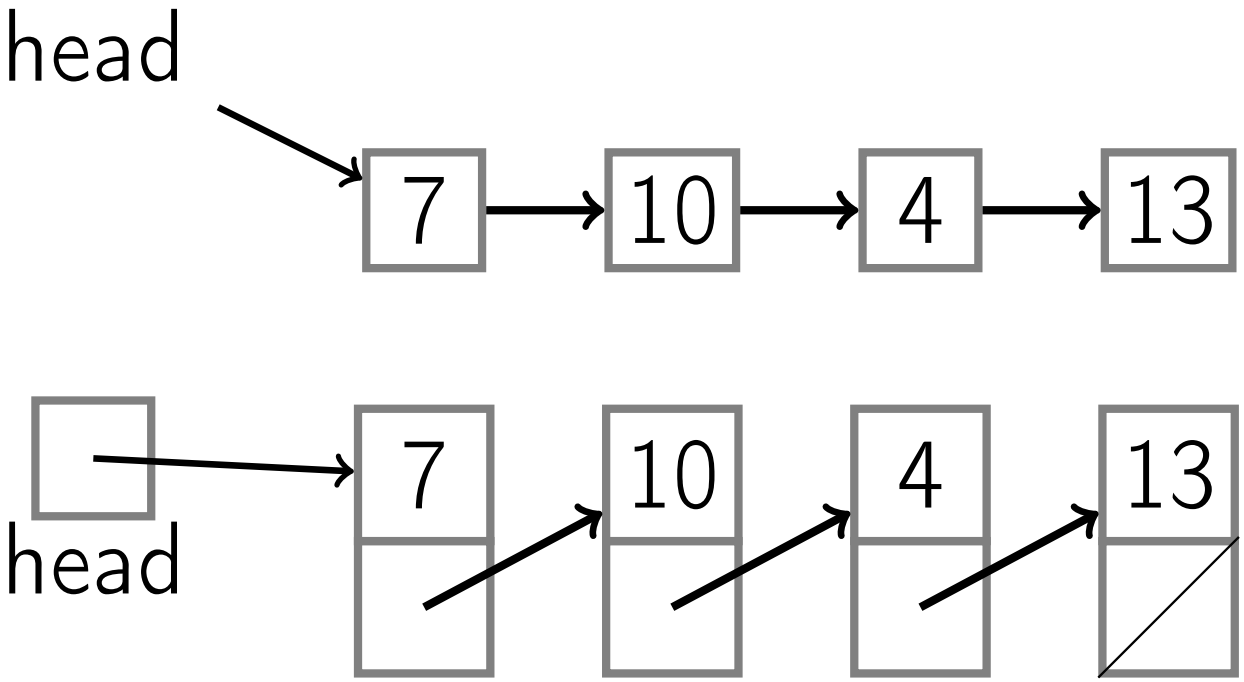
Singly-Linked List



Node contains:

- `key`
- `next` pointer

List API

`PushFront(Key)` add to front

List API

`PushFront(Key)`	add to front
`Key TopFront()`	return front item

List API

`PushFront(Key)`	add to front
`Key TopFront()`	return front item
`PopFront()`	remove front item

List API

`PushFront(Key)`	add to front
`Key TopFront()`	return front item
`PopFront()`	remove front item
`PushBack(Key)`	add to back
	also known as `Append`

List API

`PushFront(Key)`	add to front
`Key TopFront()`	return front item
`PopFront()`	remove front item
`PushBack(Key)`	add to back
`Key TopBack()`	return back item

List API

`PushFront(Key)`	add to front
`Key TopFront()`	return front item
`PopFront()`	remove front item
`PushBack(Key)`	add to back
`Key TopBack()`	return back item
`PopBack()`	remove back item

List API

`PushFront(Key)`	add to front
`Key TopFront()`	return front item
`PopFront()`	remove front item
`PushBack(Key)`	add to back
`Key TopBack()`	return back item
`PopBack()`	remove back item
`Boolean Find(Key)`	is key in list?

List API

`PushFront(Key)`	add to front
`Key TopFront()`	return front item
`PopFront()`	remove front item
`PushBack(Key)`	add to back
`Key TopBack()`	return back item
`PopBack()`	remove back item
`Boolean Find(Key)`	is key in list?
`Erase(Key)`	remove key from list

List API

`PushFront(Key)`	add to front
`Key TopFront()`	return front item
`PopFront()`	remove front item
`PushBack(Key)`	add to back
`Key TopBack()`	return back item
`PopBack()`	remove back item
`Boolean Find(Key)`	is key in list?
`Erase(Key)`	remove key from list
`Boolean Empty()`	empty list?

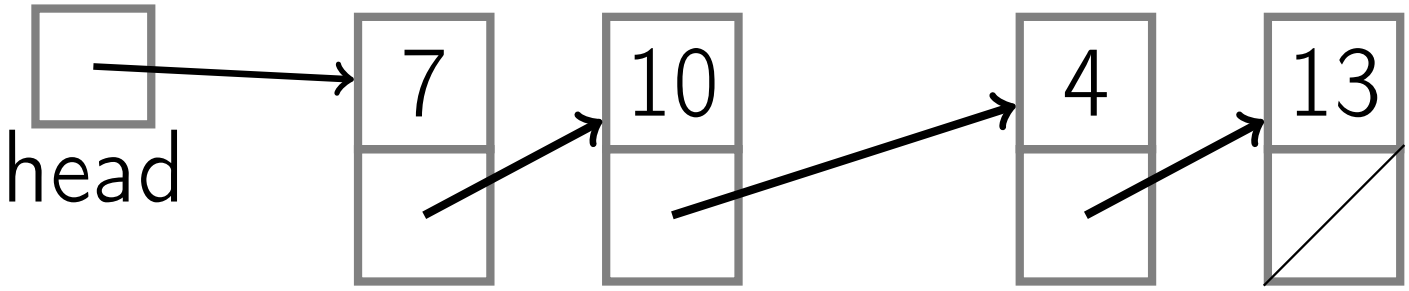
List API

`PushFront(Key)`	add to front
`Key TopFront()`	return front item
`PopFront()`	remove front item
`PushBack(Key)`	add to back
`Key TopBack()`	return back item
`PopBack()`	remove back item
`Boolean Find(Key)`	is key in list?
`Erase(Key)`	remove key from list
`Boolean Empty()`	empty list?
`AddBefore(Node, Key)`	adds key before node

List API

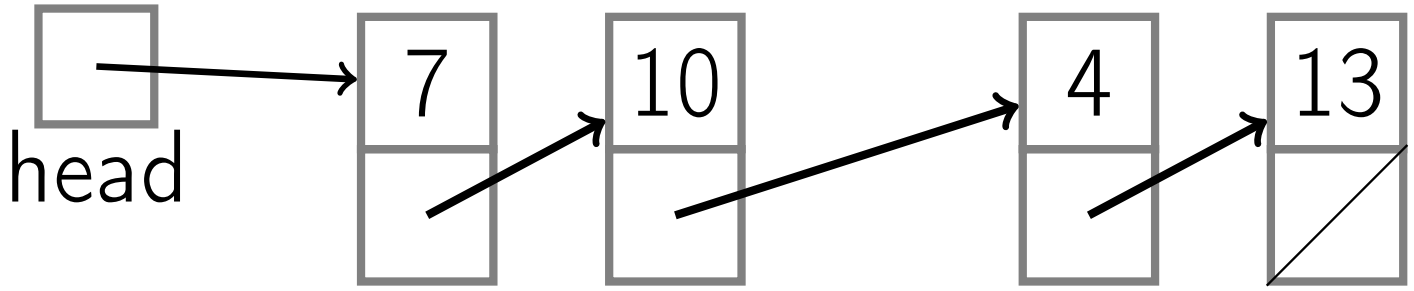
`PushFront(Key)`	add to front
`Key TopFront()`	return front item
`PopFront()`	remove front item
`PushBack(Key)`	add to back
`Key TopBack()`	return back item
`PopBack()`	remove back item
`Boolean Find(Key)`	is key in list?
`Erase(Key)`	remove key from list
`Boolean Empty()`	empty list?
`AddBefore(Node, Key)`	adds key before node
`AddAfter(Node, Key)`	adds key after node

Times for Some Operations



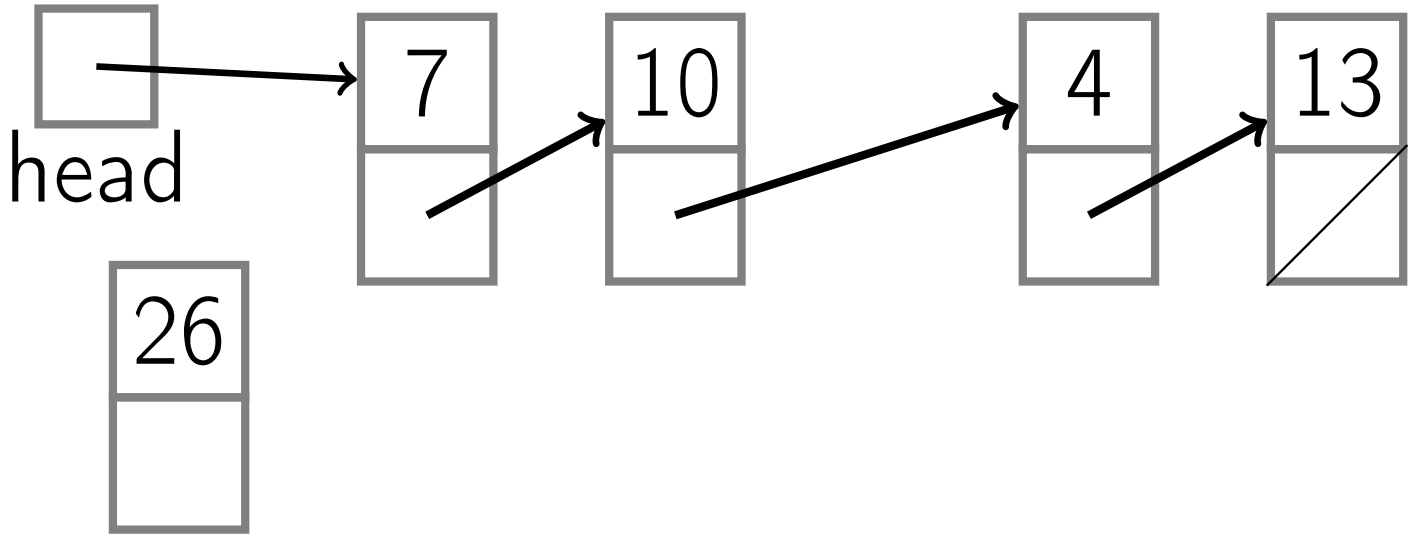
Times for Some Operations

`PushFront`



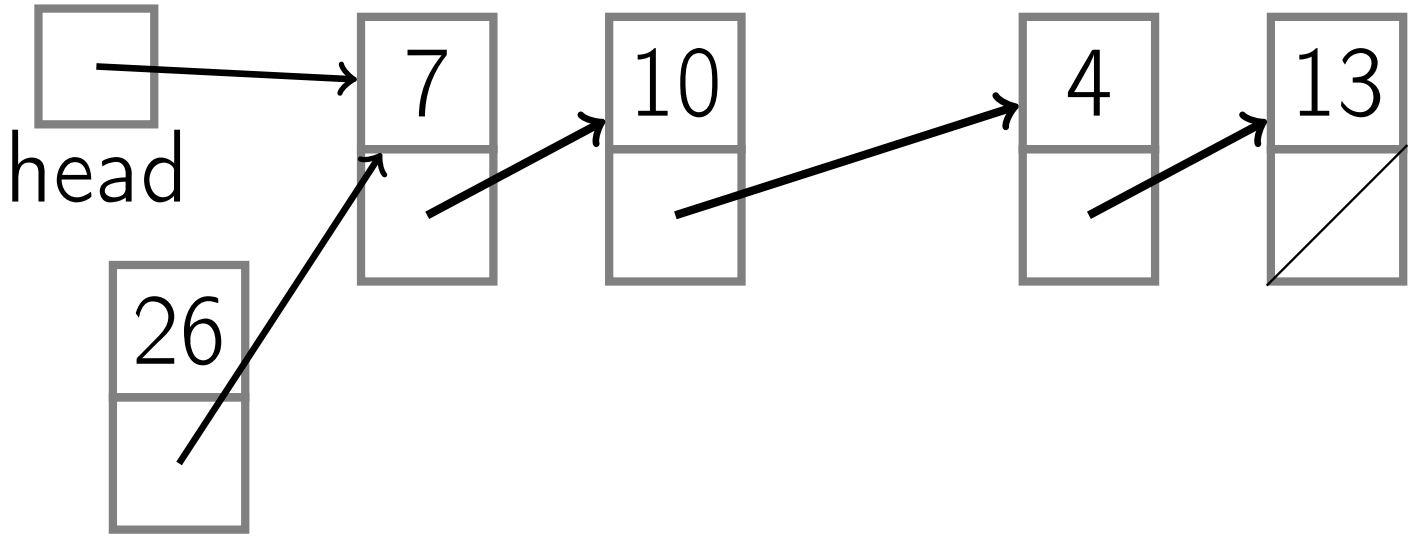
Times for Some Operations

`PushFront`



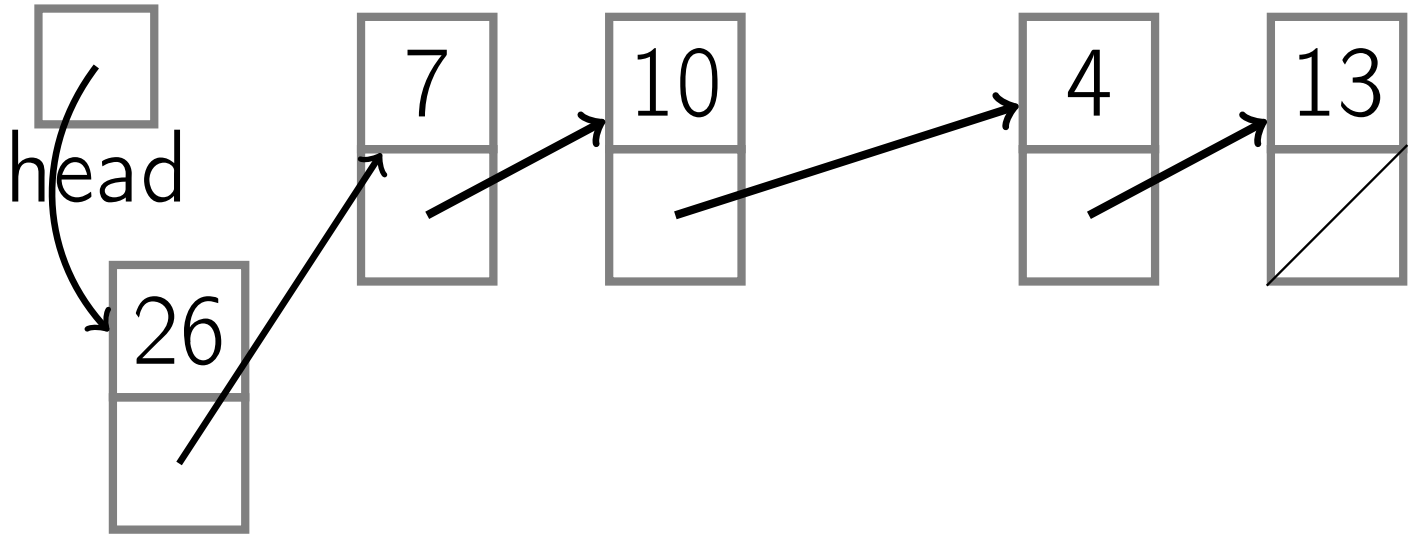
Times for Some Operations

`PushFront`



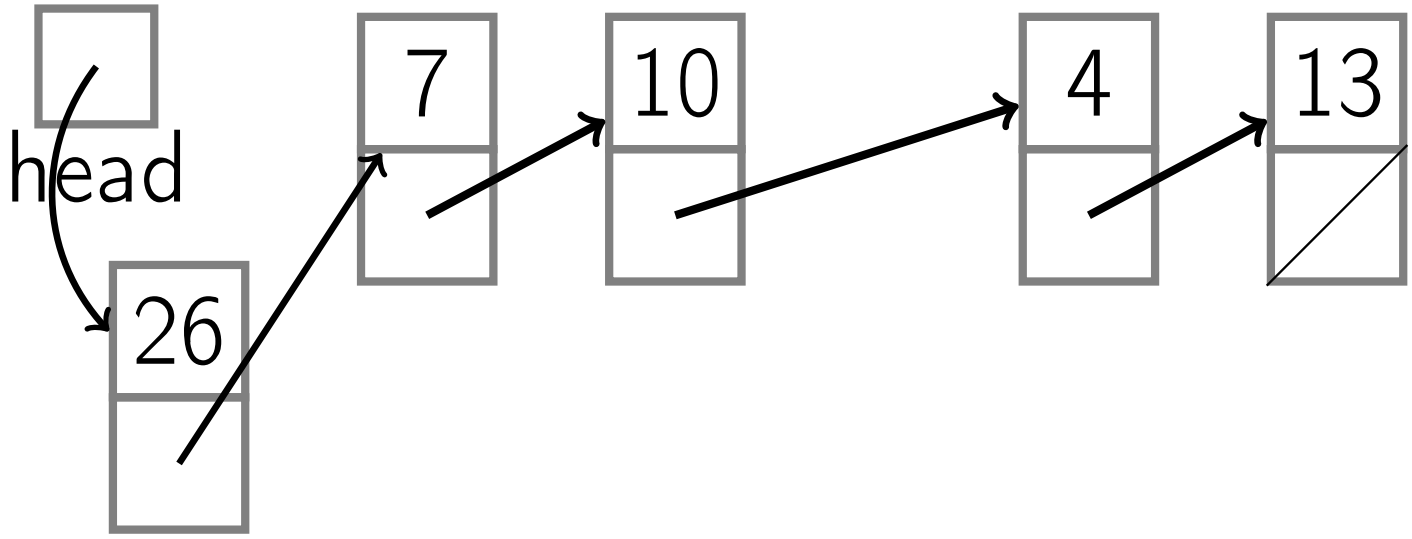
Times for Some Operations

`PushFront` $O(1)$



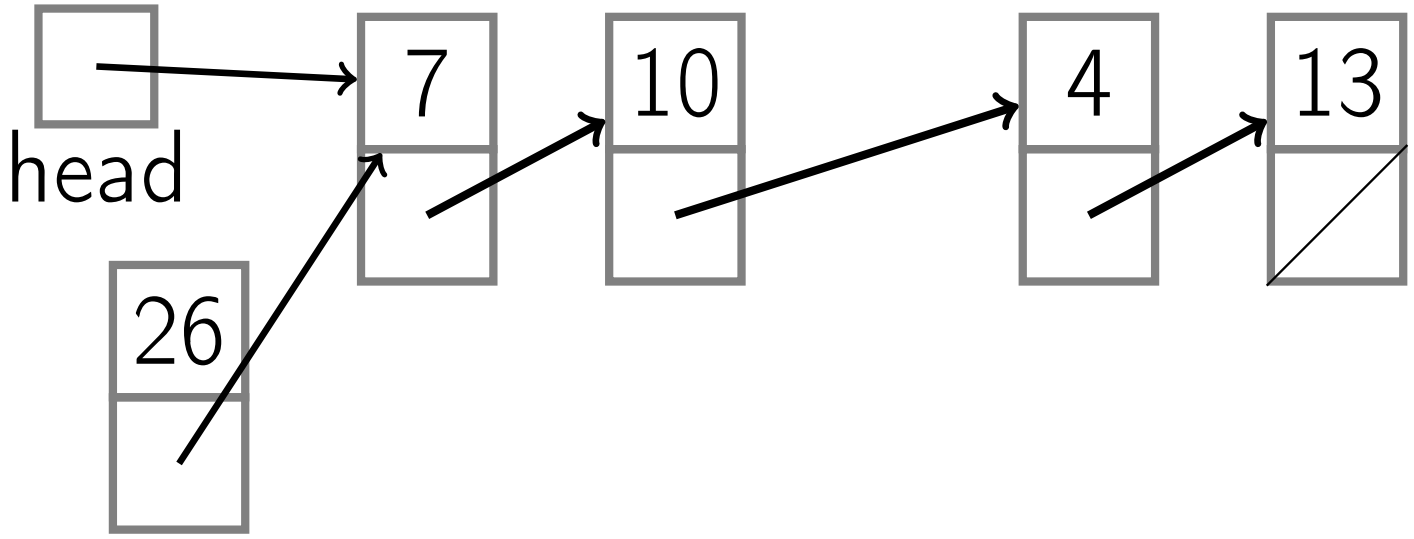
Times for Some Operations

`PopFront`



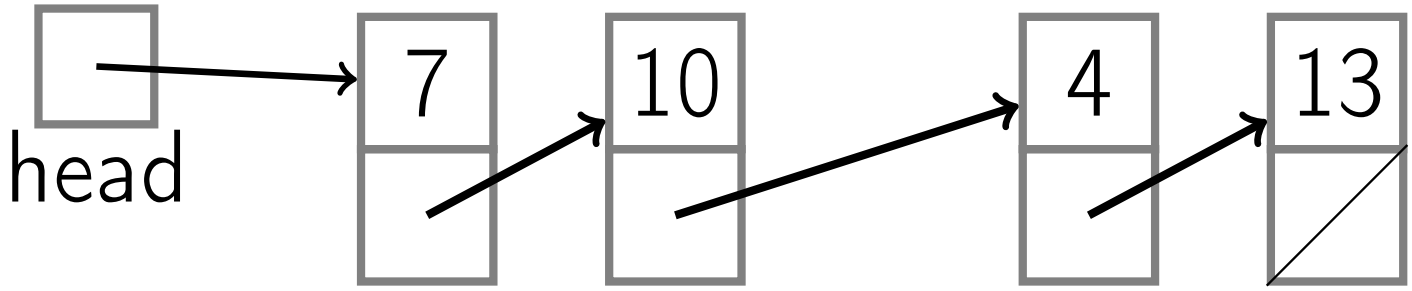
Times for Some Operations

`PopFront`



Times for Some Operations

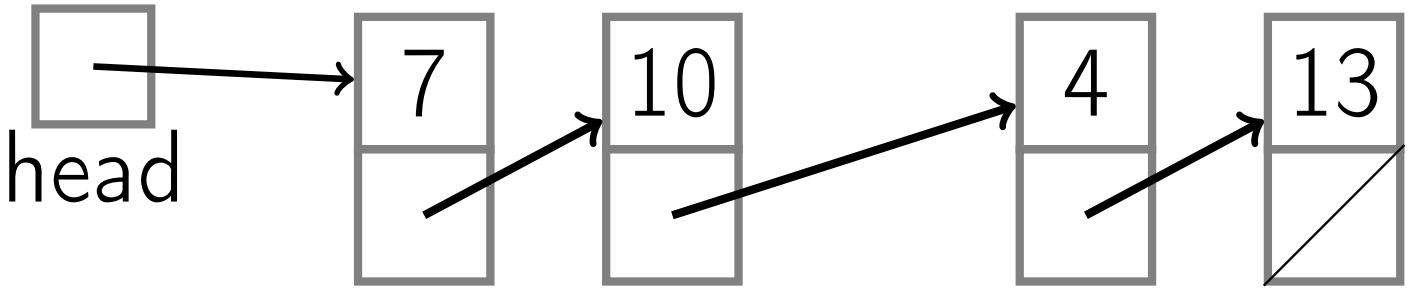
`PopFront` $O(1)$



Times for Some Operations

`PushBack`

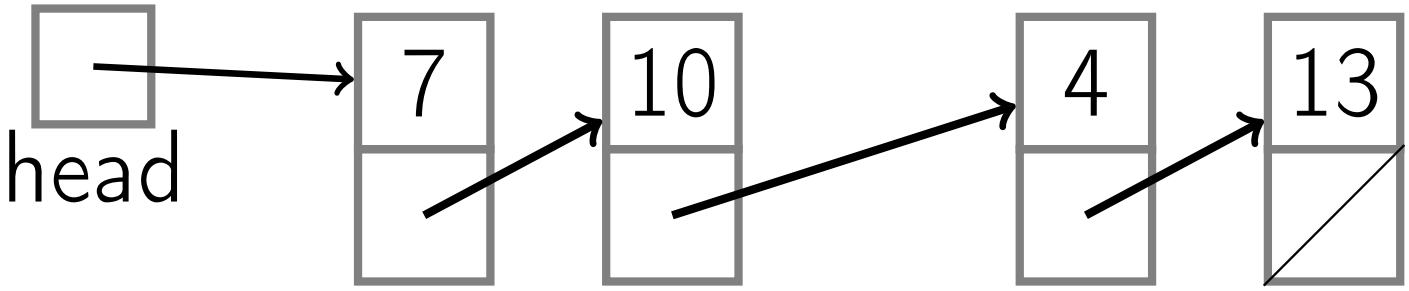
(no tail)



Times for Some Operations

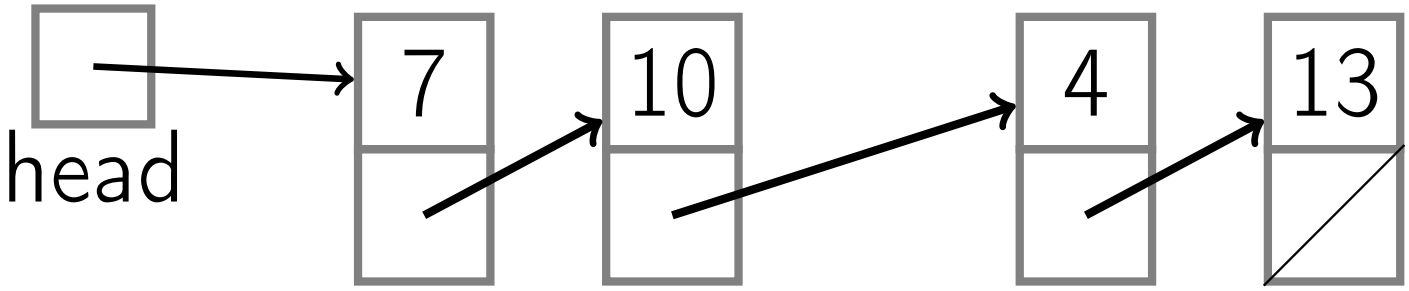
`PushBack` $O(n)$

(no tail)



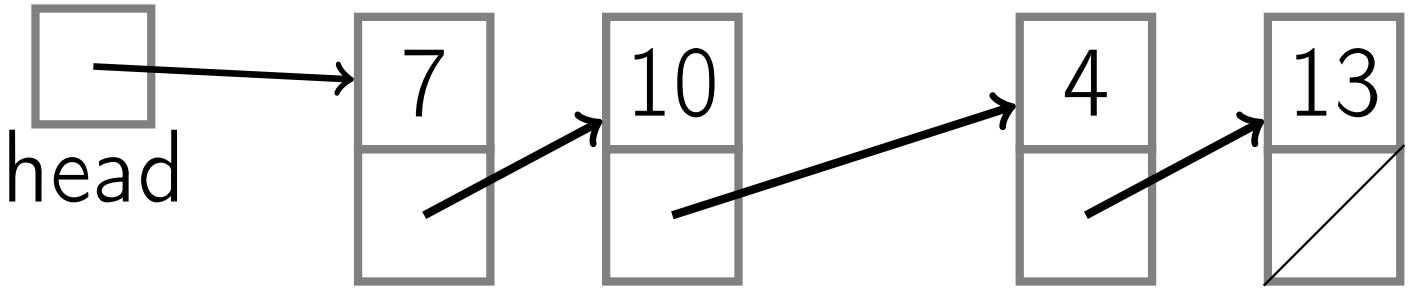
Times for Some Operations

PopBack
(no tail)

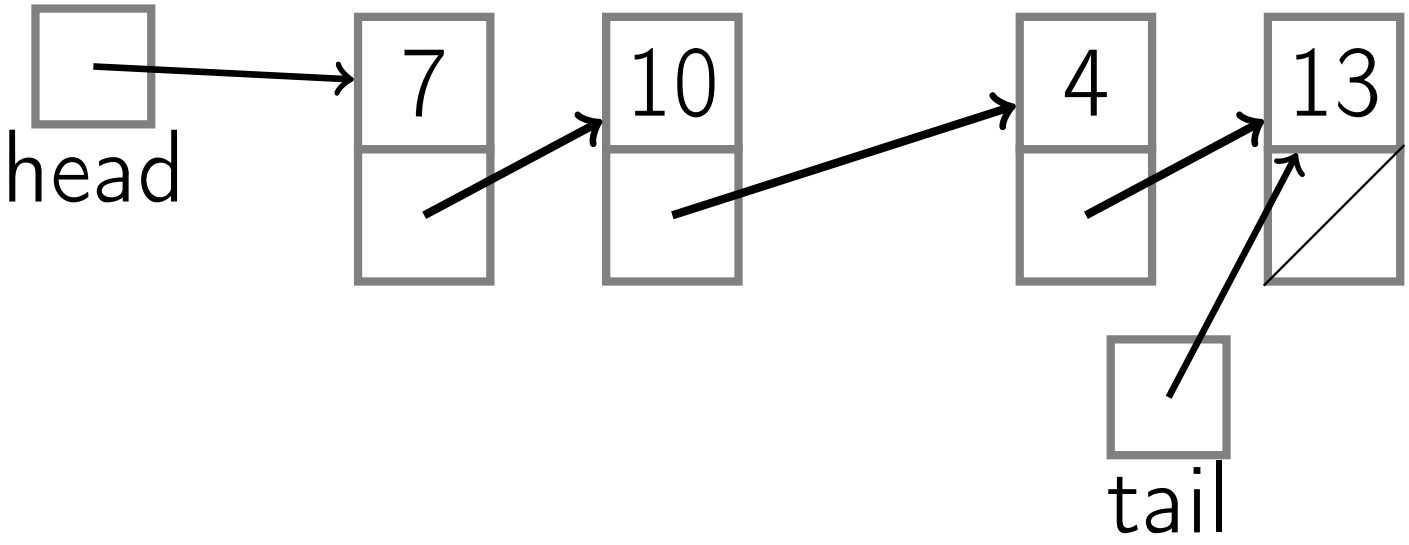


Times for Some Operations

`PopBack` $O(n)$
(no tail)

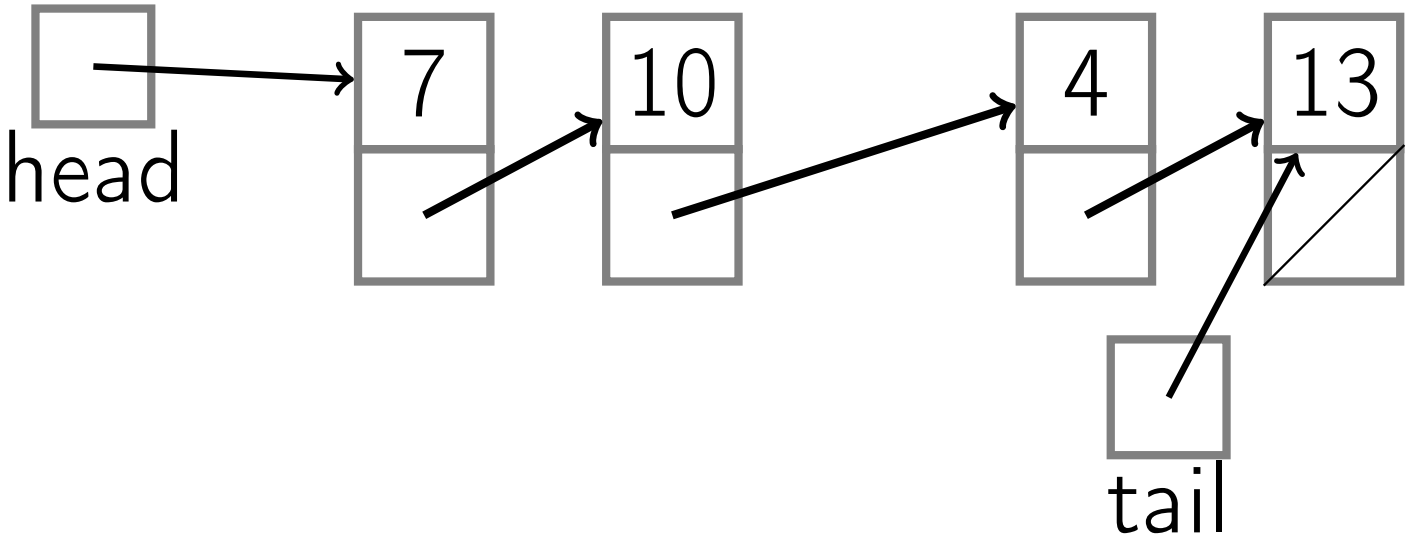


Times for Some Operations



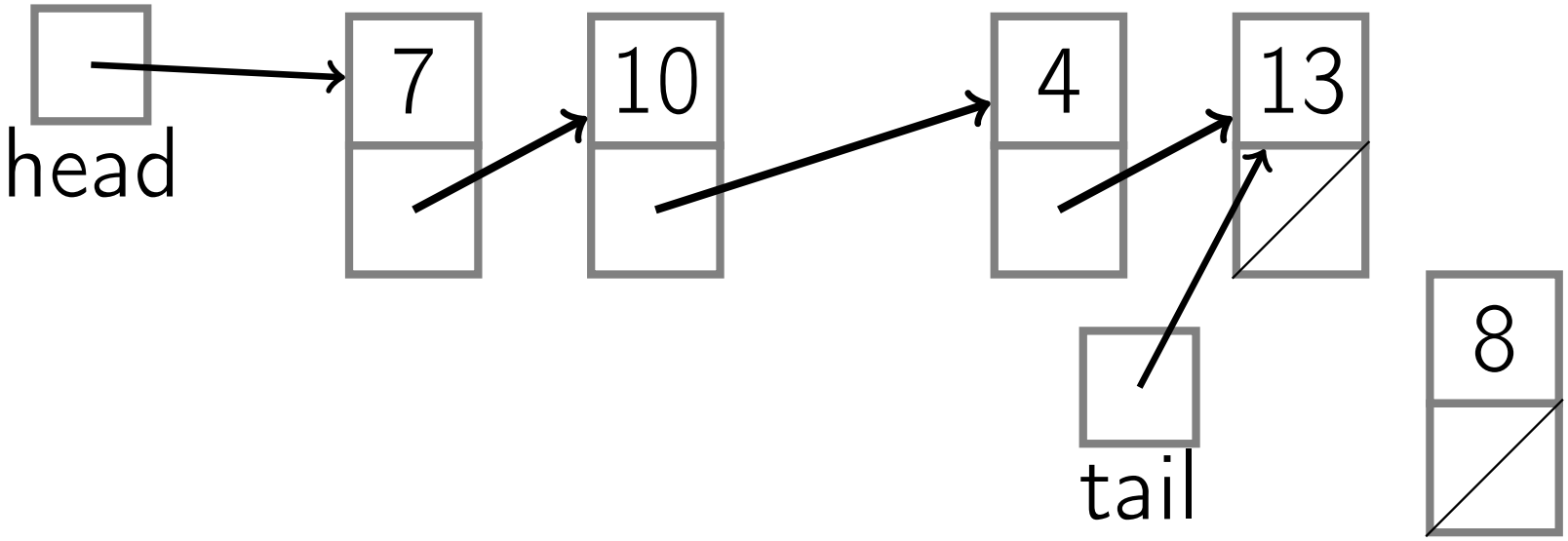
Times for Some Operations

`PushBack`
(with tail)



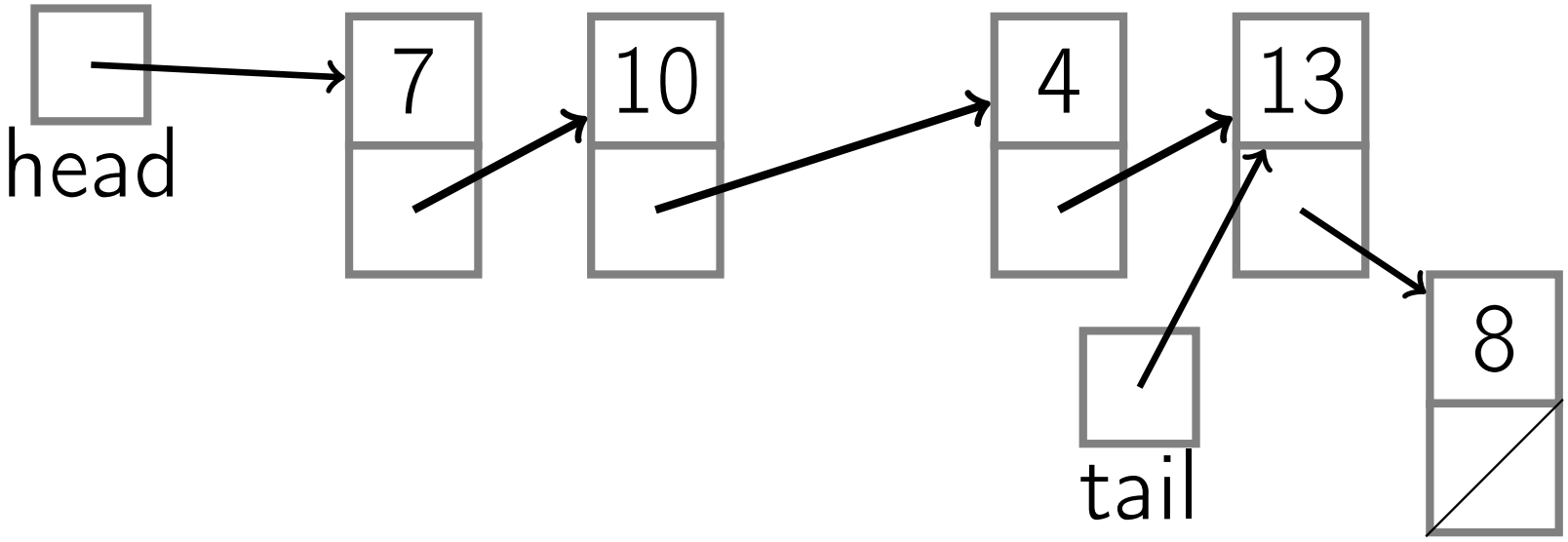
Times for Some Operations

`PushBack`
(with tail)



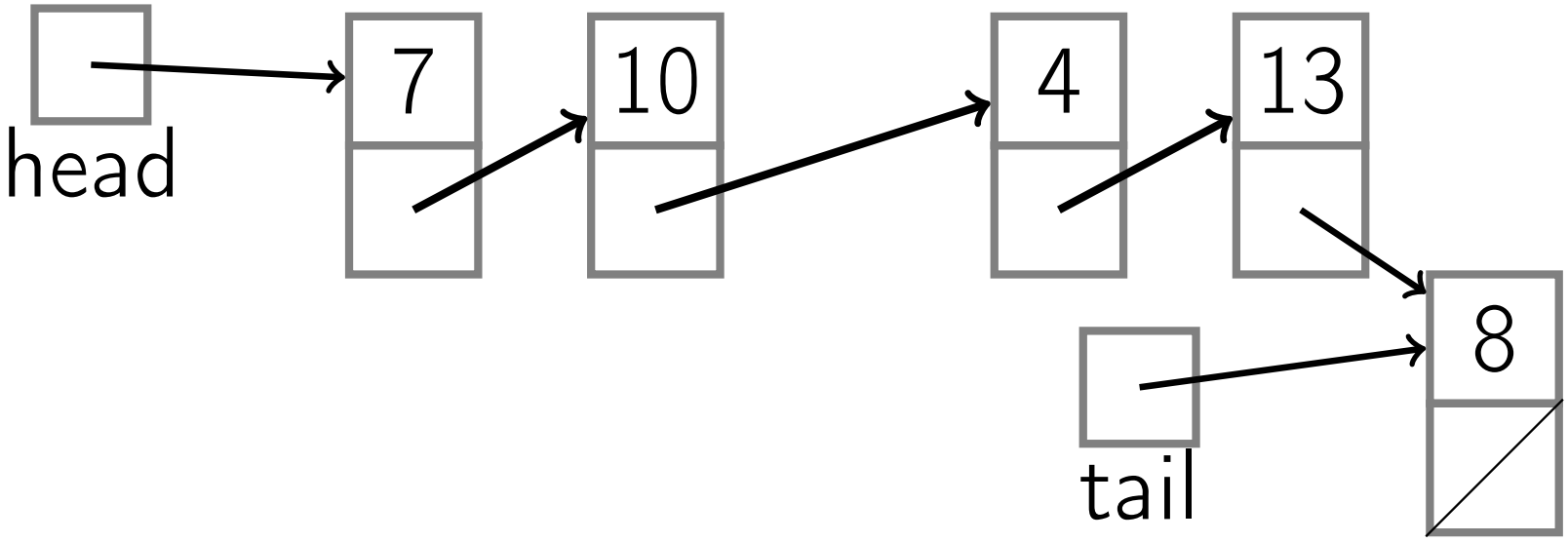
Times for Some Operations

`PushBack`
(with tail)



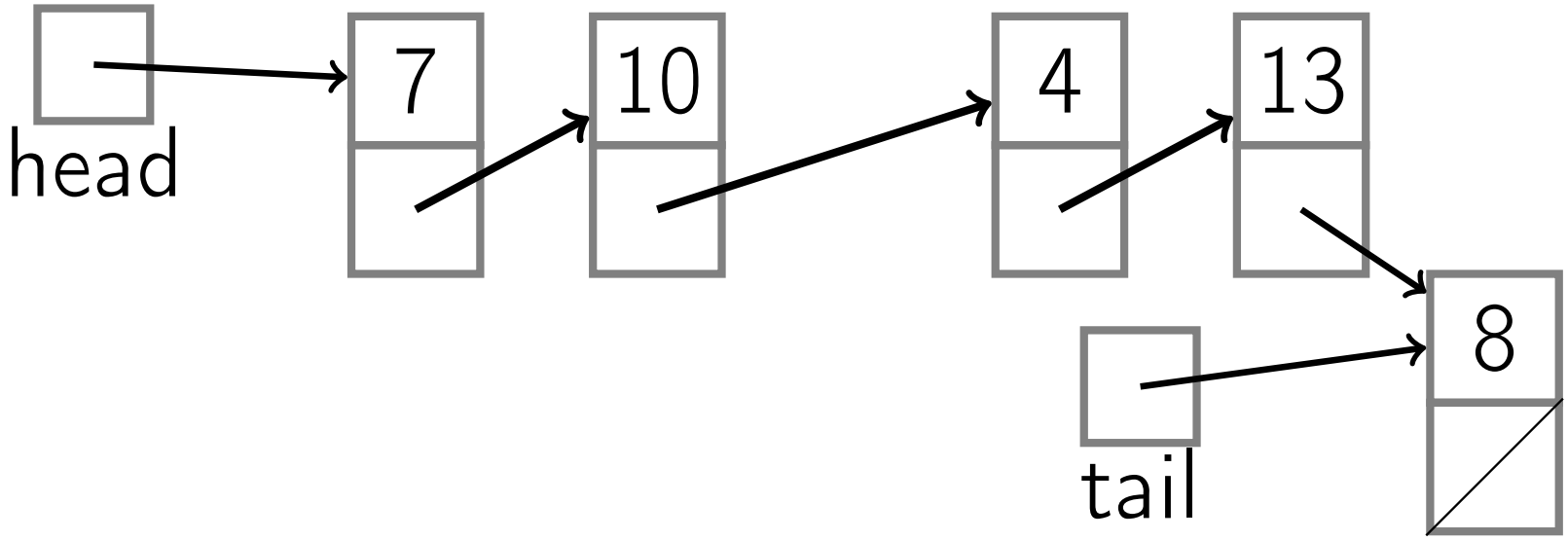
Times for Some Operations

`PushBack` $O(1)$
(with tail)



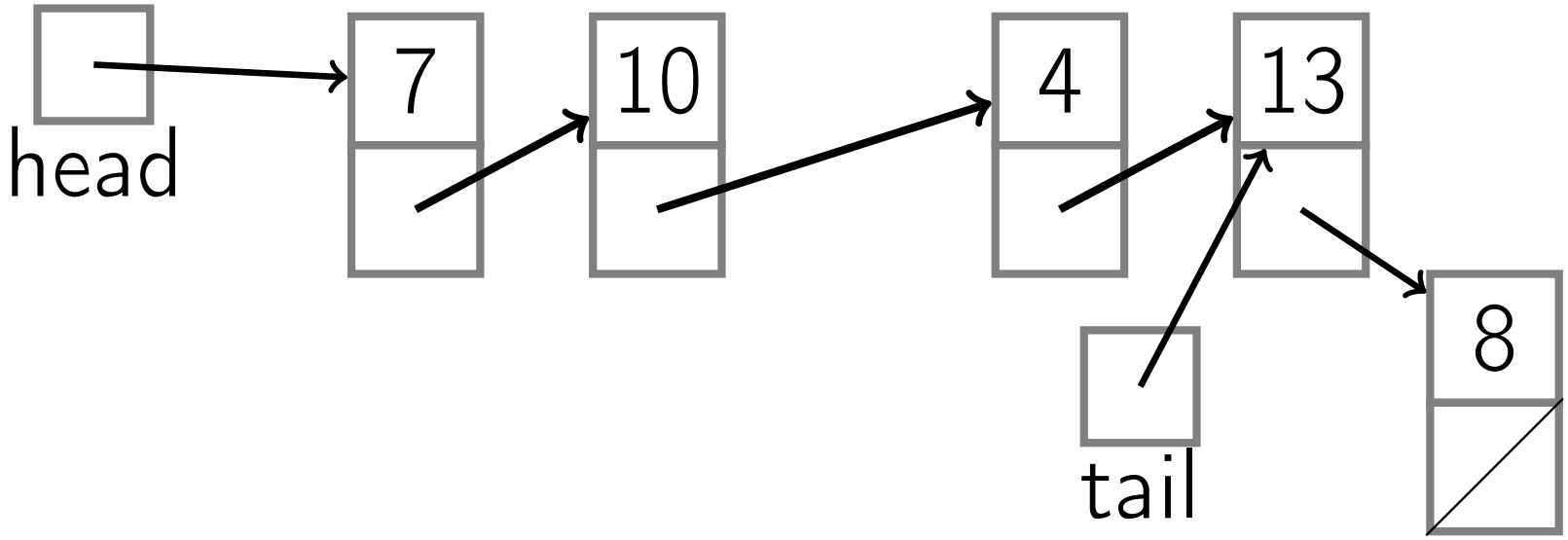
Times for Some Operations

PopBack
(with tail)



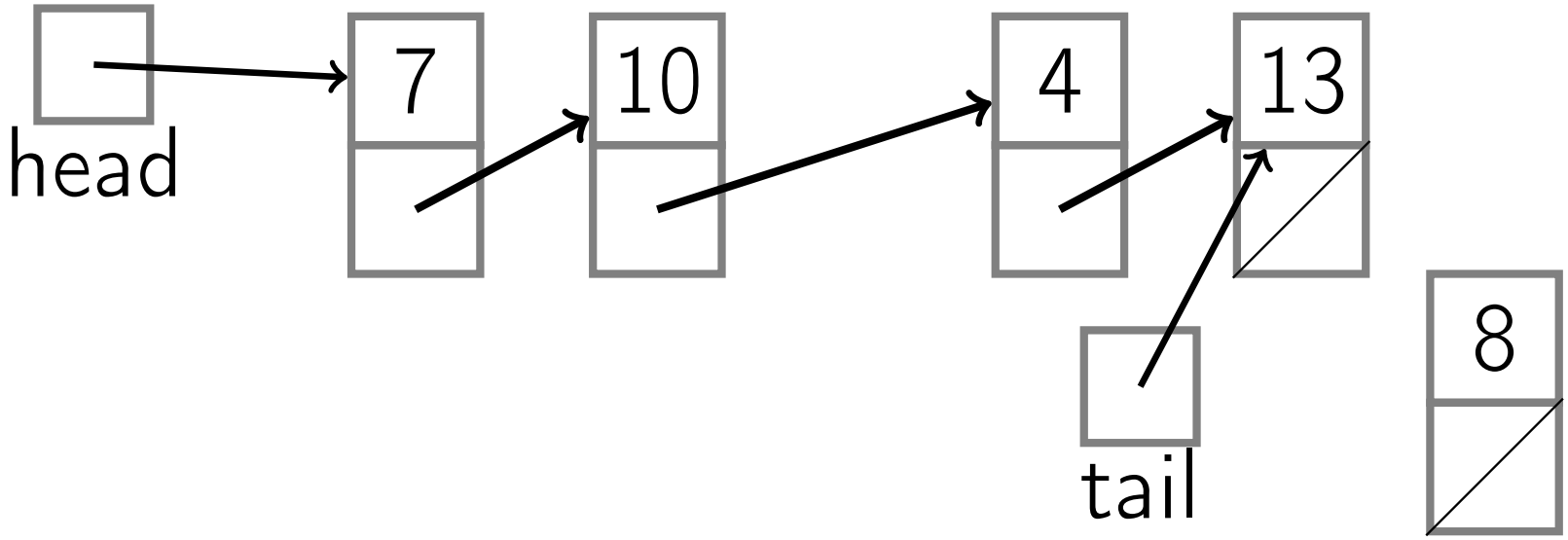
Times for Some Operations

PopBack
(with tail)



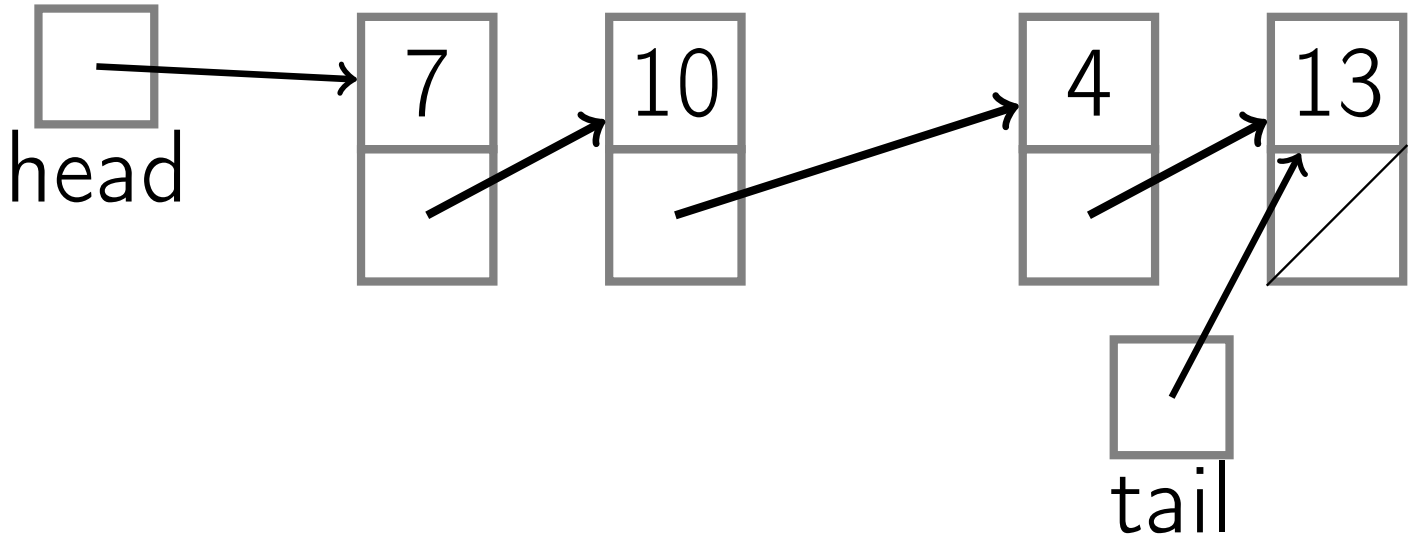
Times for Some Operations

PopBack
(with tail)



Times for Some Operations

`PopBack` $O(n)$
(with tail)



Singly-linked List

PushFront(*key*)

node ←new node
node.key ← *key*
node.next ← *head*
head ← *node*
if *tail* = nil:
    tail ← *head*

Singly-linked List

PopFront()

```
if head = nil:
  ERROR: empty list
head ← head.next
if head = nil:
  tail ← nil
```

Singly-linked List

PushBack(*key*)

node ←new node

node.key ← *key*

node.next =nil

Singly-linked List

PushBack(*key*)

```
node ←new node
node.key ← key
node.next =nil
if tail = nil:
    head ← tail ← node
```

Singly-linked List

PushBack(*key*)

```
node ←new node
node.key ← key
node.next =nil
if tail = nil:
    head ← tail ← node
else:
    tail.next ← node
    tail ← node
```

Singly-linked List

`PopBack()`

Singly-linked List

PopBack()

```
if head = nil:  ERROR: empty list
```

Singly-linked List

PopBack()

```
if head = nil:   ERROR: empty list
if head = tail:
   head ← tail ←nil
```

Singly-linked List

PopBack()

```
if head = nil:  ERROR: empty list
if head = tail:
   head ← tail ←nil
else:
   p ← head
   while p.next.next ≠ nil:
      p ← p.next
```

Singly-linked List

PopBack()

```
if head = nil:  ERROR: empty list
if head = tail:
   head ← tail ←nil
else:
   p ← head
   while p.next.next ≠ nil:
      p ← p.next
   p.next ← nil; tail ← p
```

Singly-linked List

AddAfter(*node*, *key*)

*node*2 ←new node

*node*2.*key* ← *key*

*node*2.*next* = *node*.*next*

node.*next* = *node*2

if *tail* = *node*:

    tail ← *node*2

Singly-Linked List	no tail	with tail
`PushFront(Key)`	$O(1)$	

Singly-Linked List	no tail	with tail
`PushFront(Key)`	$O(1)$	
`TopFront()`	$O(1)$	

Singly-Linked List	no tail	with tail
`PushFront(Key)`	$O(1)$	
`TopFront()`	$O(1)$	
`PopFront()`	$O(1)$	

Singly-Linked List	no tail	with tail
`PushFront(Key)`	$O(1)$	
`TopFront()`	$O(1)$	
`PopFront()`	$O(1)$	
`PushBack(Key)`	$O(n)$	$O(1)$

Singly-Linked List	no tail	with tail
`PushFront(Key)`	$O(1)$	
`TopFront()`	$O(1)$	
`PopFront()`	$O(1)$	
`PushBack(Key)`	$O(n)$	$O(1)$
`TopBack()`	$O(n)$	$O(1)$

Singly-Linked List	no tail	with tail
`PushFront(Key)`	$O(1)$	
`TopFront()`	$O(1)$	
`PopFront()`	$O(1)$	
`PushBack(Key)`	$O(n)$	$O(1)$
`TopBack()`	$O(n)$	$O(1)$
`PopBack()`	$O(n)$	

Singly-Linked List	no tail	with tail
`PushFront(Key)`	$O(1)$	
`TopFront()`	$O(1)$	
`PopFront()`	$O(1)$	
`PushBack(Key)`	$O(n)$	$O(1)$
`TopBack()`	$O(n)$	$O(1)$
`PopBack()`	$O(n)$	
`Find(Key)`	$O(n)$	

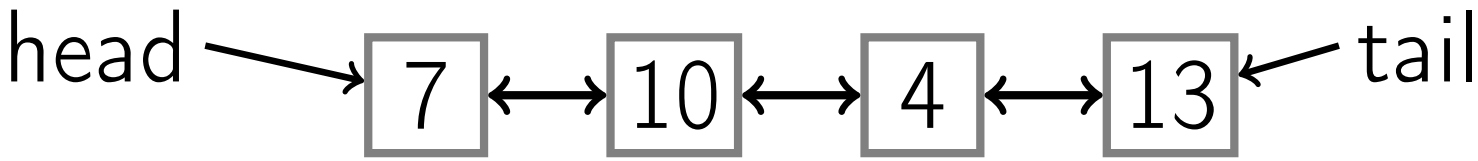
Singly-Linked List	no tail	with tail
`PushFront(Key)`	$O(1)$	
`TopFront()`	$O(1)$	
`PopFront()`	$O(1)$	
`PushBack(Key)`	$O(n)$	$O(1)$
`TopBack()`	$O(n)$	$O(1)$
`PopBack()`	$O(n)$	
`Find(Key)`	$O(n)$	
`Erase(Key)`	$O(n)$	

Singly-Linked List	no tail	with tail
`PushFront(Key)`	$O(1)$	
`TopFront()`	$O(1)$	
`PopFront()`	$O(1)$	
`PushBack(Key)`	$O(n)$	$O(1)$
`TopBack()`	$O(n)$	$O(1)$
`PopBack()`	$O(n)$	
`Find(Key)`	$O(n)$	
`Erase(Key)`	$O(n)$	
`Empty()`	$O(1)$	

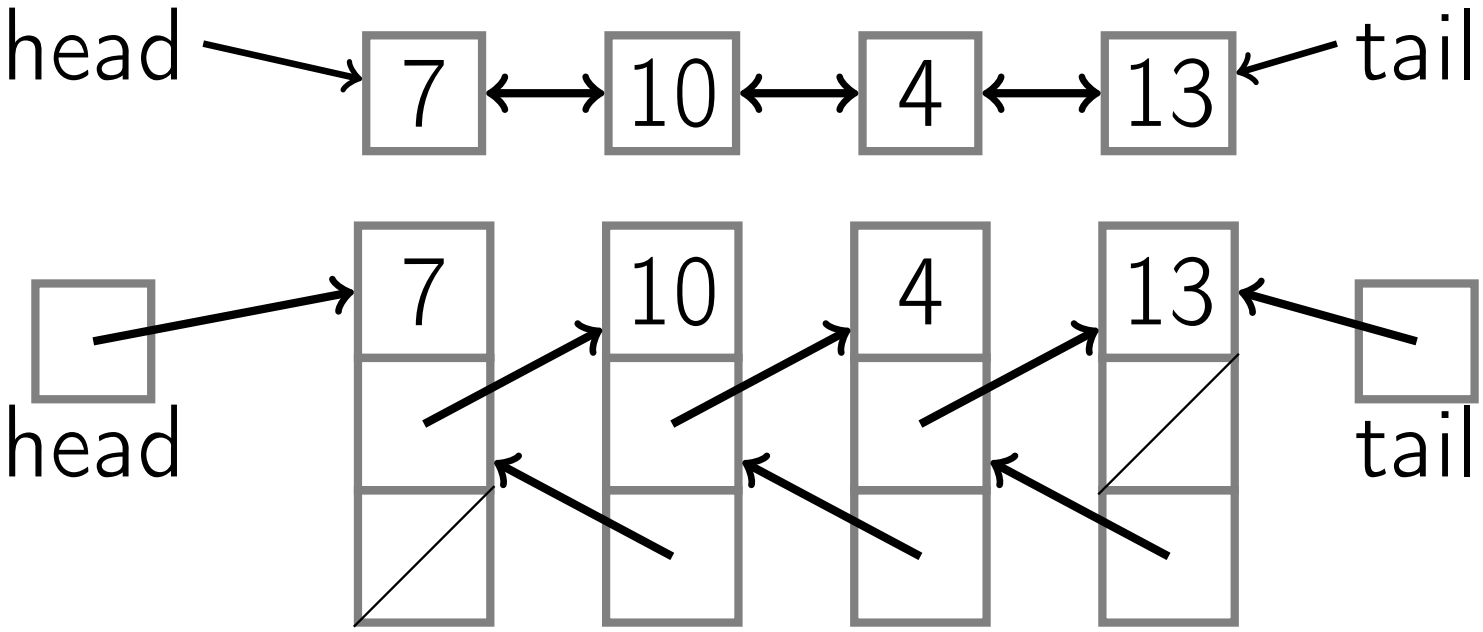
Singly-Linked List	no tail	with tail
`PushFront(Key)`	$O(1)$	
`TopFront()`	$O(1)$	
`PopFront()`	$O(1)$	
`PushBack(Key)`	$O(n)$	$O(1)$
`TopBack()`	$O(n)$	$O(1)$
`PopBack()`	$O(n)$	
`Find(Key)`	$O(n)$	
`Erase(Key)`	$O(n)$	
`Empty()`	$O(1)$	
`AddBefore(Node, Key)`	$O(n)$	

Singly-Linked List	no tail	with tail
`PushFront(Key)`	$O(1)$	
`TopFront()`	$O(1)$	
`PopFront()`	$O(1)$	
`PushBack(Key)`	$O(n)$	$O(1)$
`TopBack()`	$O(n)$	$O(1)$
`PopBack()`	$O(n)$	
`Find(Key)`	$O(n)$	
`Erase(Key)`	$O(n)$	
`Empty()`	$O(1)$	
`AddBefore(Node, Key)`	$O(n)$	
`AddAfter(Node, Key)`	$O(1)$	

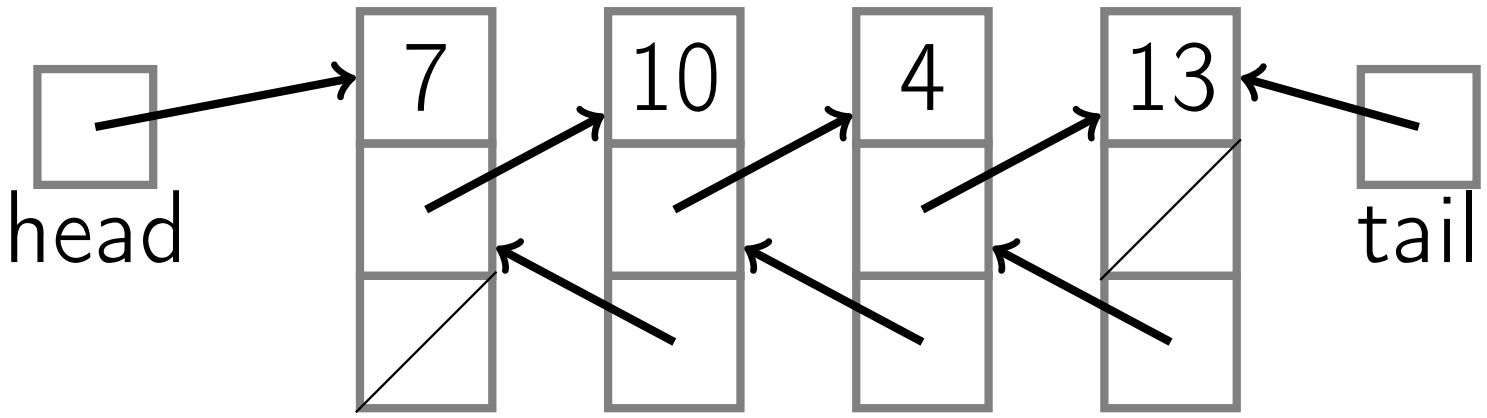
Doubly-Linked List



Doubly-Linked List



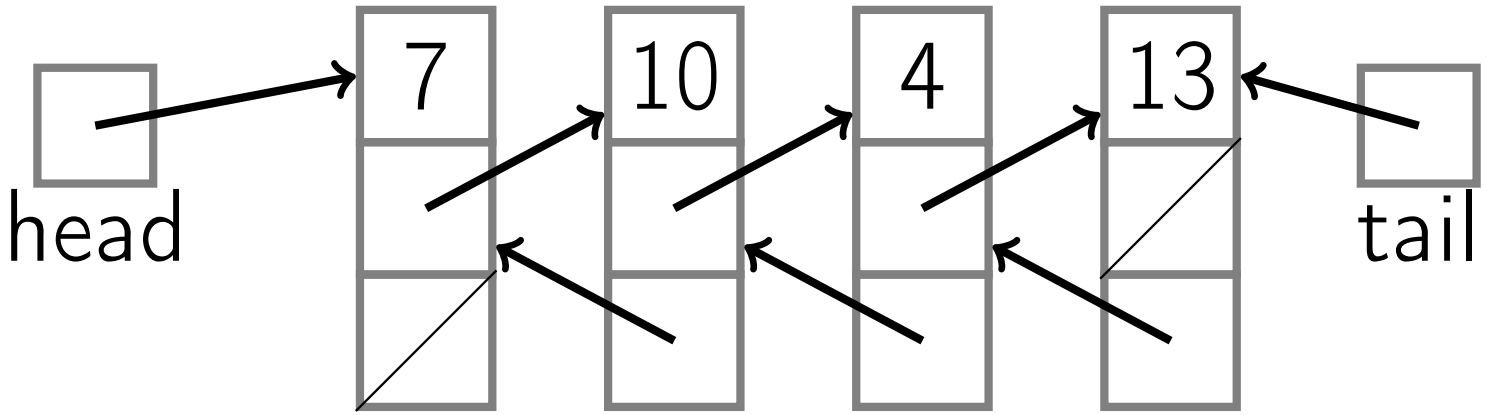
Doubly-Linked List



Node contains:

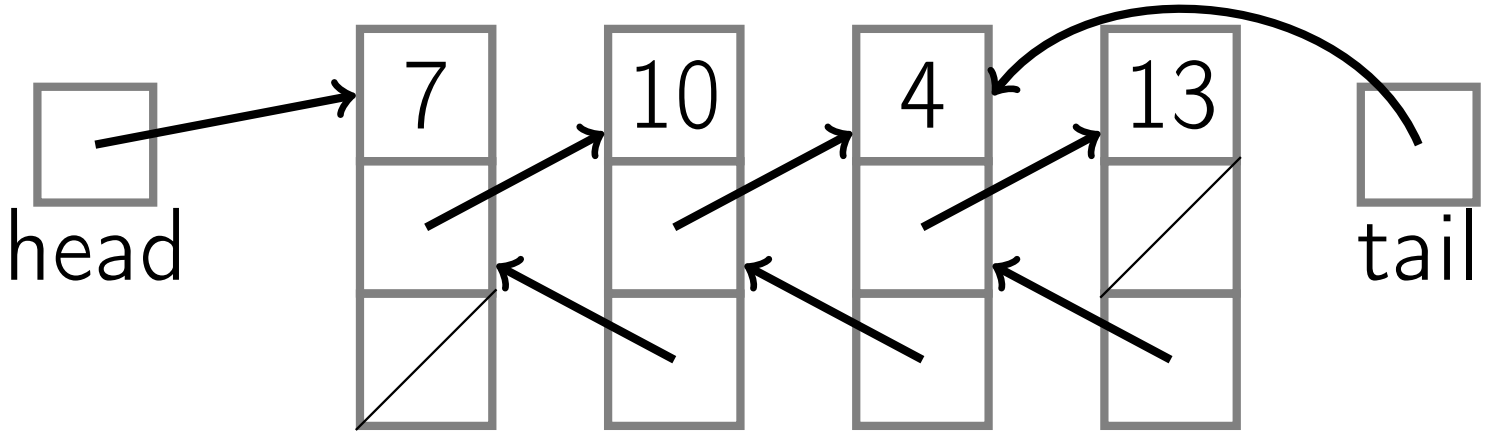
- `key`
- `next` pointer
- `prev` pointer

Doubly-Linked List



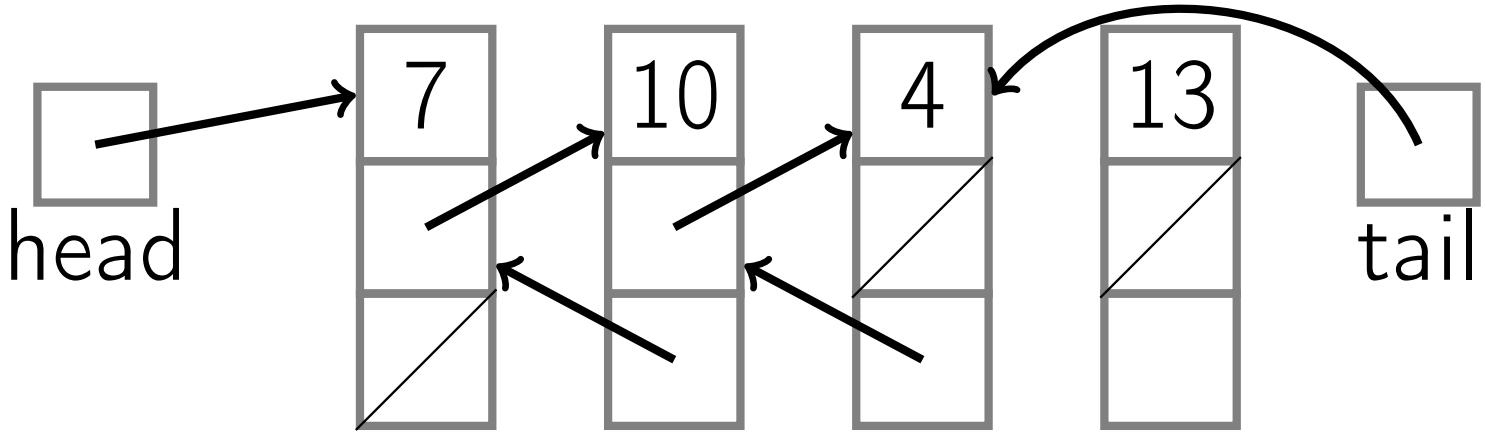
`PopBack`

Doubly-Linked List



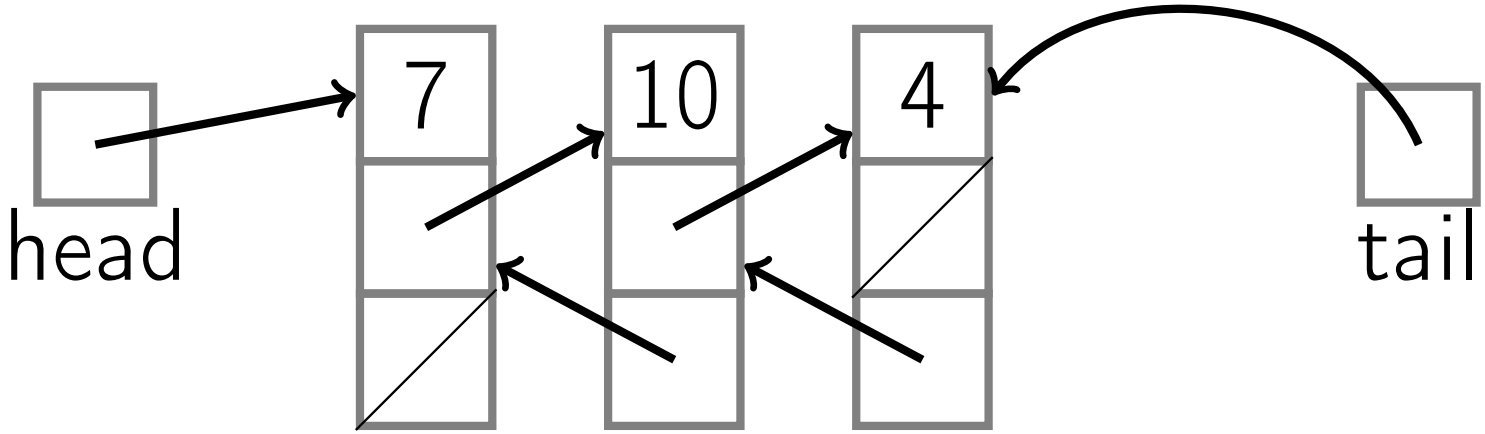
`PopBack`

Doubly-Linked List



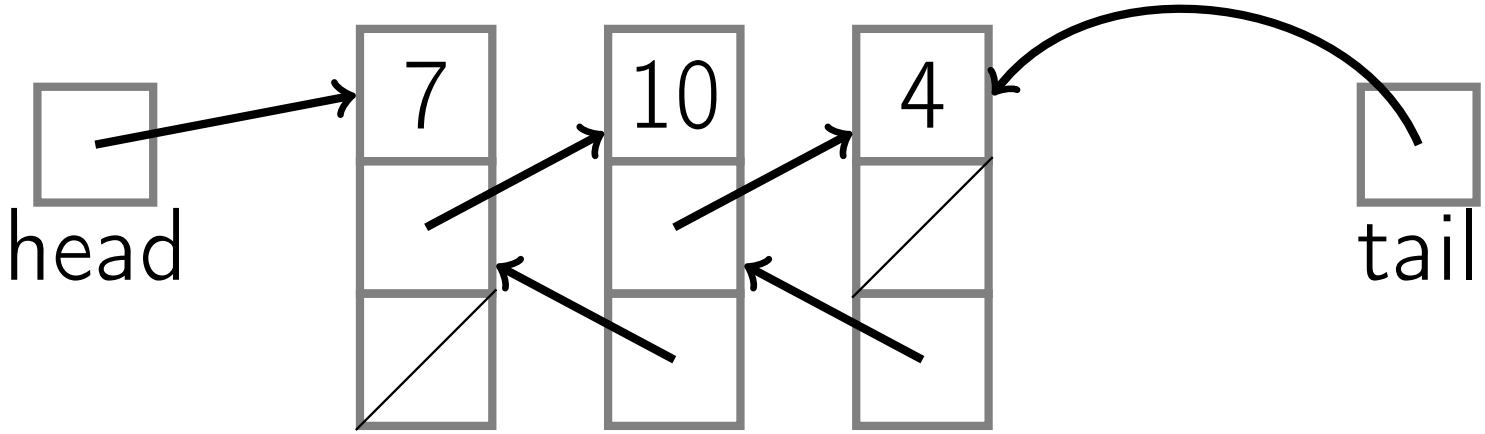
`PopBack`

Doubly-Linked List



`PopBack`

Doubly-Linked List



`PopBack` $O(1)$

Doubly-linked List

PushBack(*key*)

node $\leftarrow$`new node`

node.*key* $\leftarrow$ *key*; *node*.*next* $=$`nil`

Doubly-linked List

PushBack(*key*)

```
node ←new node
node.key ← key ;  node.next =nil
if  tail = nil :
    head ← tail ← node
    node.prev ←nil
```

Doubly-linked List

PushBack(*key*)

```
node ←new node
node.key ← key ;  node.next =nil
if  tail = nil :
    head ← tail ← node
    node.prev ←nil
else:
    tail .next ← node
    node.prev ← tail
    tail ← node
```

Doubly-linked List

`PopBack()`

Doubly-linked List

PopBack()

```
if head = nil:  ERROR: empty list
```

Doubly-linked List

PopBack()

```
if head = nil:   ERROR: empty list
if head = tail:
   head ← tail ←nil
```

Doubly-linked List

PopBack()

```
if head = nil:   ERROR: empty list
if head = tail:
   head ← tail ←nil
else:
   tail ← tail.prev
   tail.next ←nil
```

Doubly-linked List

AddAfter(*node*, *key*)

```
node2 ←new node
node2.key ← key
node2.next ← node.next
node2.prev ← node
node.next ← node2
if node2.next ≠nil:
    node2.next.prev ← node2
if tail = node:
    tail ← node2
```

Doubly-linked List

AddBefore(*node*, *key*)

```
node2 ←new node
node2.key ← key
node2.next ← node
node2.prev ← node.prev
node.prev ← node2
if node2.prev ≠nil:
    node2.prev.next ← node2
if head = node:
    head ← node2
```

Singly-Linked List	no tail	with tail
`PushFront(Key)`	$O(1)$	
`TopFront()`	$O(1)$	
`PopFront()`	$O(1)$	
`PushBack(Key)`	$O(n)$	$O(1)$
`TopBack()`	$O(n)$	$O(1)$
`PopBack()`	$O(n)$	
`Find(Key)`	$O(n)$	
`Erase(Key)`	$O(n)$	
`Empty()`	$O(1)$	
`AddBefore(Node, Key)`	$O(n)$	
`AddAfter(Node, Key)`	$O(1)$	

Doubly-Linked List	no tail	with tail
`PushFront(Key)`	$O(1)$	
`TopFront()`	$O(1)$	
`PopFront()`	$O(1)$	
`PushBack(Key)`	$O(n)$	$O(1)$
`TopBack()`	$O(n)$	$O(1)$
`PopBack()`	~~$O(n)$~~ $O(1)$	
`Find(Key)`	$O(n)$	
`Erase(Key)`	$O(n)$	
`Empty()`	$O(1)$	
`AddBefore(Node, Key)`	~~$O(n)$~~ $O(1)$	
`AddAfter(Node, Key)`	$O(1)$	

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- With doubly-linked list, constant time to insert between nodes or remove a node.