Maps,

Java: Collections, Exceptions

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Programming Language Concepts

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Abstract data types

- Separate public interface from private implementation

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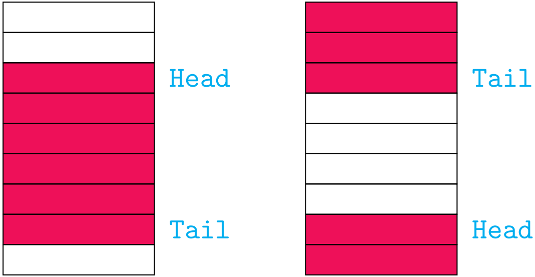
- For instance, a (generic) queue

```
public class Queue<E> {
  public void add (E element){...};
  public E remove(){...};
  public int size(){...};
  ...
}
```

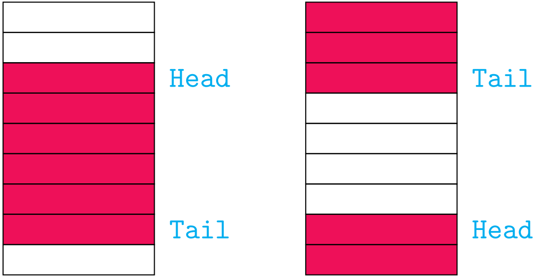
Abstract data types

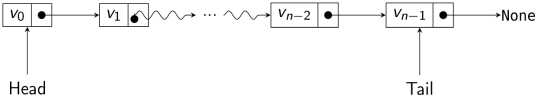
- Separate public interface from private implementation
- For instance, a (generic) queue
- Concrete implementation could be a circular array



Abstract data types

- Separate public interface from private implementation
- For instance, a (generic) queue
- Concrete implementation could be a circular array
- Or a linked list





Abstract data types

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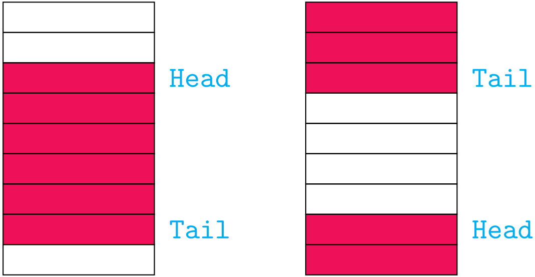
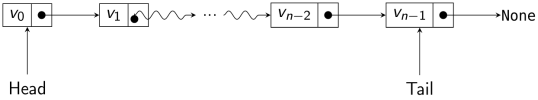
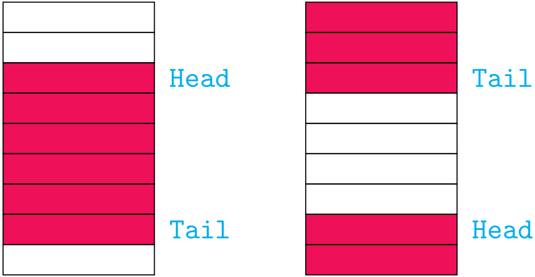
- Or a linked list
- Implementer of class `Queue` can choose either one

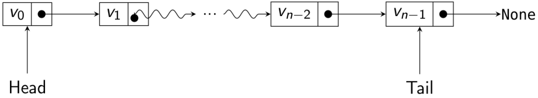




Abstract data types

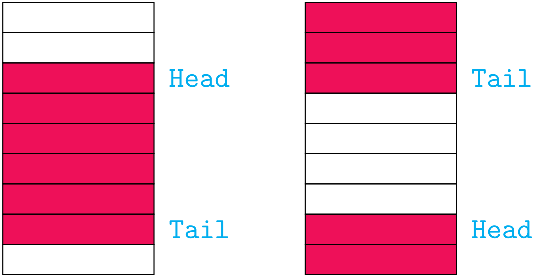
- Separate public interface from private implementation
- For instance, a (generic) queue
- Concrete implementation could be a circular array
- Or a linked list
- Implementer of class Queue can choose either one
- Public interface is unchanged

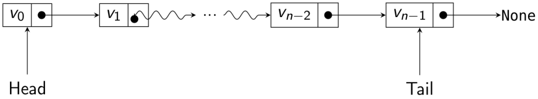




Abstract data types . . .

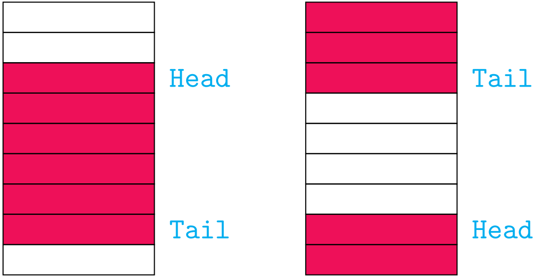
- Is the user indifferent to choice of implementation?

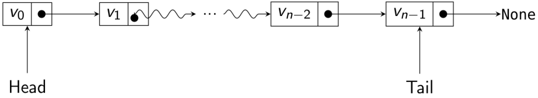




Abstract data types . . .

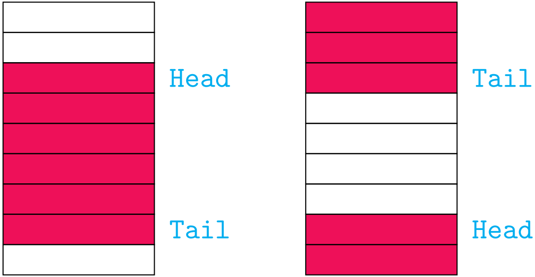
- Is the user indifferent to choice of implementation?
- Interface does not capture other aspects

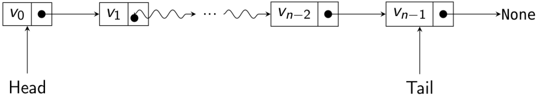




Abstract data types . . .

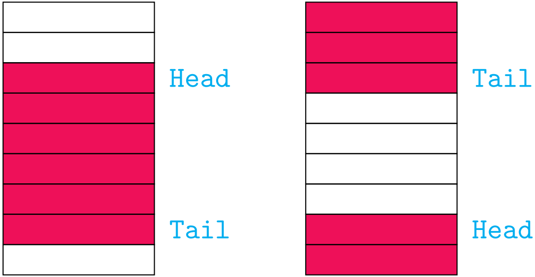
- Is the user indifferent to choice of implementation?
- Interface does not capture other aspects
- Efficiency
  - Circular array is better — one time storage allocation

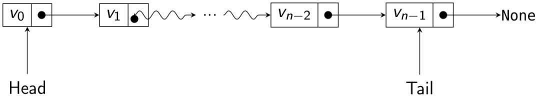




Abstract data types . . .

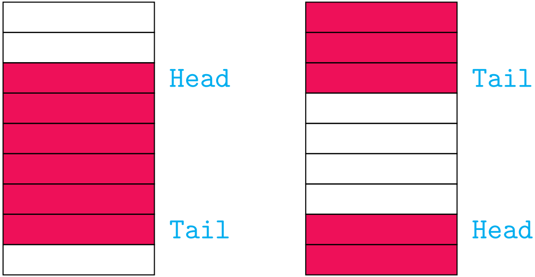
- Is the user indifferent to choice of implementation?
- Interface does not capture other aspects
- Efficiency
    - Circular array is better — one time storage allocation
- Flexibility
    - Linked list is better — circular array has bounded size

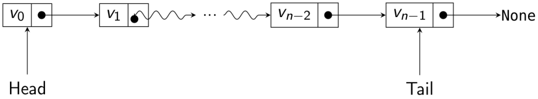




Abstract data types . . .

- Is the user indifferent to choice of implementation?
- Interface does not capture other aspects
- Efficiency
  - Circular array is better — one time storage allocation
- Flexibility
  - Linked list is better — circular array has bounded size
- Offer user a choice of implementation?





Multiple impementations

- Create two separate implementations

```
public class CircularArrayQueue<E> {
  public void add (E element){...};
  public E remove(){...};
  public int size(){...};
  ...
}
```

```
public class LinkedListQueue<E> {
  public void add (E element){...};
  public E remove(){...};
  public int size(){...};
  ...
}
```

Multiple impementations

- Create two separate implementations
- User chooses

```
CircularArrayQueue<Date> dateq;
LinkedListQueue<String> stringq;

dateq =
   new CircularArrayQueue<Date>();
stringq =
   new LinkedListQueue<String>();
}
```

```
public class CircularArrayQueue<E> {
  public void add (E element){...};
  public E remove(){...};
  public int size(){...};
  ...
}


public class LinkedListQueue<E> {
  public void add (E element){...};
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```

Multiple impementations

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```
CircularArrayQueue<Date> dateq;
LinkedListQueue<String> stringq;

dateq =
   new CircularArrayQueue<Date>();
stringq =
   new LinkedListQueue<String>();
}
```

- What if we later realize we need a flexible size `dateq`?

```
public class CircularArrayQueue<E> {
  public void add (E element){...};
  public E remove(){...};
  public int size(){...};
  ...
}
```

```
public class LinkedListQueue<E> {
  public void add (E element){...};
  public E remove(){...};
  public int size(){...};
  ...
}
```

Multiple impementations

- Create two separate implementations
- User chooses

```
CircularArrayQueue<Date> dateq;
LinkedListQueue<String> stringq;

dateq =
   new CircularArrayQueue<Date>();
stringq =
   new LinkedListQueue<String>();
}
```

- What if we later realize we need a flexible size `dateq`?
- Change declaration for `dateq`

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public class CircularArrayQueue<E> {
  public void add (E element){...};
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public class LinkedListQueue<E> {
  public void add (E element){...};
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}
```

Multiple impementations

- Create two separate implementations
- User chooses

```
CircularArrayQueue<Date> dateq;
LinkedListQueue<String> stringq;

dateq =
   new CircularArrayQueue<Date>();
stringq =
   new LinkedListQueue<String>();
}
```

- What if we later realize we need a flexible size `dateq`?
- Change declaration for `dateq`
- And also every function header, auxiliary variable, . . . associated with it

```
public class CircularArrayQueue<E> {
  public void add (E element){...};
  public E remove(){...};
  public int size(){...};
  ...
}

public class LinkedListQueue<E> {
  public void add (E element){...};
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}
```

Adding indirection

- Instead, create a `Queue` interface

```
public interface Queue<E> {
  abstract void add (E element);
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Adding indirection

- Instead, create a `Queue` interface
- Concrete implementations implement the interface

```
public interface Queue<E> {
  abstract void add (E element);
  abstract E remove();
  abstract int size();
}
public class CircularArrayQueue<E>
    implements Queue<E> {
  public void add (E element){...};
  public E remove(){...};
  public int size(){...};
  ...
}
public class LinkedListQueue<E>
    implements Queue<E> {
  public void add (E element){...};
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  ...
}
```

Adding indirection

- Instead, create a `Queue` interface
- Concrete implementations implement the interface
- Use the interface to declare variables

```
Queue<Date> dateq;
Queue<String> stringq;

dateq =
   new CircularArrayQueue<Date>();
stringq =
   new LinkedListQueue<String>();
}
```

Only change this

```
public interface Queue<E> {
  abstract void add (E element);
  abstract E remove();
  abstract int size();
}
public class CircularArrayQueue<E>
    implements Queue<E> {
  public void add (E element){...};
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public class LinkedListQueue<E>
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Adding indirection

- Instead, create a Queue interface
- Concrete implementations implement the interface
- Use the interface to declare variables

```
Queue<Date> dateq;
Queue<String> stringq;

dateq =
   new CircularArrayQueue<Date>();
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}
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- Benefit of indirection — to use a different implementation for dateq, only need to update the instantiation

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  - Interfaces add a level of indirection

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  - Organization provides senior staff with an office car
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  - Don't want to maintain a pool of cars? Contract with a taxi service

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  - Don't want to maintain a pool of cars? Contract with a taxi service
  - Don't want to negotiate tenders? Reimburse taxi bills

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"Fundamental theorem of software engineering"

All problems in computer science can be solved by another level of indirection.

Butler Lampson, Turing Award 1992

Built-in data types

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- Java originally had many such pre-defined classes
  - `Vector`, `Stack`, `Hashtable`, `Bitset`, ...
- Choose the one you need
- ... but changing a choice requires multiple updates
- Instead, organize these data structures by functionality
- Create a hierarchy of abstract interfaces and concrete implementations
  - Provide a level of indirection

The Collection interface

- The Collection interface abstracts properties of grouped data
  - Arrays, lists, sets, . . .
  - But not key-value structures like dictionaries

```
public interface Collection<E>{
  boolean add(E element);
  Iterator<E> iterator();
  ...
}
```

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- add() — add to the collection

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- iterator() — get an object that implements Iterator interface

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public interface Collection<E>{
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```
public interface Iterator<E>{
  E next();
  boolean hasNext();
  void remove();
  ...
}
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- add() — add to the collection
- iterator() — get an object that implements Iterator interface
- Use iterator to loop through the elements

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public interface Collection<E>{
  boolean add(E element);
  Iterator<E> iterator();
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}

public interface Iterator<E>{
  E next();
  boolean hasNext();
  void remove();
  ...
}

Collection<String> cstr = new ...;
Iterator<String> iter = cstr.iterator();
while (iter.hasNext()) {
  String element = iter.next();
  // do something with element
}
```

Using iterators

- Use iterator to loop through the elements

```
Collection<String> cstr = new ...;
Iterator<String> iter = cstr.iterator();
while (iter.hasNext()) {
  String element = iter.next();
  // do something with element
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Using iterators

- Use iterator to loop through the elements
- Java later added "for each" loop
    - Implicitly creates an iterator and runs through it

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Collection<String> cstr = new ...;
Iterator<String> iter = cstr.iterator();
while (iter.hasNext()) {
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}
```

```
Collection<String> cstr = new ...;
for (String element : cstr){
  // do something with element
}
```

Using iterators

- Use iterator to loop through the elements
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- Generic functions to operate on collections

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Collection<String> cstr = new ...;
Iterator<String> iter = cstr.iterator();
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  // do something with element
}
```

```
Collection<String> cstr = new ...;
for (String element : cstr){
  // do something with element
}
```

```
public static <E> boolean
       contains(Collection<E> c, Object obj) {
  for (E element : c)
    if (element.equals(obj))
      return true;
  return false;
}
```

Using iterators

- Use iterator to loop through the elements
- Java later added "for each" loop
  - Implicitly creates an iterator and runs through it
- Generic functions to operate on collections
- How does this line work?

```
if (element.equals(obj))
```

```
Collection<String> cstr = new ...;
Iterator<String> iter = cstr.iterator();
while (iter.hasNext()) {
  String element = iter.next();
  // do something with element
}
```

```
Collection<String> cstr = new ...;
for (String element : cstr){
  // do something with element
}
```

```
public static <E> boolean
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Using iterators

- Use iterator to loop through the elements
- Java later added “for each” loop
    - Implicitly creates an iterator and runs through it
- Generic functions to operate on collections
- How does this line work?

  ```
  if (element.equals(obj))
  ```

- Later!

```
Collection<String> cstr = new ...;
Iterator<String> iter = cstr.iterator();
while (iter.hasNext()) {
  String element = iter.next();
  // do something with element
}
```

```
Collection<String> cstr = new ...;
for (String element : cstr){
  // do something with element
}
```

```
public static <E> boolean
       contains(Collection<E> c, Object obj) {
  for (E element : c)
    if (element.equals(obj))
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}
```

Removing elements

- Iterator also has a `remove()` method
    - Which element does it remove?

```
public interface Iterator<E>{
  E next();
  boolean hasNext();
  void remove();
  ...
}
```

Removing elements

- Iterator also has a `remove()` method
  - Which element does it remove?
- The element that was last accessed using `next()`

```
public interface Iterator<E>{
  E next();
  boolean hasNext();
  void remove();
  ...
}
```

```
Collection<String> cstr = new ...;
Iterator<String> iter = cstr.iterator();
while (iter.hasNext()) {
  String element = iter.next();
  // Delete element if it has some property
  if (property(element)) {
     iter.remove();
  }
}
```

Removing elements

- Iterator also has a `remove()` method
  - Which element does it remove?
- The element that was last accessed using `next()`
- To remove consecutive elements, must interleave a `next()`

```
public interface Iterator<E>{
  E next();
  boolean hasNext();
  void remove();
  ...
}
```

```
Collection<String> cstr = new ...;
Iterator<String> iter = cstr.iterator();
...
iter.remove();
iter.remove(); // Error
```

Removing elements

- Iterator also has a `remove()` method
  - Which element does it remove?
- The element that was last accessed using `next()`
- To remove consecutive elements, must interleave a `next()`

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  E next();
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  ...
}
```

```
Collection<String> cstr = new ...;
Iterator<String> iter = cstr.iterator();
...
iter.remove();
iter.next();
iter.remove();
```

Removing elements

- Iterator also has a `remove()` method
  - Which element does it remove?
- The element that was last accessed using `next()`
- To remove consecutive elements, must interleave a `next()`
- To remove the first element, need to access it first

```
public interface Iterator<E>{
  E next();
  boolean hasNext();
  void remove();
  ...
}

Collection<String> cstr = new ...;
Iterator<String> iter = cstr.iterator();

// Remove first element in cstr
iter.next();
iter.remove();
```

The Collection interface — the full story

- How does this line work?

  ```
  if (element.equals(obj))
  ```

```
public static <E> boolean
       contains(Collection<E> c, Object obj) {
  for (E element : c)
    if (element.equals(obj))
      return true;
    return false;
}
```

The Collection interface — the full story

- How does this line work?

  ```
  if (element.equals(obj))
  ```

- Actually, `Collection` defines a much larger set of abstract methods
  - `addAll(from)` adds elements from a compatible collection
  - `removeAll(c)` removes elements present in `c`
  - A different `remove()` from the one in `Iterator`

```
public static <E> boolean
       contains(Collection<E> c, Object obj) {
  for (E element : c)
    if (element.equals(obj))
      return true;
    return false;
}
```

```
public interface Collection<E>{
  boolean add(E element);
  Iterator<E> iterator();
  int size() boolean isEmpty();
  boolean contains(Object obj);
  boolean containsAll(Collection<?> c);
  boolean equals(Object other);
  boolean addAll(Collection<? extends E> from);
  boolean remove(Object obj);
  boolean removeAll(Collection<?> c);
  ...
}
```

The `Collection` interface — the full story

- How does this line work?

  `if (element.equals(obj))`

- Actually, `Collection` defines a much larger set of abstract methods
  - `addAll(from)` adds elements from a compatible collection
  - `removeAll(c)` removes elements present in `c`
  - A different `remove()` from the one in `Iterator`
- To implement the `Collection` interface, need to implement all these methods!

```
public static <E> boolean
       contains(Collection<E> c, Object obj) {
  for (E element : c)
    if (element.equals(obj))
      return true;
    return false;
}
```

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public interface Collection<E>{
  boolean add(E element);
  Iterator<E> iterator();
  int size() boolean isEmpty();
  boolean contains(Object obj);
  boolean containsAll(Collection<?> c);
  boolean equals(Object other);
  boolean addAll(Collection<? extends E> from);
  boolean remove(Object obj);
  boolean removeAll(Collection<?> c);
  ...
}
```

The AbsractCollection class

- To implement Collection, need to implement all these methods!

```
public interface Collection<E>{
  boolean add(E element);
  Iterator<E> iterator();
  int size() boolean isEmpty();
  boolean contains(Object obj);
  boolean containsAll(Collection<?> c);
  boolean equals(Object other);
  boolean addAll(Collection<? extends E> from);
  boolean remove(Object obj);
  boolean removeAll(Collection<?> c);
  ...
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```

The AbsractCollection class

- To implement Collection, need to implement all these methods!
- “Correct” solution — provide default implementations in the interface

```
public interface Collection<E>{
  boolean add(E element);
  Iterator<E> iterator();
  int size() boolean isEmpty();
  boolean contains(Object obj);
  boolean containsAll(Collection<?> c);
  boolean equals(Object other);
  boolean addAll(Collection<? extends E> from);
  boolean remove(Object obj);
  boolean removeAll(Collection<?> c);
  ...
}
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- Added to Java interfaces later!

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The AbsractCollection class

- To implement Collection, need to implement all these methods!
- "Correct" solution — provide default implementations in the interface
- Added to Java interfaces later!
- Instead, AbstractCollection abstract class implements Collection

```
public abstract class AbstractCollection<E>
                               implements Collection<E> {
  ...
  public abstract Iterator<E> iterator();

  public boolean contains(Object obj) {
    for (E element : this)
      if (element.equals(obj))
        return true;
    return false;
  }
  ...
}
```

The AbsractCollection class

- To implement Collection, need to implement all these methods!
- "Correct" solution — provide default implementations in the interface
- Added to Java interfaces later!
- Instead, AbstractCollection abstract class implements Collection
- Concrete classes now extend AbstractCollection
  - Need to define iterator() based on internal representation
  - Can choose to override contains(), ...

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Concrete collections

- The Collection interface abstracts properties of grouped data
  - Arrays, lists, sets, . . .
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- The `Collection` interface abstracts properties of grouped data
  - Arrays, lists, sets, . . .
  - But not key-value structures like dictionaries
- Collections can be further organized based on additional properties
  - Are the elements ordered?
  - Are duplicates allowed?
  - Are there constraints on how elements are added, removed?

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- Collections can be further organized based on additional properties
  - Are the elements ordered?
  - Are duplicates allowed?
  - Are there constraints on how elements are added, removed?
- In the spirit of indirection, these are captured by interfaces that extend `Collection`
  - Interface `List` for ordered collections
  - Interface `Set` for collections without duplicates
  - Interface `Queue` for ordered collections with constraints on addition and deletion

The List interface

- An ordered collection can be accessed in two ways
  - Through an iterator
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The `List` interface

- An ordered collection can be accessed in two ways
  - Through an iterator
  - By position — random access
- Additional functions for random access

```
public interface List<E>
                 extends Collection<E>{
  void add(int index, E element);
  void remove(int index);
  E get(int index);
  E set(int index, E element);
}
```

l[i]

l[i] = v

The `List` interface

- An ordered collection can be accessed in two ways
  - Through an iterator
  - By position — random access
- Additional functions for random access
- `ListIterator` extends `Iterator`
  - `void add(E element)` to insert an element before the current index
  - `void previous()` to go to previous element
  - `boolean hasPrevious()` checks that it is legal to go backwards

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public interface List<E>
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  ListIterator<E> listIterator();
}
```

The `List` interface and random access

- Random access is not equally efficient for all ordered collections
  - In an array, can compute location of element at index `i`
  - In a linked list, must start at the beginning and traverse `i` links

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The List interface and random access

- Random access is not equally efficient for all ordered collections
  - In an array, can compute location of element at index i
  - In a linked list, must start at the beginning and traverse i links
- Tagging interface RandomAccess
  - Tells us whether a List supports random access or not
  - Can choose algorithmic strategy based on this

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  void add(int index, E element);
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```
if (c instanceof RandomAccess) {
  // use random access algorithm
} else {
  // use sequential access algorithm
}
```

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- Instead, map the value to its position
  - Hash function
- Or arrange values in a two dimensional structure
  - Balanced search tree

Concrete sets

- `HashSet` implements a hash table
  - Underlying storage is an array
  - Map value `v` to a position `h(v)`
  - If `h(v)` is unoccupied, store `v` at that position
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  - Maintains a sorted collection
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- Insertion is more complex than a hash table
  - Time $O(\log n)$ if the set has n elements

The Queue interface

- Ordered, remove front, insert rear
- Queue interface supports the following

```
boolean add(E element);
E remove();
```

  - If queue full, add() flags an error
  - If queue empty, remove() flags an error

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- Interface Deque, double ended queue

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  boolean addFirst(E element);
  boolean addLast(E element);
  boolean offerFirst(E element);
  boolean offerLast(E element);
  E pollFirst();
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  E getFirst();
  E getLast();
  E peekFirst();
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- Interface `PriorityQueue`
  - `remove()` returns highest priority item

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E peekLast();
```

- Interface PriorityQueue
  - remove() returns highest priority item
- Concrete implementations
  - LinkedList — implements Queue
  - ArrayDeque — circular array Deque

Maps

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- Key-value structures come under the Map interface
  - Two type parameters
  - K is the type for keys
  - V is the type for values
  - get(k) fetches value for key k
  - put(k,v) updates value for key k

```
public interface Map<K,V>{
  V get(Object key);
  V put(K key, V Value);

  boolean containsKey(Object key);
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- As expected, keys form a set
  - Only one entry per key-value
  - Assigning a fresh value to existing key overwrite the old value
  - `put(k,v)` returns the previous value associated with `k`, or `null`

Extracting keys and values

- Methods to extract keys and values

```
Set<K> keySet();
Collection<V> values();
Set<Map.Entry<K, V>> entrySet()
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for (String key : keys) {
  do something with key
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- Use `entrySet()` to operate on key and associated value without looking up map again

```
for (Map.Entry<String, Employee> entry :
                       staff.entrySet()){
  String k = entry.getKey();
  Employee v = entry.getValue();
  do something with k, v
}
```

Concrete implementations of `Map`

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- Remembers the order in which keys were inserted
- Hash table entries are also connected as a (doubly) linked list
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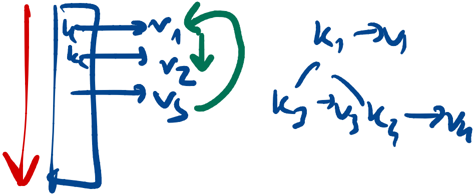

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    - Each `get()` or `put()` moves key-value pair to end of list
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- Similarly, `LinkedHashSet`

When things go wrong

- Our code could encounter many types of errors
  - *User input* — enter invalid filenames or URLs
  - *Device errors* — printer jam, network connection drops
  - *Resource limitations* — disk full
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- Signalling errors
  - Return an invalid value: -1 at end of file, `null`
  - What if there is no obvious invalid value?

Exception handling

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- Declare if a method can throw an exception
  - Compiler can check whether calling code has made a provision to handle the exception

Java's classification of errors

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  - Array index out of bounds, invalid hash key, ...
- Checked exceptions
  - Typically user-defined, code assumptions violated
    - In a list of orders, quantities should be positive integers

Catching and handling exceptions

- try–catch
  - Enclose code that may generate exception in a try block
  - Exception handler in catch block
  - Similar to Python

```
try {
  ...
  call a function that may
    throw an exception
  ..
}
catch (ExceptionType e){
  ...
  examine e and handle it
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- Otherwise, uncaught exception is passed back to the code that called this code

```
try {
  ...
  call a function that may
    throw an exception
  ..
}
catch (ExceptionType e){
  ...
  examine e and handle it
  ...
}
```

Catching and handling exceptions

- try–catch
  - Enclose code that may generate exception in a try block
  - Exception handler in catch block
  - Similar to Python
- If try encounters an exception, rest of the code in the block is skipped
- If exception matches the type in catch, handler code executes
- Otherwise, uncaught exception is passed back to the code that called this code
- Top level uncaught exception — program crash

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Catching and handling exceptions

- Can catch more than one type of exception
  - Multiple `catch` blocks

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try {
  code that might throw exceptions
}
catch (FileNotFoundException e) {
  handle missing files
}
catch (UnknownHostException e) {
  handle unknown hosts
}
catch (IOException e) {
  handle all other I/O issues
}
```

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- Exceptions are classes in the Java class hiearachy
  - `catch (ExceptionType e)` matches any subtype of `ExceptionType`

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- Exceptions are classes in the Java class hiearachy
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- Catch blocks are tried in sequence
  - Match exception type against each one in turn
- Order catch blocks by argument type, more specific to less specific
  - IOException would intercept FileNotFoundException

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Generating exceptions

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- `Error` — JVM runtime issue
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- Code calls another function that generates an exception
- Your code detects an error and generates an exception
  - `throw` a checked exception

Notifying checked exceptions

- Example: you write a method `readData()`
  - Header line provides length of data
    - `Content-Length: 2048`
  - Actual data read is less than promised length

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throw new EOFException();
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  - `EOFException`, subtype of `IOException`
  - "Signals that EOF has been reached unexpectedly during input"
- Create an object of exception type and `throw` it

```
throw new EOFException();
```

- Can also pass a diagnostic message when constructing exception object

```
String errormsg = "Content-Length:" + contentlen + ", Received: " + rcvdlen;
throw new EOFException(errormsg);
```

Throwing exceptions . . .

- How does caller know that `readData()` generates `EOFException`?

Throwing exceptions ...

- How does caller know that `readData()` generates `EOFException`?
- Declare exceptions thrown in header

```
String readData(Scanner in)
    throws EOFException {
  ...
  while (...) {
    if (!in.hasNext()) {
      // EOF encountered
      if (n < len) {
        String errmsg = ...
        throw new EOFException(errmsg);
      }
    ...
  }
  return(s);
}
```

Throwing exceptions . . .

- How does caller know that `readData()` generates `EOFException`?
- Declare exceptions thrown in header
- Can throw multiple types of exceptions

```
String readFile(String filename)
    throws FileNotFoundException,
           EOFException { ... }
```

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- Declare exceptions thrown in header
- Can throw multiple types of exceptions

```
String readFile(String filename)
    throws FileNotFoundException,
           EOFException { ... }
```

- Can throw any subtype of declared exception type

```
String readFile(String filename)
    throws IOException { ... }
```

  - Can throw `FileNotFoundException`, `EOFException`, both subclasses of `IOException`

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String readData(Scanner in)
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  ...
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        throw new EOFException(errmsg);
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    ...
  }
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```

Throwing exceptions . . .

- Method declares the exceptions it throws

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}
```

Throwing exceptions . . .

- Method declares the exceptions it throws
- If you call such a method, you must handle it

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String readData(Scanner in)
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- Need not advertise unchecked exceptions
  - `Error`, `RunTimeException`

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Throwing exceptions . . .

- Method declares the exceptions it throws
- If you call such a method, you must handle it
- ... or pass it on; your method should advertise that it throws the same exception
- Need not advertise unchecked exceptions
  - `Error`, `RunTimeException`
- Should not normally generate `RunTimeException`
  - Fix the error or report suitable checked exception

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      }
    ...
  }
  return(s);
}
```

Customized exceptions

- Don’t want negative numbers in a `LinearList`

Customized exceptions

- Don't want negative numbers in a LinearList
- Define a new class extending Exception

```
public class NegativeException extends Exception{

  private int error_value;
   // Negative value that generated exception

  public NegativeException(String message, int i){
    super(message);  // Appeal to superclass
    error_value = i; // constructor to set message
  }

  public int report_error_value(){
    return error_value;
  }
}
```

Customized exceptions

- Don't want negative numbers in a LinearList
- Define a new class extending Exception
- Throw this from LinearList
    - Note that add advertises the fact that it throws a NegativeException

```
public class NegativeException extends Exception{
   ...
}

public class LinearList{
  ...
  public add(int i) throws NegativeException{
    ...
    if (i < 0){
      throw new NegativeException("Negative input",i);
    }
    ...
  }
}
```

More on catching exceptions

- Can extract information about the exception

```
try {
  ...
  call a function that may
    throw an exception
  ..
}
catch (ExceptionType e){
  ...
  String errormsg = e.getMessage();
  ...
}
```

More on catching exceptions

- Can extract information about the exception
- Chaining exceptions
  - Process and throw a new exception from `catch`

```
try {
  ...
  access database
  ..
}
catch (SQLException e){
  ...
  String errormsg =
     "database error" + e.getMessage();
  throw new ServletException(errormsg);
  ...
}
```

More on catching exceptions

- Can extract information about the exception
- Chaining exceptions
  - Process and throw a new exception from `catch`
- `Throwable` has additional methods to track chain of exceptions
  - `getCause()`, `initCause()`

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- Add information when you chain exceptions

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try {
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  access database
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}
catch (SQLException e){
  ...
  String errormsg =
     "database error" + e.getMessage();
  ServletException newe =
     new ServletException(errormsg);
  newe.initCause(e);
  throw newe;
  ...
}
```

More on catching exceptions

- Can extract information about the exception
- Chaining exceptions
  - Process and throw a new exception from `catch`
- `Throwable` has additional methods to track chain of exceptions
  - `getCause()`, `initCause()`
- Add information when you chain exceptions
- Retrieve information when you catch exception

```
try {
  ...
}
catch (ServletException e){
  ...
  Throwable original = e.getCause();
  ...
}
```

Cleaning up resources

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- Add a block labelled `finally`

```
try{
     ...
   }

catch (ExceptionType1 e){...}

catch (ExceptionType2 e){...}

finally{
     ...
  // Always executed, whether try
  // terminates normally or
  // exceptionally. Use for clean up.
}
```

Cleaning up resources

- When exception occurs, rest of the `try` block is skipped
- May need to do some clean up (close files, deallocate resources, . . .)
- Add a block labelled `finally`
- Different scenarios

```
FileInputStream in =
  new FileInputStream(...);
try {
  // 1
  code that might throw exceptions
  // 2
}
catch (IOException e) {
  // 3
  show error message
  // 4
}
finally {
  // 5
  in.close();
}
// 6
```

Cleaning up resources

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  - No error — 1,2,5,6

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- May need to do some clean up (close files, deallocate resources, . . .)
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  - IOException in try, no exception in catch — 1,3,4,5,6

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- May need to do some clean up (close files, deallocate resources, ...)
- Add a block labelled `finally`
- Different scenarios
  - No error — 1,2,5,6
  - `IOException` in `try`, no exception in `catch` — 1,3,4,5,6
  - `IOException` in `try`, chained exception in `catch` — 1,3,5

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