Chapter 7

Stacks and Queues

Stacks and queues are linear data structures that store lists of values. They differ in the operations that store and retrieve the data.

Stacks store data with the `push()` operation and retrieve data with the `pop()` operation. The order is last-in first-out, so stacks are known as LIFO lists. Queues store data with the `enqueue()` operation and retrieve data with the `dequeue()` operation. The order is first-in first-out, so queues are known as FIFO lists.

7.1 Abstract Stacks and Queues

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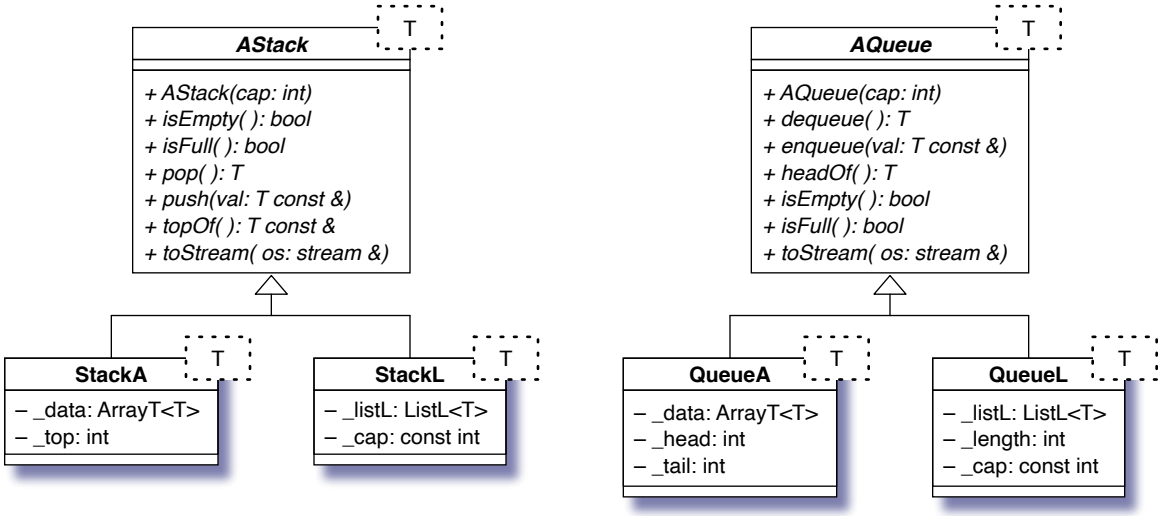

(a) Abstract and concrete stacks.

(b) Abstract and concrete queues.

Figure 7.1 The UML diagram of abstract and concrete stacks and queues.

language.

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7.2 Array Implementations

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The array implementation of a stack

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Hello, here is some text without a meaning. This text should show what a printed


```
// ========= StackA =========
template<class T>
class StackA : public AStack<T> {
private:
    ArrayT<T> _data;
    int _top;

public:
    explicit StackA(int cap = 1);
    // Post: This stack is allocated with a capacity of cap
    // and initialized to be empty.

    bool isEmpty() const override;
    // Post: true is returned if this stack is empty;
    // otherwise, false is returned.

    bool isFull() const override;
    // Post: true is returned if this stack is full;
    // otherwise, false is returned.

    T pop() override;
    // Pre: This stack is not empty.
    // Post: The top value in this stack is removed and returned.

    void push(T const &val) override;
    // Pre: This stack is not full.
    // Post: val is stored on top of this stack.

    T const &topOf() const override;
    // Pre: This stack is not empty.
    // Post: The top value from this stack is returned.

    void toStream(ostream &os) const override;
    // Post: All the items on this stack from top to bottom
    // are written to os.
};
```

Figure 7.2 `StackA.hpp`. Specification for the `StackA` data structure. The listing continues in the next figure.

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```
// ========= Constructor =========
template<class T>
StackA<T>::StackA(int cap):
    _data(cap),
    _top(-1) {
}

// ========= isEmpty =========
template<class T>
bool StackA<T>::isEmpty() const {
    cerr << "isEmpty: Exercise for the student." << endl;
    throw -1;
}

// ========= isFull =========
template<class T>
bool StackA<T>::isFull() const {
    cerr << "isFull: Exercise for the student." << endl;
    throw -1;
}

// ========= pop =========
template<class T>
T StackA<T>::pop() {
    if (isEmpty()) {
        cerr << "pop precondition violated: "
             << "Cannot pop from an empty stack." << endl;
        throw -1;
    }
    cerr << "pop: Exercise for the student." << endl;
    throw -1;
}

// ========= push =========
template<class T>
void StackA<T>::push(T const &val) {
    cerr << "push: Exercise for the student." << endl;
    throw -1;
}
```

Figure 7.3 `StackA.hpp` (continued). Operations for the `StackA` data structure. The listing continues in the next figure.


```
// ========= topOf =========
template<class T>
T const &StackA<T>::topOf() const {
    if (isEmpty()) {
        cerr << "topOf precondition violated: "
             << "An empty stack has no top." << endl;
        throw -1;
    }
    cerr << "topOf: Exercise for the student." << endl;
    throw -1;
}

// ========= operator<< =========
template<class T>
ostream &operator<<(ostream &os, StackA<T> const &rhs) {
    rhs.toStream(os);
    return os;
}

// ========= toStream =========
template<class T>
void StackA<T>::toStream(ostream &os) const {
    os << "(";
    for (int i = _top; i > 0; i--) {
        os << _data[i] << ", ";
    }
    if (_top == -1) {
        os << ")";
    }
    else {
        os << _data[0] << ")";
    }
}
```

Figure 7.4 `StackA.hpp` (continued). Output for the `StackA` data structure. This concludes the listing.

language.

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

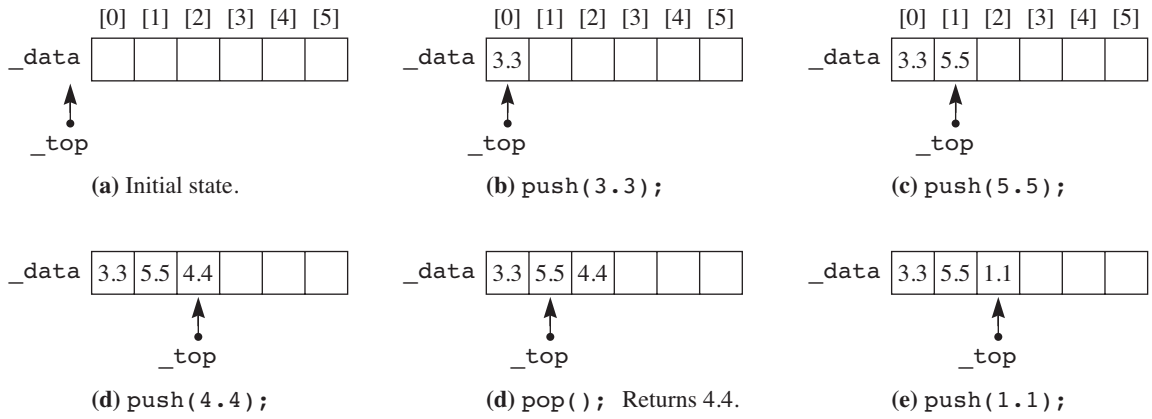

Figure 7.5 Action of `push()` and `pop()` with the `StackA` data structure.

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The circular queue

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Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really?


```
// ========= QueueA =========
template<class T>
class QueueA : public AQueue<T> {
private:
    ArrayT<T> _data;
    int _head, _tail;

public:
    explicit QueueA(int cap = 1);
    // Post: This queue is allocated with a capacity of cap
    // and initialized to be empty.

    T dequeue() override;
    // Pre: This queue is not empty.
    // Post: The head value in this queue is removed and returned.

    void enqueue(T const &val) override;
    // Pre: This queue is not full.
    // Post: val is stored at the tail of this queue.

    T const &headOf() const override;
    // Pre: This queue is not empty.
    // Post: The head value from this queue is returned.

    bool isEmpty() const override;
    // Post: true is returned if this queue is empty;
    // otherwise, false is returned.

    bool isFull() const override;
    // Post: true is returned if this queue is full;
    // otherwise, false is returned.

    void toStream(ostream &os) const override;
    // Post: All the items on this queue from tail to head
    // are written to os.
};
```

Figure 7.6 `QueueA.hpp`. Specification for the `QueueA` data structure. The listing continues in the next figure.

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```
// ========= Constructor =========
template<class T>
QueueA<T>::QueueA(int cap) :
    _data(cap + 1),
    _head(0),
    _tail(0) {
}

// ========= operator<< =========
template<class T>
ostream &operator<<(ostream &os, QueueA<T> const &rhs) {
    rhs.toStream(os);
    return os;
}

// ========= toStream =========
template<class T>
void QueueA<T>::toStream(ostream &os) const {
    cerr << "toStream: Exercise for the student." << endl;
    throw -1;
}
```

Figure 7.7 `QueueA.hpp` (continued). Constructor and output for the `QueueA` data structure. Operations that are exercises for the student are not shown. This concludes the listing.

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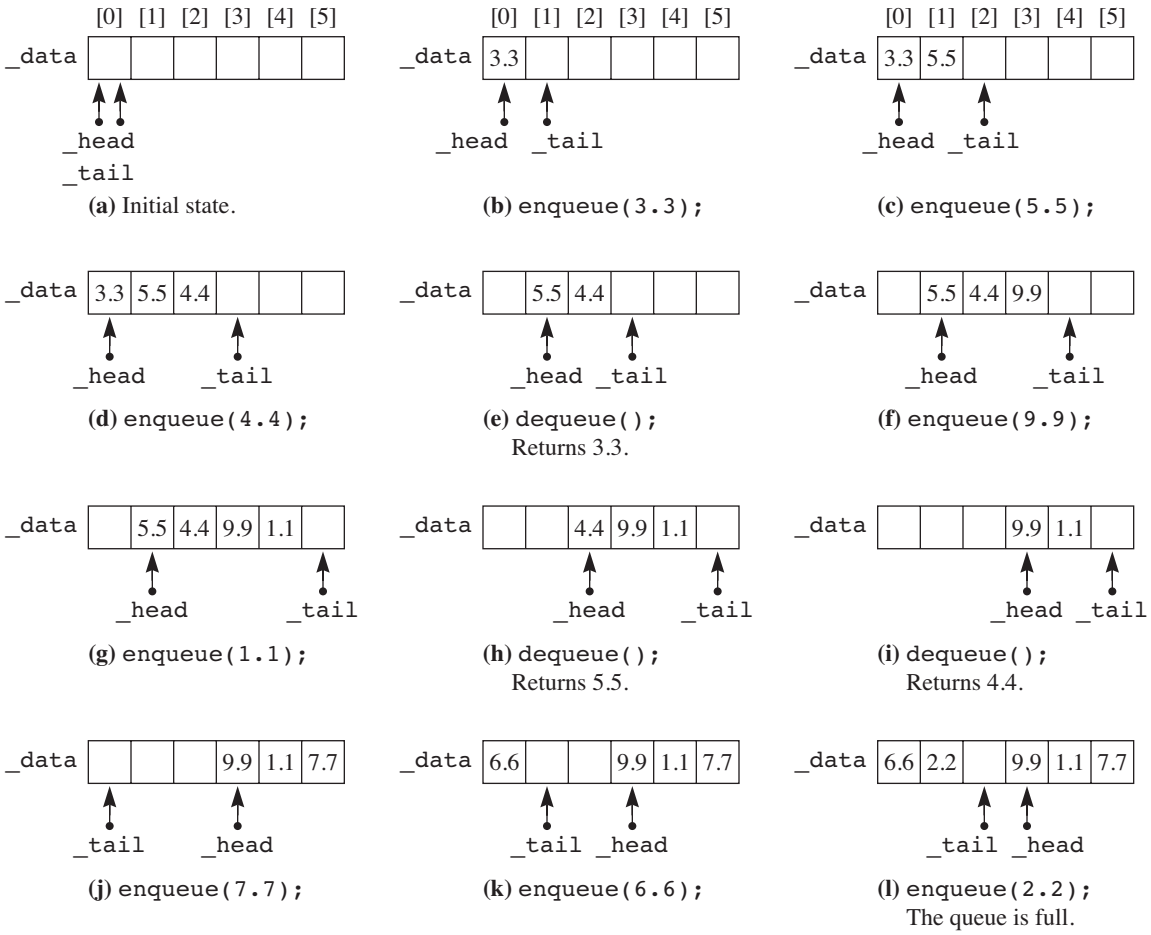

Figure 7.8 Action of `enqueue()` and `dequeue()` with the `QueueA` data structure.

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7.3 The Adapter Pattern

The adapter pattern is also known as a wrapper.

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The list implementation of a stack

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Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really?

```
// ========= StackL =========
template<class T>
class StackL : public AStack<T> {
private:
    ListL<T> _listL;
    const int _cap;

public:
    StackL(int cap = 1);
    // This stack is initialized to be empty.

    bool isEmpty() const override;
    // Post: true is returned if this stack contains no element;
    // otherwise, false is returned.

    bool isFull() const override;
    // Post: true is returned if the number of elements in this stack
    // is equal to its cap;
    // otherwise, false is returned.

    T pop() override;
    // Pre: This stack is not empty.
    // Post: The top value in this stack is removed and returned.

    void push(T const &val) override;
    // Post: val is stored on top of this stack.

    T const &topOf() const override;
    // Pre: This stack is not empty.
    // Post: The top value from this stack is returned.

    void toStream(ostream &os) const override;
    // Post: All the items on this stack from top to bottom
    // are written to os.
};
```

Figure 7.9 `StackL.hpp`. Specification for the `StackL` data structure. The listing continues in the next figure.

Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

Hello, here is some text without a meaning. This text should show what a printed

```
// ========= Constructor =========
template<class T>
StackL<T>::StackL(int cap):
    _listL(),
    _cap(cap) {
}

// ========= isEmpty =========
template<class T>
bool StackL<T>::isEmpty() const {
    return _listL.isEmpty();
}

// ========= isFull =========
template<class T>
bool StackL<T>::isFull() const {
    return _listL.length() == _cap;
}

// ========= push =========
template<class T>
void StackL<T>::push(const T &val) {
    if (isFull()) {
        cerr << "push precondition violated: "
             << "Cannot push onto a full stack." << endl;
        throw -1;
    }
    _listL.prepend(val);
}

// ========= operator<< =========
template<class T>
ostream &operator<<(ostream &os, StackL<T> const &rhs) {
    rhs.toStream(os);
    return os;
}

// ========= toStream =========
template<class T>
void StackL<T>::toStream(ostream &os) const {
    _listL.toStream(os);
}
```

Figure 7.10 `StackL.hpp` (continued). Operations for the `StackL` data structure. Operations that are exercises for the student are not shown. This concludes the listing.


```
// ========= QueueL =========
template<class T>
class QueueL : public AQueue<T> {
private:
    // Attribute is exercise for the student.

public:
    QueueL(int cap = 1);
    // This queue is allocated and initialized to be empty.

    T dequeue() override;
    // Pre: This queue is not empty.
    // Post: The head value in this queue is removed and returned.

    void enqueue(T const &val) override;
    // Post: val is stored at the tail of this queue.

    T const &headOf() const override;
    // Pre: This queue is not empty.
    // Post: The head value from this queue is returned.

    bool isEmpty() const override;
    // Post: true is returned if this queue contains no element;
    // otherwise, false is returned.

    bool isFull() const override;
    // Post: true if the number of elements contained
    // in this queue is equal to the queue's capacity;
    // otherwise false is returned.

    void toStream(ostream &os) const override;
    // Post: All the items on this queue from tail to head
    // are written to os.
};
```

Figure 7.11 `QueueL.hpp`. Specification for the `QueueL` data structure. The implementation is an exercise for the student and is not shown.

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The list implementation of a queue

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language. There is no need for special content, but the length of words should match the language.

7.4 The Priority Queue

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

The heap implementation of a priority queue

This is the second paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

And after the second paragraph follows the third paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

After this fourth paragraph, we start a new paragraph sequence. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

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```
// ========= PriorityQ =========
template<class T>
class PriorityQ {
private:
    ArrayT<T> _data;
    int _hiIndex;

public:
    PriorityQ(int cap);
    // Post: This priority queue is allocated with a capacity of cap
    // and initialized to be empty.

    T extractMax();
    // Pre: This priority queue is not empty.
    // Post: The maximum value in this priority queue is removed
    // and returned.

    int heapSize() const;
    // Post: The size of this priority queue is returned.

    void increaseKey(int i, T const &key);
    // Pre: This priority queue is not empty, 0 <= i < heapSize(),
    // and key is at least as large as the key at index i.
    // Post: The value of the element at index i is increased to key.

    void insert(T const &val);
    // Pre: This priority queue is not full.
    // Post: val is stored in this priority queue.

    bool isEmpty() const;
    // Post: true is returned if this priority queue is full;
    // otherwise, false is returned.

    bool isFull() const;
    // Post: true is returned if this priority queue is full;
    // otherwise, false is returned.

    T const &maximum() const;
    // Pre: This priority queue is not empty.
    // Post: The maximum value from this priority queue is returned.

    void toStream(ostream &os) const;
    // Post: Each item on this priority queue prefixed with its index
    // is written to os.
};
```

Figure 7.12 `PriorityQ.hpp`. Specification for the `PriorityQ` data structure.

language. There is no need for special content, but the length of words should match the language.

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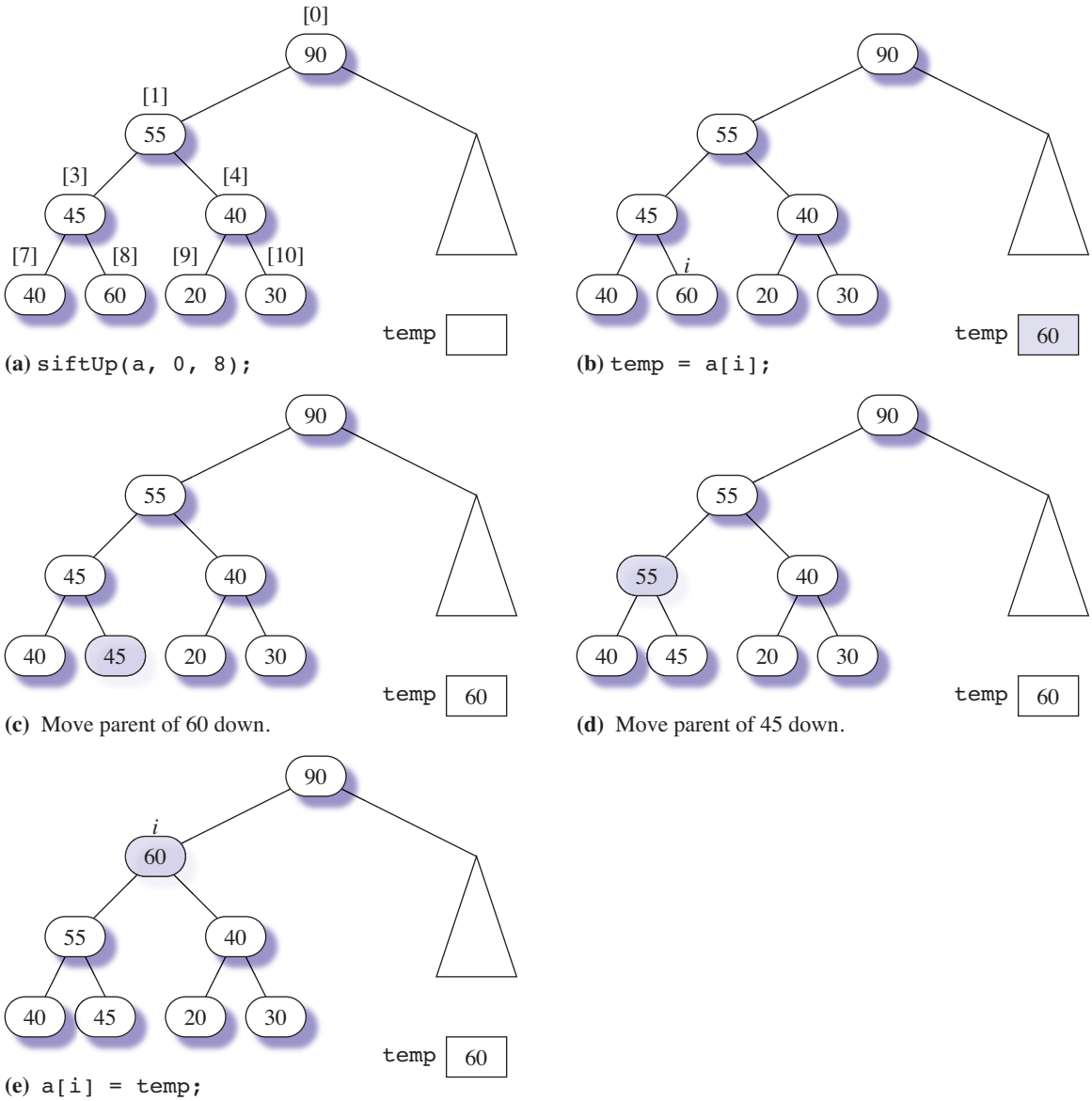

Figure 7.13 Action of `siftUp()` with the `PriorityQ` data structure.

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```
// ========= siftUp =========
template<class T>
void siftUp(ASeq<T> &a, int lo, int i) {
    // Pre: maxHeap(a[lo..i - 1]).
    // Post: maxHeap(a[lo..i]).
    T temp = a[i];
    int parent = (i + lo - 1) / 2;
    while (lo < i && a[parent] < temp) {
        cerr << ”siftUp: Exercise for the student.” << endl;
        throw -1;
    }
    a[i] = temp;
}
```

Figure 7.14 `Heapifier.hpp` in the `ASorter` project. Implementation of the `siftUp()` function.

about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

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Hello, here is some text without a meaning. This text should show what a printed

```
// ========= Constructor =========
template<class T>
PriorityQ<T>::PriorityQ(int cap) :
    _data(cap),
    _hiIndex(-1) {
}

// ========= heapSize =========
template<class T>
int PriorityQ<T>::heapSize() const {
    return _hiIndex + 1;
}

// ========= insert =========
template<class T>
void PriorityQ<T>::insert(T const &val) {
    if (isFull()) {
        cerr << "insert precondition violated: "
             << "Cannot insert into a full priority queue." << endl;
        throw -1;
    }
    _data[++_hiIndex] = val;
    siftUp(_data, 0, _hiIndex);
}

// ========= isEmpty =========
template<class T>
bool PriorityQ<T>::isEmpty() const {
    return _hiIndex == -1;
}

// ========= maximum =========
template<class T>
T const &PriorityQ<T>::maximum() const {
    if (isEmpty()) {
        cerr << "maximum precondition violated: "
             << "An empty priority queue has no maximum." << endl;
        throw -1;
    }
    return _data[0];
}
```

Figure 7.15 `PriorityQ.hpp` (continued). Operations for the `PriorityQ` data structure. Operations that are exercises for the student are not shown. The listing continues in the next figure.


```
// ========= operator<< =========
template<class T>
ostream &operator<<(ostream &os, PriorityQ<T> const &rhs) {
    rhs.toStream(os);
    return os;
}

// ========= toStream =========
template<class T>
void PriorityQ<T>::toStream(ostream &os) const {
    for (int i = 0; i <= _hiIndex; i++) {
        os << i << ":" << _data[i] << "  ";
    }
}
```

Figure 7.16 `PriorityQ.hpp` (continued). The output operations for the `PriorityQ` data structure. This concludes the listing.

text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

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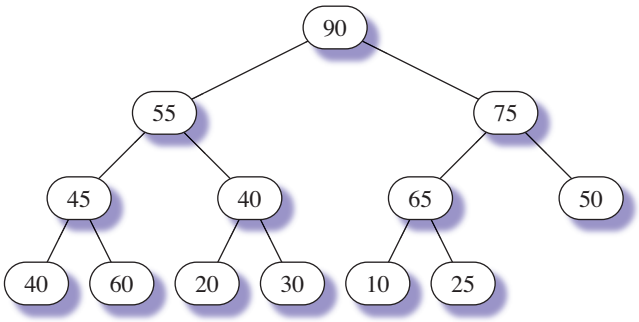
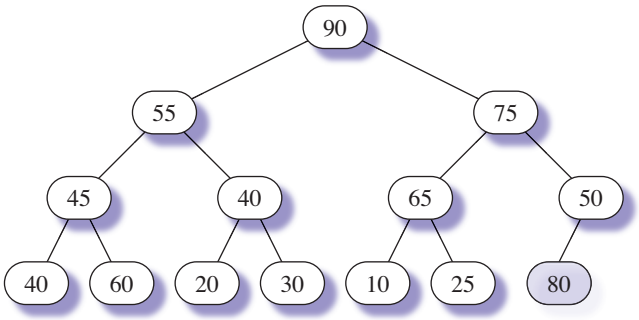
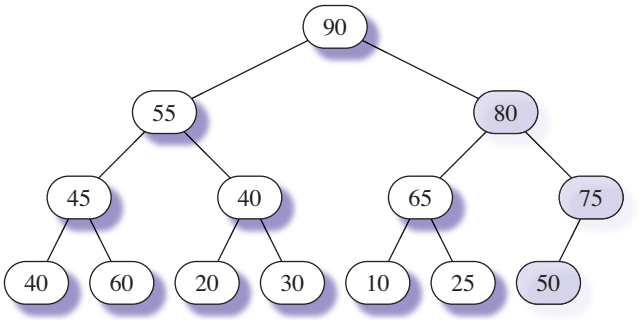


(a) `insert(80);`



(b) `_data[++_hiIndex] = val;`



(c) `siftUp(_data, 0, _hiIndex);`

Figure 7.17 Action of `insert()` with the `PriorityQ` data structure.

text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

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about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

Exercises

7–1 What is the worst case asymptotic bound $\Theta(n)$, where n is the number of elements stored in the data structure, for each of the following operations?

(a) `push()` for the `StackA` data structure.

(b) `pop()` for the `StackA` data structure.

(c) `enqueue()` for the `QueueA` data structure.

(d) `dequeue()` for the `QueueA` data structure.

(e) `push()` for the `StackL` data structure.

(f) `pop()` for the `StackL` data structure.

(g) `enqueue()` for the `StackL` data structure.

(h) `dequeue()` for the `StackL` data structure.

(i) `insert()` for the `PriorityQ` data structure.

(j) `extractMax()` for the `PriorityQ` data structure.

(k) `maximum()` for the `PriorityQ` data structure.

(l) `increaseKey()` for the `PriorityQ` data structure.

7–2 Implement the methods `isEmpty()`, `isFull()`, `push()`, `pop()`, and `topOf()` for the `StackA` data structure.

7–3 Implement the methods `isEmpty()`, `isFull()`, `enqueue()`, `dequeue()`, `headOf()`, and `toStream()` for the `QueueA` data structure.

7–4 Implement the methods `pop()` and `topOf()` for the `StackL` data structure.

7–5 Implement the attributes, the constructor, and the methods `isEmpty()`, `isFull()`, `enqueue()`, `dequeue()`, `headOf()`, `operator<<()`, and `toStream()` for the `QueueL` data structure.

7–6 Implement the methods `isFull()`, `siftUp()`, `extractMax()`, and `increaseKey()` for the `PriorityQ` data structure.

