

Basic Data Structures: Stacks and Queues

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Data Structures
Data Structures and Algorithms

Outline

1 Stacks

2 Queues

Definition

Stack: Abstract data type with the following operations:

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- **Push(Key):** adds key to collection

Definition

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- `Push(Key)`: adds key to collection
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Definition

Stack: Abstract data type with the following operations:

- `Push(Key)`: adds key to collection
- `Key Top()`: returns most recently-added key
- `Key Pop()`: removes and returns most recently-added key
- `Boolean Empty()`: are there any elements?

Balanced Brackets

Input: A string *str* consisting of '(', ')', '[', ']' characters.

Output: Return whether or not the string's parentheses and square brackets are balanced.

Balanced Brackets

Balanced:

- “([]) [] ()”,
- “((([([])])) ())”

Unbalanced:

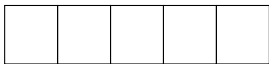
- “([]] ()”
- “] [”

IsBalanced(*str*)

```
Stack stack
for char in str:
    if char in ['(', '[']:
        stack.Push(char)
    else:
        if stack.Empty(): return False
        top ← stack.Pop()
        if (top = '[' and char != ']') or
           (top = '(' and char != ')'):
            return False
return stack.Empty()
```

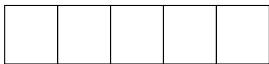
Stack Implementation with Array

numElements: 0



Stack Implementation with Array

numElements: 0



Push(a)

Stack Implementation with Array

numElements: 1

| | | | | |
|---|--|--|--|--|
| a | | | | |
|---|--|--|--|--|

Push(a)

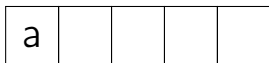
Stack Implementation with Array

numElements: 1

| | | | | |
|---|--|--|--|--|
| a | | | | |
|---|--|--|--|--|

Stack Implementation with Array

numElements: 1



Push(b)

Stack Implementation with Array

numElements: 2

| | | | | |
|---|---|--|--|--|
| a | b | | | |
|---|---|--|--|--|

Push(b)

Stack Implementation with Array

numElements: 2

| | | | | |
|---|---|--|--|--|
| a | b | | | |
|---|---|--|--|--|

Stack Implementation with Array

numElements: 2

| | | | | |
|---|---|--|--|--|
| a | b | | | |
|---|---|--|--|--|

Top()

Stack Implementation with Array

numElements: 2

| | | | | |
|---|---|--|--|--|
| a | b | | | |
|---|---|--|--|--|

Top() \rightarrow b

Stack Implementation with Array

numElements: 2

| | | | | |
|---|---|--|--|--|
| a | b | | | |
|---|---|--|--|--|

Stack Implementation with Array

numElements: 2

| | | | | |
|---|---|--|--|--|
| a | b | | | |
|---|---|--|--|--|

Push(c)

Stack Implementation with Array

numElements: 3

| | | | | |
|---|---|---|--|--|
| a | b | c | | |
|---|---|---|--|--|

Push(c)

Stack Implementation with Array

numElements: 3

| | | | | |
|---|---|---|--|--|
| a | b | c | | |
|---|---|---|--|--|

Stack Implementation with Array

numElements: 3

| | | | | |
|---|---|---|--|--|
| a | b | c | | |
|---|---|---|--|--|

Pop()

Stack Implementation with Array

numElements: 2

| | | | | |
|---|---|--|--|--|
| a | b | | | |
|---|---|--|--|--|

Pop() \rightarrow c

Stack Implementation with Array

numElements: 2

| | | | | |
|---|---|--|--|--|
| a | b | | | |
|---|---|--|--|--|

Stack Implementation with Array

numElements: 2

| | | | | |
|---|---|--|--|--|
| a | b | | | |
|---|---|--|--|--|

Push(d)

Stack Implementation with Array

numElements: 3

| | | | | |
|---|---|---|--|--|
| a | b | d | | |
|---|---|---|--|--|

Push(d)

Stack Implementation with Array

numElements: 3

| | | | | |
|---|---|---|--|--|
| a | b | d | | |
|---|---|---|--|--|

Stack Implementation with Array

numElements: 3

| | | | | |
|---|---|---|--|--|
| a | b | d | | |
|---|---|---|--|--|

Push(e)

Stack Implementation with Array

numElements: 4

| | | | | |
|---|---|---|---|--|
| a | b | d | e | |
|---|---|---|---|--|

Push(e)

Stack Implementation with Array

numElements: 4

| | | | | |
|---|---|---|---|--|
| a | b | d | e | |
|---|---|---|---|--|

Stack Implementation with Array

numElements: 4

| | | | | |
|---|---|---|---|--|
| a | b | d | e | |
|---|---|---|---|--|

Push(f)

Stack Implementation with Array

numElements: 5

| | | | | |
|---|---|---|---|---|
| a | b | d | e | f |
|---|---|---|---|---|

Push(f)

Stack Implementation with Array

numElements: 5

| | | | | |
|---|---|---|---|---|
| a | b | d | e | f |
|---|---|---|---|---|

Stack Implementation with Array

numElements: 5

| | | | | |
|---|---|---|---|---|
| a | b | d | e | f |
|---|---|---|---|---|

Push(g)

Stack Implementation with Array

numElements: 5

| | | | | |
|---|---|---|---|---|
| a | b | d | e | f |
|---|---|---|---|---|

Push(g) → ERROR

Stack Implementation with Array

numElements: 5

| | | | | |
|---|---|---|---|---|
| a | b | d | e | f |
|---|---|---|---|---|

Stack Implementation with Array

numElements: 5

| | | | | |
|---|---|---|---|---|
| a | b | d | e | f |
|---|---|---|---|---|

Empty()

Stack Implementation with Array

numElements: 5

| | | | | |
|---|---|---|---|---|
| a | b | d | e | f |
|---|---|---|---|---|

Empty() \rightarrow False

Stack Implementation with Array

numElements: 5

| | | | | |
|---|---|---|---|---|
| a | b | d | e | f |
|---|---|---|---|---|

Stack Implementation with Array

numElements: 5

| | | | | |
|---|---|---|---|---|
| a | b | d | e | f |
|---|---|---|---|---|

Pop()

Stack Implementation with Array

numElements: 4

| | | | | |
|---|---|---|---|--|
| a | b | d | e | |
|---|---|---|---|--|

Pop() \rightarrow f

Stack Implementation with Array

numElements: 4

| | | | | |
|---|---|---|---|--|
| a | b | d | e | |
|---|---|---|---|--|

Stack Implementation with Array

numElements: 4

| | | | | |
|---|---|---|---|--|
| a | b | d | e | |
|---|---|---|---|--|

Pop()

Stack Implementation with Array

numElements: 3

| | | | | |
|---|---|---|--|--|
| a | b | d | | |
|---|---|---|--|--|

Pop() \rightarrow e

Stack Implementation with Array

numElements: 3

| | | | | |
|---|---|---|--|--|
| a | b | d | | |
|---|---|---|--|--|

Stack Implementation with Array

numElements: 3

| | | | | |
|---|---|---|--|--|
| a | b | d | | |
|---|---|---|--|--|

Pop()

Stack Implementation with Array

numElements: 2

| | | | | |
|---|---|--|--|--|
| a | b | | | |
|---|---|--|--|--|

Pop() \rightarrow d

Stack Implementation with Array

numElements: 2

| | | | | |
|---|---|--|--|--|
| a | b | | | |
|---|---|--|--|--|

Stack Implementation with Array

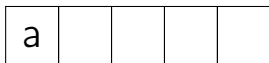
numElements: 2

| | | | | |
|---|---|--|--|--|
| a | b | | | |
|---|---|--|--|--|

Pop()

Stack Implementation with Array

numElements: 1



Pop() \rightarrow b

Stack Implementation with Array

numElements: 1

| | | | | |
|---|--|--|--|--|
| a | | | | |
|---|--|--|--|--|

Stack Implementation with Array

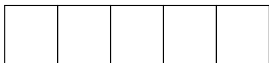
numElements: 1

| | | | | |
|---|--|--|--|--|
| a | | | | |
|---|--|--|--|--|

Pop()

Stack Implementation with Array

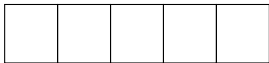
numElements: 0



Pop() \rightarrow a

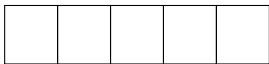
Stack Implementation with Array

numElements: 0



Stack Implementation with Array

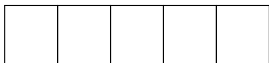
numElements: 0



Empty()

Stack Implementation with Array

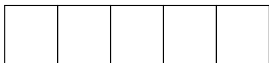
numElements: 0



Empty() \rightarrow True

Stack Implementation with Array

numElements: 0



Stack Implementation with Linked List



head

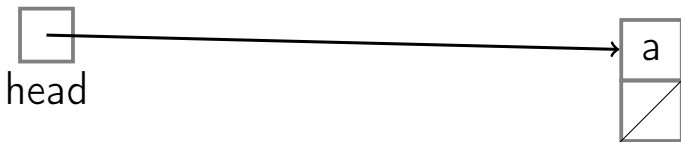
Stack Implementation with Linked List



head

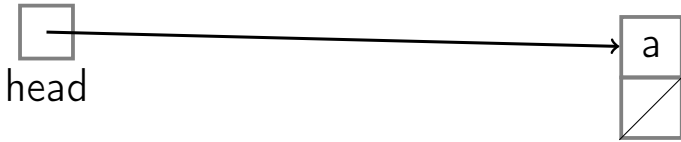
Push(a)

Stack Implementation with Linked List



Push(a)

Stack Implementation with Linked List



Stack Implementation with Linked List



Push(b)

Stack Implementation with Linked List



Push(b)

Stack Implementation with Linked List



Stack Implementation with Linked List



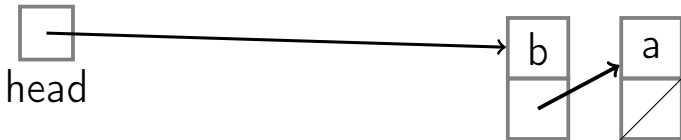
Top()

Stack Implementation with Linked List

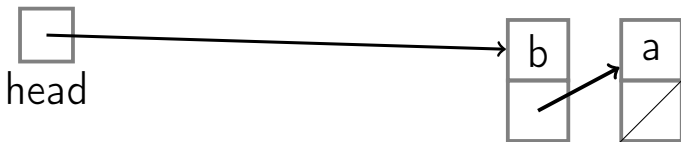


$\text{Top}() \rightarrow b$

Stack Implementation with Linked List

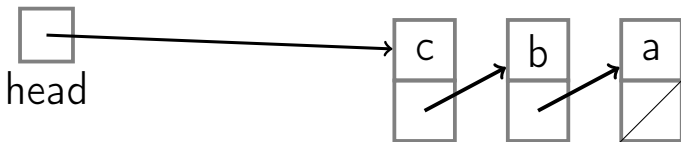


Stack Implementation with Linked List



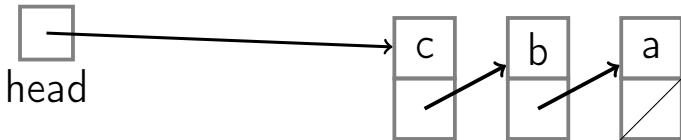
Push(c)

Stack Implementation with Linked List

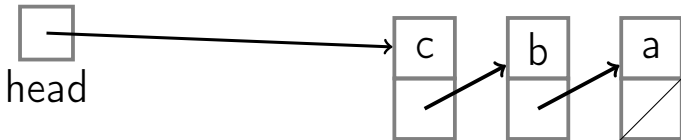


Push(c)

Stack Implementation with Linked List



Stack Implementation with Linked List



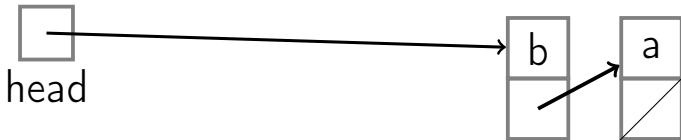
Pop()

Stack Implementation with Linked List



Pop() \rightarrow c

Stack Implementation with Linked List

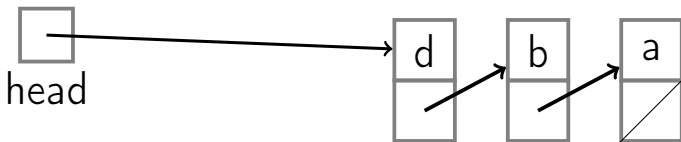


Stack Implementation with Linked List



Push(d)

Stack Implementation with Linked List

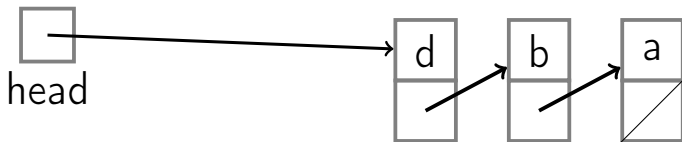


Push(d)

Stack Implementation with Linked List

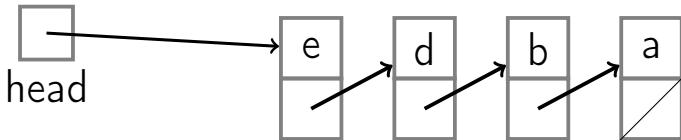


Stack Implementation with Linked List



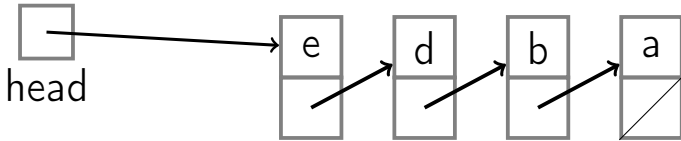
Push(e)

Stack Implementation with Linked List

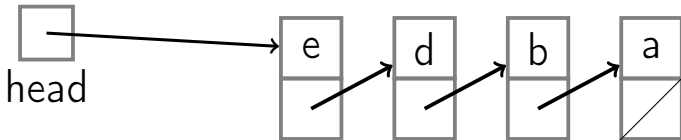


Push(e)

Stack Implementation with Linked List

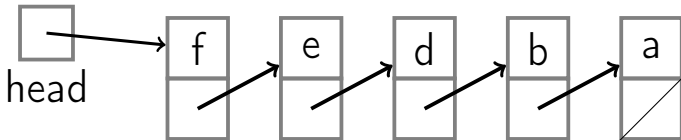


Stack Implementation with Linked List



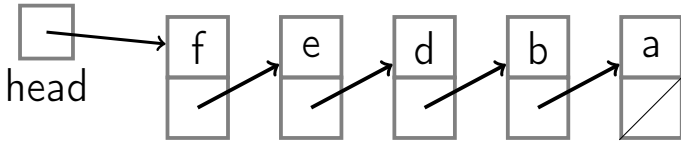
Push(f)

Stack Implementation with Linked List

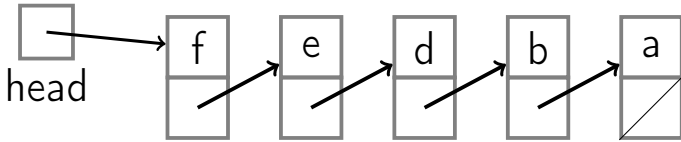


Push(f)

Stack Implementation with Linked List

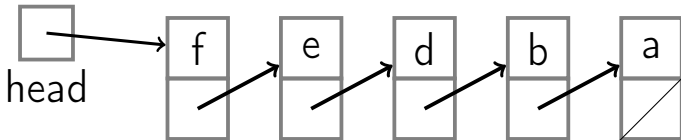


Stack Implementation with Linked List



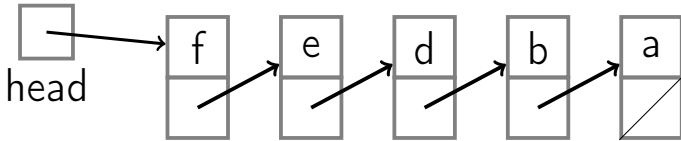
Empty()

Stack Implementation with Linked List

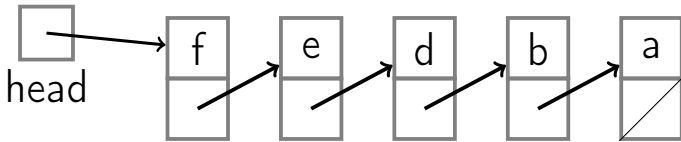


`Empty()` \rightarrow `False`

Stack Implementation with Linked List

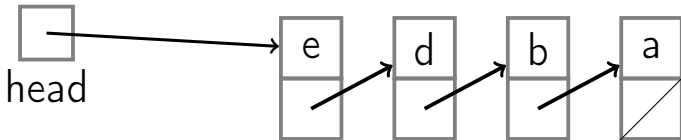


Stack Implementation with Linked List



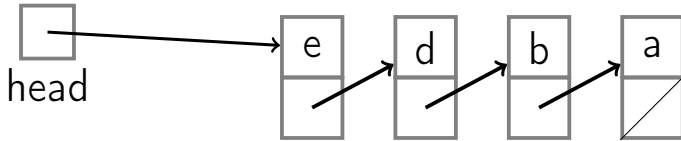
Pop()

Stack Implementation with Linked List

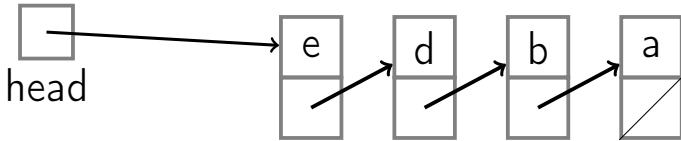


Pop() → f

Stack Implementation with Linked List

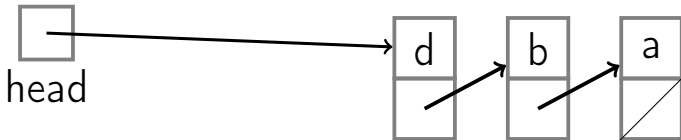


Stack Implementation with Linked List



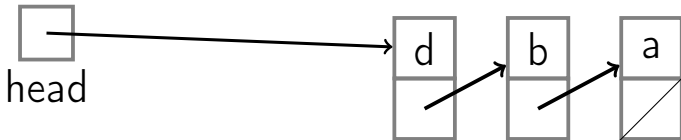
Pop()

Stack Implementation with Linked List



Pop() \rightarrow e

Stack Implementation with Linked List

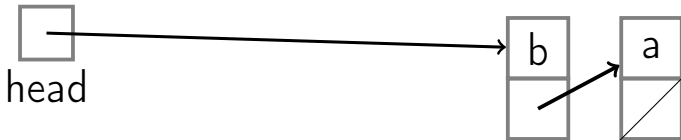


Stack Implementation with Linked List



Pop()

Stack Implementation with Linked List



Pop() \rightarrow d

Stack Implementation with Linked List



Stack Implementation with Linked List



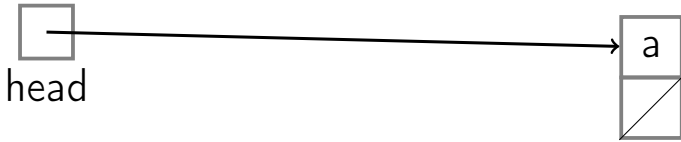
Pop()

Stack Implementation with Linked List



Pop() \rightarrow b

Stack Implementation with Linked List



Stack Implementation with Linked List



Pop()

Stack Implementation with Linked List



Pop() \rightarrow a

Stack Implementation with Linked List



head

Stack Implementation with Linked List



head

Empty()

Stack Implementation with Linked List



head

`Empty() → True`

Stack Implementation with Linked List



head

Stack Implementation with Linked List

Stack Implementation with Linked List

Stack Implementation with Linked List

Summary

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- Each stack operation is $O(1)$: Push, Pop, Top, Empty.

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- Each stack operation is $O(1)$: Push, Pop, Top, Empty.
- Stacks are occasionally known as LIFO queues.

Outline

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2 Queues

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- `Enqueue(Key)`: adds key to collection
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- `Boolean Empty()`: are there any elements?

FIFO: First-In, First-Out

Queue Implementation with Linked List



head



tail

Queue Implementation with Linked List



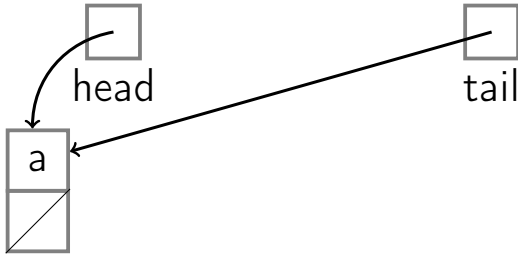
head



tail

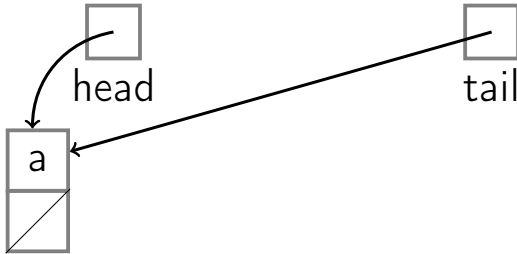
Enqueue(a)

Queue Implementation with Linked List

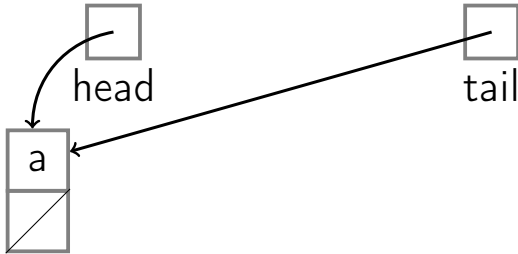


Enqueue(a)

Queue Implementation with Linked List

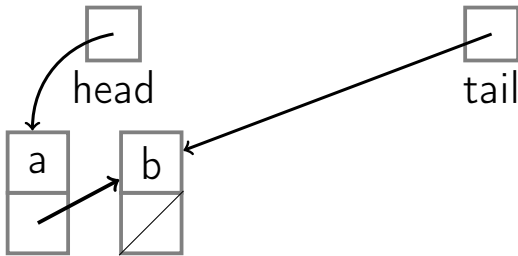


Queue Implementation with Linked List



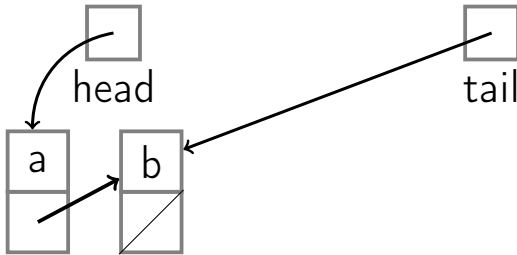
Enqueue(b)

Queue Implementation with Linked List

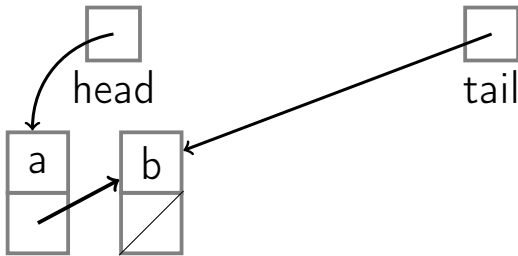


Enqueue(b)

Queue Implementation with Linked List

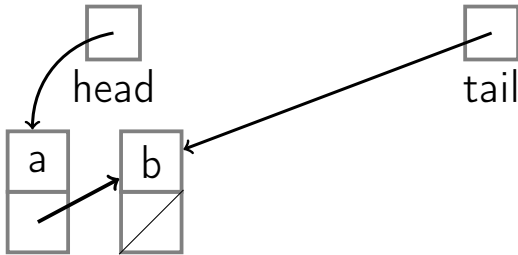


Queue Implementation with Linked List



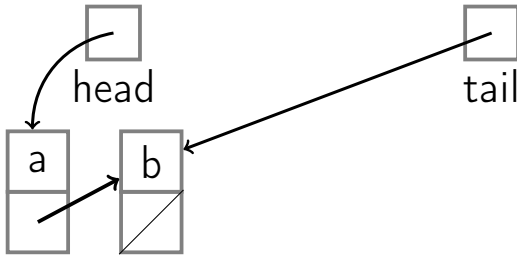
Empty()

Queue Implementation with Linked List

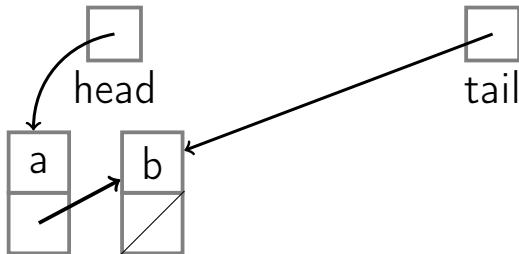


`Empty() → False`

Queue Implementation with Linked List

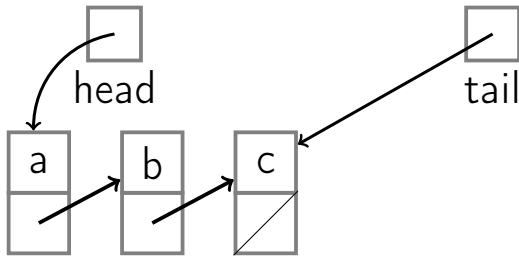


Queue Implementation with Linked List



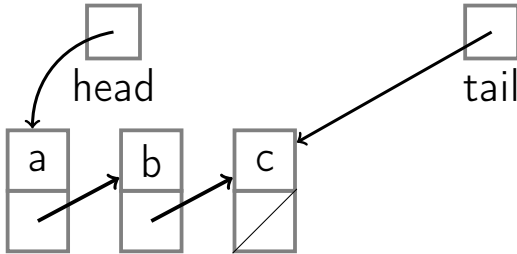
Enqueue(c)

Queue Implementation with Linked List

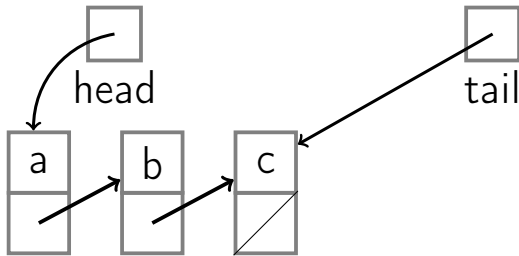


Enqueue(c)

Queue Implementation with Linked List

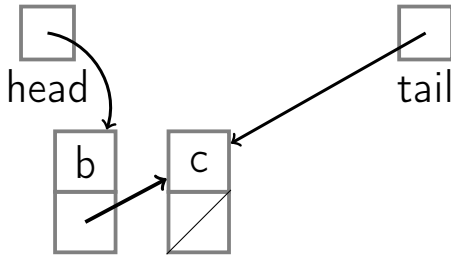


Queue Implementation with Linked List



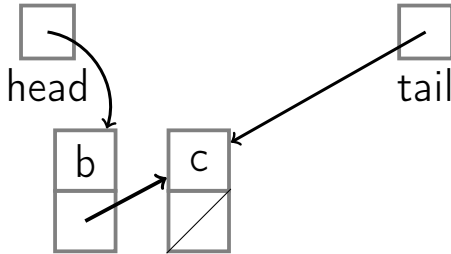
Dequeue()

Queue Implementation with Linked List

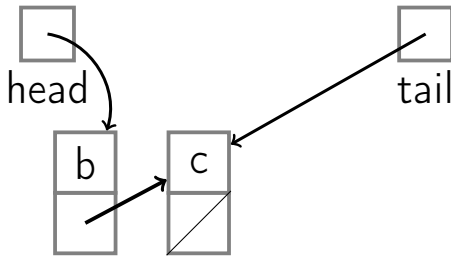


Dequeue() \rightarrow a

Queue Implementation with Linked List

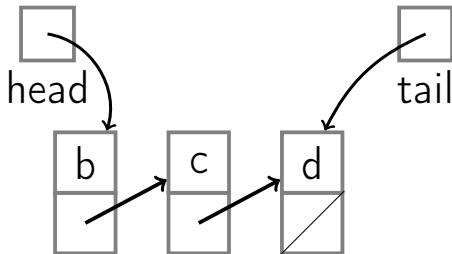


Queue Implementation with Linked List



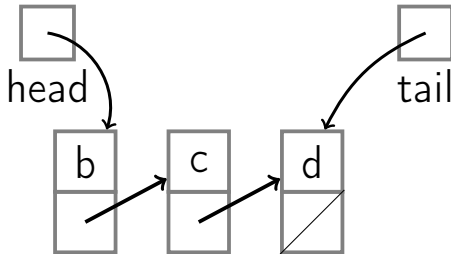
Enqueue(d)

Queue Implementation with Linked List

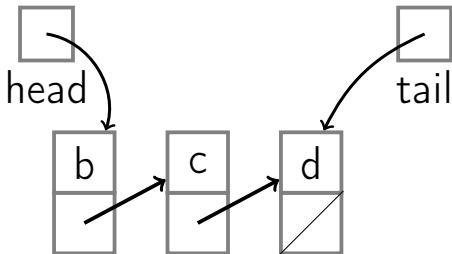


Enqueue(d)

Queue Implementation with Linked List

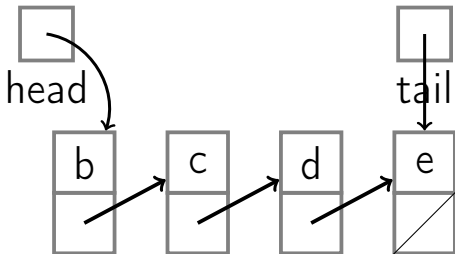


Queue Implementation with Linked List



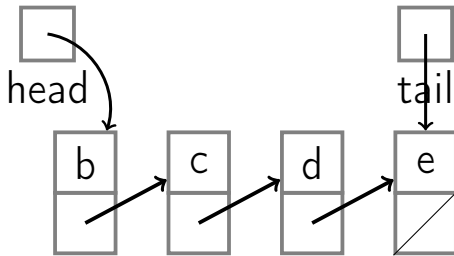
Enqueue(e)

Queue Implementation with Linked List

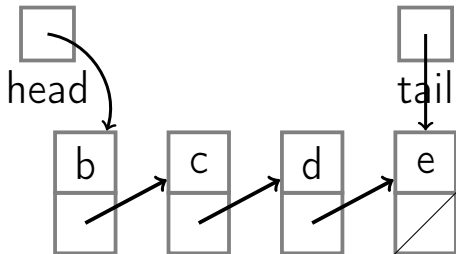


Enqueue(e)

Queue Implementation with Linked List

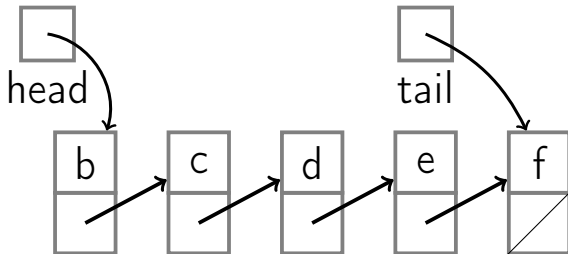


Queue Implementation with Linked List



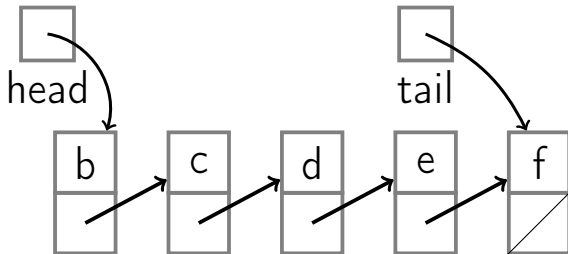
Enqueue(f)

Queue Implementation with Linked List

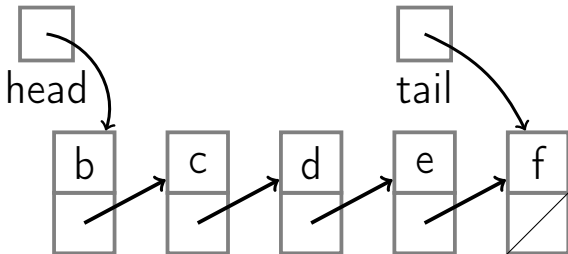


Enqueue(f)

Queue Implementation with Linked List

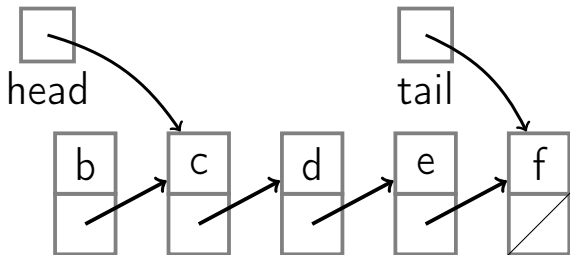


Queue Implementation with Linked List



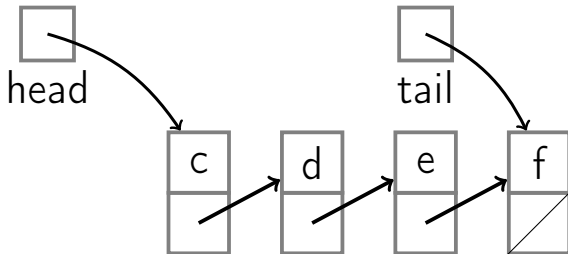
Dequeue()

Queue Implementation with Linked List

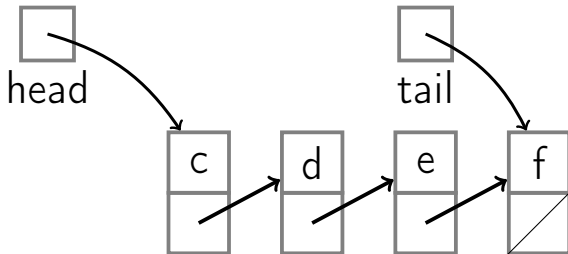


Dequeue() → b

Queue Implementation with Linked List

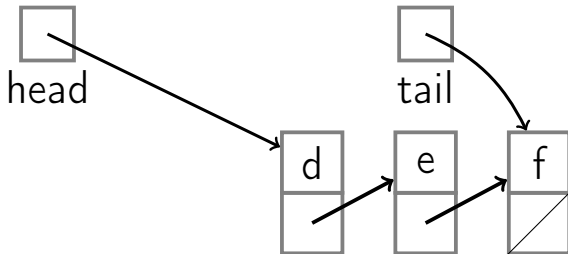


Queue Implementation with Linked List



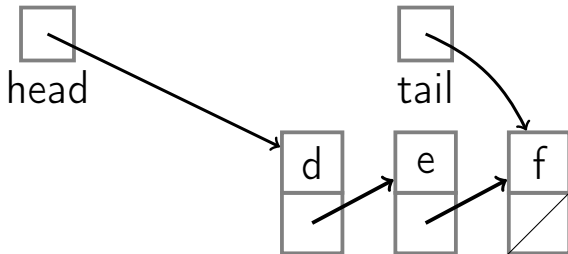
Dequeue()

Queue Implementation with Linked List

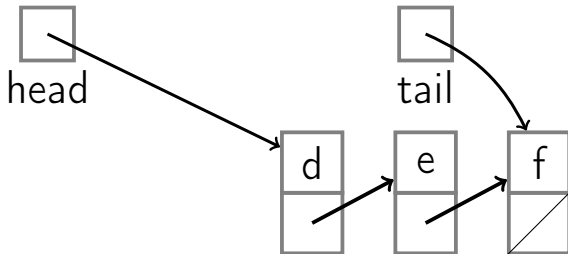


Dequeue() \rightarrow c

Queue Implementation with Linked List

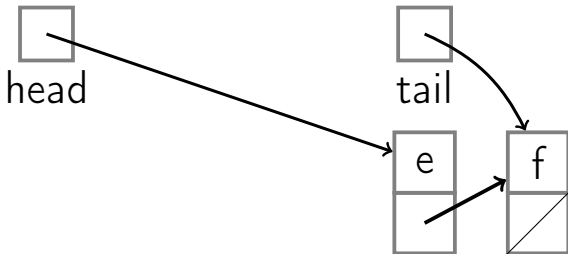


Queue Implementation with Linked List



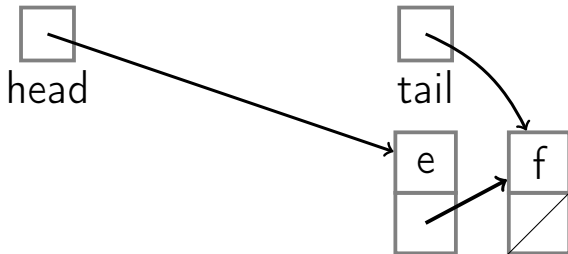
Dequeue()

Queue Implementation with Linked List

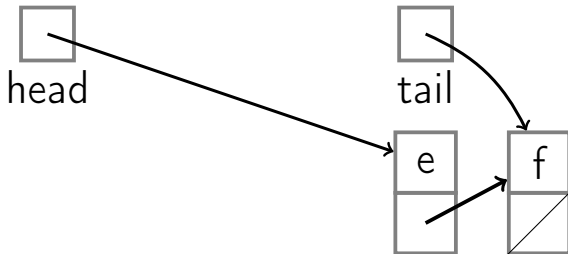


`Dequeue()` \rightarrow d

Queue Implementation with Linked List

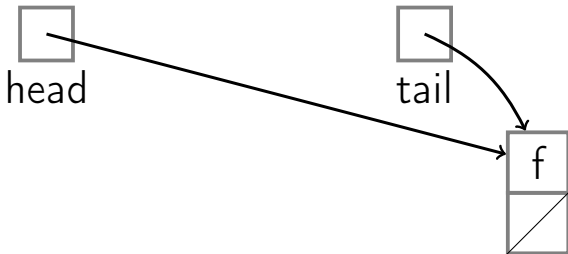


Queue Implementation with Linked List



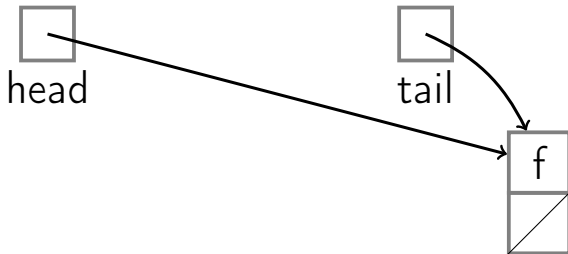
`Dequeue()`

Queue Implementation with Linked List

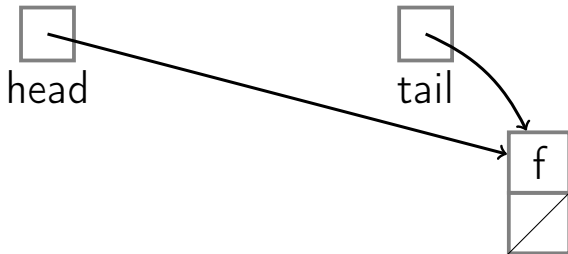


`Dequeue()` \rightarrow e

Queue Implementation with Linked List



Queue Implementation with Linked List



Dequeue()

Queue Implementation with Linked List



head



tail

Dequeue() \rightarrow f

Queue Implementation with Linked List



head



tail

Queue Implementation with Linked List



head



tail

Empty()

Queue Implementation with Linked List



head



tail

`Empty()` \rightarrow `True`

Queue Implementation with Linked List



head



tail

Queue Implementation with Linked List

- Enqueue: use `List.PushBack`

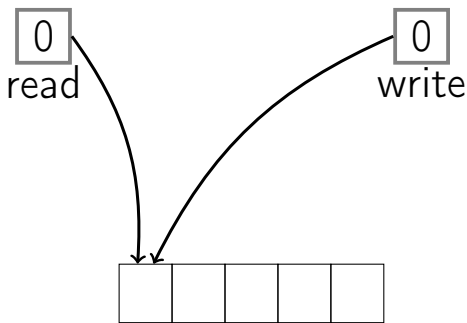
Queue Implementation with Linked List

- Enqueue: use `List.PushBack`
- Dequeue: use `List.TopFront` and `List.PopFront`

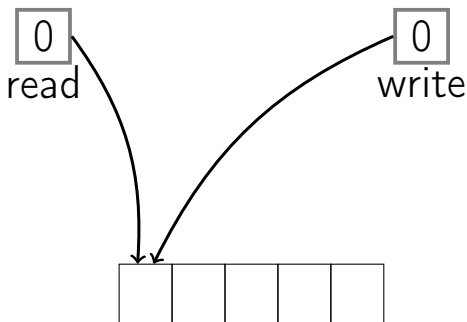
Queue Implementation with Linked List

- Enqueue: use `List.PushBack`
- Dequeue: use `List.TopFront` and `List.PopFront`
- Empty: use `List.Empty`

Queue Implementation with Array

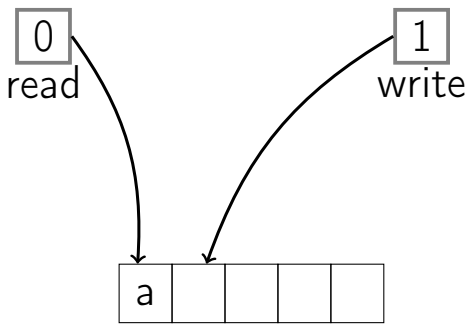


Queue Implementation with Array



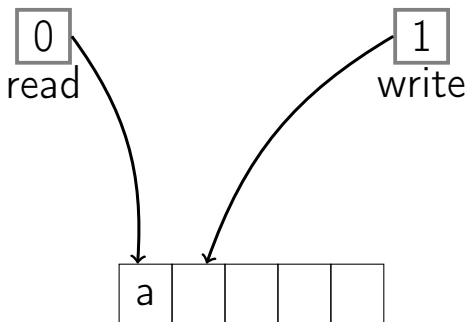
Enqueue(a)

Queue Implementation with Array

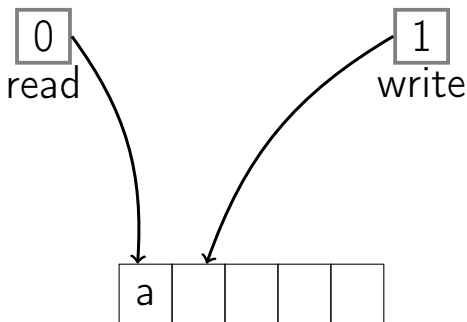


Enqueue(a)

Queue Implementation with Array

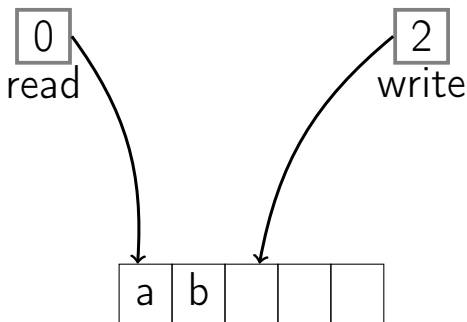


Queue Implementation with Array



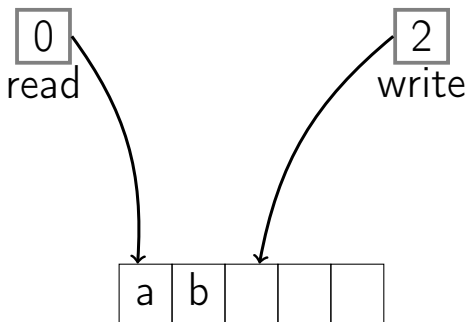
Enqueue(b)

Queue Implementation with Array

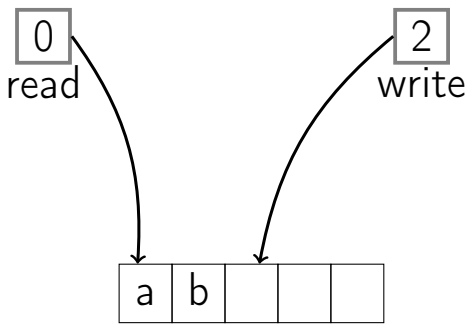


Enqueue(b)

Queue Implementation with Array

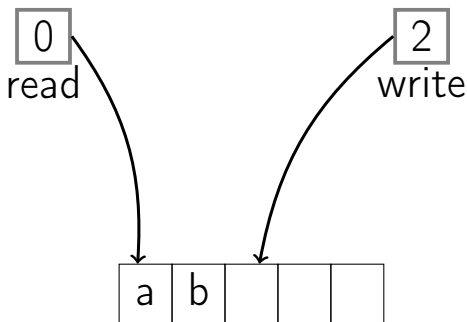


Queue Implementation with Array



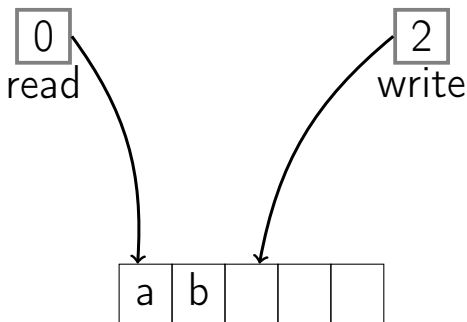
Empty()

Queue Implementation with Array

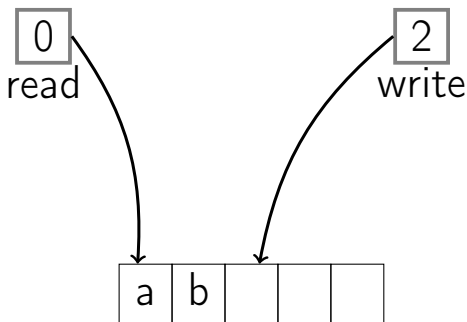


`Empty()` \rightarrow `False`

Queue Implementation with Array

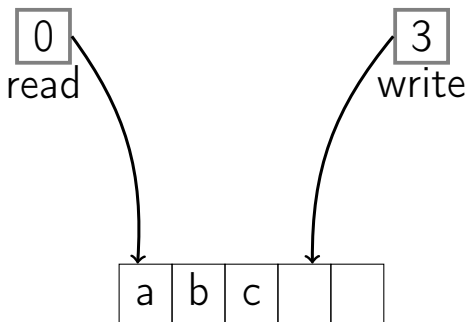


Queue Implementation with Array



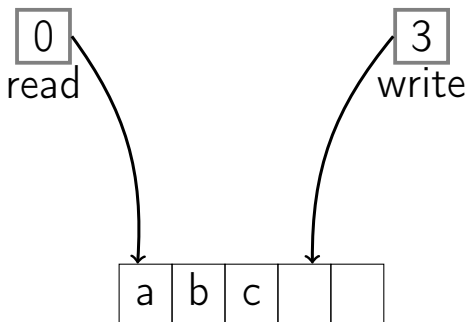
Enqueue(c)

Queue Implementation with Array

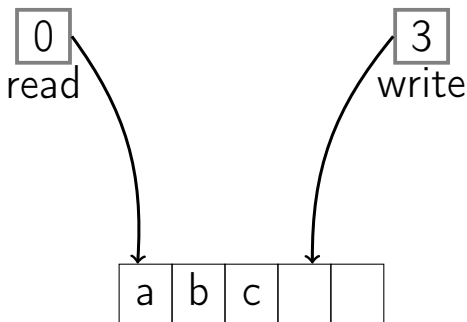


Enqueue(c)

Queue Implementation with Array

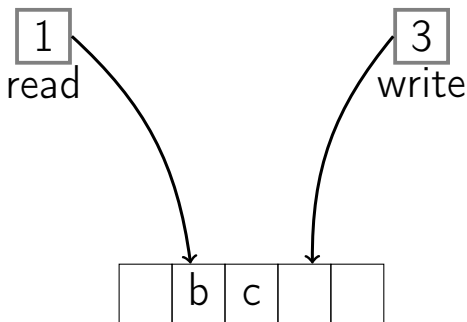


Queue Implementation with Array



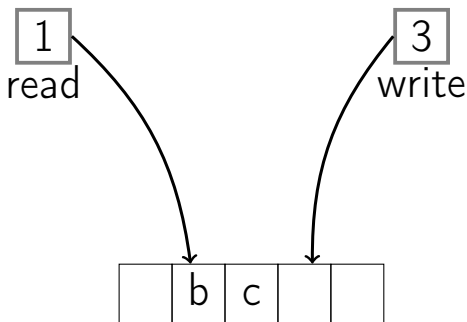
Dequeue()

Queue Implementation with Array

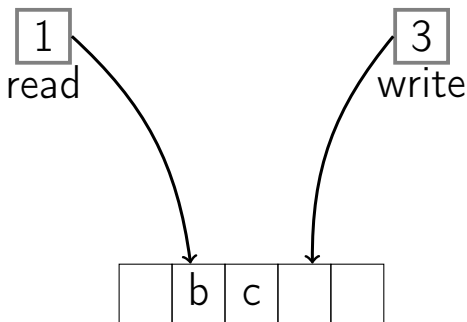


Dequeue() \rightarrow a

Queue Implementation with Array

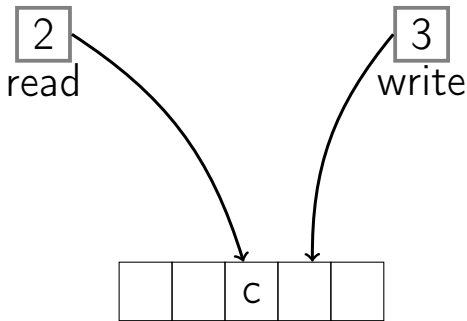


Queue Implementation with Array



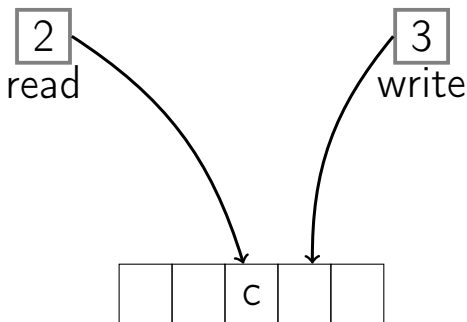
Dequeue()

Queue Implementation with Array

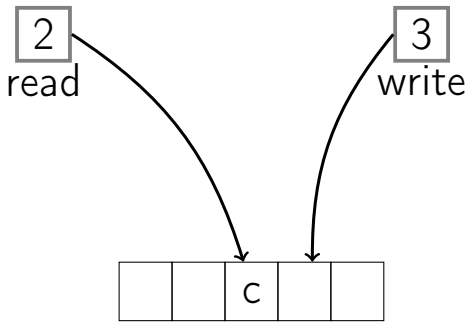


Dequeue() \rightarrow b

Queue Implementation with Array

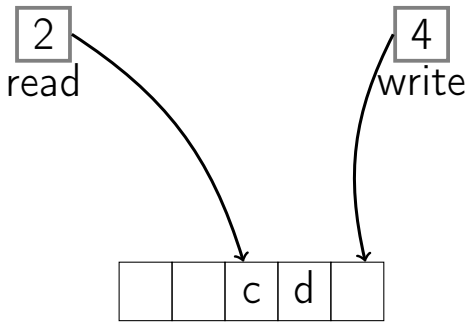


Queue Implementation with Array



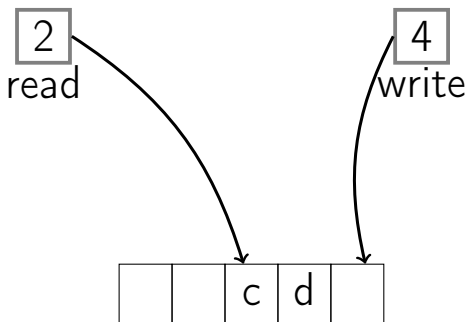
Enqueue(d)

Queue Implementation with Array

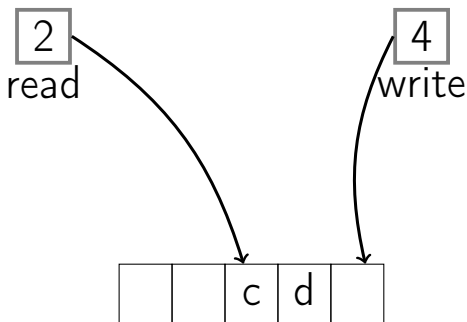


Enqueue(d)

Queue Implementation with Array

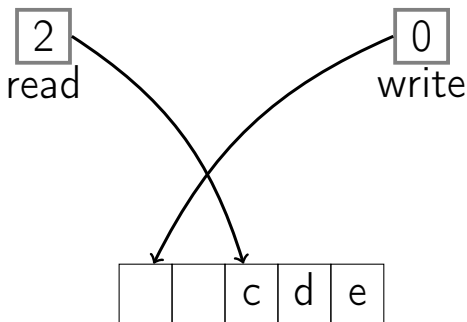


Queue Implementation with Array



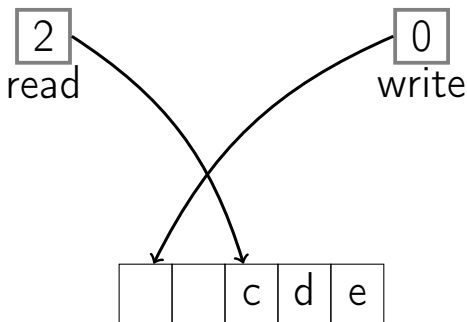
Enqueue(e)

Queue Implementation with Array

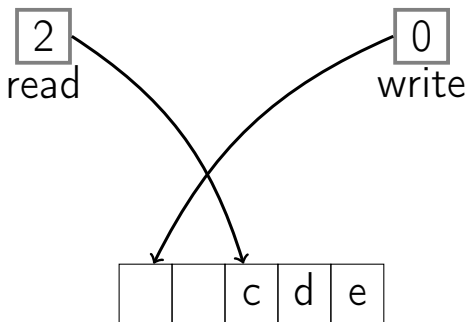


Enqueue(e)

Queue Implementation with Array

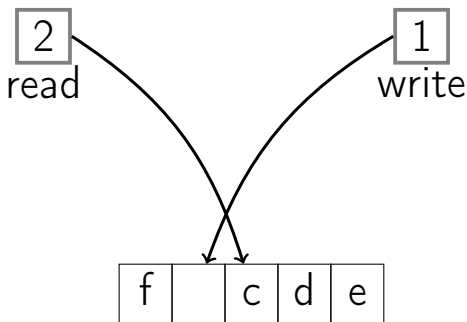


Queue Implementation with Array



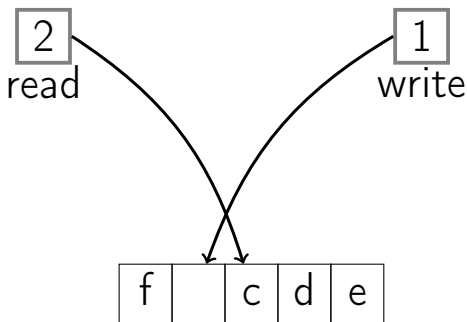
Enqueue(f)

Queue Implementation with Array

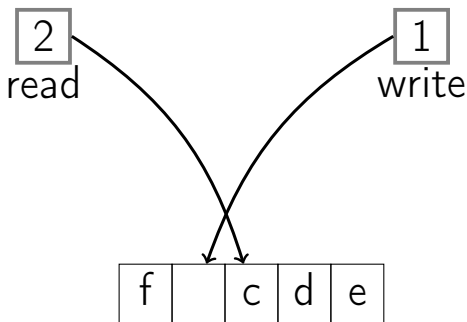


Enqueue(f)

Queue Implementation with Array

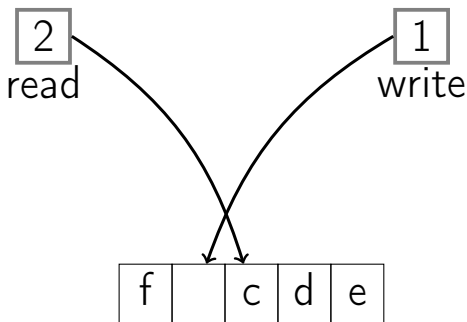


Queue Implementation with Array



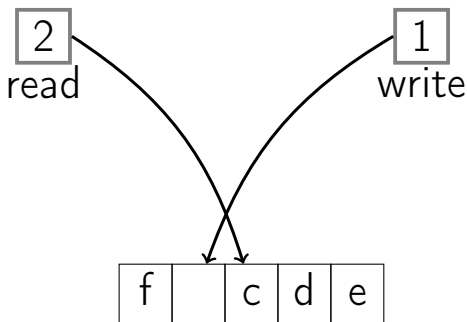
Enqueue(g)

Queue Implementation with Array

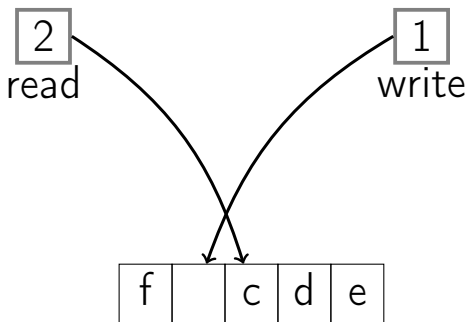


Enqueue(g) \rightarrow ERROR

Queue Implementation with Array

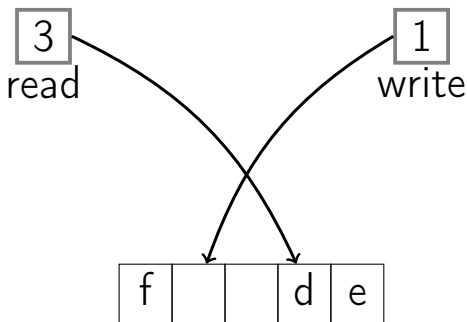


Queue Implementation with Array



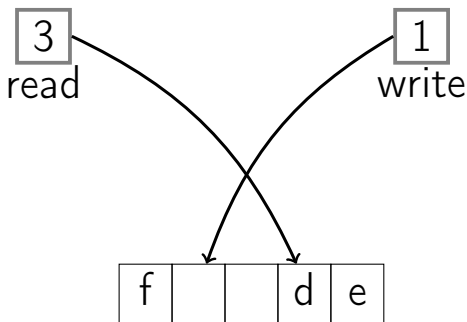
Dequeue()

Queue Implementation with Array

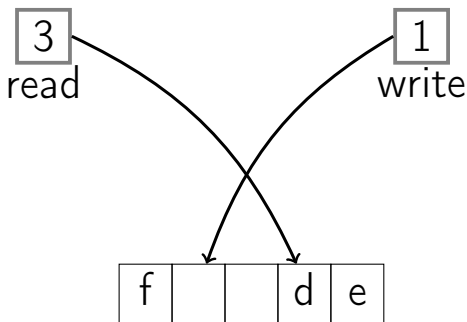


Dequeue() \rightarrow c

Queue Implementation with Array

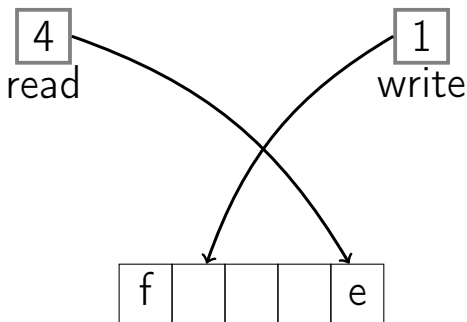


Queue Implementation with Array



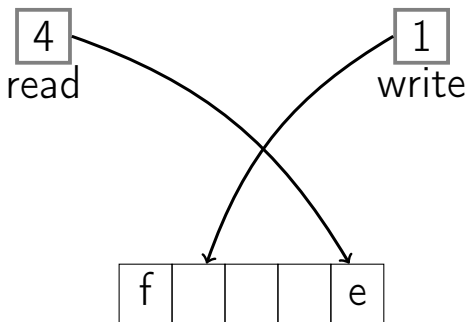
Dequeue()

Queue Implementation with Array

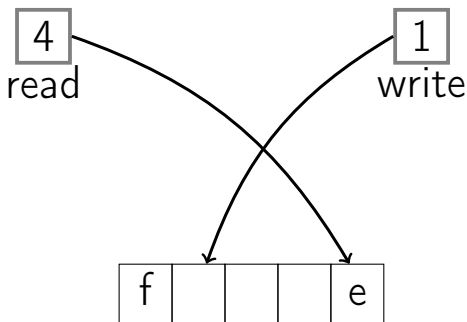


Dequeue() \rightarrow d

Queue Implementation with Array

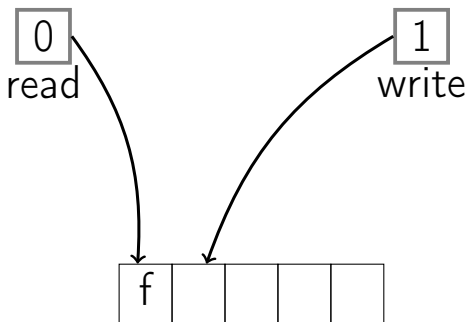


Queue Implementation with Array



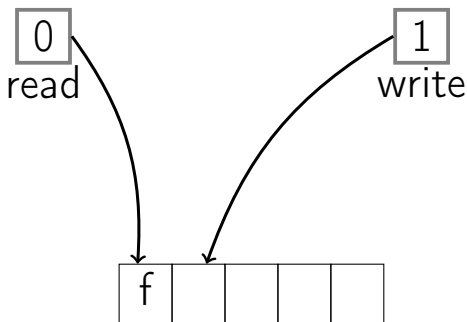
Dequeue()

Queue Implementation with Array

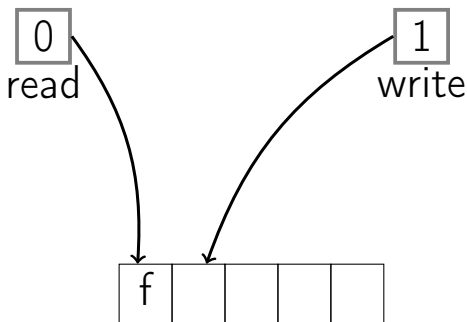


Dequeue() \rightarrow e

Queue Implementation with Array

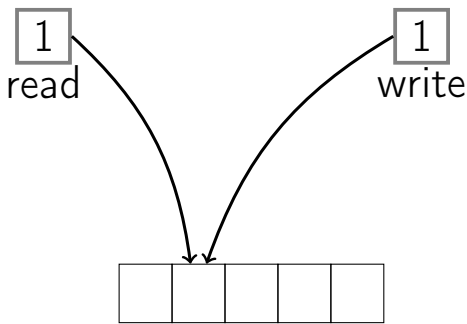


Queue Implementation with Array



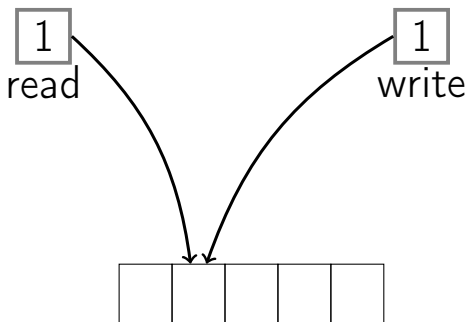
Dequeue()

Queue Implementation with Array

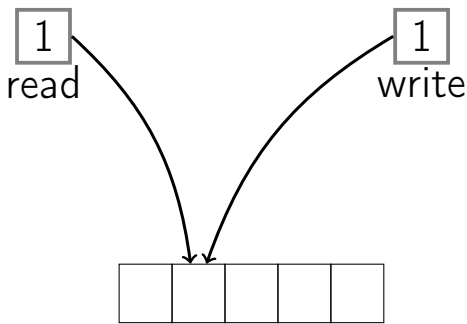


Dequeue() \rightarrow f

Queue Implementation with Array

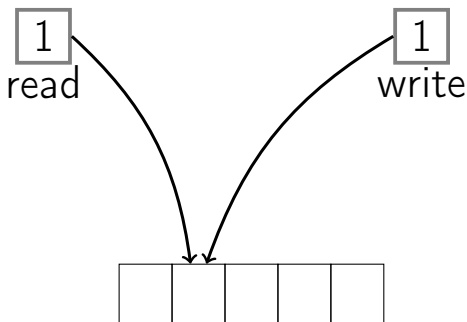


Queue Implementation with Array



Empty()

Queue Implementation with Array



`Empty() → True`

Summary

Summary

- Queues can be implemented with either a linked list (with tail pointer) or an array.

Summary

- Queues can be implemented with either a linked list (with tail pointer) or an array.
- Each queue operation is $O(1)$: Enqueue, Dequeue, Empty.