CS 600.226: Data Structures

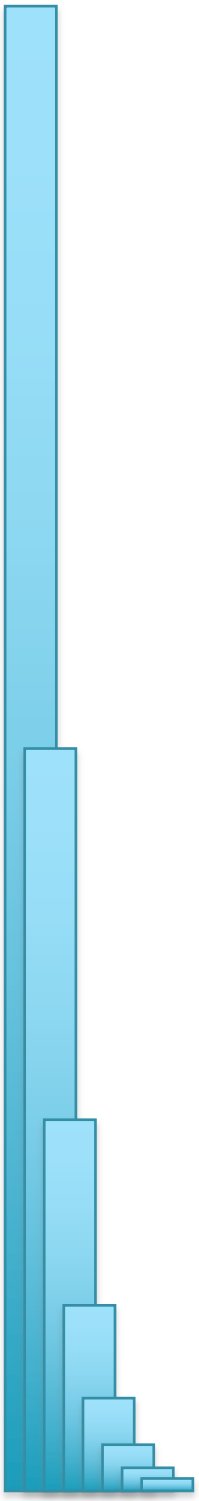
Michael Schatz

Sept 5, 2018

Lecture 3: Introduction to Interfaces

Agenda

1. *Quick Review*
2. *Introduction to Java Interfaces*
3. *Introduction to Generics, Exceptions and Arrays*



Welcome!

Course Webpage: https://github.com/schatzlab/datastructures2018

Course Discussions: https://piazza.com/jhu/fall2018/600226/home

Office Hours: Wednesday @ 2:45pm – 4pm, Malone 323
CA office hours throughout the week ☺

Programming Language: Java with Checkstyle and JUnit
Virtual Machine (Lubuntu) or CS acct.

Accounts for Majors (CS/CE) & Minors:

If you do not already have a personal CS departmental unix account, please complete an account request form ASAP. Check "Linux Undergrad" for account type. (Note - must be declared to be eligible.)

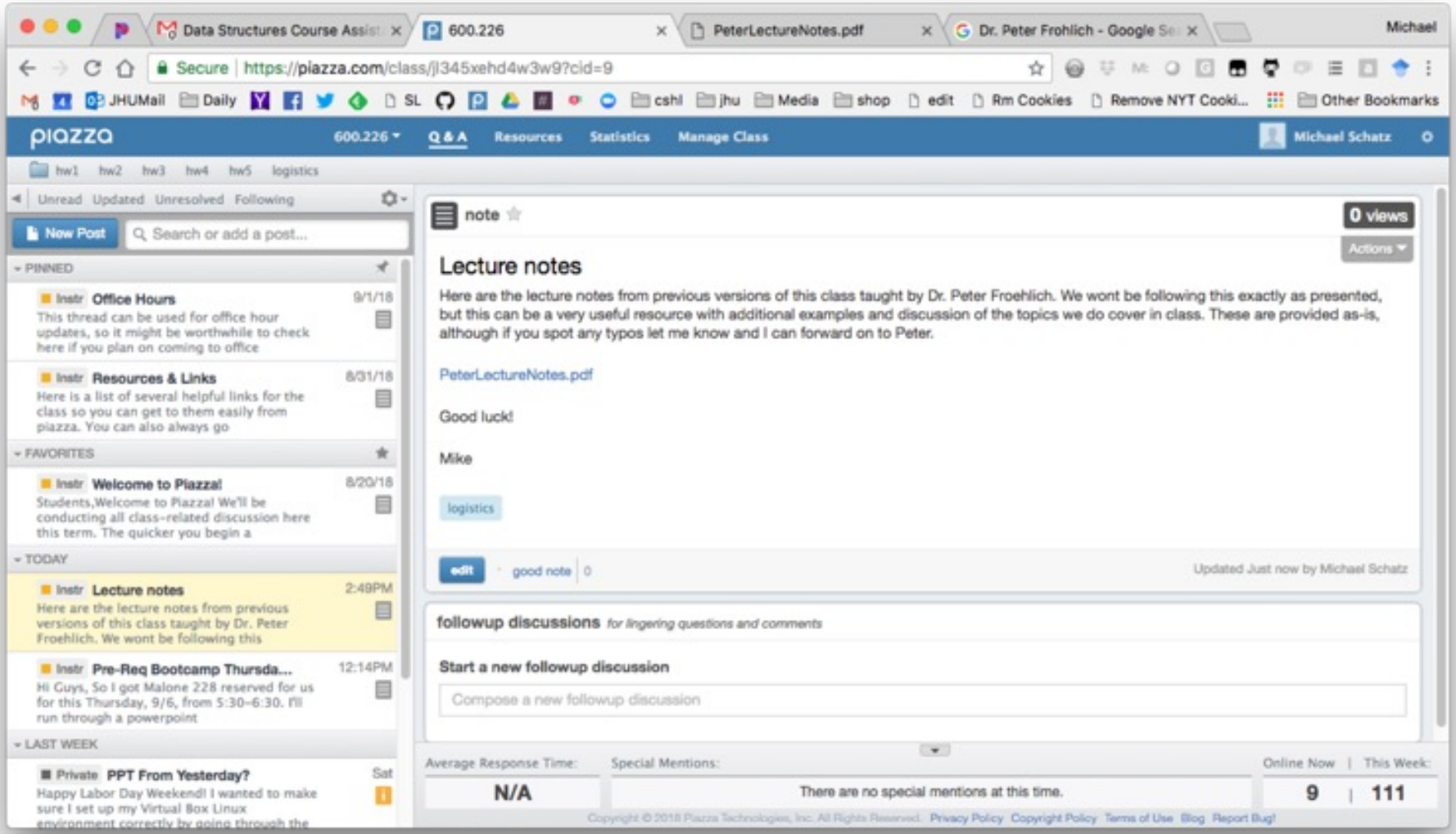
Accounts for Others:

We will need to make accounts. Do people need them?

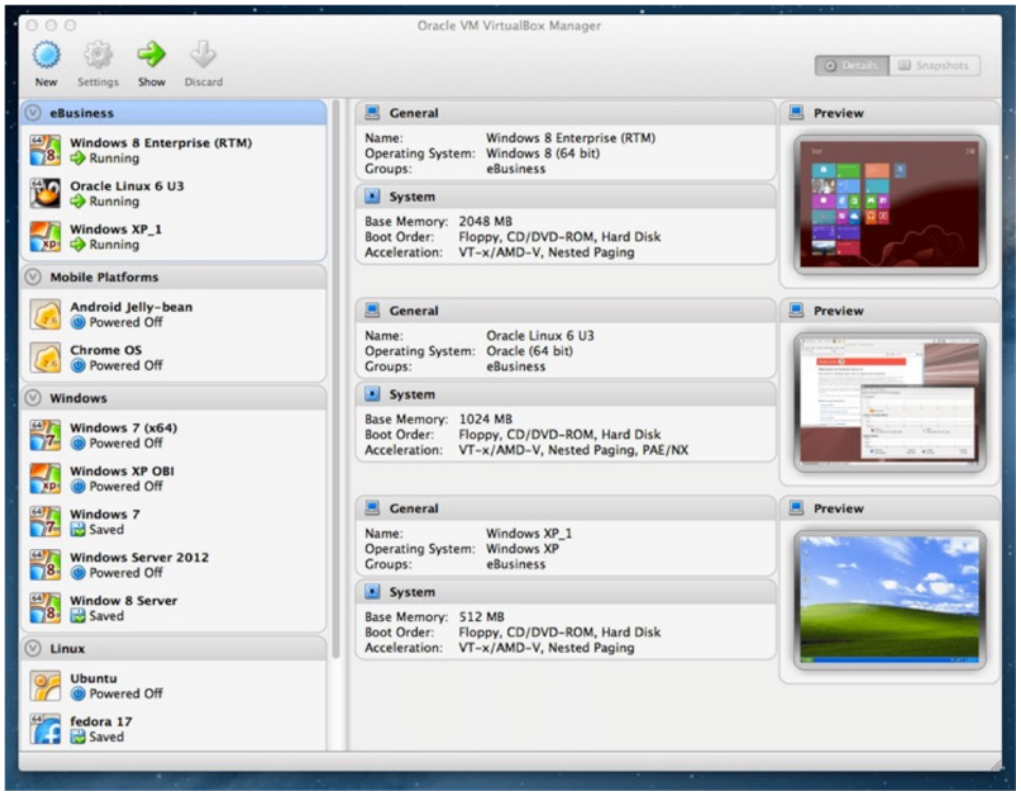
CS Lab access:

Students must see Steve DiBlasio, with your J-card, in Malone G61A to get CS Lab access. The CS Lab is Malone 122 and that's where course TA/CAs will be available for help.

Piazza! Lecture Notes! Q&A!

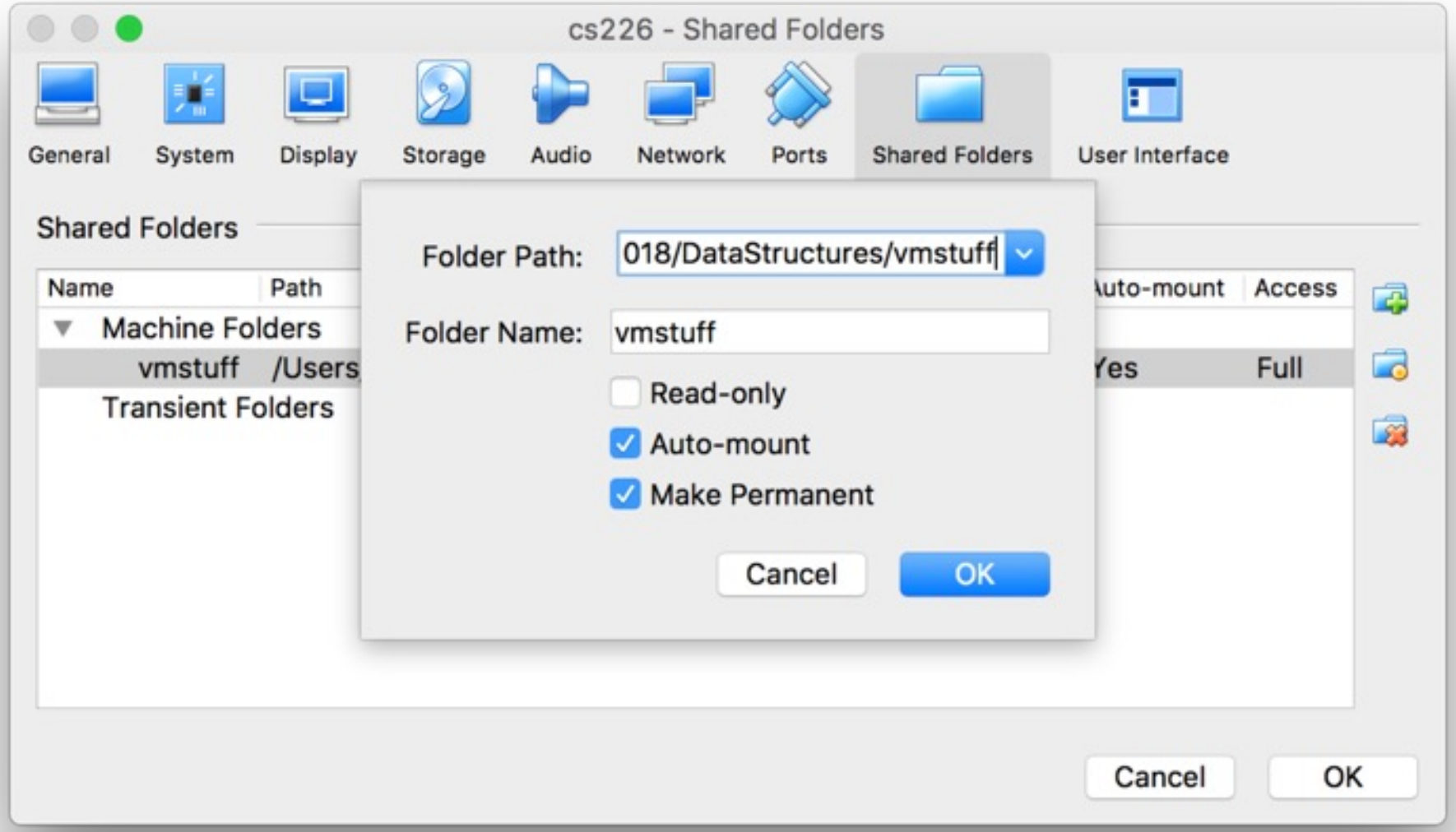


VirtualBox

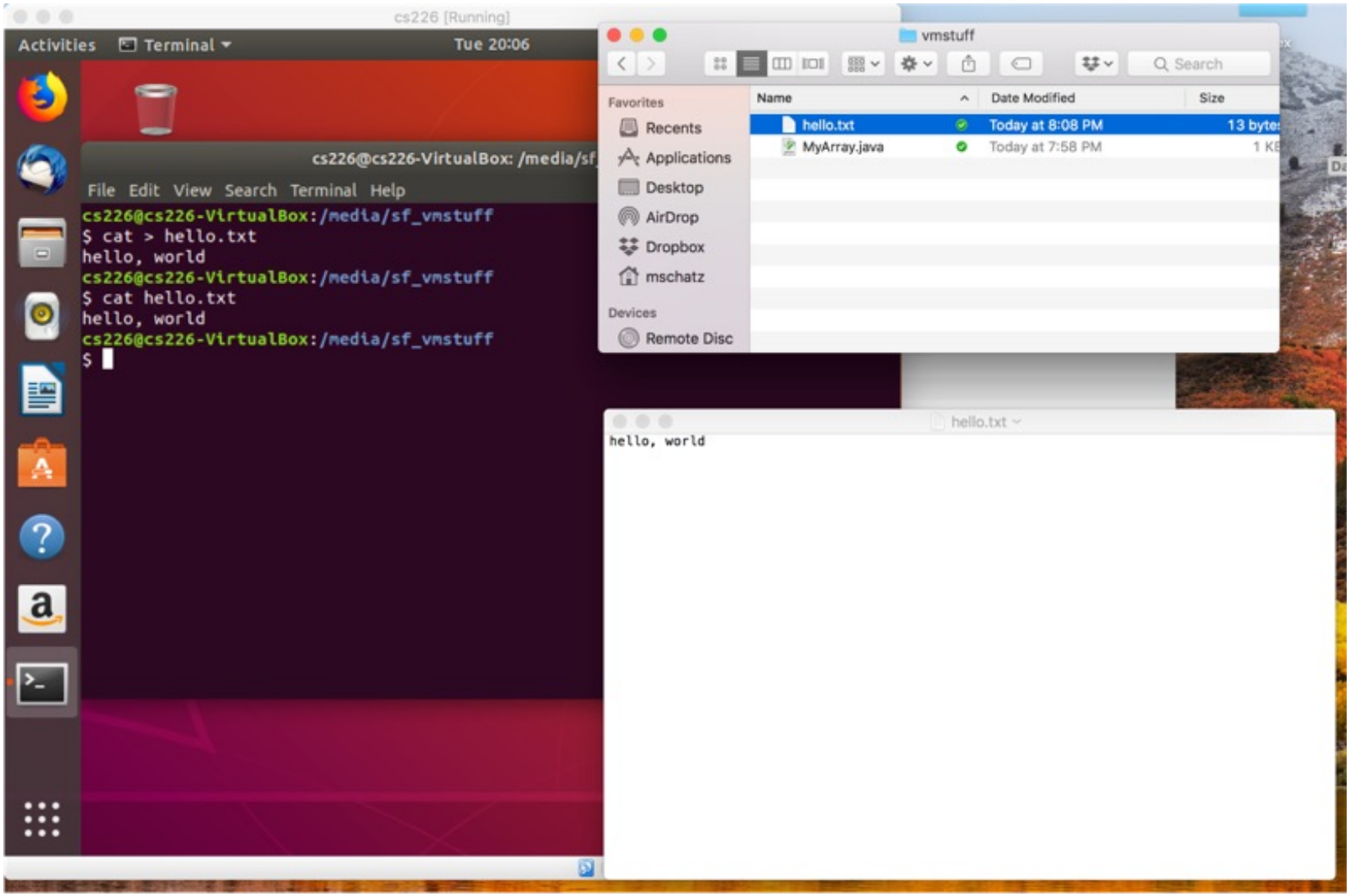


- Client application available for Mac, Windows, Linux
- Available to run our reference virtual machine running linux
  - Guaranteed that your development environment matches testing environment
  - Make sure to install the Extension Pack and Guest Additions too

VirtualBox Shared Folders



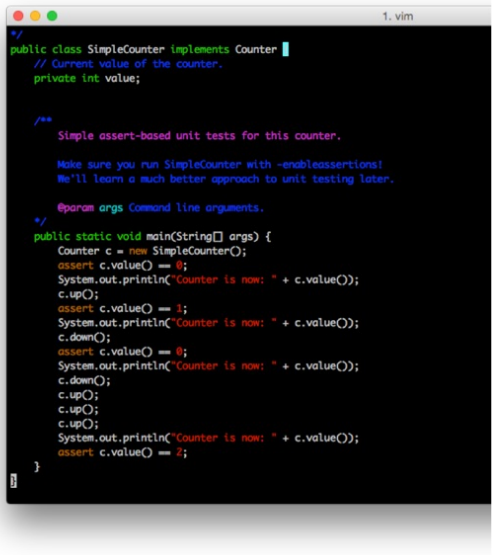
VirtualBox Shared Folders




```
$ sudo usermod -aG vboxsf cs226
$ /sbin/shutdown -r now
```

Java Environments

Command Line Everything

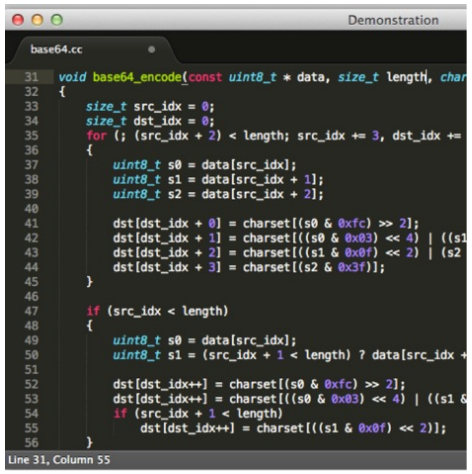


$ vim HelloWorld.java

$ javac HelloWorld.java
$ java HelloWorld

Universal, fast, flexible
Steep learning curve

GUI Editor + Command Line

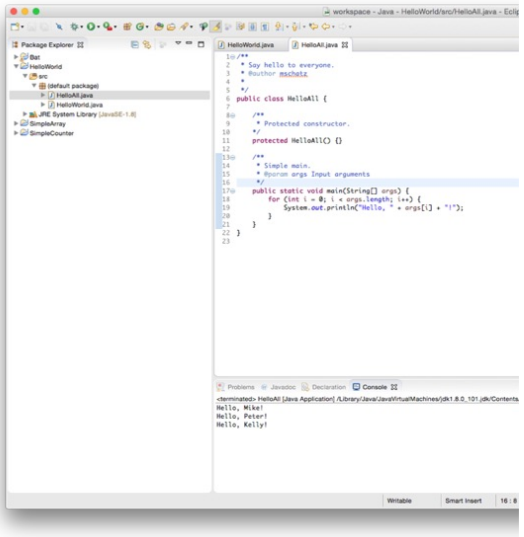


Sublime Text

$ javac HelloWorld.java
$ java HelloWorld

Nearly universal, flexible
Moderate learning curve

Integrated Development Environment (IDE)

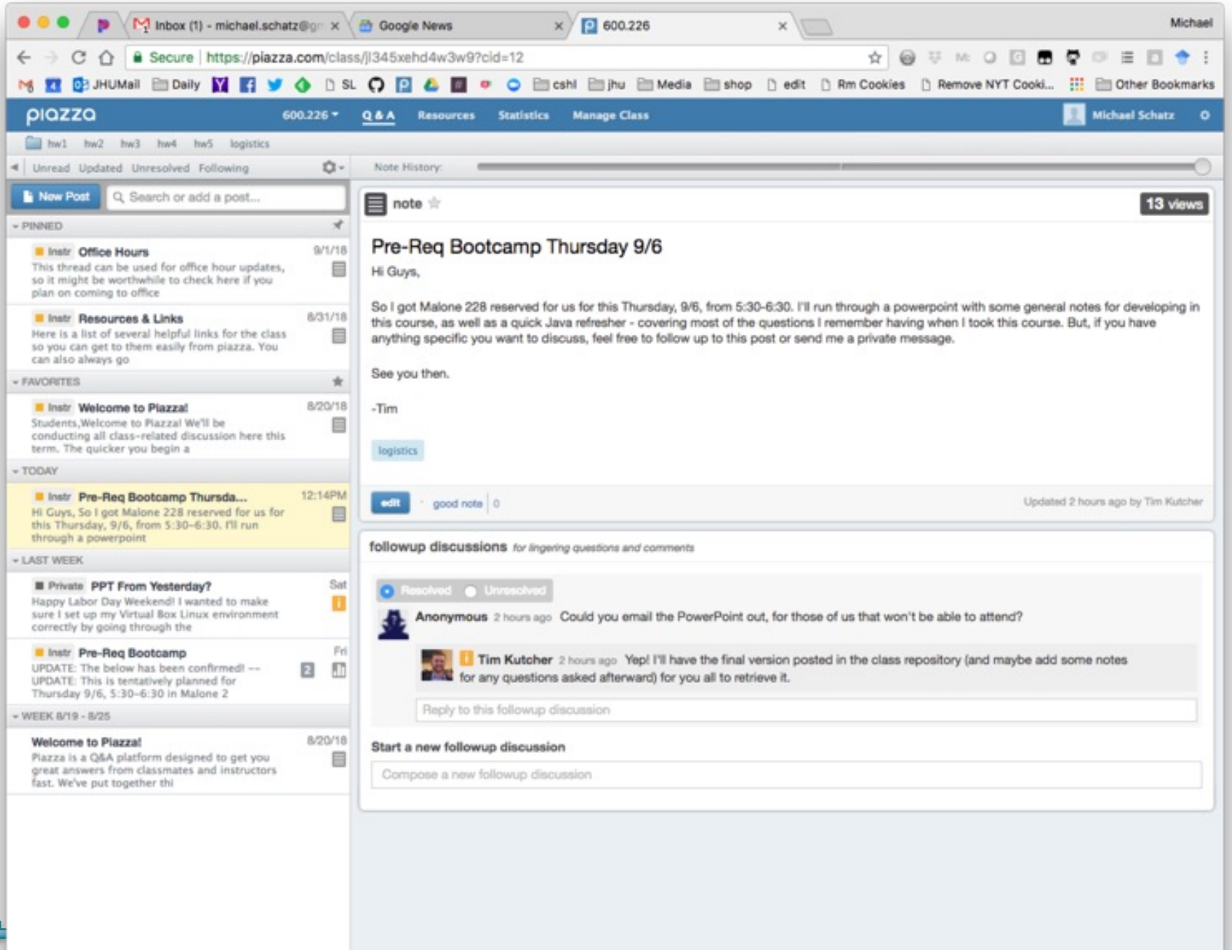


Eclipse / IntelliJ

Most Support
Most "magical"

Code may not work during grading ☹

Bootcamp: Thursday @ 5:30 Malone 228



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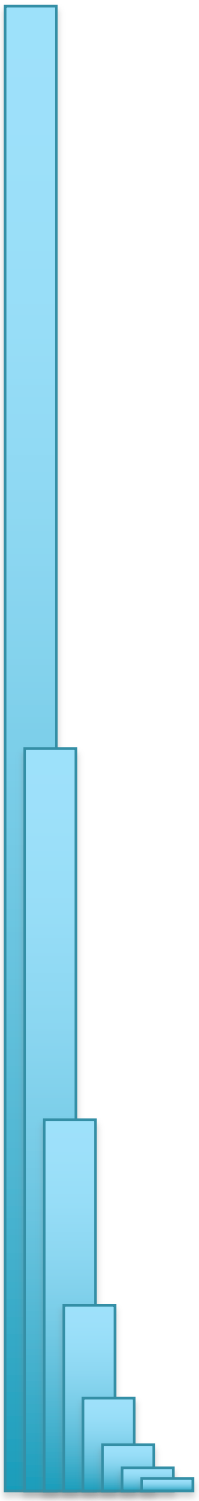

Interfaces

Introduction to Java Interfaces

Objects define their interaction with the outside world through the methods that they expose. Methods form the object's interface with the outside world; the buttons on the front of your television set, for example, are the interface between you and the electrical wiring on the other side of its plastic casing. You press the "power" button to turn the television on and off. […] ***An interface is a group of related methods with empty bodies.***

https://docs.oracle.com/javase/tutorial/java/concepts/interface.html


```
interface Counter {
  int value();
  void up();
  void down();
}
```

Interfaces Review

- ***Interfaces establish the "contract" between the implementation and any potential client code***
  - Helps to abstract our the key features of a data structure
  - You can trivially replace the use of one implementation with another as long as they implement the same interface
  - Teams can work on different pieces of a large system knowing that everything will work together in the end

  - ***Java Interfaces are groups of related methods with empty bodies***
  - Defines the syntax of what is available

```
interface Counter {
  int value();
  void up();
  void down();
}
```

Whats wrong with this interface?

Interfaces Review

- ***Interfaces establish the "contract" between the implementation and any potential client code***
  - Helps to abstract our the key features of a data structure
  - You can trivially replace the use of one implementation with another as long as they implement the same interface
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  - ***Java Interfaces are groups of related methods with empty bodies***
  - Defines the syntax of what is available

```
interface Counter {
  int banana();
  void orange();
  void grape();
}
```

Whats wrong with this interface?

Algebraic Specification of Abstract Data Types

```
# Counter ADT Specification.

adt Counter                          # name of specification
  uses Integer                       # specification(s) this one needs (imports)
  defines Counter                    # type(s) defined by this specification

  operations                         # operations(s) defined in this specification
    new: ---> Counter                  # constructor, "convert" TO Counter
    up: Counter ---> Counter           # mutators, make Counters from Counters
    down: Counter ---> Counter         # (in Java they'd change their receiver!)
    value: Counter ---> Integer        # observer, "convert" FROM Counter

  axioms                             # axioms for the operations defined above
    value(new()) >= 0                  # value of a new Counter is >= 0
    value(up(c)) > value(c)            # value of up'd Counter is > value before
    value(down(c)) <= value(c)         # value of down'd Counter is <= value before
```

Axioms should be read as universally quantified. For example, the second axiom is "for all counters c, the value of up(c) is > the value of c" if read out aloud. The "rule of thumb" for finding axioms is to combine all constructors/mutators with all observers and then stare at that until we figure it out. :-)

Axioms are enforced by asserts and other test cases!

Variables and Types (1)

```
adt Counter
  uses Integer
  defines Counter

  operations
    new: ---> Counter
    up: Counter ---> Counter
    down: Counter ---> Counter
    value: Counter ---> Integer

  axioms
    value(new()) >= 0
    value(up(c)) > value(c)
    value(down(c)) <= value(c)
```

```
interface Counter {
  int value();
  void up();
  void down();
}
```

Does this specification allow for floating point numbers? How would you fix it?

Variables and Types (2)

```
adt Counter
  uses Float
  defines Counter

  operations
    new: ---> Counter
    up: Counter ---> Counter
    down: Counter ---> Counter
    value: Counter ---> Float

  axioms
    value(new()) >= 0.0
    value(up(c)) > value(c)
    value(down(c)) <= value(c)
```

```
interface Counter {
  float value();
  void up();
  void down();
}
```

What if you want to allow the counter to use either floats or ints? How would you code it?

Variable Types

```
adt Variable
  uses Any
  defines Variable<T: Any>
    operations
      new: T ---> Variable<T>
      get: Variable<T> ---> T
      set: Variable<T> x T ---> Variable<T>
    axioms
      get(new(t)) = t
      get(set(v, t)) = t
```

"Any" defines a type with = operation
T stands for "Any" type: int, float, String, …
v and t are values of type T

```
adt Counter
  uses Any
  defines Counter<T: Any>
  operations
    new: T ---> Counter<T>
    up: Counter<T> ---> Counter<T>
    down: Counter<T> ---> Counter<T>
    value: Counter<T> ---> T
  axioms
    value(new(t)) = t
    value(up(c)) > value(c)
    value(down(c)) <= value(c)
```

Using t with new() enables more flexibility than initializing to 0, 3.14 or any other specific value

T must define >, <=, and =
new() takes a starting value t

Java Generics

In a nutshell, generics enable *types* (classes and interfaces) to be parameters when defining classes, interfaces and methods. Much like the more familiar *formal parameters* used in method declarations, type parameters provide a way for you to re-use the same code with different inputs.

- ***Stronger type checks at compile time.***
  A Java compiler applies strong type checking to generic code and issues errors if the code violates type safety. Fixing compile-time errors is easier than fixing runtime errors, which can be difficult to find.
- ***Elimination of casts.***
  The following code snippet without generics requires casting:

```
List list = new ArrayList();
list.add("hello");
String s = (String) list.get(0);
```

  When re-written to use generics, the code does not require casting:

```
List<String> list = new ArrayList<String>();
list.add("hello");
String s = list.get(0); // no cast
```

- ***Enabling programmers to implement generic algorithms.***
  By using generics, programmers can implement generic algorithms that work on collections of different types, can be customized, and are type safe and easier to read.

https://docs.oracle.com/javase/tutorial/java/generics/why.html

Implementing Variable Types with Generics

Variable.java

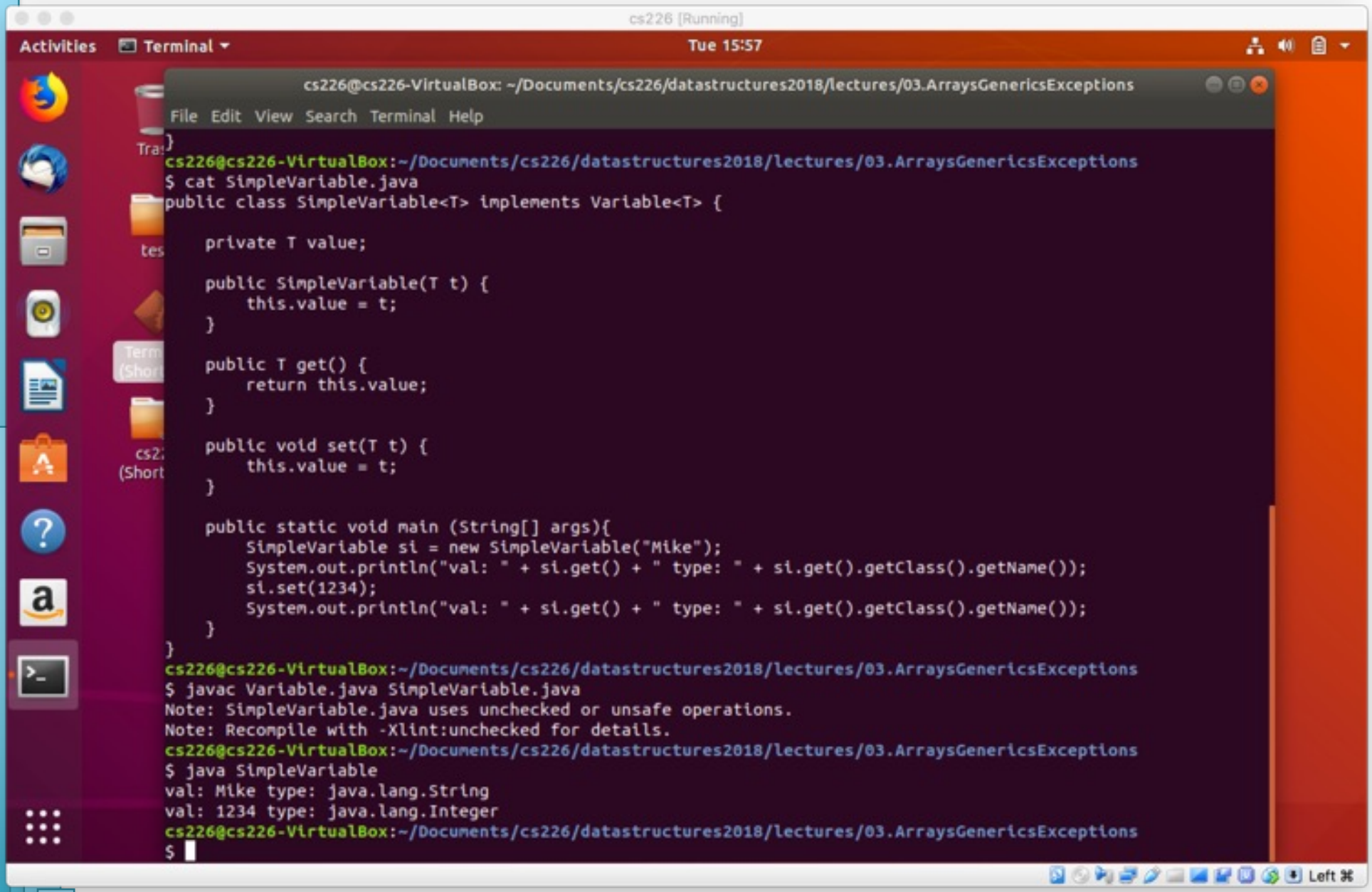
```
public interface Variable <T> {
    public T get();
    public void set(T t);
}
```

SimpleVariable.java

```
public class SimpleVariable<T> implements Variable<T> {
    private T value;
    public SimpleVariable(T t) {
        this.value = t;
    }
    public T get() {
        return this.value;
    }
    public void set(T t) {
        this.value = t;
    }
    public static void main (String[] args){
        SimpleVariable si = new SimpleVariable("Mike");
        System.out.println("val: " + si.get() +
                           " type: " + si.get().getClass().getName());
        si.set(1234);
        System.out.println("val: " + si.get() +
                           " type: " + si.get().getClass().getName());
    }
}
```

At compile time it will automagically define set(String) and set(Integer)

Implementing Variable Types with Generics



Implementing Variable Types with Generics

SimpleVariable.java

```
public static void main (String[] args){
  SimpleVariable si = new SimpleVariable("Mike");
  System.out.println("val: " + si.get() +
                     " type: " + si.get().getClass().getName());

  SimpleVariable<String> ssi = si;
  String vals = ssi.get();
  System.out.println(vals);

  si.set(1234);
  System.out.println("val: " + si.get() +
                     " type: " + si.get().getClass().getName());

  SimpleVariable<Integer> isi = si;
  System.out.println(isi.get() + 10);
  }
}
```

Defining the variable type as SimpleVariable<String> allows us to skip the cast!

Interfaces Review

- ***Interfaces establish the "contract" between the implementation and any potential client code***
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  - You can trivially replace the use of one implementation with another as long as they implement the same interface
  - Teams can work on different pieces of a large system knowing that everything will work together in the end

  - ***Java Interfaces are groups of related methods with empty bodies***
  - Defines the syntax of what is available

```
interface Counter {
  int value();
  void up();
  void down();
}
```

- Use an algebraic specification to define the semantics
- Use genetics to allow flexibility across types

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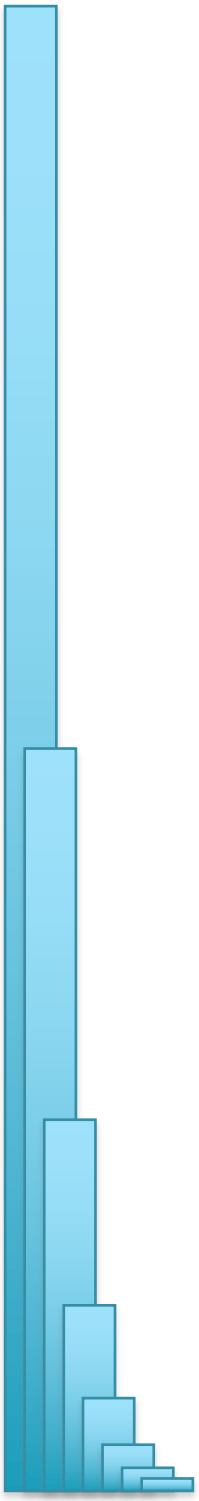
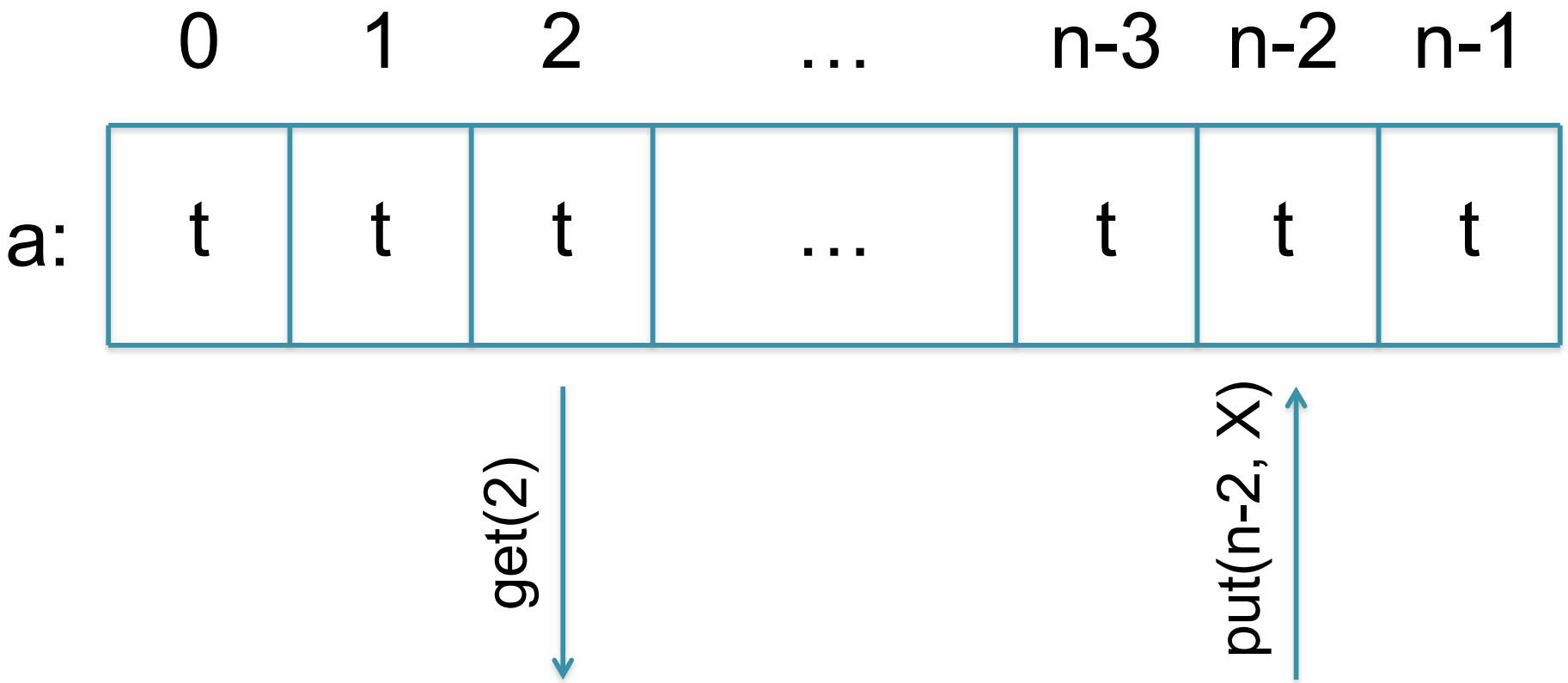


Our first data structure: Arrays



- Fixed length data structure
- Constant time get() and put() methods
- Definitely needs to be generic ☺

Array ADT

```
adt Array
  uses Any, Integer
  defines Array<T: Any>

  operations
      new: Integer x T ---> Array<T>
      get: Array<T> x Integer ---> T
      put: Array<T> x Integer x T ---> Array<T>
      length: Array<T> ---> Integer

  axioms
      get(new(n, t), i) = t
      get(put(a, i, t), j) = (if i = j then t else get(a, j))
      length(new(n, t)) = n
      length(put(a, i, t)) = length(a)

  preconditions
      new(n, t): 0 < n
      get(a, i): 0 <= i < length(a)
      put(a, i, t): 0 <= i < length(a)
```

Uses two related ADTs

Defines method signatures

Enforced by asserts

Enforced by exceptions

Array Interface

```
/**
    Arrays with integer positions.

    The constructor should take a length &gt; 0 as well as a default
    value to "plaster" all over the new array. The constructor should
    throw LengthException if length &le; 0.

        Array(int length, T default) throws LengthException

 @param <T> Element type.
*/

public interface Array<T>  {
    /**
        Change value at index.

        @param i Index to write value at.
        @param t Value to write at index.
        @throws IndexException if i &lt; 0 or i &gt; length-1.
    */
    void put(int i, T t) throws IndexException;

...
```

Array Interface

```
...

    /**
        Value at index.

        @param i Index to read value at.
        @return Value read at index.
        @throws IndexException if i &lt; 0 or i &gt; length-1.
    */
    T get(int i) throws IndexException;

    /**
        Length of array.

        @return Length of array, always &gt; 0.
    */
    int length();
}
```

Array Exceptions

IndexException.java

```
/**
    Exception for invalid index.

    Data structures using (integer) indices throw IndexException
    if a given index is out of range.
*/
public class IndexException extends RuntimeException {
    private static final long serialVersionUID = 0L;
}
```

LengthException.java

```
/**
    Exception for invalid length.

    Data structures that have a fixed (integer) length throw
    LengthException if a given length is out of range.
*/
public class LengthException extends RuntimeException {
    private static final long serialVersionUID = 0L;
}
```

The type is the main item of interest, but other information could be returned

Simple Array 1

SimpleArray.Java

```
/**
    Array implementation on top of basic Java array.

    The obvious implementation of the Array interface, absolutely positively
    nothing fancy going on here.

    There are two reasons for this class to exist: First it's an example for
    the style of code we're about to write a lot of. Second it's useful
    because Java's generics don't really play well with Java's basic arrays;
    we'll use SimpleArray in lots of places where Java's arrays would give us
    generic grief.

    @param <T> Element type.
*/
public class SimpleArray<T> implements Array<T> {
    // The underlying data structure of our abstract Array.
    private T[] data;

    /**
        Constructs a new SimpleArray.

        @param n Length of array, must be n &gt; 0.
        @param t Default value to store in each slot.
        @throws LengthException if n &le; 0.
    */
    public SimpleArray(int n, T t) throws LengthException {
...
```

Why bother?

Simple Array 2

```
...

public SimpleArray(int n, T t) throws LengthException {
        if (n <= 0) {
            throw new LengthException();
        }

        // This cast works around Java's problems with generic arrays.
        // The resulting warning is acceptable because there simply is
        // no better way of doing this.
        this.data = (T[]) new Object[n];

        // Array slots are null by default.
        if (t == null) {
            return;
        }

        for (int i = 0; i < n; i++) {
            this.data[i] = t;
        }
    }

...
```

Workaround for java syntax

Simple Array 3

```
...
    // If we let ArrayIndexOutOfBoundsException propagate, we leak an
    // implementation detail we should probably hide. (Also that name
    // is so horrible, it deserves to live in a dark cave in Mordor.)

    @Override
    public T get(int i) throws IndexException {
        try {
            return this.data[i];
        } catch (ArrayIndexOutOfBoundsException e) {
            throw new IndexException();
        }
    }

    @Override
    public void put(int i, T t) throws IndexException {
        try {
            this.data[i] = t;
        } catch (ArrayIndexOutOfBoundsException e) {
            throw new IndexException();
        }
    }

    @Override
    public int length() {
        return this.data.length;
    }
...
```

These let us “hide” the exceptions from our underlying datatypes

Simple Array 4

```
...
    public static void main(String [] args) throws
      IndexException, LengthException {
        Array<String> a = new SimpleArray<String>(4, "226");
        assert a.length() == 4;
        for (int i =0; i <a.length(); i++){
            assert a.get(i).equals("226");
        }
        a.put(2, "Peter");
        assert a.length() == 4;
        assert a.get(2).equals ("Peter");
        assert a.get(0).equals ("226");
        assert a.get(1).equals ("226");
        assert a.get(3).equals ("226");

        System.out.println("Passed the value assertions");
...
```

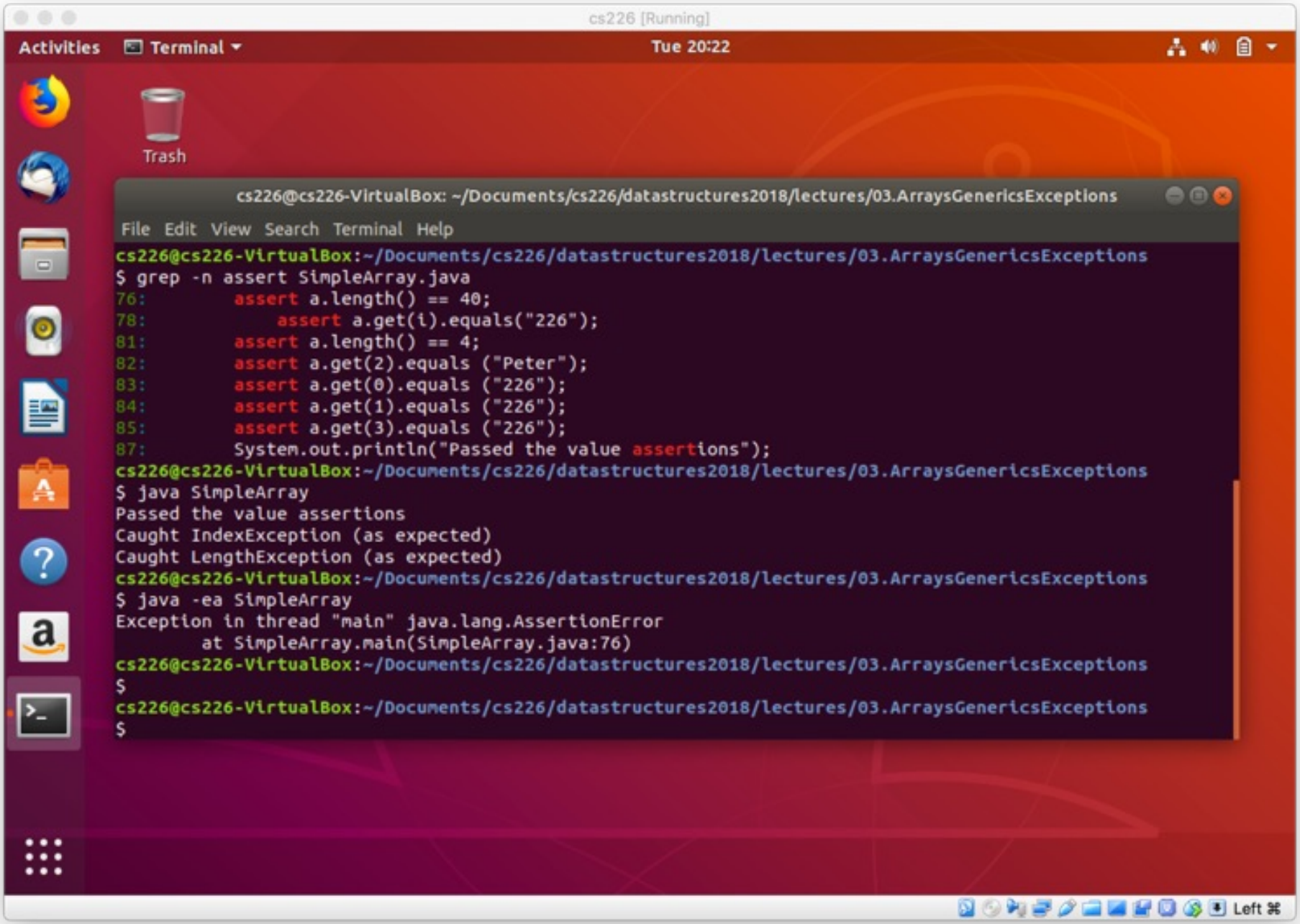
Simple Array 5

```
...

        try {
          a.put(a.length(), "Paul");
          System.out.println("Didnt get the exception");
        }
        catch (IndexException e)
        {
          System.out.println("Caught IndexException (as expected)");
        }

        try {
          Array<String> b = new SimpleArray<String>(0, "Mike");
          System.out.println("No exception after creating second array");
        }
        catch (LengthException e)
        {
          System.out.println("Caught LengthException (as expected)");
        }
    }
}
```

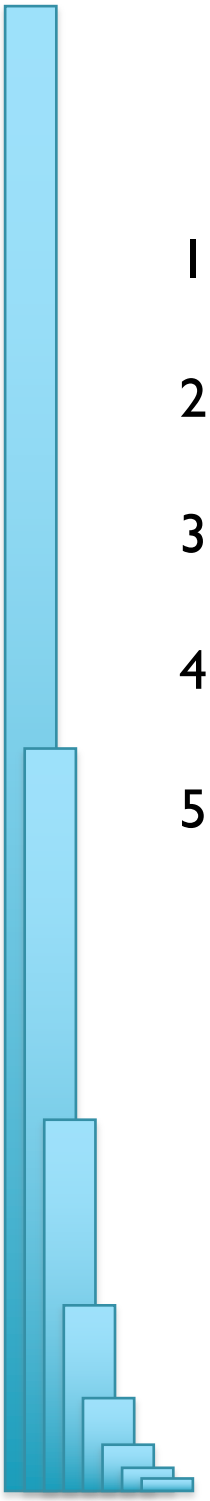
Running with Assertions



$ java -ea SimpleArray

Next Steps

1. Reflect on the magic and power of interfaces, generics, and exceptions ☺
2. Check on Piazza
3. Download class virtual machine, get CS account and/or set up Linux!
4. Get comfortable with a editor (VI rules!) and/or an IDE (Eclipse for Java)
5. Get comfortable with checkstyle




Welcome to CS 600.226
https://github.com/schatzlab/datastructures2018

Questions?