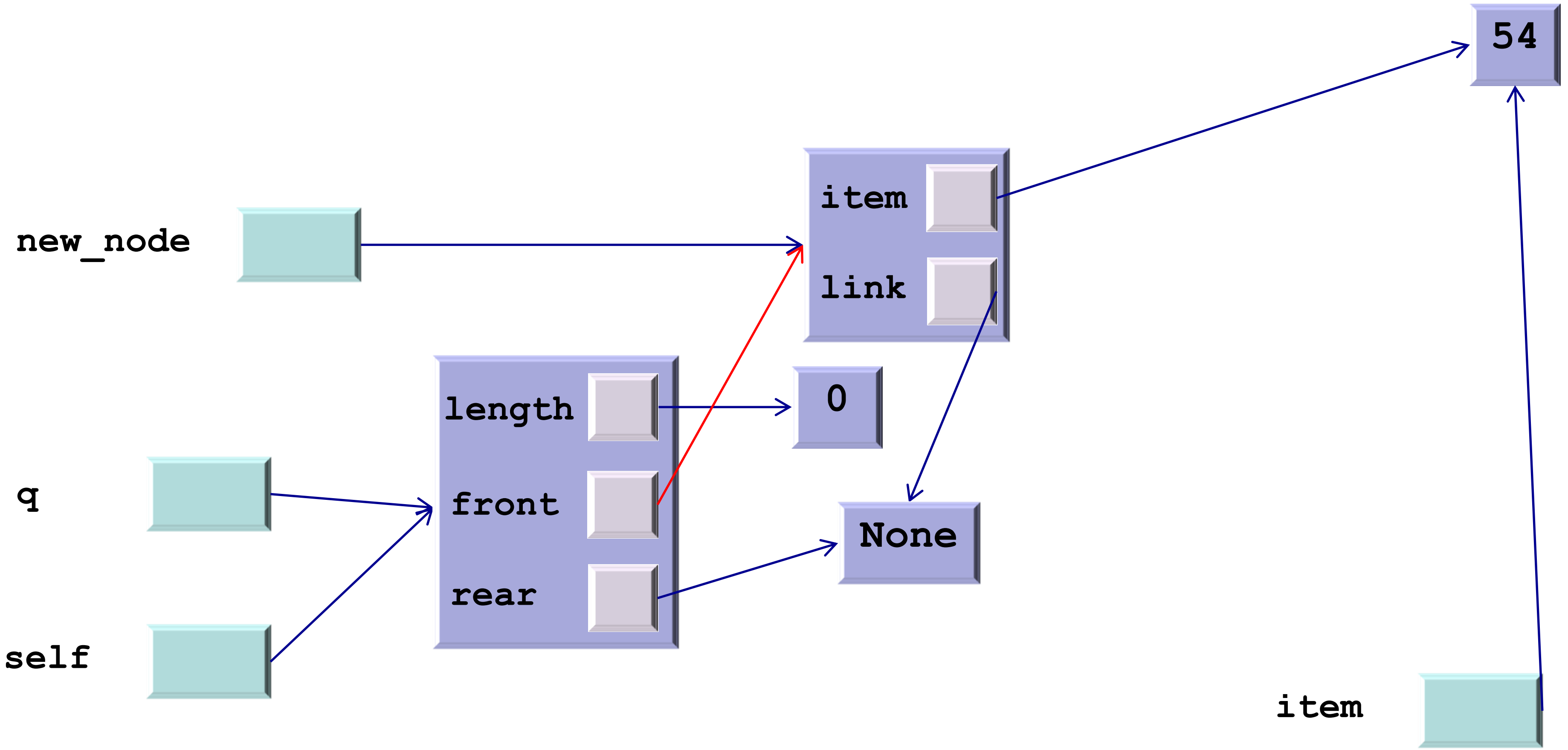

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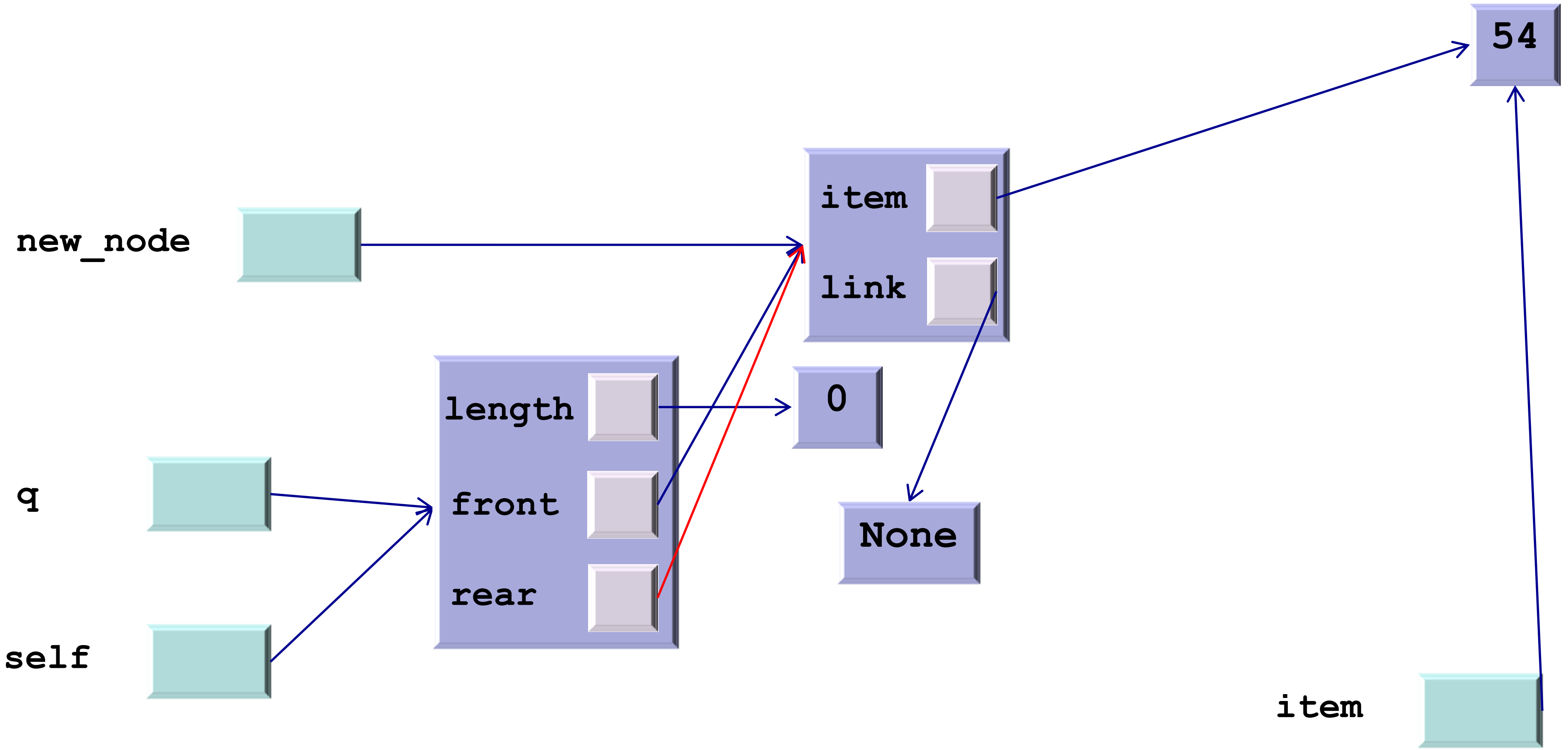
```

q.append(54)



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```
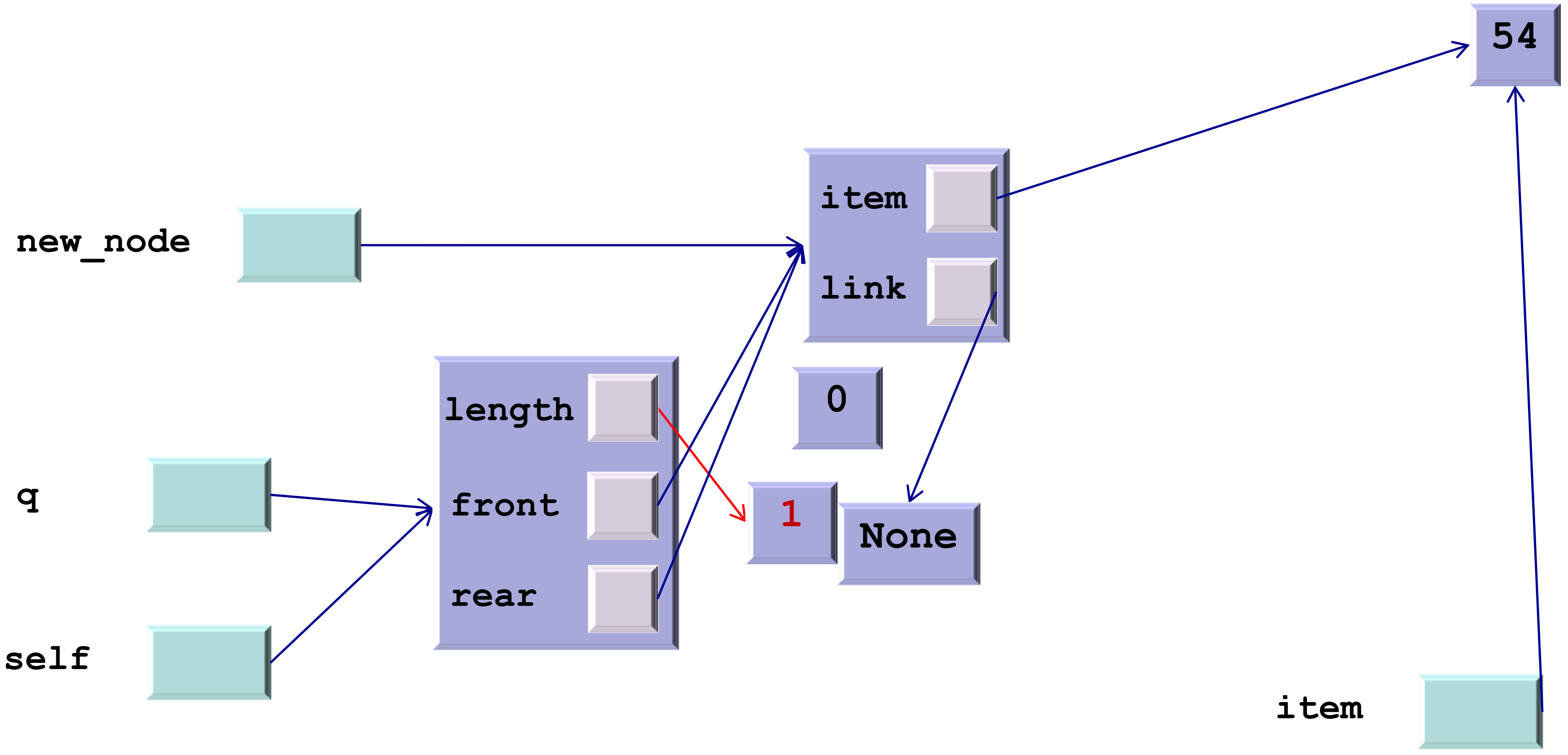

q.append(54)



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        self.rear.link = new_node
    self.rear = new_node
    self.length += 1
```

q.append(54)

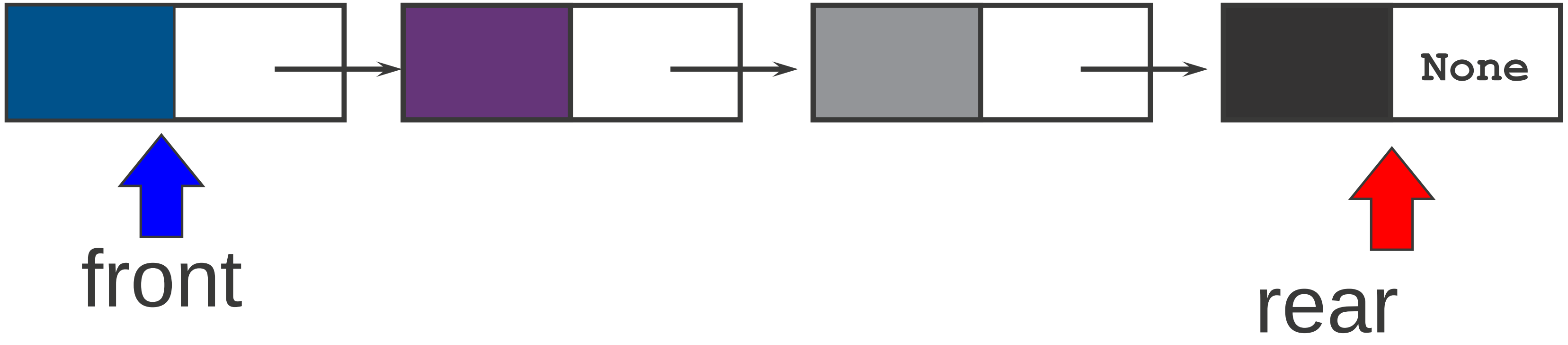
Linked Queues
Serve

Serve: algorithm

- **Linear array implementation:**
  - If it is empty: raise exception
  - Else:
    - Remember item to return
    - Increase front
    - Return item
- **In a linked list**
  - Almost identical
  - We simply move front along rather than increase it

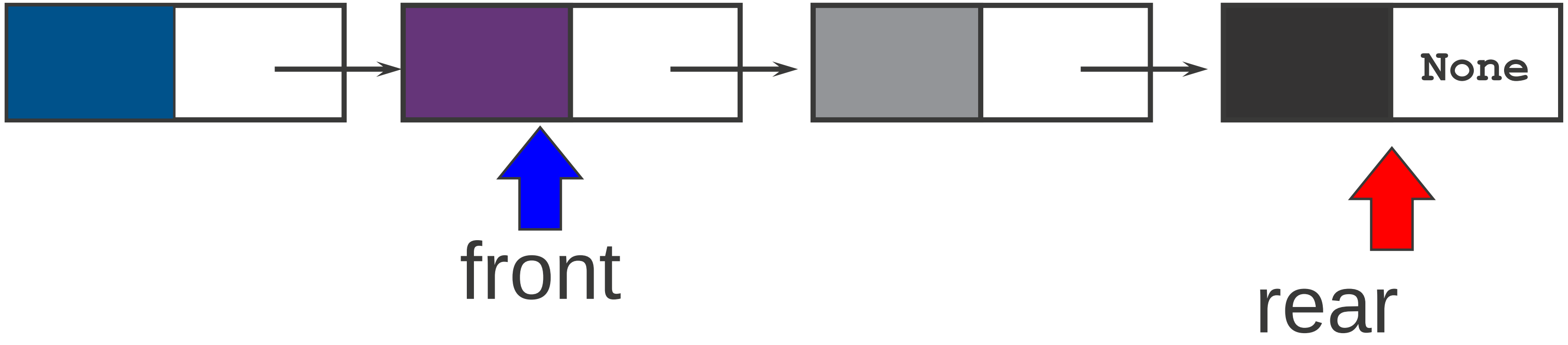
Serve: algorithm

- **Remember the item in the front node**



Serve: algorithm

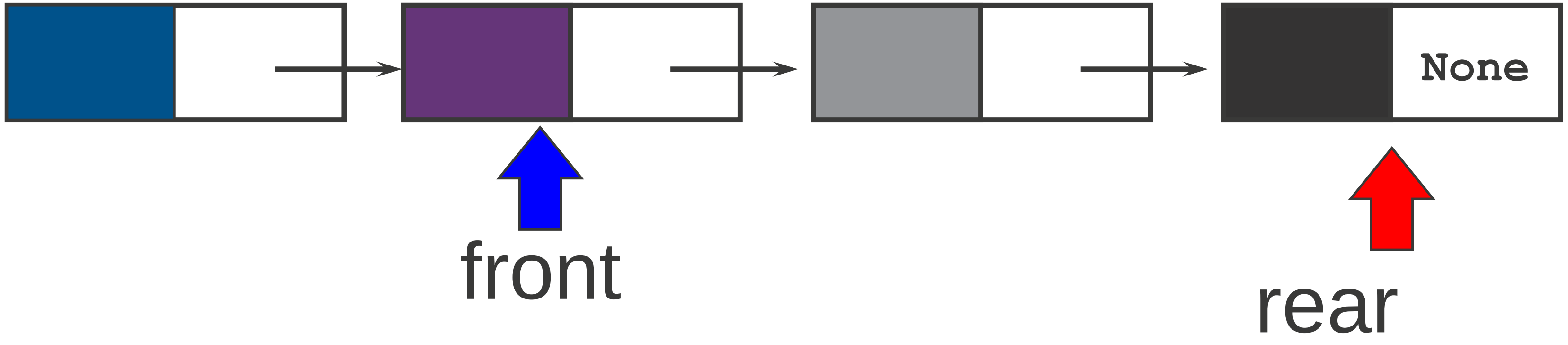
- Remember the item in the front node
- Make the next node the new front



Serve: algorithm

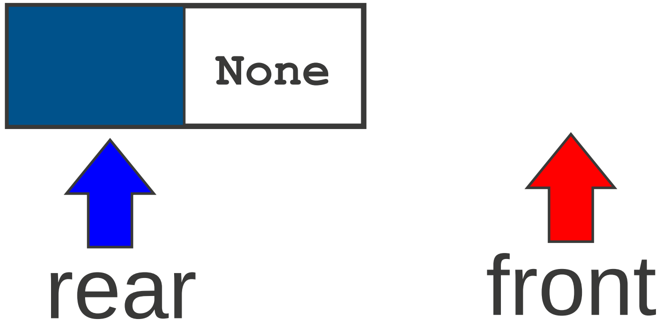
- Remember the item in the front node
- Make the next node the new front
- Return the item

Does this general algorithm always work?



Serve: algorithm

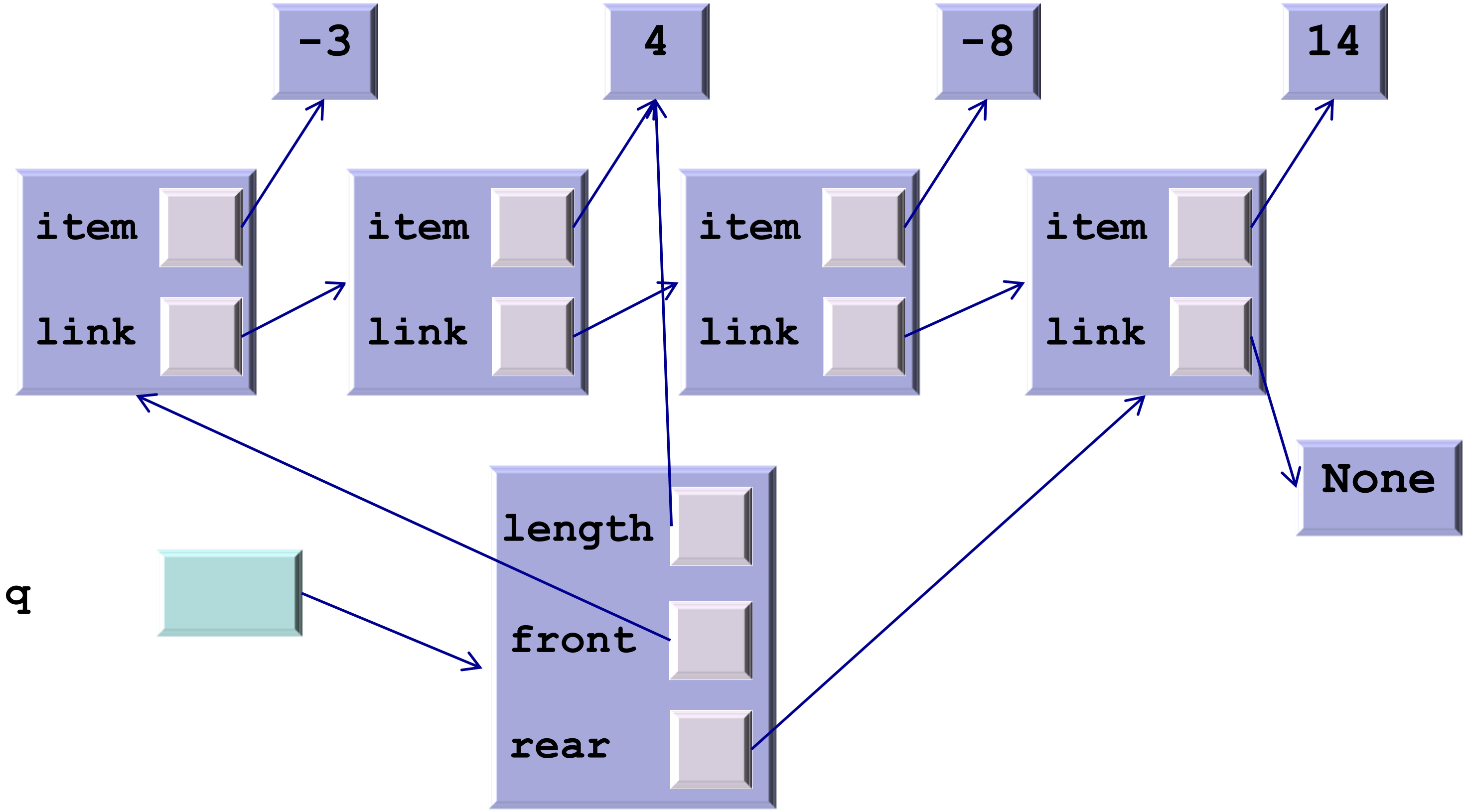
- **If the Queue becomes empty, we end up in a possibly dangerous configuration**
- **Better to set rear to `None`**



Serve method

```
def serve(self) -> T:
    if not self.is_empty():
        item = self.front.item  # store the item to serve
        self.front = self.front.link  # move front
        self.length -= 1
        if self.is_empty():   # if now empty
            self.rear = None  # move rear
        return item
    else:
        raise ValueError("Queue is empty")
```

Complexity? **O(1)**



q.serve()

```
def serve(self) -> T:
    if not self.is_empty():
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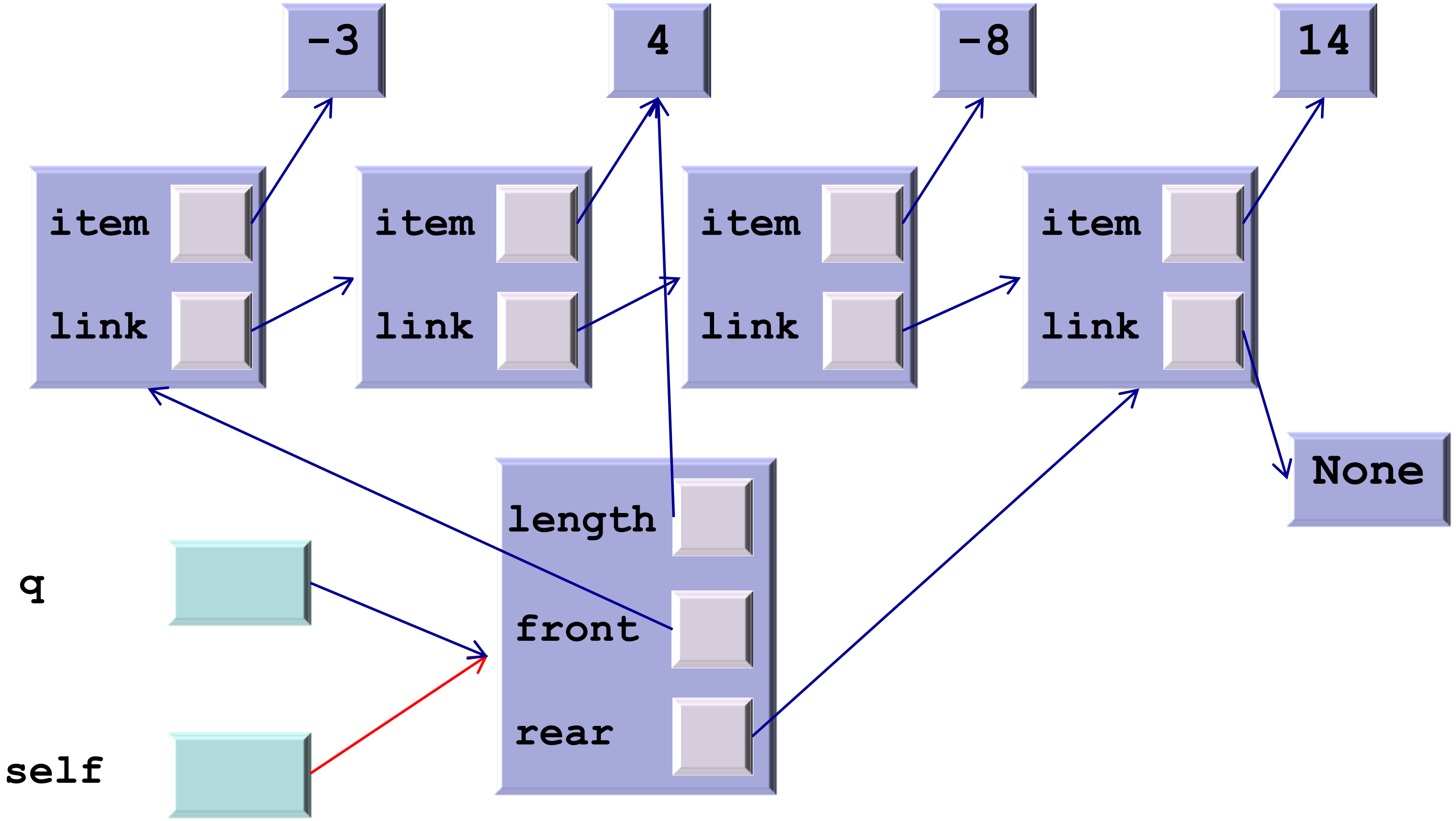

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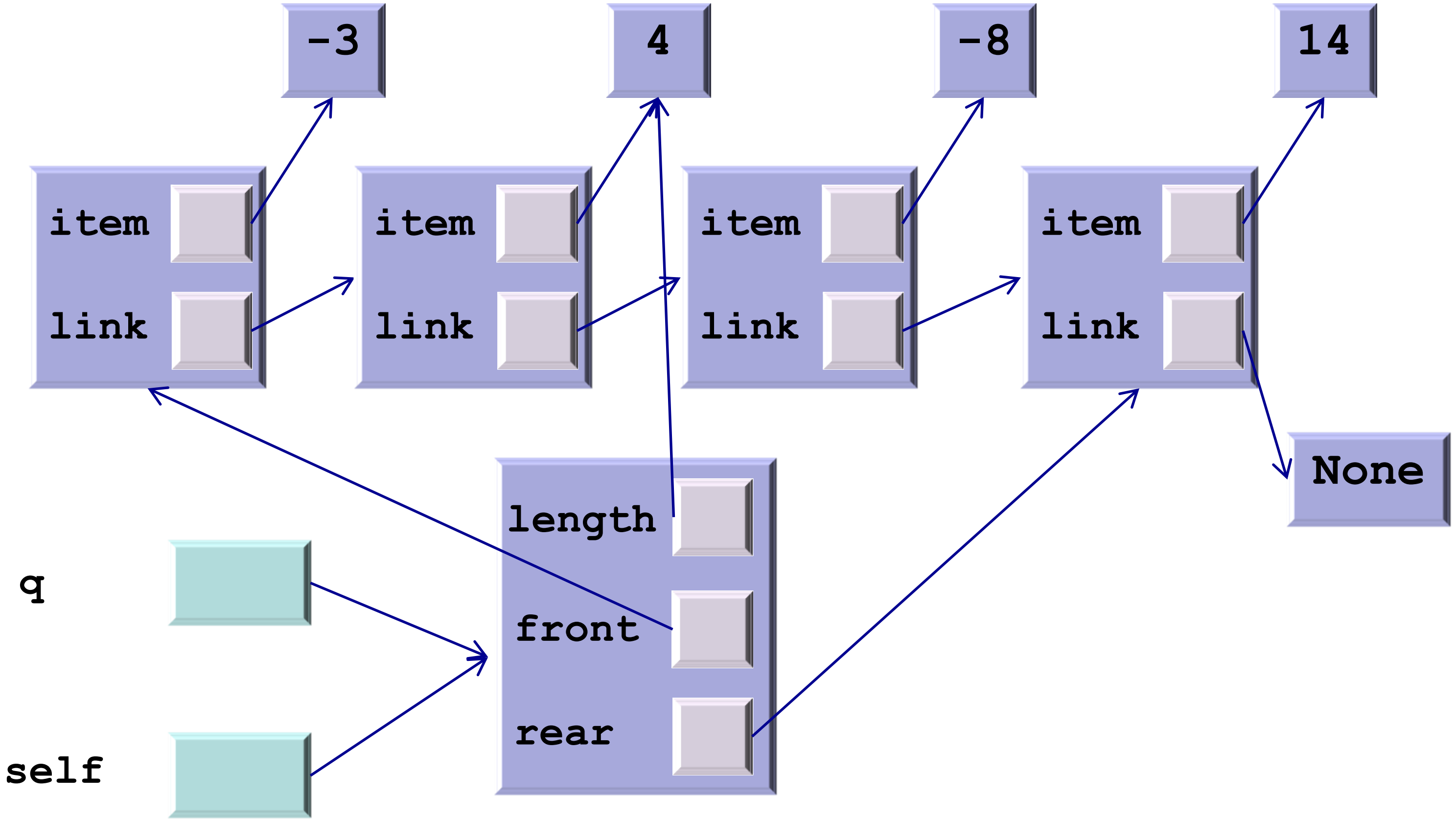

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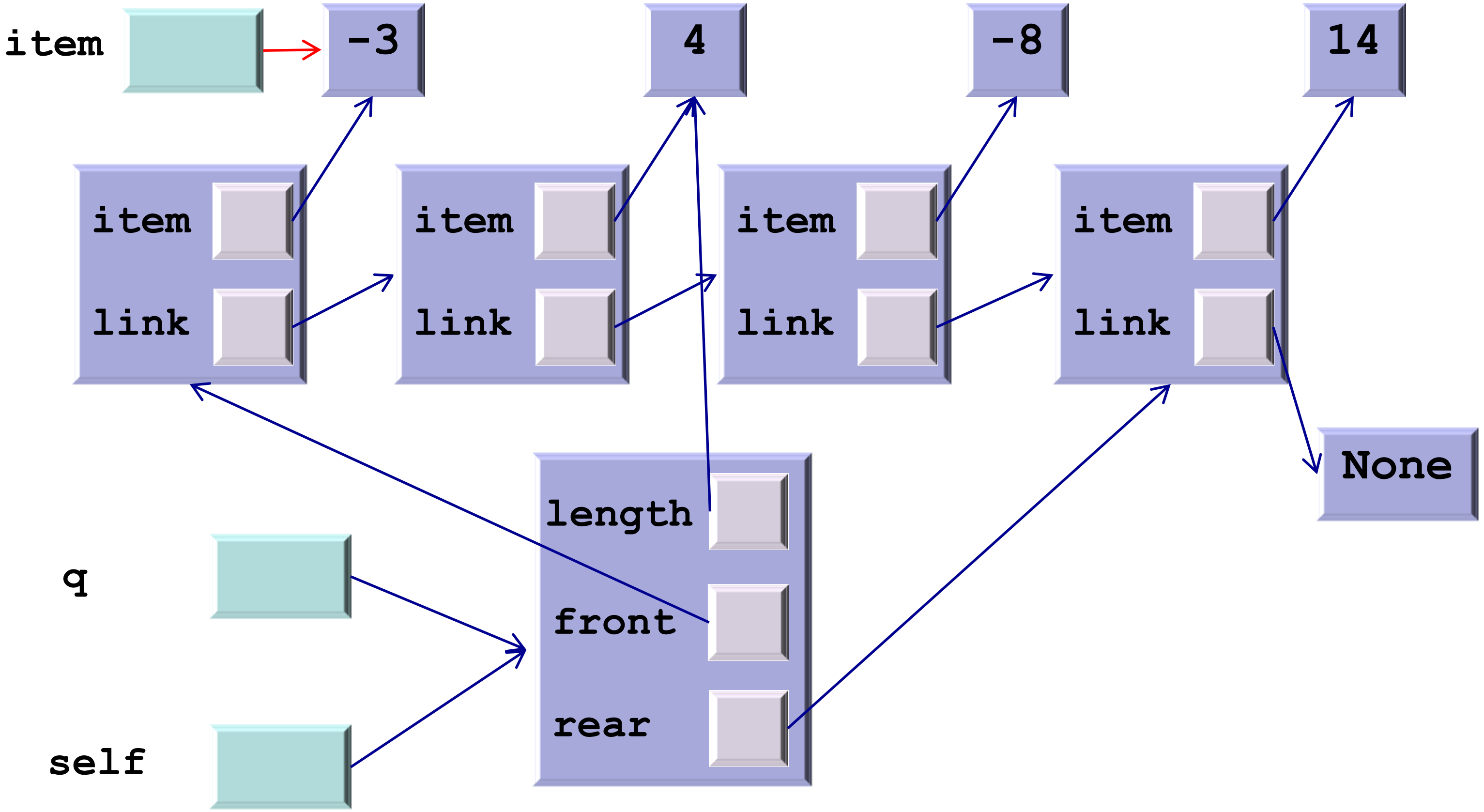

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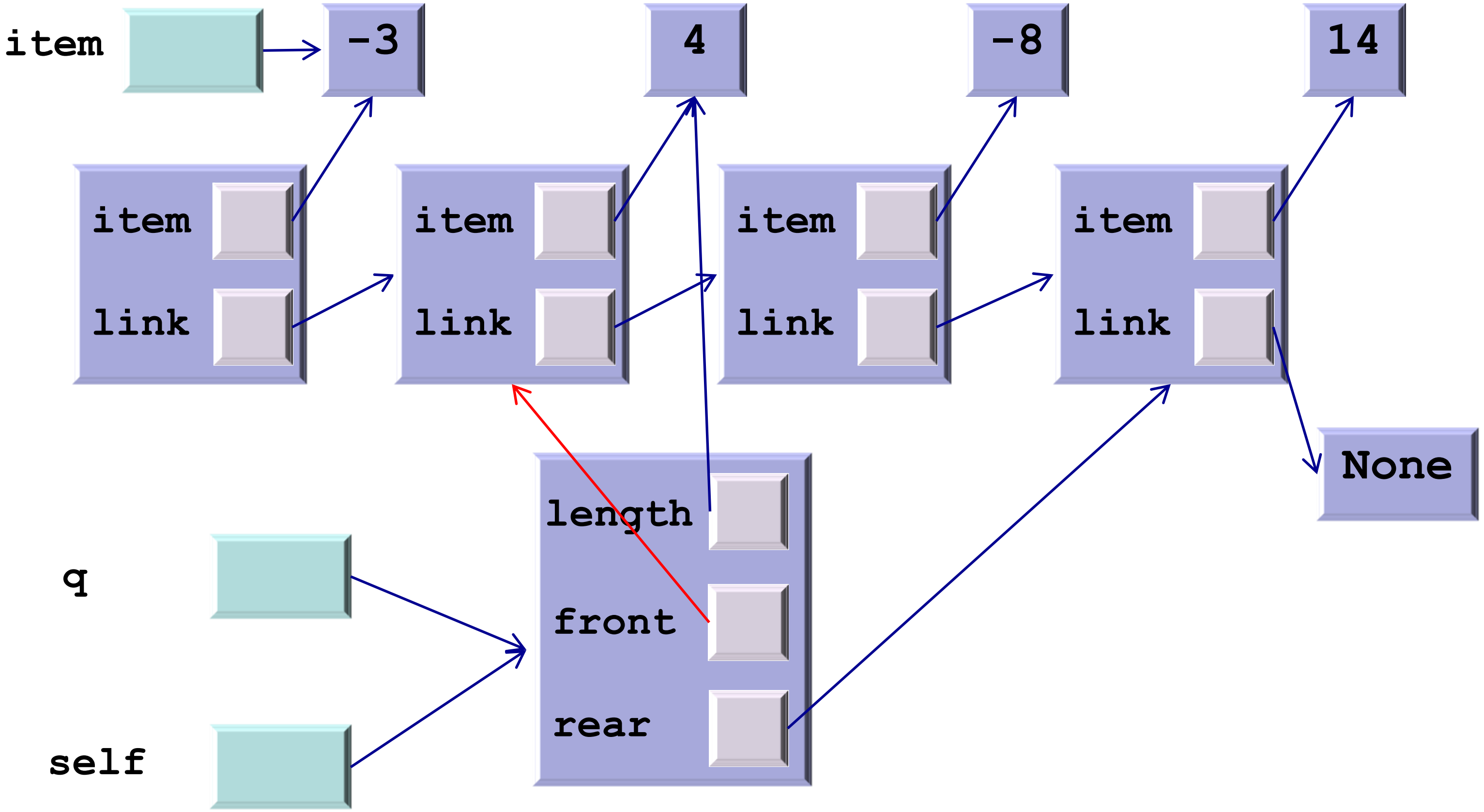

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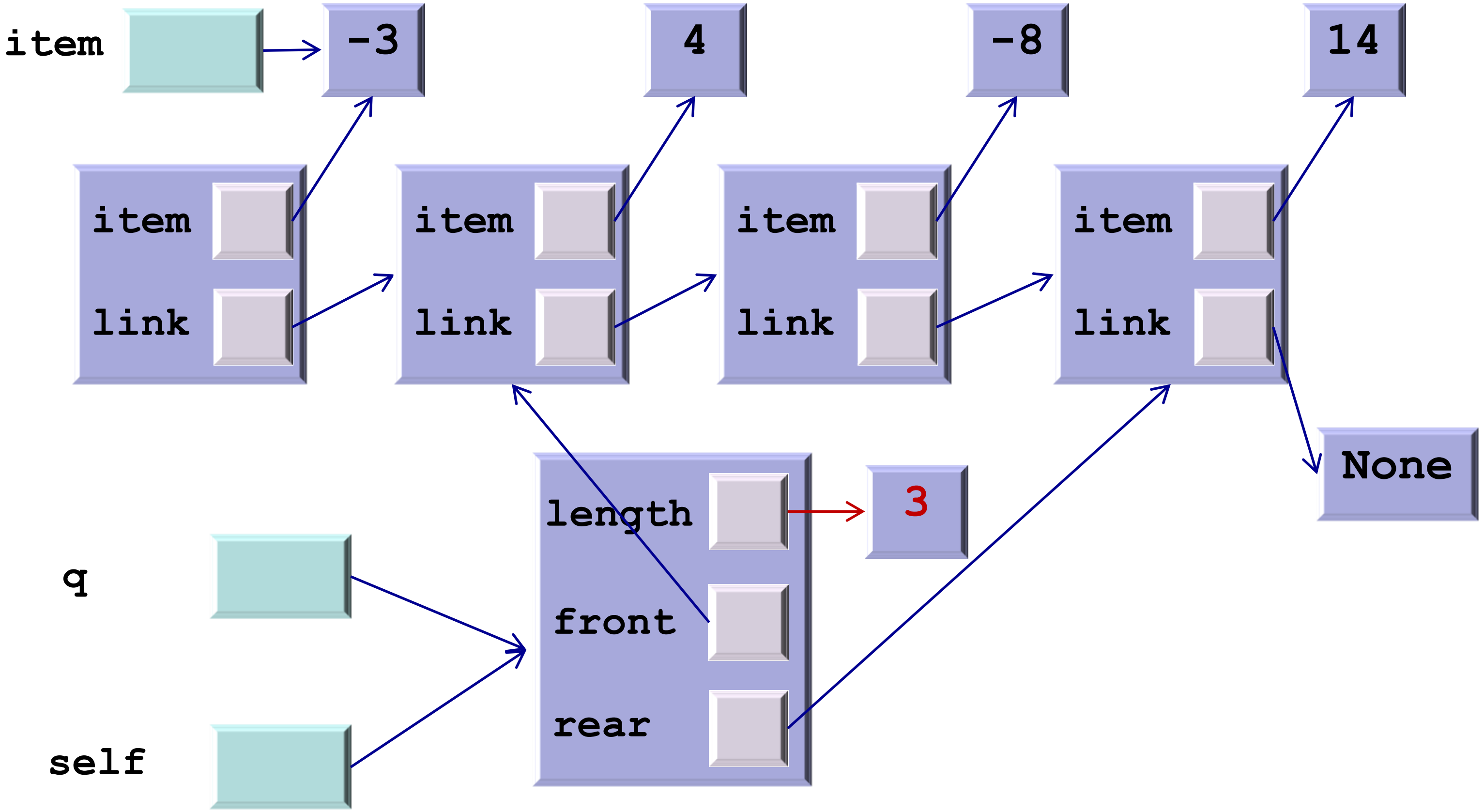

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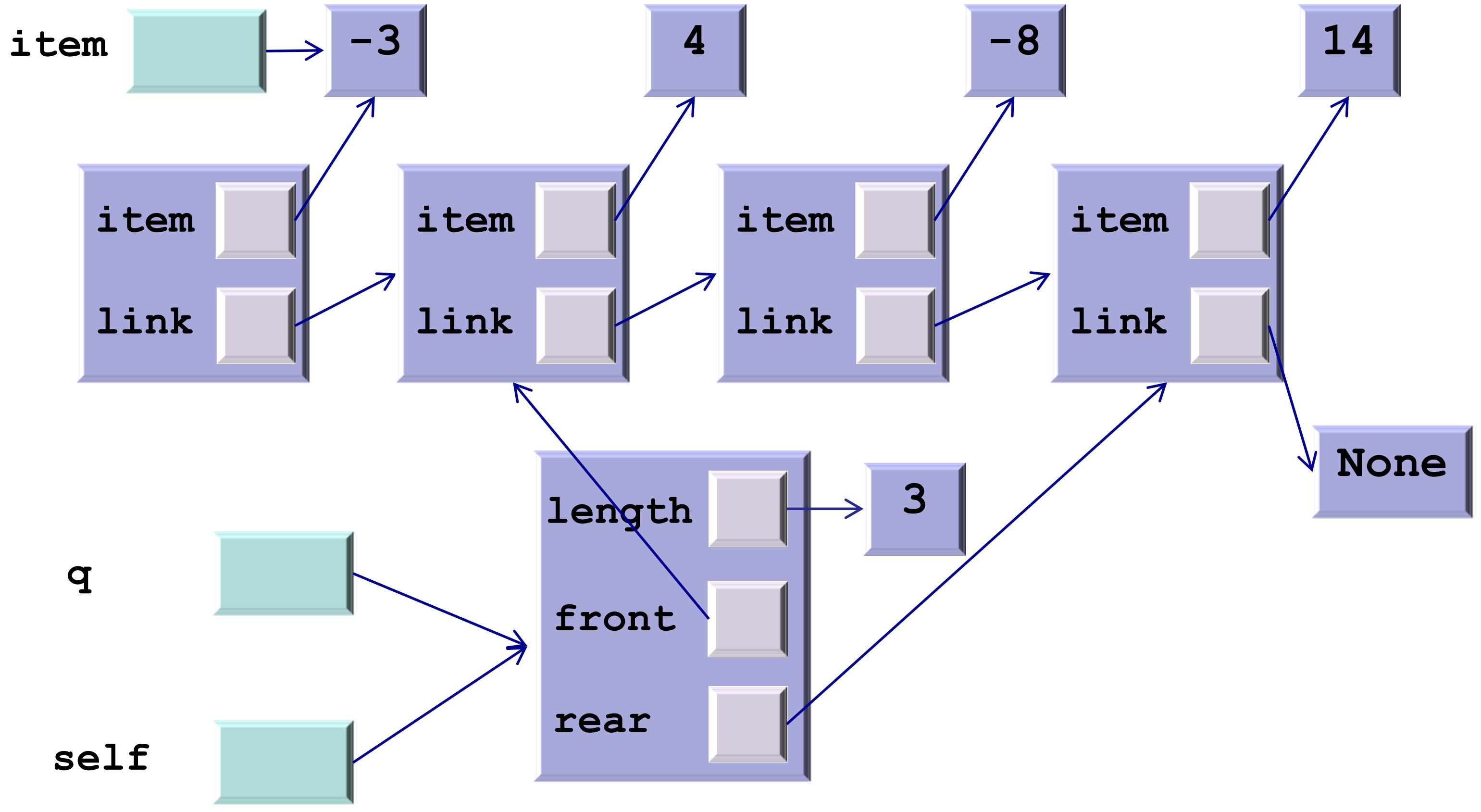

q.serve()

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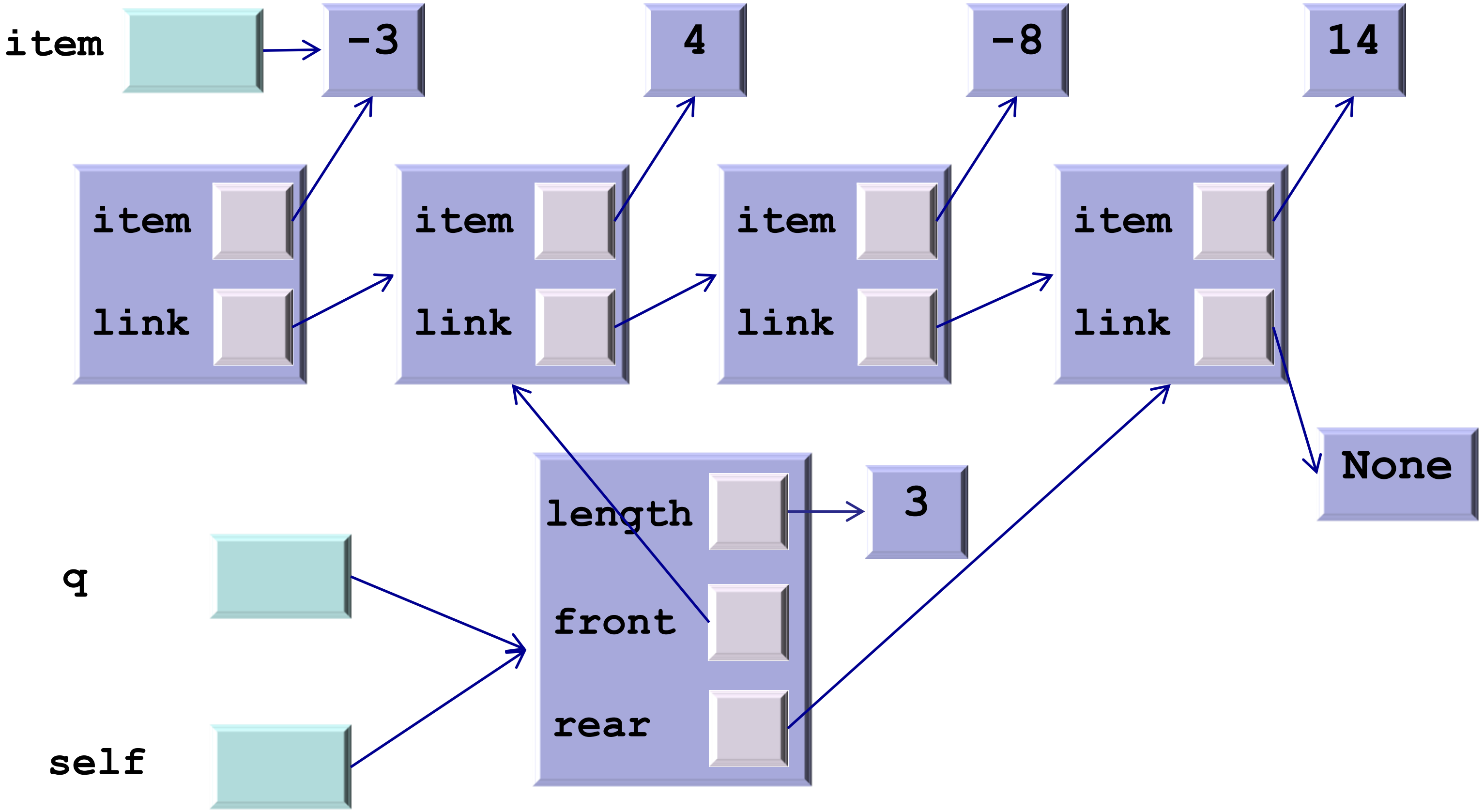

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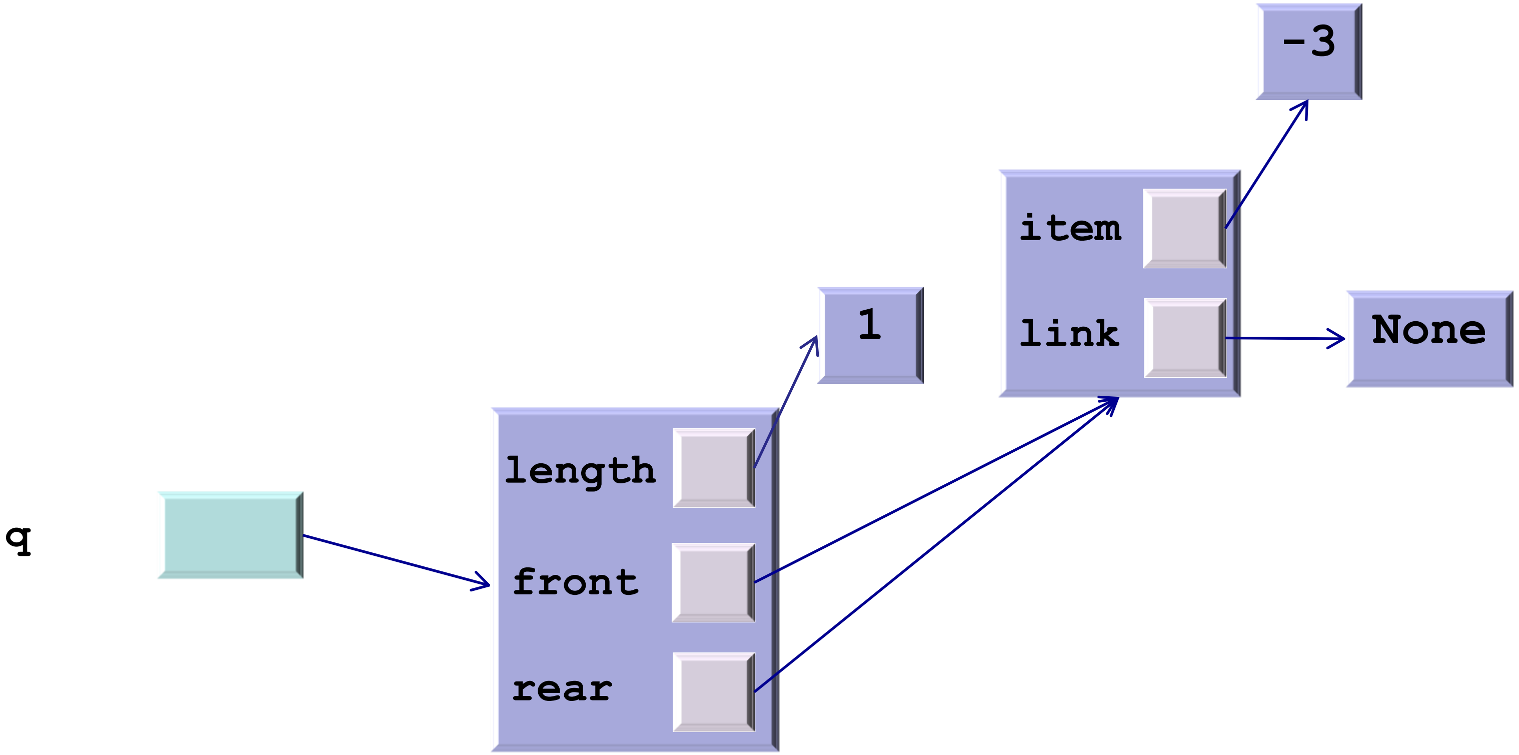

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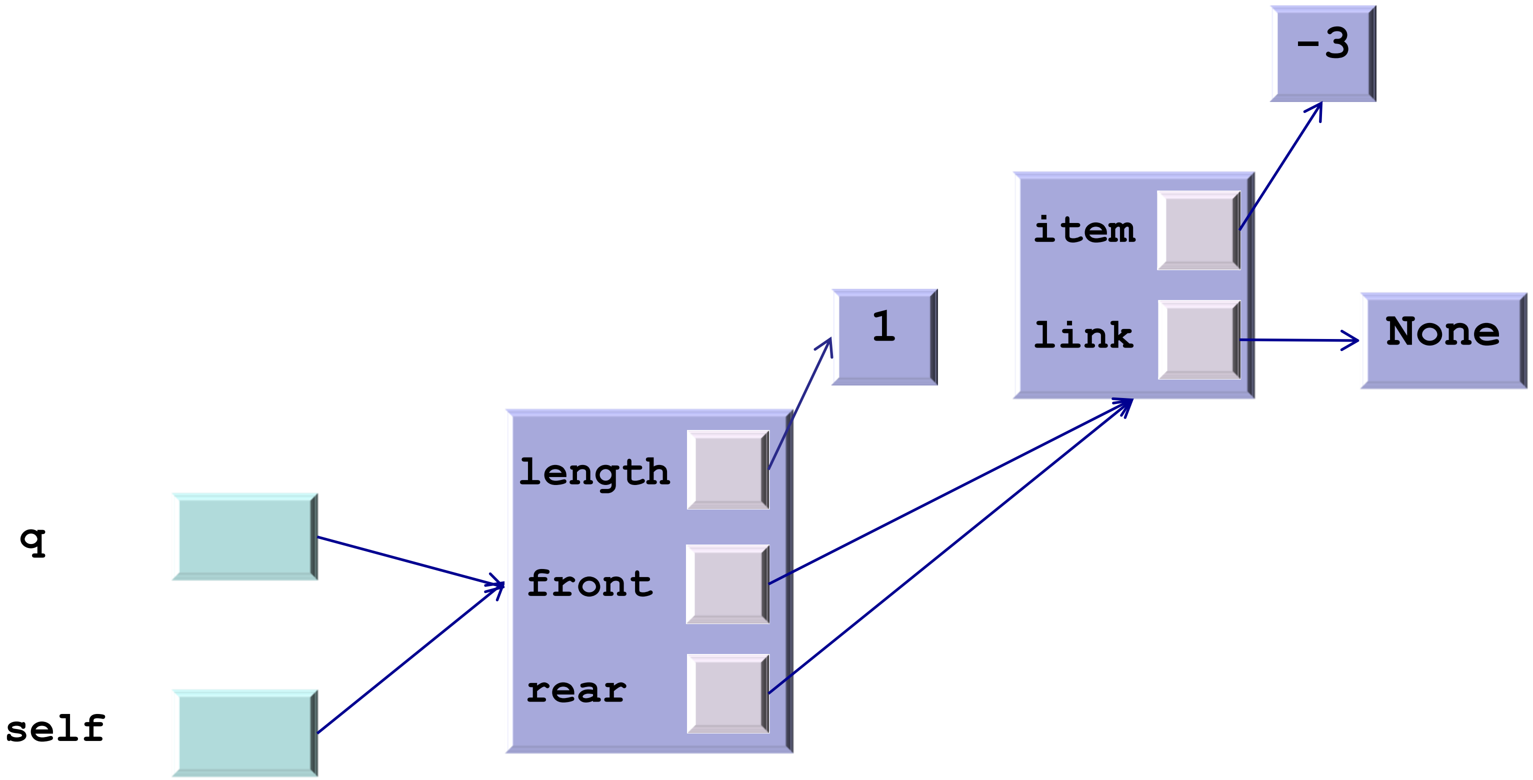

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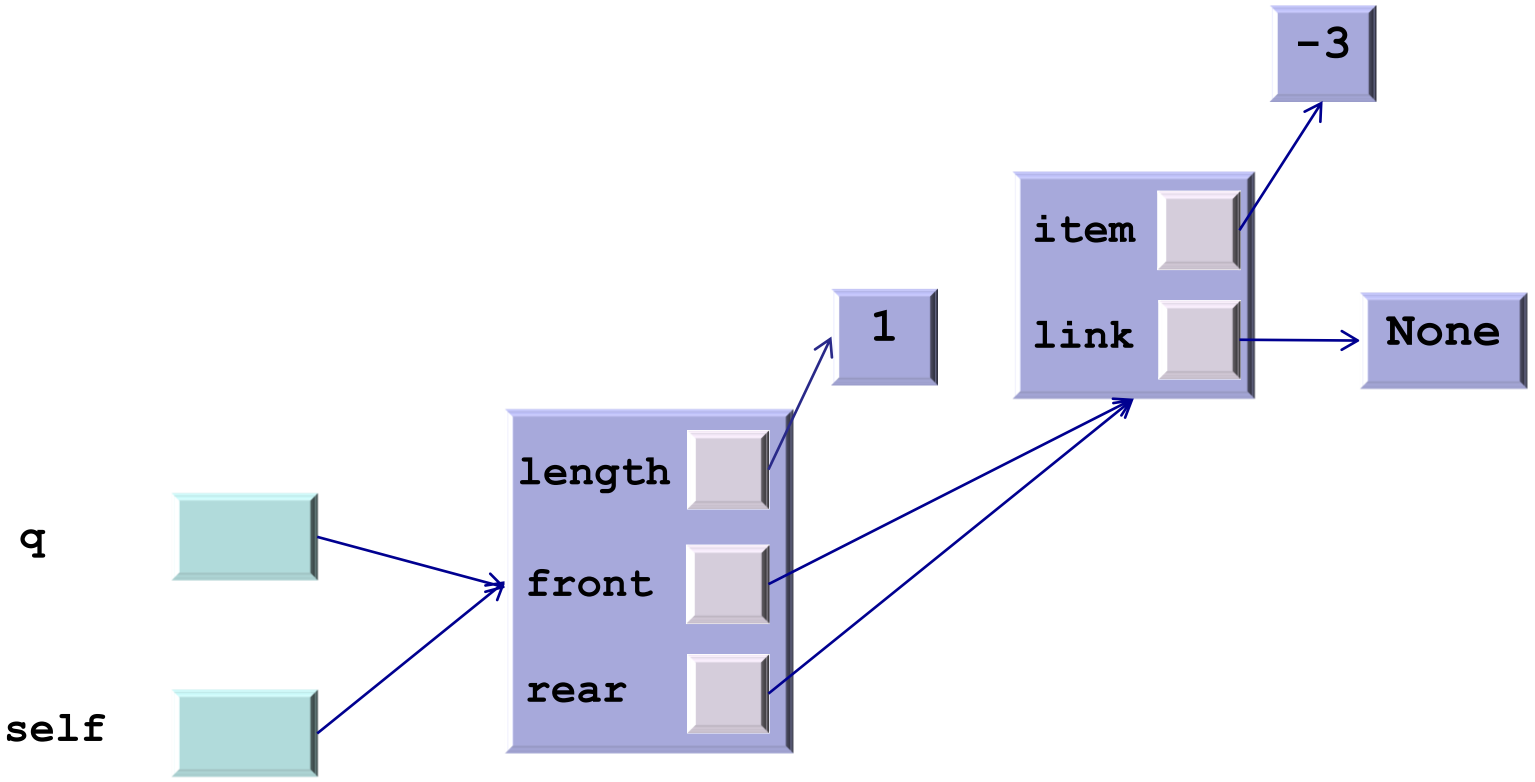

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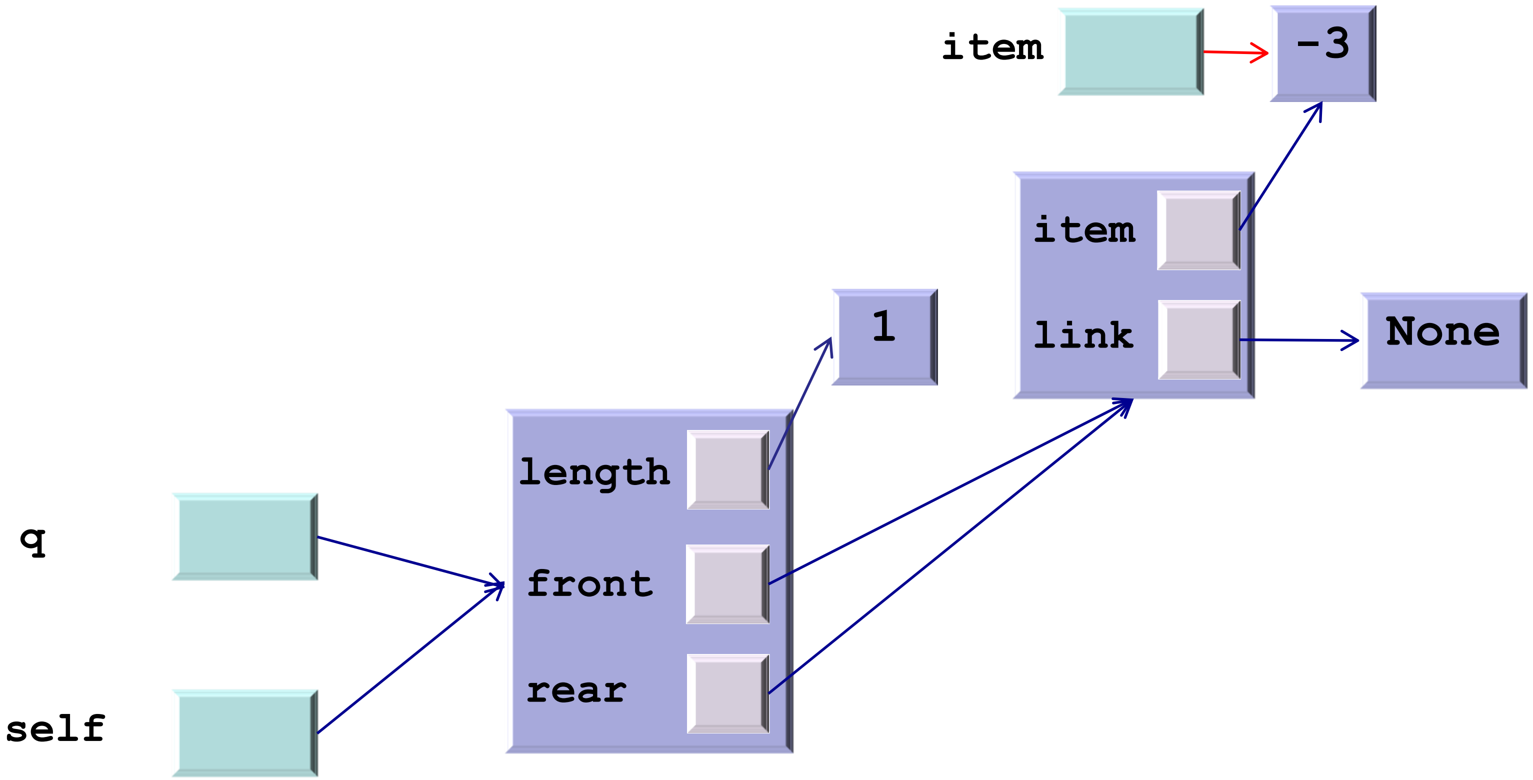

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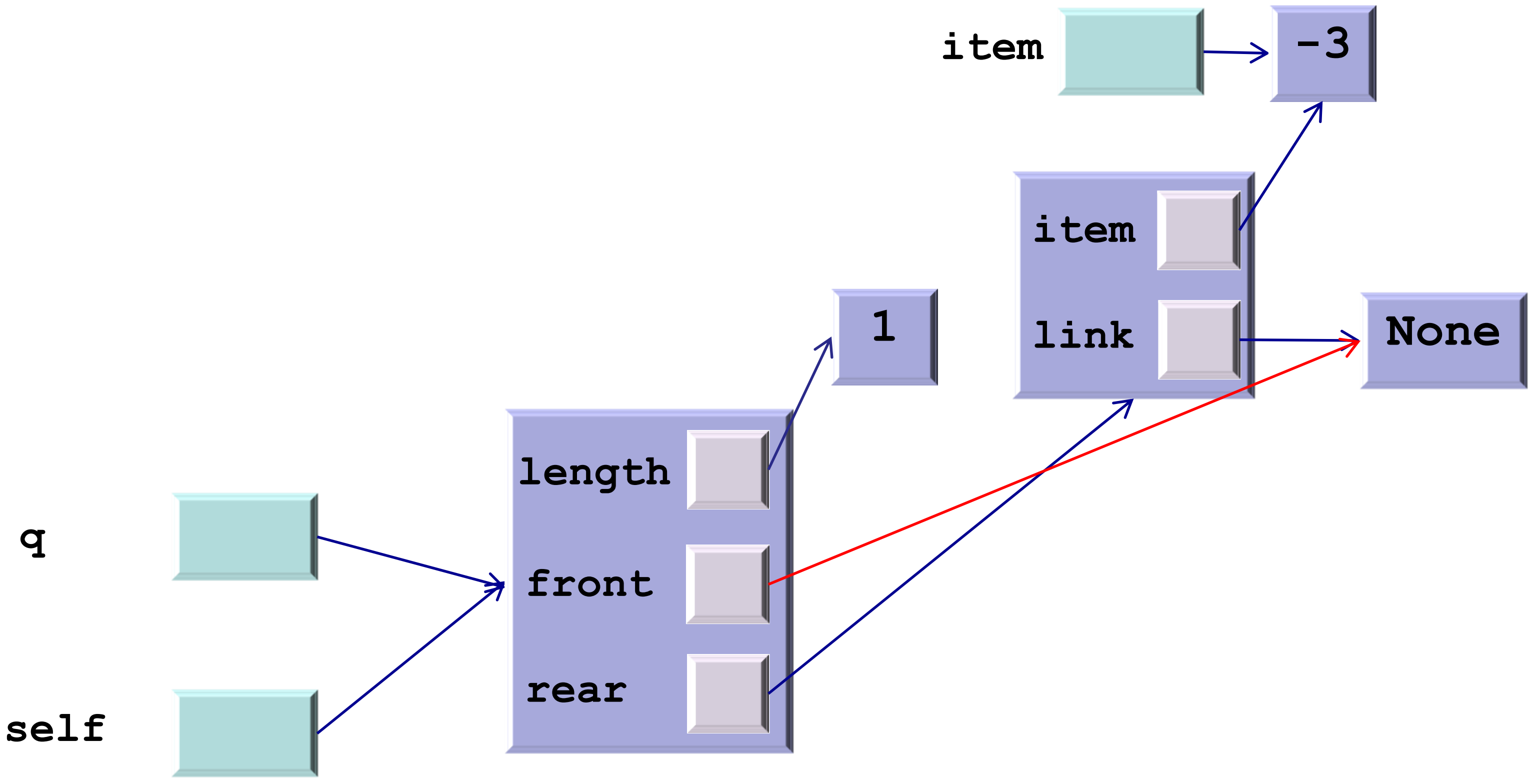

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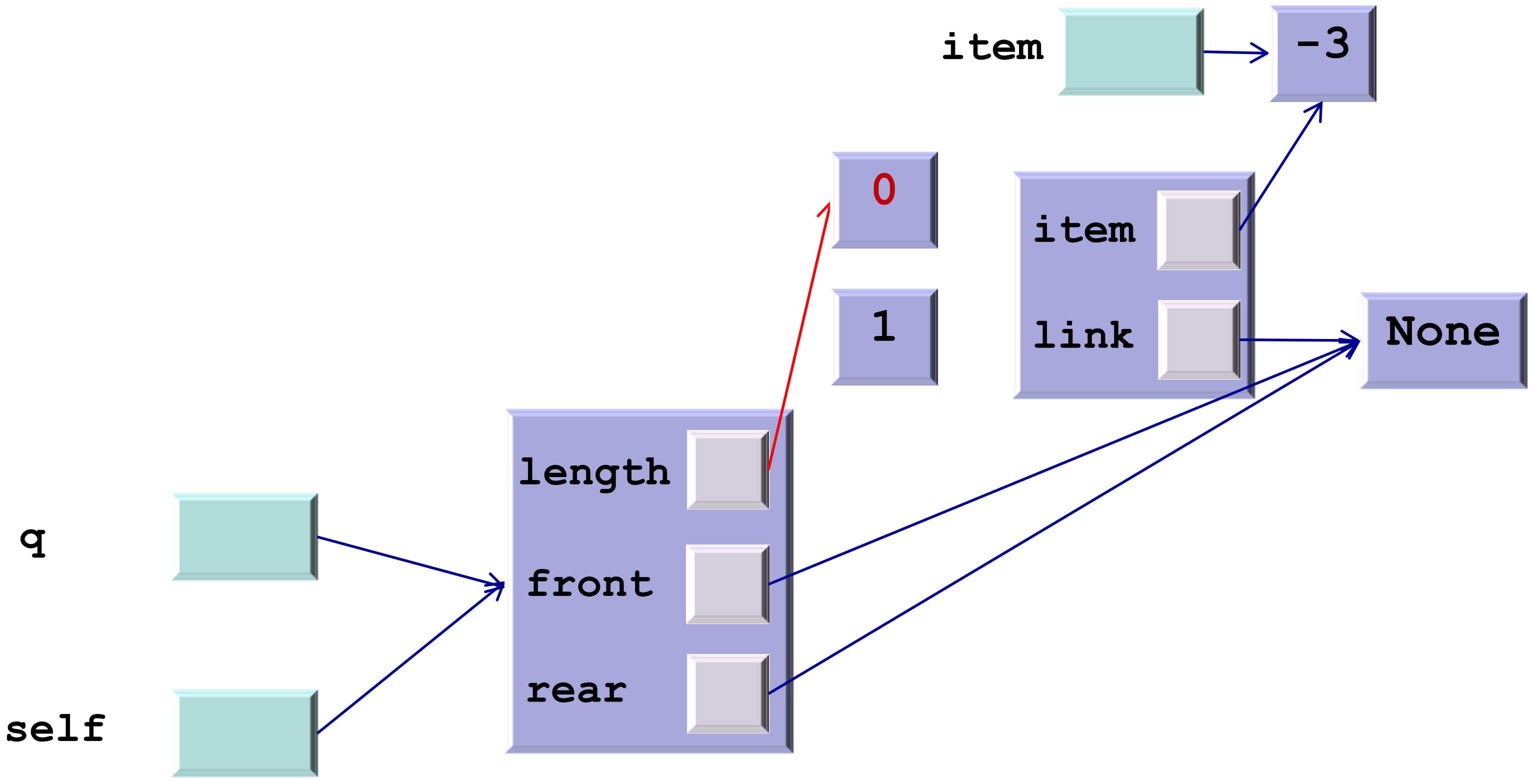

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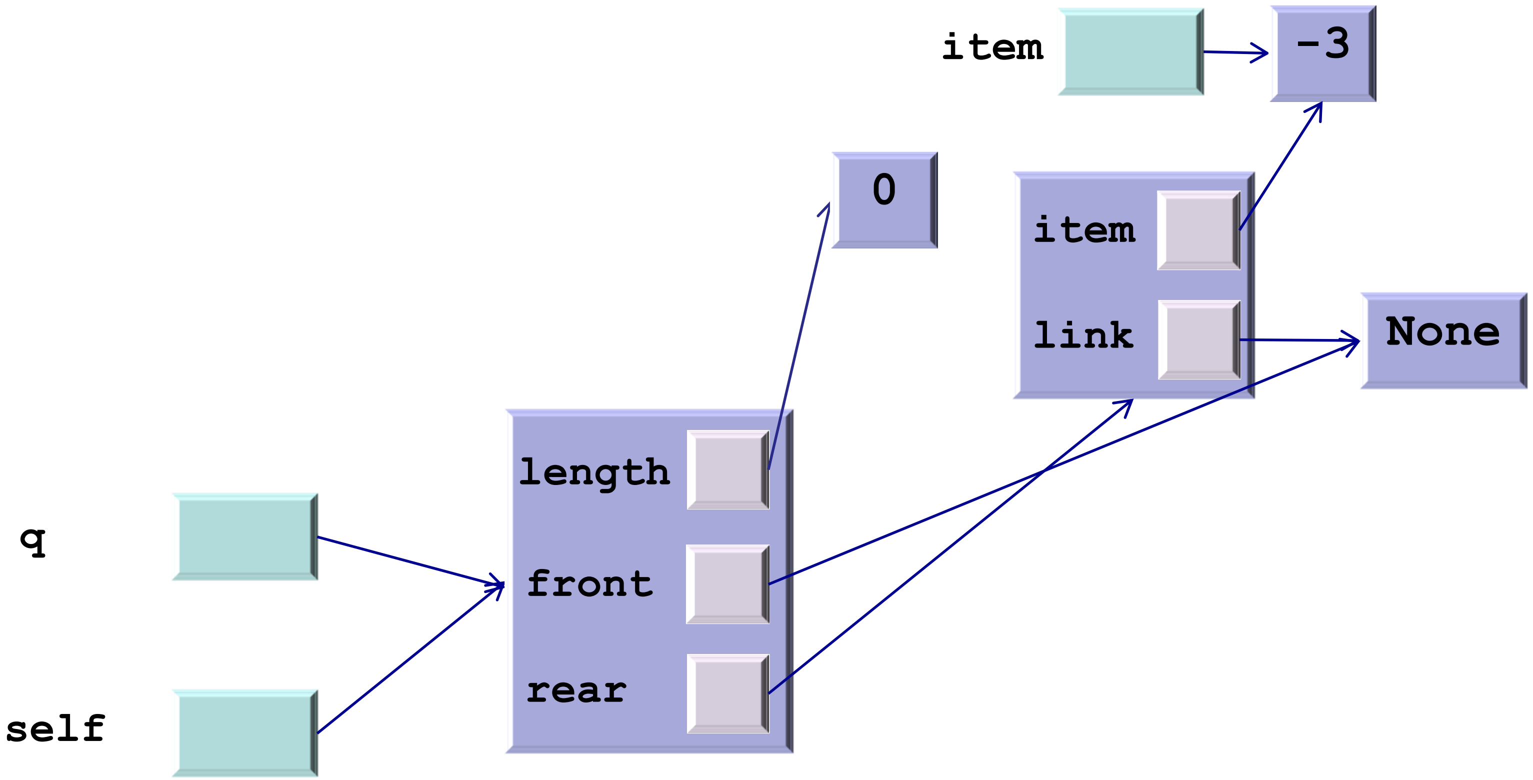

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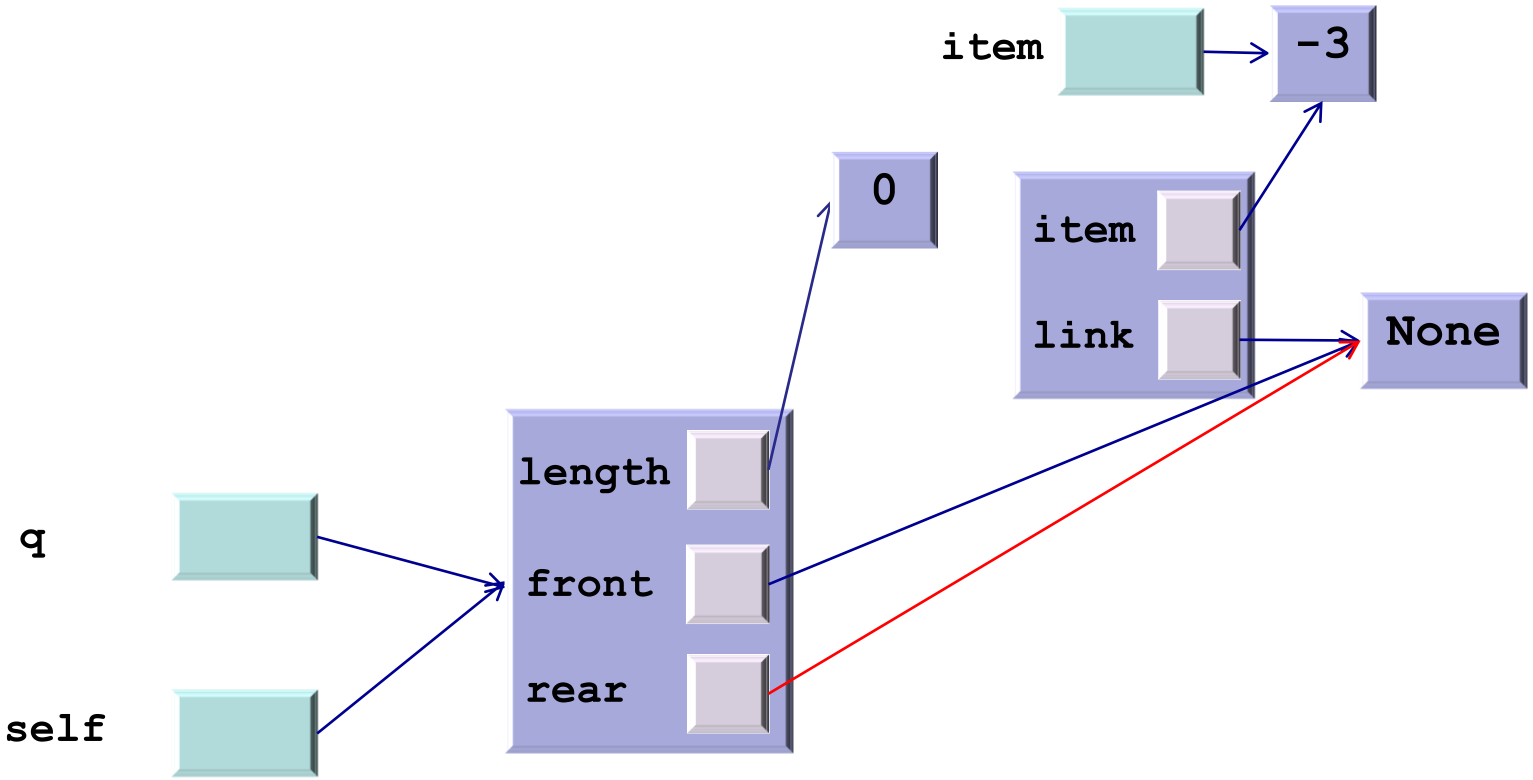

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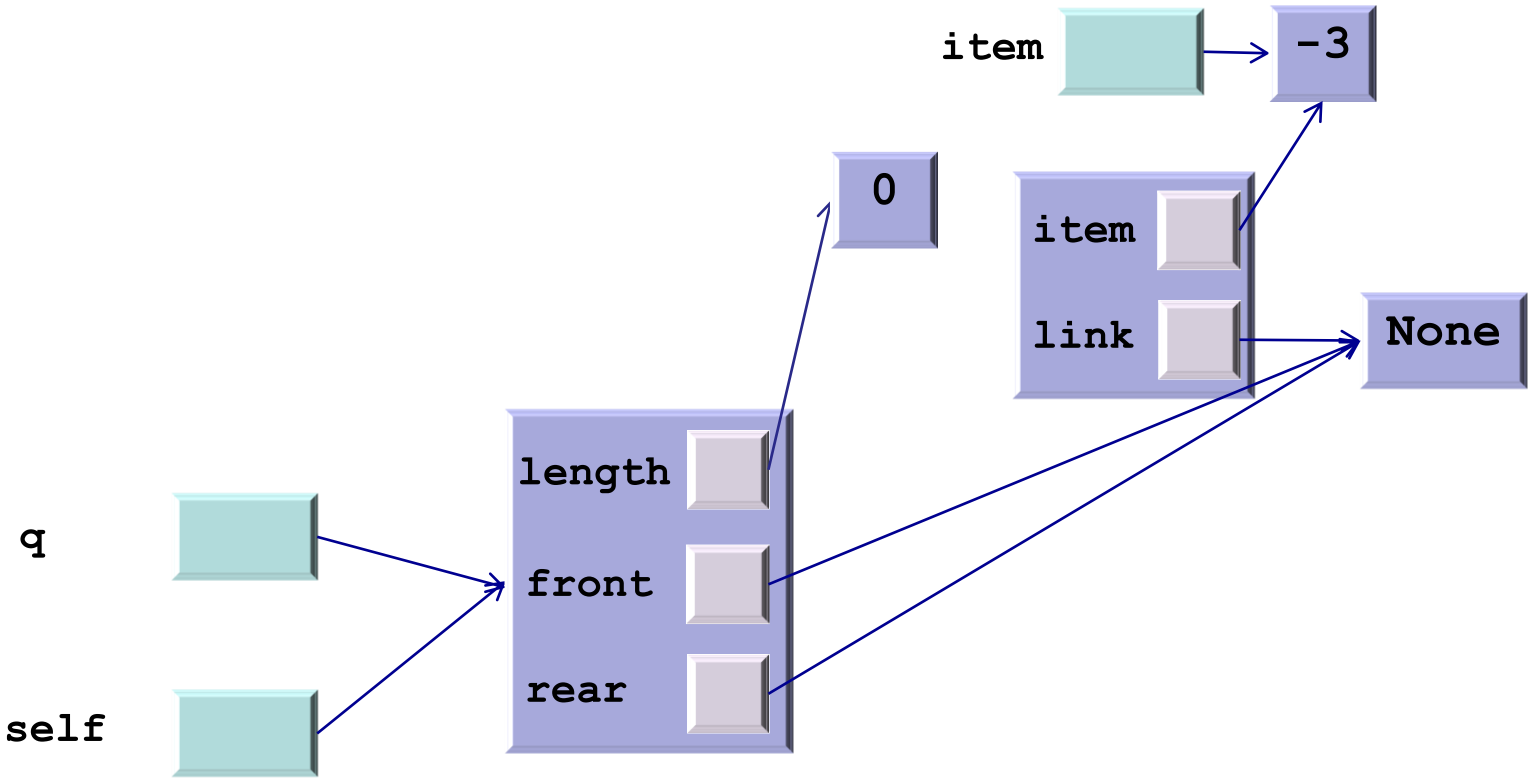

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```

MONASH University

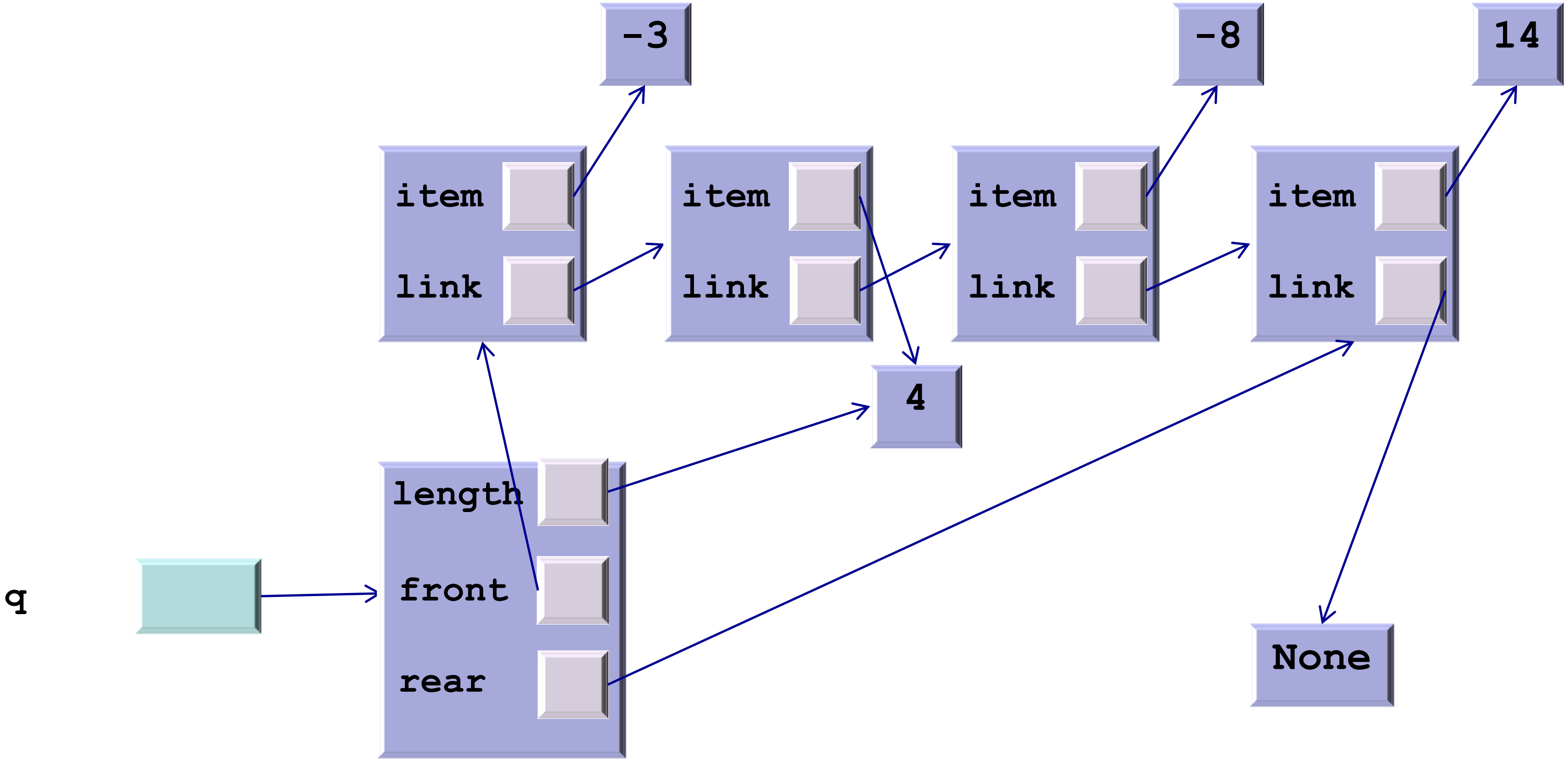
Using LinkQueue

Exercise: add to **LinkQueue** a method that halves the queue by deleting the nodes at index 1, 3, 5, etc

```
def halve(self) -> None:
    current = self.front
    # while at least two elements not traversed in the queue
    while current is not None and current.link is not None:
        if current.link is self.rear: # if even node is last
            self.rear = current # move rear up
        current.link = current.link.link # bypass odd node
        current = current.link # keep on traversing – next two
        length -= 1
```

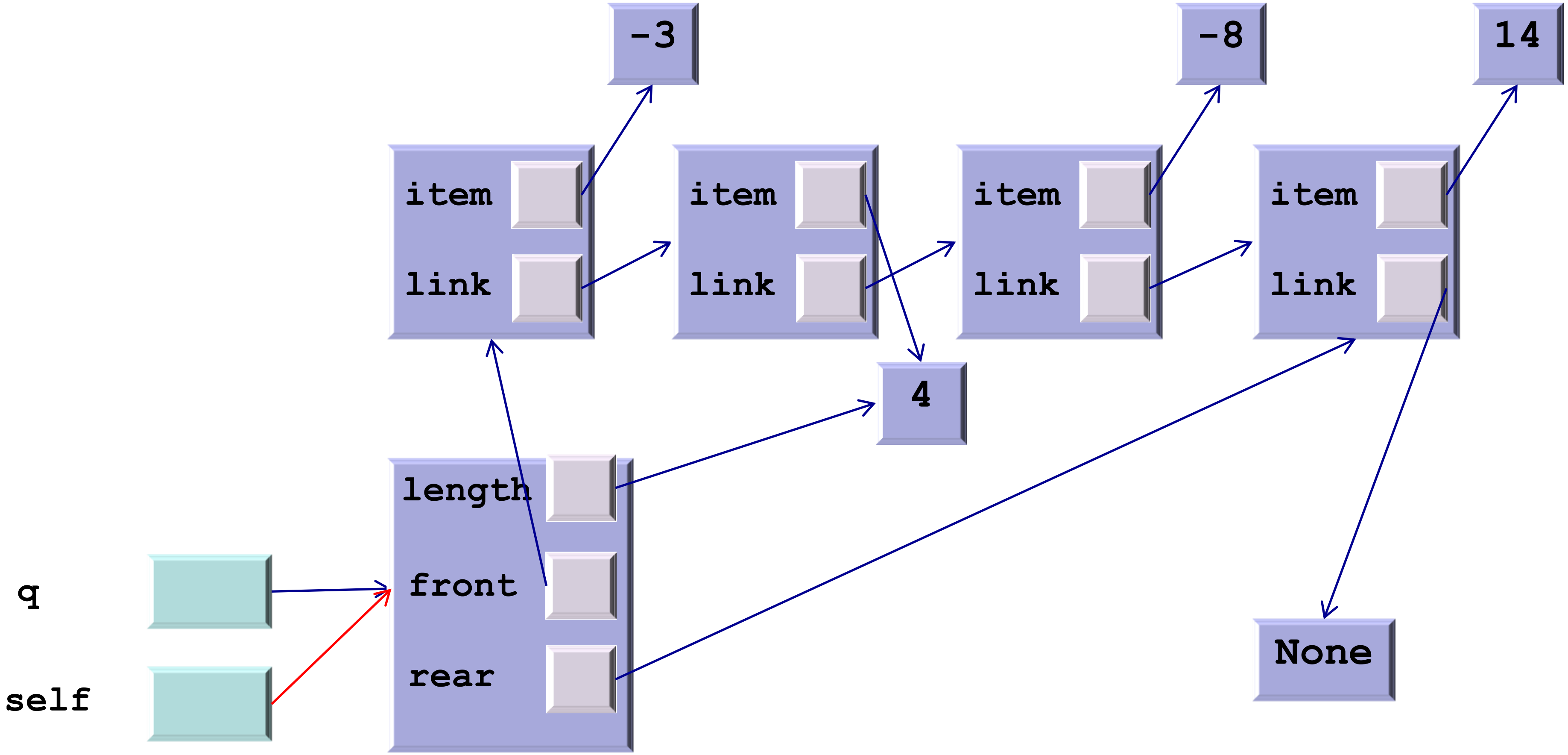
```
def halve(self) -> None:
    current = self.front
    while current is not None and current.link is not None:
        if current.link is self.rear:
             self.rear = current
        current.link = current.link.link
        current = current.link
        length -= 1
```

q.halve()



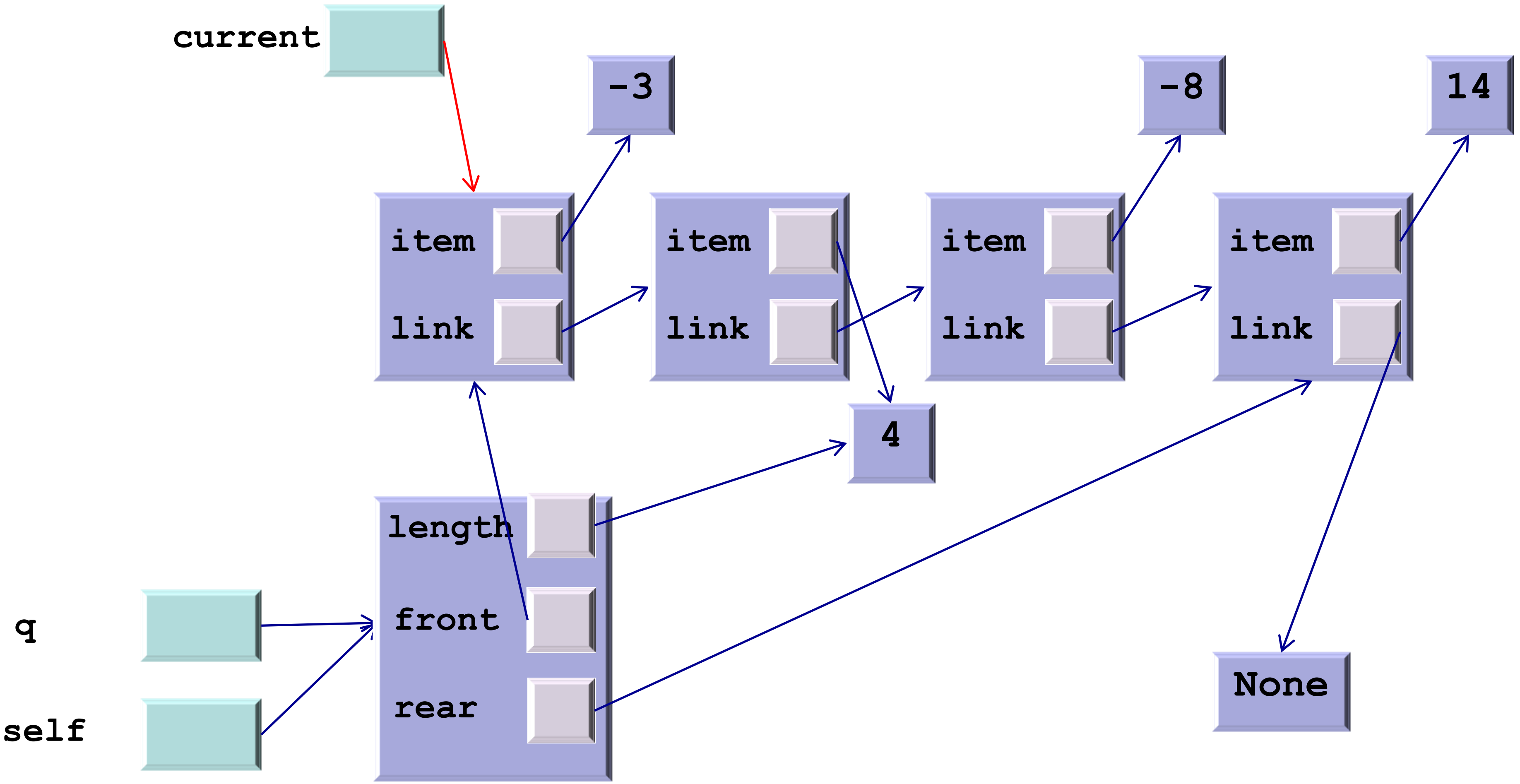
```
def halve(self) -> None:
    current = self.front
    while current is not None and current.link is not None:
        if current.link is self.rear:
            self.rear = current
        current.link = current.link.link
        current = current.link
        length -= 1
```

q.halve()



```
def halve(self) -> None:
    current = self.front
    while current is not None and current.link is not None:
        if current.link is self.rear:
            self.rear = current
        current.link = current.link.link
        current = current.link
        length -= 1
```

q.halve()



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        current = current.link
        length -= 1
```
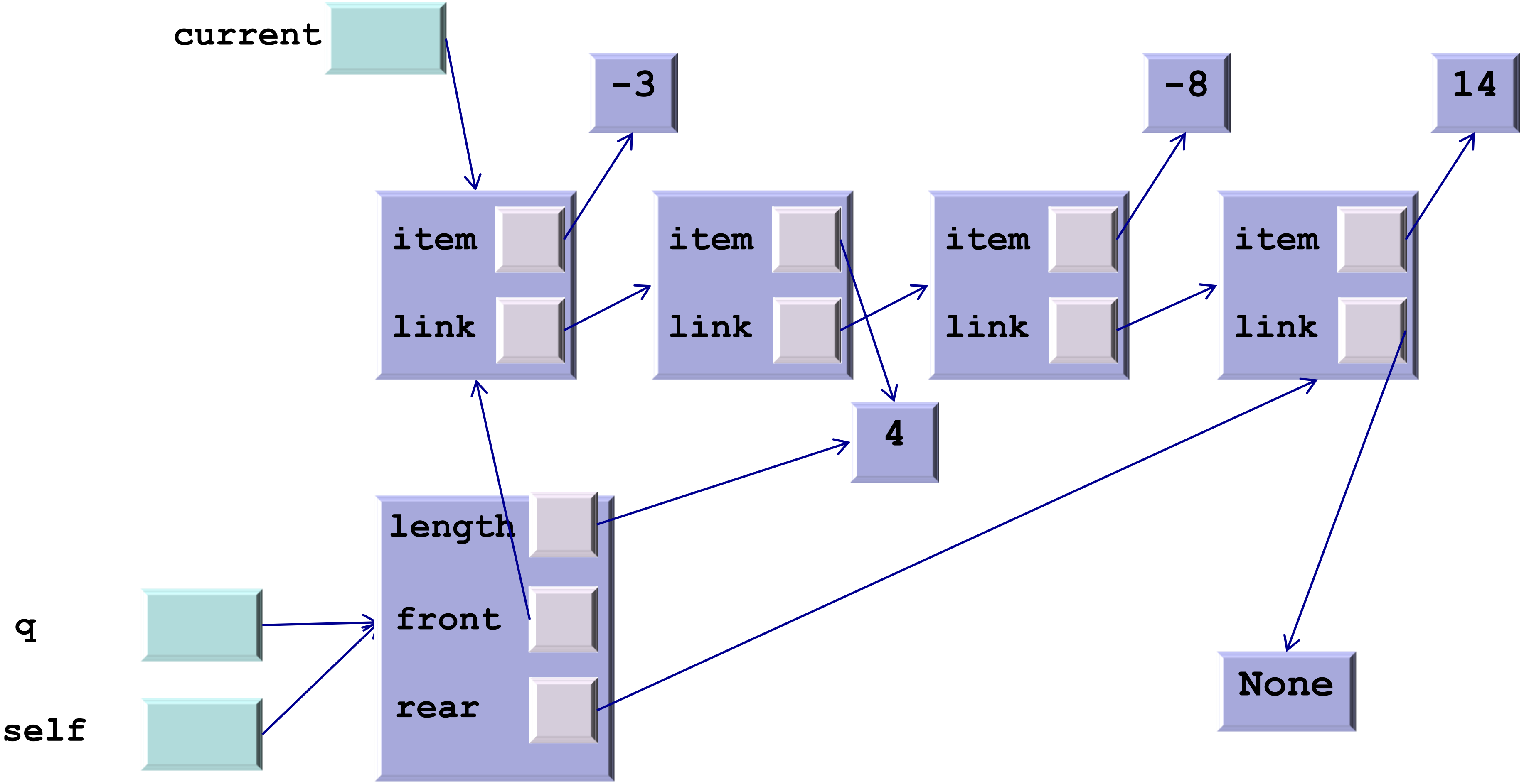

q.halve()



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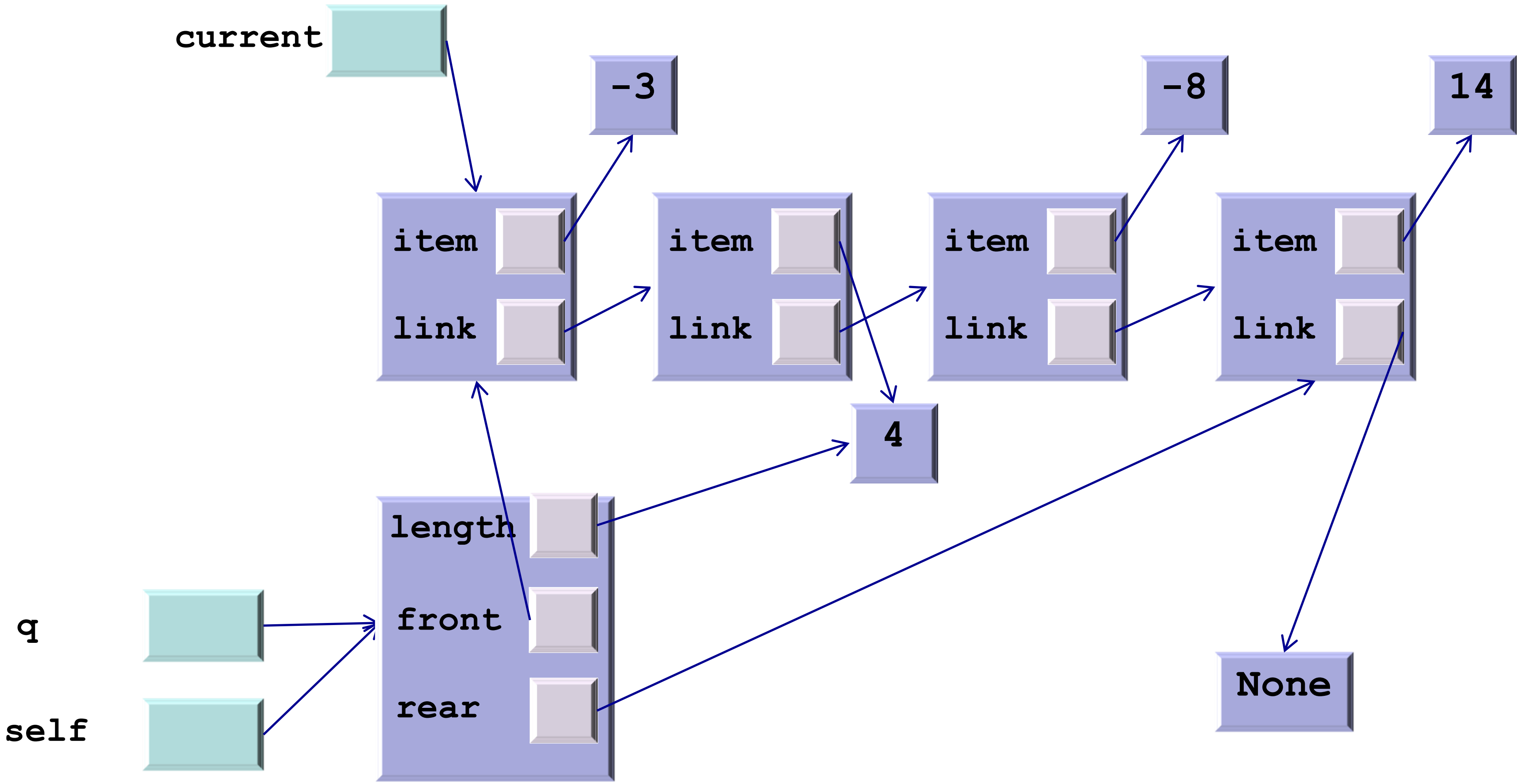
        length -= 1
```

q.halve()



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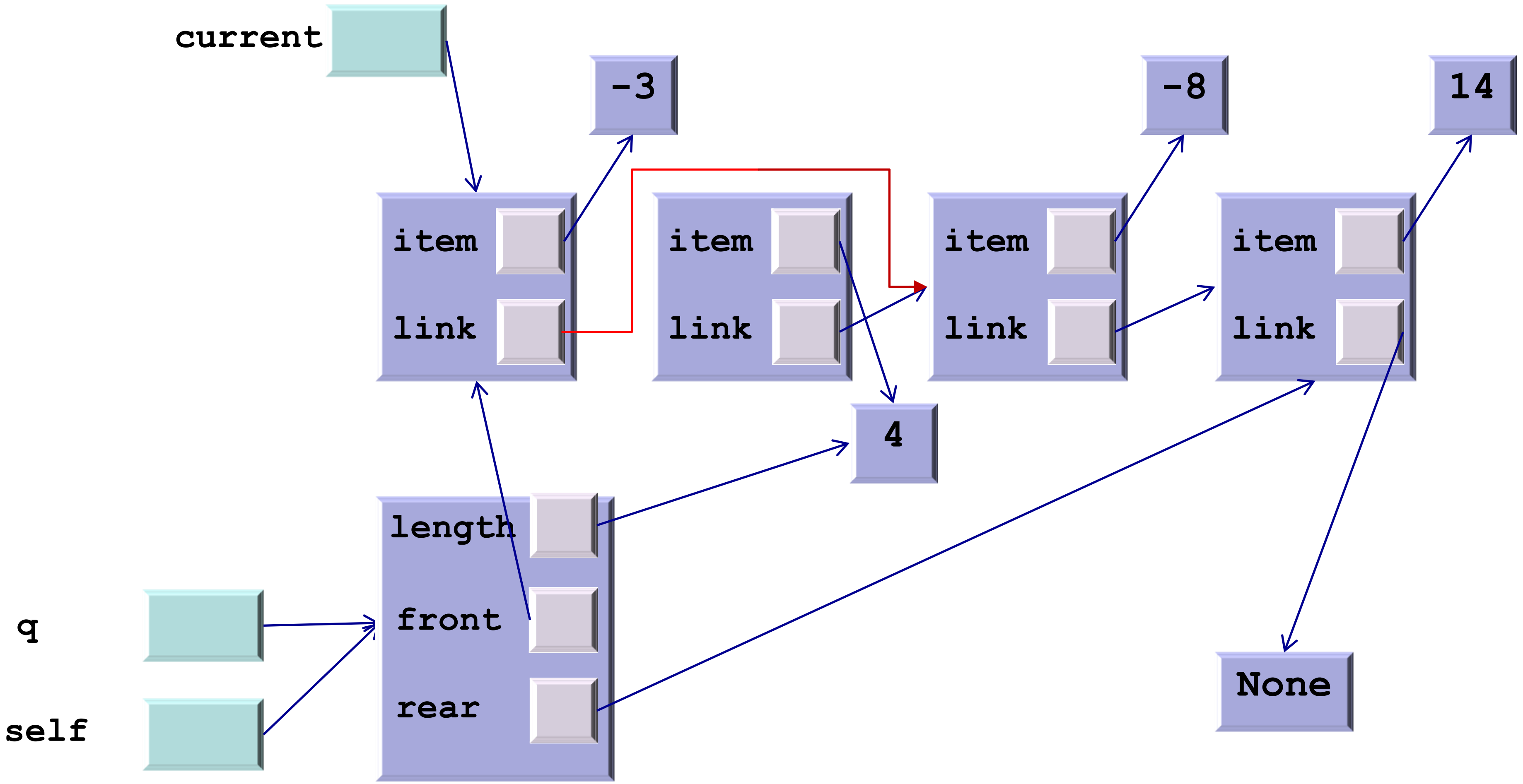
q.halve()



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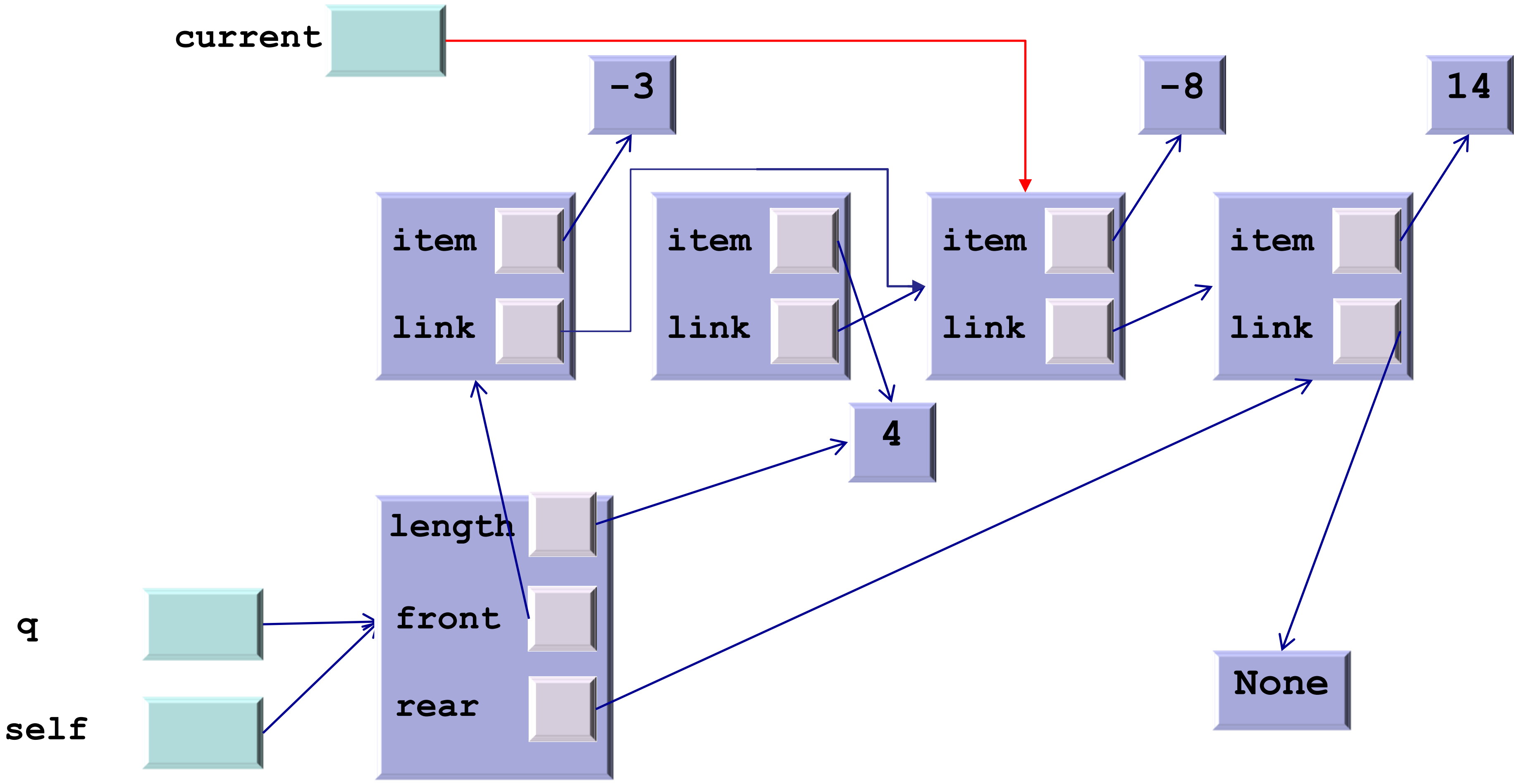
q.halve()



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```
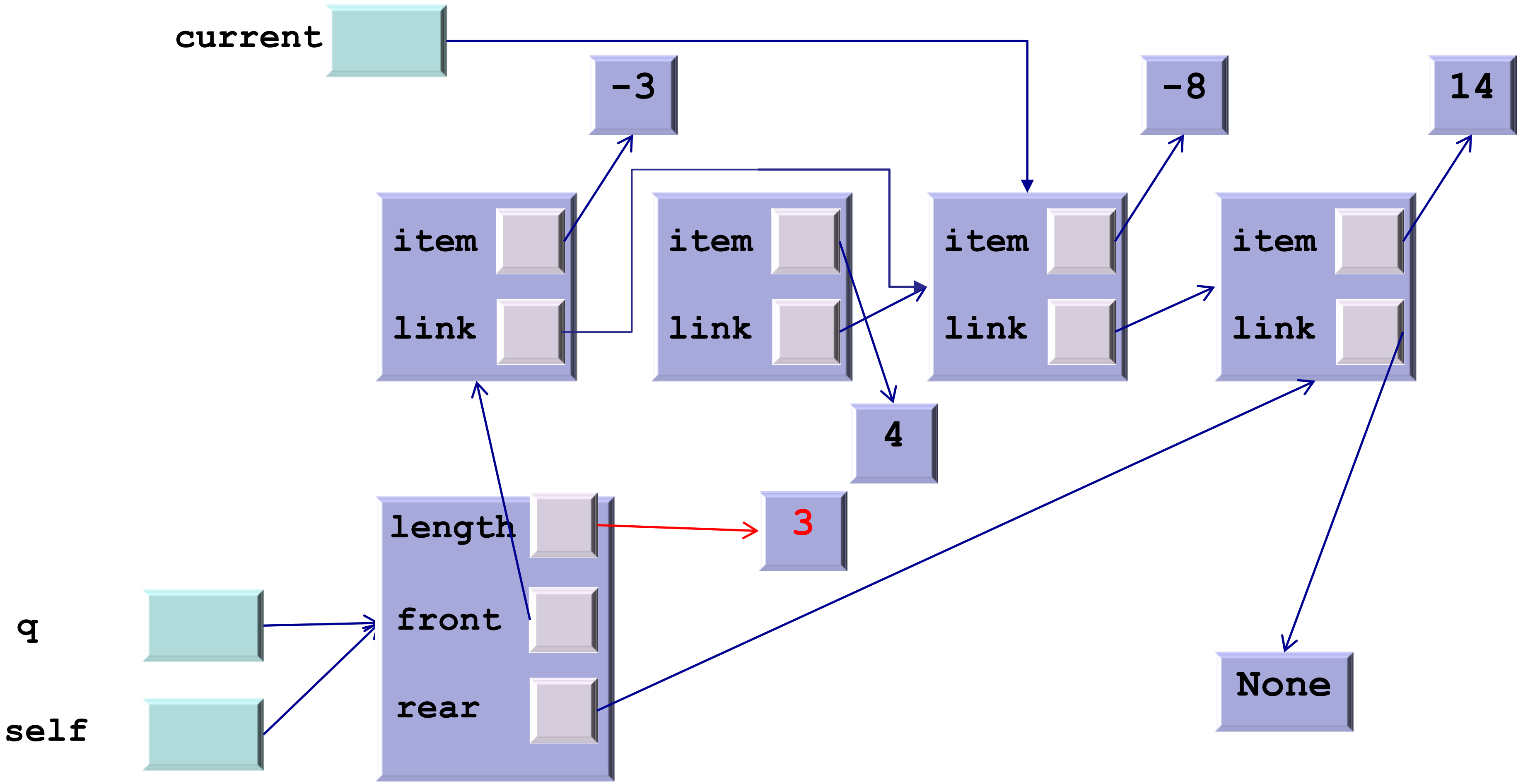
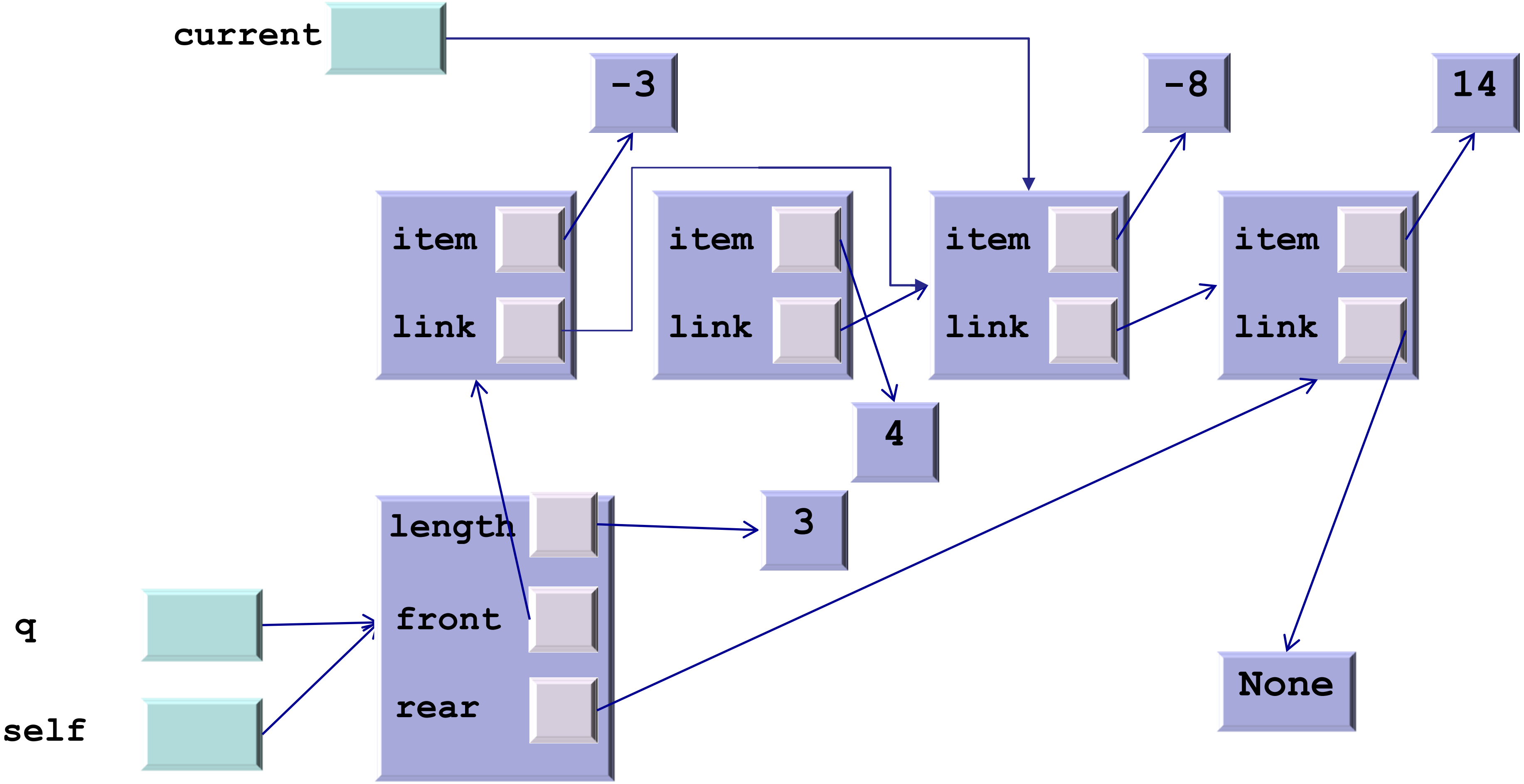

q.halve()



```
def halve(self) -> None:
    current = self.front
    while current is not None and current.link is not None:
        if current.link is self.rear:
            self.rear = current
        current.link = current.link.link
        current = current.link
        length -= 1
```

q.halve()



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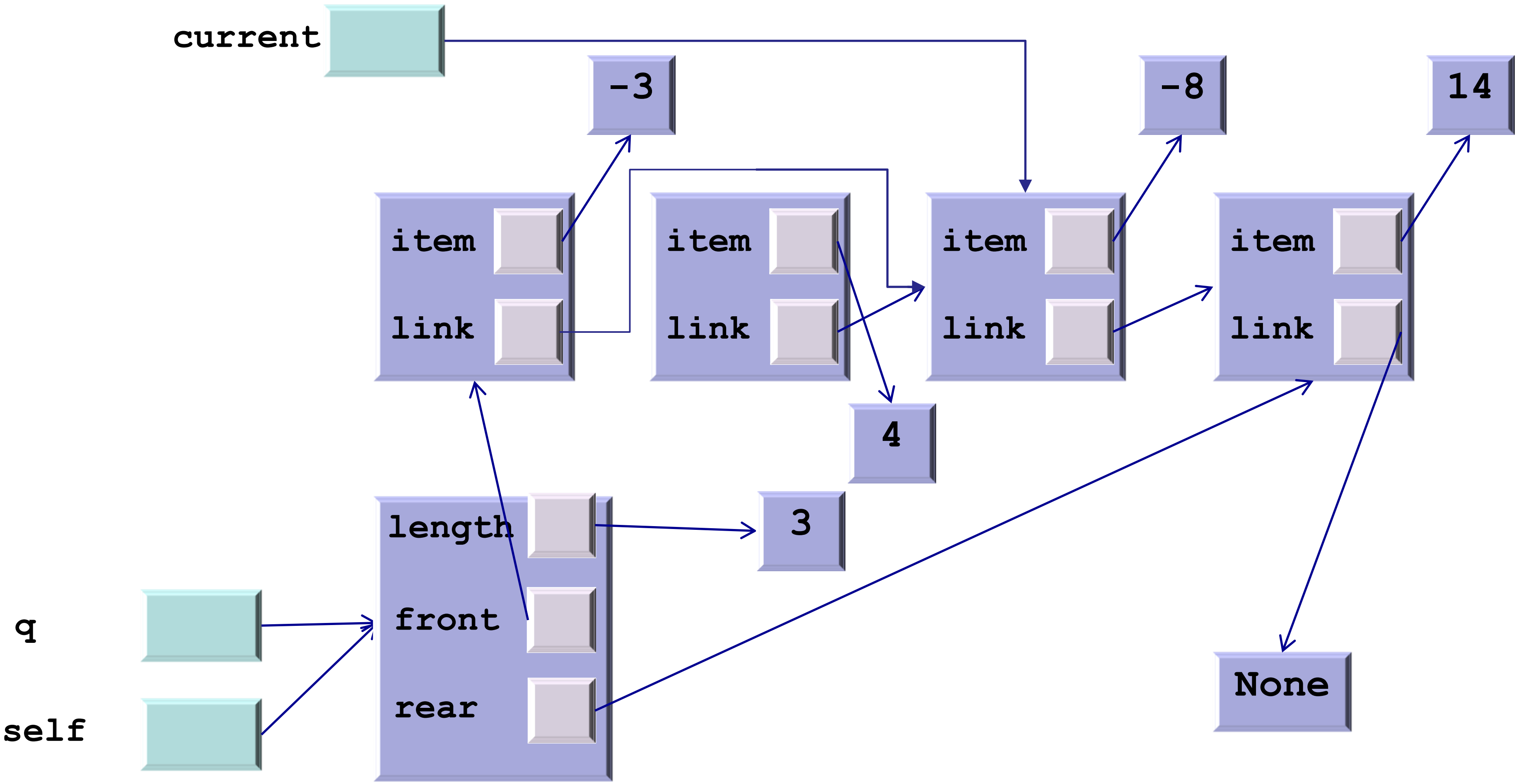

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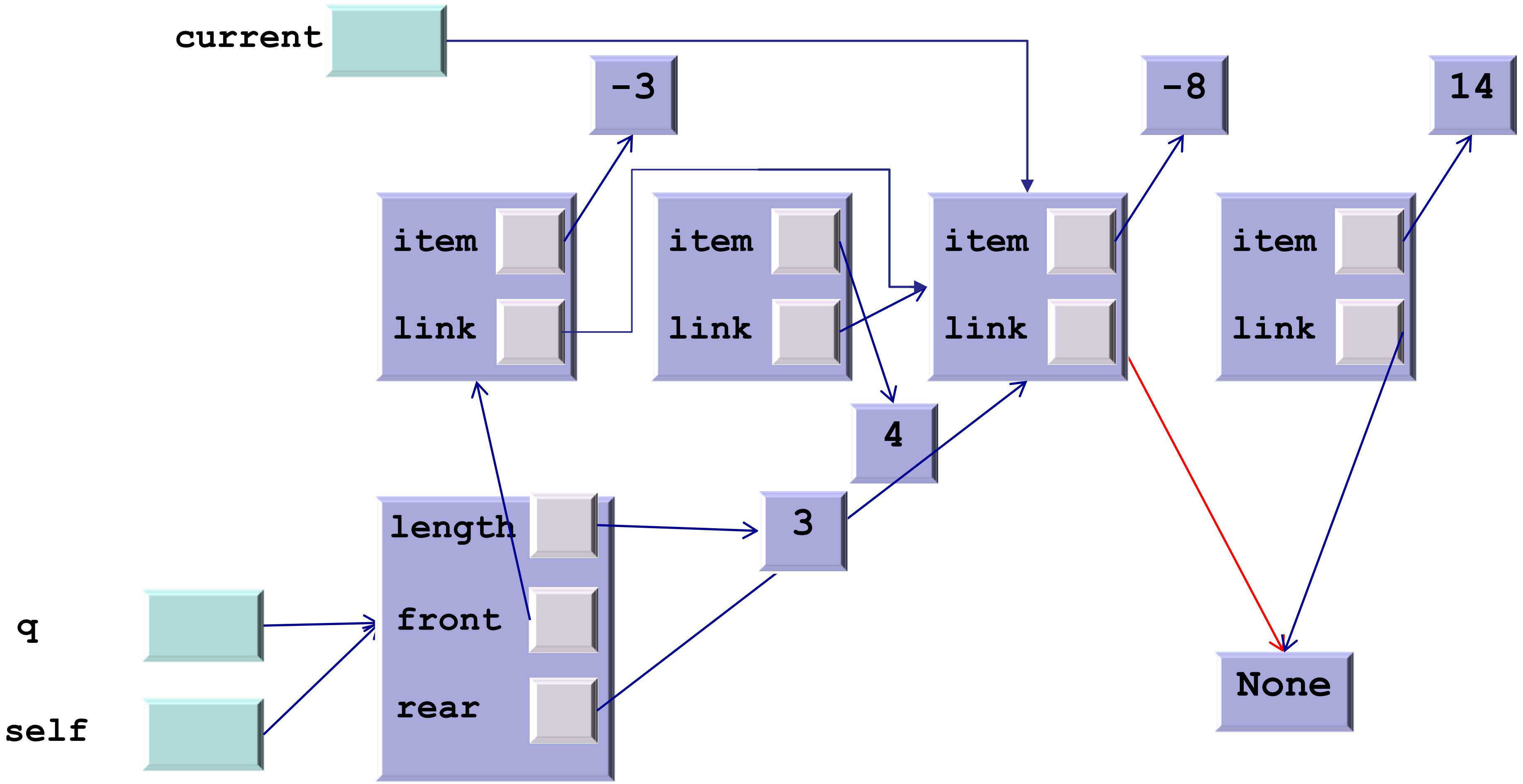

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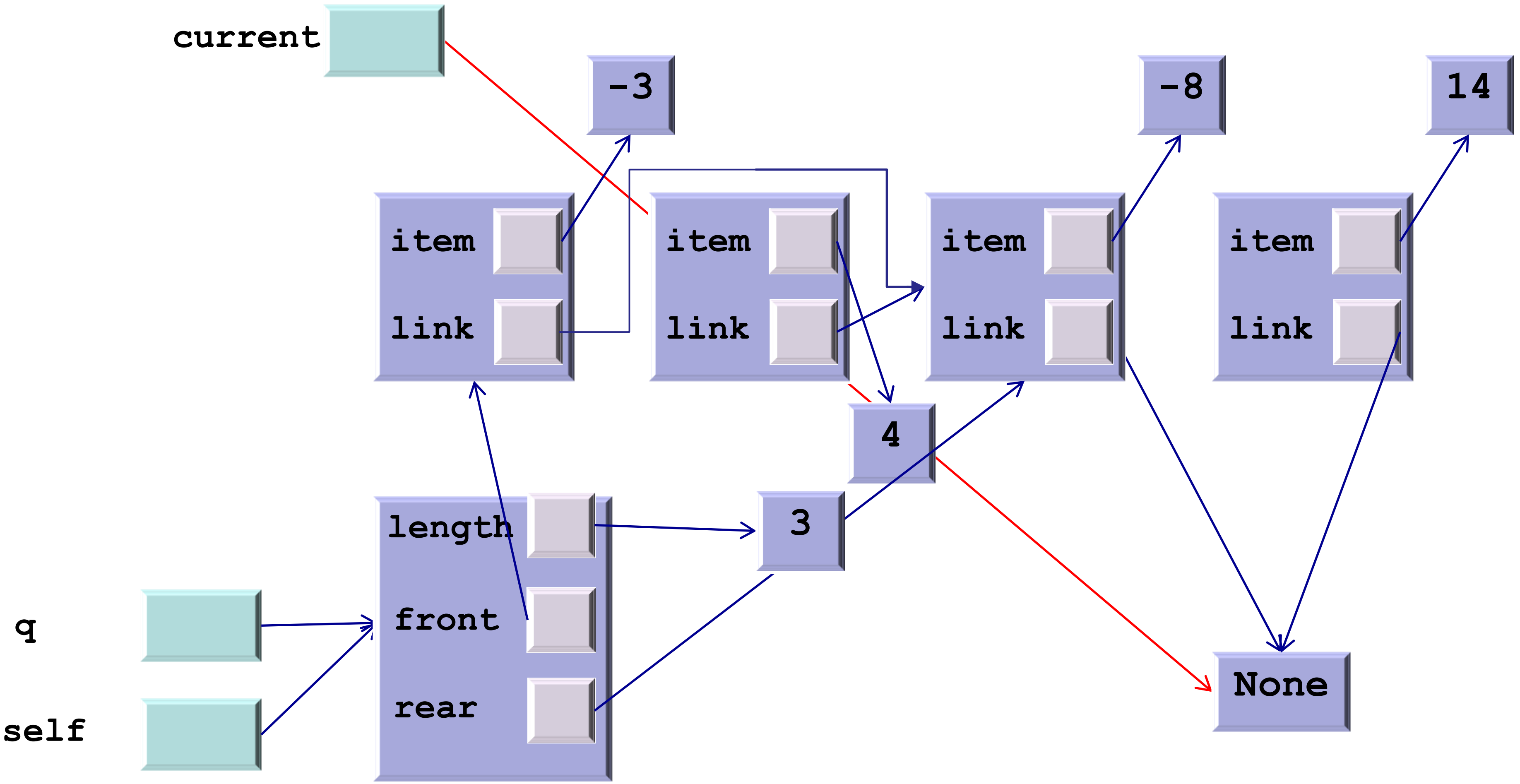

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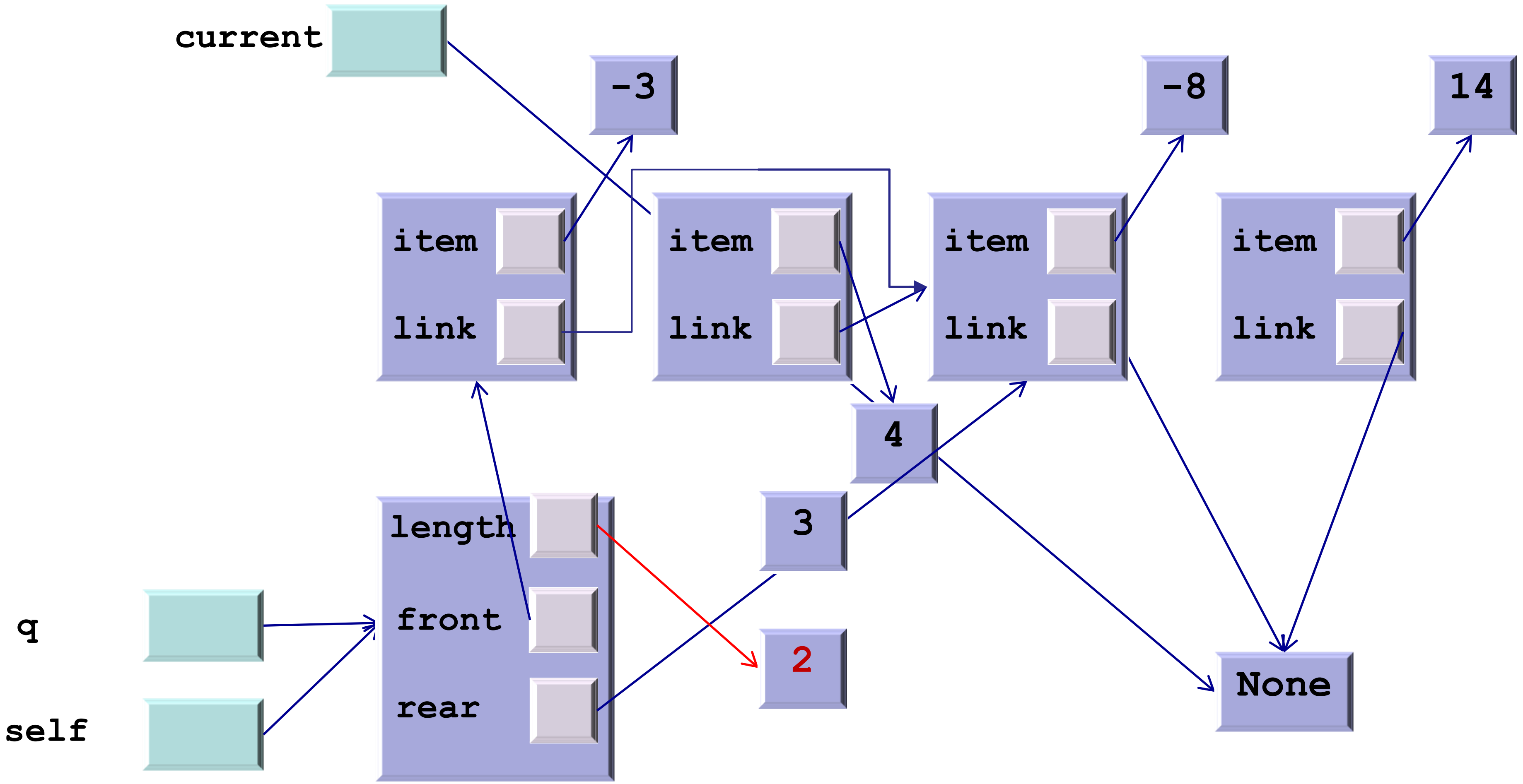

Remember: Abstract Data Types

- **Any data type provides:**
  - Storage for a collection of data items
  - A set of operations to interact with the data
- **An abstract one does not provide any info on how:**
  - The storage is organised
  - The operations are implemented
- **Users can only interact with the data through the provided operations**

Separates the WHAT from the HOW
and ignores the HOW

Abstract Data Types (cont)

- **Example: a Stack ADT has operations:**
  - push, pop, is_empty, reset, etc
  - Implementation? Could be array, could be linked, or something else, a user does not know
- **As a user I just need to know its operations**
- **Do not confuse Data Type with Data Structure**
  - Data Structure: particular way in which the data is organised (structured) in memory
  - The way a given Data Type is implemented

Abstract Data Types: pros and cons

- **Main advantage: maintenance**
  - Changing the implementation of the ADT does not mean changing the user's code

- **Main disadvantage: efficiency**
  - Having access to the implementation (ADT as an inner class) might allow good programmers to improve time/space performance

Abstract Data Types: advice

- **Always design your data types abstractly**
  - Use the class methods if you can (even as god!)
- **Late modifications to its implementation will not affect the rest of your code**
- **Readability is also improved: use meaningful names for operations**
- **Correctness easier to verify: after proper testing to all methods**

Summary

- **We now understand how to use linked data structures in implementing**
  - Stacks
  - Queues
- **We are able to:**
  - Implement, use and modify linked stacks and linked queues
  - Decide when it is appropriate to use them (rather than arrays)