AdminISTRIVIA

- HW4 due yesterday!
- HW5 out now, due next Wednesday (5/4) at 11 pm!
- Any questions?
Agenda

• Graph concepts

• HW5

• Script Testing

• Equals and Hashcode

• Extra Reasoning Practice
Graphs
A graph represents relationships

A graph is a set of **nodes** and a set of **edges** between them.

Nodes may be **labeled**.

Edges may be **labeled**.

Edges may have a **direction**.
Example: Road Map

Nodes: intersections (cities)
Label: name/location

Edges: roads
Label: name/length
Example: Airline Flights

Nodes: airports  
Label: airport code

Edges: flights  
Label: cost/time
Example: CSE courses

Nodes: Courses
Label: Course name

Edges: pointer to next class
Label: none
You’ve used graphs before!

Singly linked Lists:

![Diagram of a singly linked list with nodes labeled 3, -25, and 0.]

**Nodes:** Linked list node  
**Label:** integer

**Edges:** pointer to next node  
**Label:** none
You’ve used graphs before!

Doubly linked Lists:

Nodes: Linked list node
Label: integer

Edges: pointers to prev/next nodes
Label: none
You’ve used graphs before!

Binary trees:

Nodes: Tree node
Label: Integer

Edges: pointers to children
Label: none
An edge points from source to dest.

Each edge “points” from a source to a destination.

- **Outgoing** from source
- **Incoming** to destination

N.B.: We’re only dealing with directed graphs from here on out.
An edge points from source to dest.

Each edge “points” from a source to a destination.

- **Outgoing** from source
- **Incoming** to destination

Edge A is Node 1 \(\rightarrow\) Node 2.

- Outgoing from Node 1
- Incoming to Node 2
An edge points from source to dest.

Each edge “points” from a source to a destination.
- **Outgoing** from source
- **Incoming** to destination

Edge C is **Node 2 → Node 3**.
- Outgoing from **Node 2**
- Incoming to **Node 3**
A node has children

A node’s outgoing edges point to its children.

- Potentially empty set
A node has children

A node’s outgoing edges point to its children.
• Potentially empty set

Node 3 has three children:
• Node 1
• Node 4
• Node 5
A node has children

A node’s outgoing edges point to its *children*.
- Potentially empty set

Node 2 has two children:
- Node 2
- Node 3
A node has parents

A node’s incoming edges point from its parents.
- Potentially empty set
A node has parents

A node’s incoming edges point from its parents.
- Potentially empty set

Node 4 has two parents:
- Node 3
- Node 5
A node has parents

A node’s incoming edges point from its parents.
• Potentially empty set

Node 5 has one parent:
• Node 3
A node has neighbors

A node’s neighbors are its children plus its parents.

- Potentially empty set
A node has neighbors

A node’s **neighbors** are its children plus its parents.
- Potentially empty set

Node 2 has four neighbors:
- Node 1 (parent)
- Node 2 (self-pointing)
- Node 3 (child)
- Node 4 (parent)
A node has neighbors

A node’s **neighbors** are its children plus its parents.

- Potentially empty set

Node 3 has four neighbors:
- Node 1 (child)
- Node 2 (parent)
- Node 4 (parent *and* child)
- Node 5 (child)
Paths between nodes

A **path** is a “chain” of edges from a **source** to a **destination**.

- Potentially empty sequence
- Might include a cycle
- Often want shortest
Paths between nodes

A path is a “chain” of edges from a source to a destination.
- Potentially empty sequence
- Might include a cycle
- Often want shortest

Path from Node 1 to Node 5:
1. Edge A: Node 1 → Node 2
2. Edge C: Node 2 → Node 3
3. Edge G: Node 3 → Node 5
Paths between nodes

A **path** is a “chain” of edges from a **source** to a **destination**.
- Potentially empty sequence
- Might include a cycle
- Often want shortest

Path from **Node 1** to **Node 5**:
1. Edge A : Node 1 → Node 2
2. Edge C : Node 2 → Node 3
3. Edge E : Node 3 → Node 4
4. Edge F : Node 4 → Node 3
5. Edge G : Node 3 → Node 5
A **path** is a “chain” of edges from a **source** to a **destination**.

- Potentially empty sequence
- Might include a cycle
- Often want shortest

Path from **Node 1** to **Node 1**:  
1. Edge A : Node 1 → Node 2  
2. Edge C : Node 2 → Node 3  
3. Edge B : Node 3 → Node 1
A **path** is a “chain” of edges from a **source** to a **destination**.

- Potentially empty sequence
- Might include a cycle
- Often want shortest

Path from **Node 2** to **Node 2**:
1. **Edge I**: Node 2 → Node 2
Possible graph operations

Creators
• Construct an empty graph

Observers
• Look up node(s) by label, children of, parents of, neighbors of, …
• Look up edge(s) by label, incoming to, outgoing from, …
• Iterate through all nodes
• Iterate through all edges

Mutators
• Insert/remove a node
• Insert/remove an edge

You might or might not want to include all of these operations in your graph ADT design.

More observers
• Find path(s) from one node to another
• Find all reachable nodes
• Count indegree, outdegree
HW5: Design before implementation

• HW5: Building an ADT for labeled, directed graphs
  – Labeled: Nodes and edges have label values (Strings)
  – Directed: Edges have direction
  – Edges with same source and destination will have unique labels

• The exact interface of your Graph class is up to you
  – So no given JUnit tests bundled with the starter code
  – Reminder: Not a generic class.

• HW5 is just designing and specifying the ADT
  – HW6 will be implementing it
HW5: What’s Included

• Your submission for HW5 should include:
  – Java class(es) that represent your ADT
    • Each with method stubs
  – Specifications for **all** classes and methods
  – Tests for your ADT
    • JUnit and Script tests (coming soon...)

• Your submission for HW5 should **not** include:
  – Any implemented methods
  – Anything private (fields, methods, classes, etc.)
    • Including RI and AF
HW5: Specifications in JavaDoc

• Write class/method specifications in proper JavaDoc comments
  – See “Resources” → “Class and Method Specifications”

• You can generate nice HTML pages cleanly presenting all your JavaDoc specifications
  – Placed in “build/docs/javadoc/”

• This is a great way to verify the JavaDoc is formatted correctly
  – And to review/proofread your work…

• Let’s look at the JavaDoc from HW4… (demo)
JavaDoc Demo

• Run the “javadoc” gradle task (in the documentation folder)

• Locate `build/docs/javadoc/index.html`, right-click, **Open In** > a browser of your choice
  – Look for formatting errors or missing components!
The design process includes crafting a good test suite
- Script tests and JUnit tests

**Script Tests** ([src/test/resources/testScripts/](/src/test/resources/testScripts/))
- Test script files `name.test` with corresponding `name.expected`
- Validate behavior intrinsic to high-level concept (abstract meaning)
- Tested properties should be expected of any solution to HW5

**JUnit Tests** ([src/test/java/graph/junitTests/](/src/test/java/graph/junitTests/))
- JUnit test classes
- Validate behavior that can't be tested with script tests.

If you can validate a behavior using either test type, use a script test!
HW5: Script Tests

Each script test is expressed as text-based script `foo.test`
- One command per line, of the form: `Command arg_1 arg_2 ...`
- Script's output compared against `foo.expected`
- Precise details specified in the homework
- Match format exactly, including whitespace!

<table>
<thead>
<tr>
<th>Command (in <code>foo.test</code>)</th>
<th>Output (in <code>foo.expected</code>)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CreateGraph name</td>
<td>created graph name</td>
</tr>
<tr>
<td>AddNode graph label</td>
<td>added node label to graph</td>
</tr>
<tr>
<td>AddEdge graph parent child label</td>
<td>added edge label from parent to child in graph</td>
</tr>
<tr>
<td>ListNodes graph</td>
<td>graph contains: label_node ...</td>
</tr>
<tr>
<td>ListChildren graph parent</td>
<td>the children of parent in graph are: child(label_edge) ...</td>
</tr>
<tr>
<td># This is comment text ...</td>
<td># This is comment text ...</td>
</tr>
</tbody>
</table>

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HW5: `example.test`

```plaintext
# Create a graph
CreateGraph graph1

# Add a pair of nodes
AddNode graph1 n1
AddNode graph1 n2

# Add an edge
AddEdge graph1 n1 n2 e1

# Print all nodes in the graph
ListNodes graph1

# Print all child nodes of n1 with outgoing edge
ListChildren graph1 n1
```
# Create a graph
created graph graph1

# Add a pair of nodes
added node n1 to graph1
added node n2 to graph1

# Add an edge
added edge e1 from n1 to n2 in graph1

# Print all nodes in the graph
graph1 contains: n1 n2

# Print all child nodes of n1 with outgoing edge
the children of n1 in graph1 are: n2(e1)
Why Script Tests?

- Everyone’s implementation could (will!) be different, so we (staff) cannot write JUnit tests for everyone to use or to use for checking everyone’s code.

- We still need a way to test that you specify and implement the proper behavior, so we use script tests that work regardless of the implementation.

- They test what the methods are doing, they don’t care how the methods are doing it.
HW5: Creating a script test

1. Write test steps as script commands in a file `foo.test`
2. Write expected (“correct”) output in a file `foo.expected`
   – …taking care to match the output format *exactly*
3. Place both files under `src/test/resources/testScripts/`
4. Run all such tests via the Gradle task `scriptTests`
   – After class implemented and `GraphTestDriver` stubs filled
HW5: Test Commands vs Methods

• Your graph should not have the exact same interface as the script test commands
  – e.g. you should not have a method called `AddNode()` that adds a node to the graph and prints out/returns the string “added node n1 to graph1”
  – This wouldn’t make much sense for other graph clients!

• But you will need the ability to add a node!

• Later, we will need some way to map script test commands `(AddNode graph1 n1)` to some Java code that uses the methods of your graph class
  – This is part of HW6; do not worry about for now
• Script tests will not cover every case for your graph:
  – What if you have additional methods that can’t be tested by our script test commands?
  – What about “bad” input for your graph?
  – What happens when you try to add the same node twice?
  – …

• We need some way to test cases that cannot be covered by our script tests

• For this, we use JUnit tests.
HW5: Creating JUnit tests

1. Create JUnit test class in src/test/java/graph/junitTests/

2. Write a test method for each unit test

3. Run all such tests via the Gradle task junitTests

```java
import org.junit.*;
import static org.junit.Assert.*;

/** Document class... */
public class FooTests {
  /** Document method... */
  @Test
  public void testBar() { ...
      /* JUnit assertions */
  }
}
```
HW5: Creating JUnit tests

• Note: Your JUnit tests will fail in HW5, because you have not implemented the actual methods yet
  – The same goes for your script tests

• You will get them passing in HW6
Equals and Hashcode
The **equals** method (review)

- Specification mandates several properties:
  - **Reflexive**: \( x . \text{equals}(x) \) is true
  - **Symmetric**: \( x . \text{equals}(y) \Leftrightarrow y . \text{equals}(x) \)
  - **Transitive**: \( x . \text{equals}(y) \land y . \text{equals}(z) \Rightarrow x . \text{equals}(z) \)
  - **Consistent**: \( x . \text{equals}(y) \) shouldn’t change, unless perhaps \( x \) or \( y \) did
  - **Null uniqueness**: \( x . \text{equals}(\text{null}) \) is false

- Several notions of equality:
  - **Referential**: literally the same object in memory
  - **Behavioral**: no sequence of operations could tell apart (excluding ==)
  - **Observational**: no sequence of **observer** operations could tell apart (excluding ==)
The `hashCode` method (review)

- Specification mandates several properties:
  - *Self-consistent*: `x.hashCode()` shouldn’t change, unless `x` did
  - *Equality-consistent*: `x.equals(y) ⇒ x.hashCode() == y.hashCode()`

- Equal objects *must* have the same hash code.
  - Implementations of `equals` and `hashCode` work together for this
  - If you override `equals`, you *must* override `hashCode` as well

- Ideally a good `hashCode` method returns different values for unequal objects, but the contract does not require this.
Overriding `equals` and `hashCode`

- A subclass method overrides a superclass method, when...
  - They have the exact same name
  - They have the exact same argument types

- An overriding method should satisfy the overridden method’s spec.

- Always use `@override` tag when overriding `equals` and `hashCode` (or any other overridden method)

- Note: Method overloading is not the same as overriding
  - Same name but distinguished by different argument types

- Keep these details in mind if you override `equals` and `hashCode`. 
equals and hashCode worksheet

• Let’s practice…
More Reasoning Practice
$$\text{intToString()}$$

Fill in the implementation of a method that converts a positive integer to its string representation in decimal (invariant given on next slide).

$$\{ \ \text{P: } x > 0 \ \}$$

String intToString(int x)

Useful facts to recall:

1. Convert char ch that is one of ‘0’, ‘1’, ..., ‘9’ to a corresponding int by doing ch – ‘0’
2. Convert int x that is one of 0, 1, ..., 9 to a corresponding char by doing (char) (x + ‘0’)

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intToString()}

{{ P: x > 0 }}

String intToString(int x) {
    StringBuilder buf =
    int k = , y = ;
    {{ Inv: P and buf stores the lowest k digits of x in reverse order and y = x / 10^k }}
    while (y != 0) {
        k = k + 1;
    }

    return buf.reverse().toString();
}
```java
intToString()

{{ P: x > 0 }}
String intToString(int x) {
    StringBuilder buf = new StringBuilder();
    int k = 0, y = x;
    {{ Inv: P and buf stores the lowest k digits of x in reverse order and y = x / 10^k }}
    while (y != 0) {
        k = k + 1;
    }
    return buf.reverse().toString();
}
```

How do we fill out the loop body?
intToString()\

{{ P: x > 0 }}
String intToString(int x) {
    StringBuilder buf = new StringBuilder();
    int k = 0, y = x;
    {{ Inv: P and buf stores the lowest k digits of x in reverse order and y = x / 10^k }}
    while (y != 0) {
        k = k + 1;
    }
    return buf.reverse().toString();
}

Inv changes k to k+1, so
• y becomes x / 10^{k+1}
• y_{post} = x / 10^{k+1} = y_{pre} / 10
intToString() 

{{ P: x > 0 }}

String intToString(int x) {
    StringBuilder buf = new StringBuilder();
    int k = 0, y = x;
    {{ Inv: P and buf stores the lowest k digits of x in reverse order and y = x / 10^k }}
    while (y != 0) {
        y = y / 10;
        k = k + 1;
    }

    return buf.reverse().toString();
}

Inv changes k to k+1, so
• y becomes x / 10^{k+1}
• y_{post} = x / 10^{k+1} = y_{pre} / 10
intToString()

{{ P: x > 0 }}
String intToString(int x) {
    StringBuilder buf = new StringBuilder();
    int k = 0, y = x;
    {{ Inv: P and buf stores the lowest k digits of x in reverse order and y = x / 10^k }}
    while (y != 0) {
        y = y / 10;
        k = k + 1;
    }

    return buf.reverse().toString();
}
**intToString()**

```java
{{ P: x > 0 }}
String intToString(int x) {
    StringBuilder buf = new StringBuilder();
    int k = 0, y = x;
    {{ Inv: P and buf stores the lowest k digits of x in reverse order and y = x / 10^k }}
    while (y != 0) {
        y = y / 10;
        k = k + 1;
    }
    return buf.reverse().toString();
}
```

**Inv changes k to k+1, so**
- buf stores lowest k+1 digits
  (k+1)-st lowest digit goes at end since buf stores them reversed
intToString()

{{ P: x > 0 }}
String intToString(int x) {
    StringBuilder buf = new StringBuilder();
    int k = 0, y = x;
    {{ Inv: P and buf stores the lowest k digits of x in reverse order and y = x / 10^k }}
    while (y != 0) {
        char ch = ?
        buf.append(ch);
        y = y / 10;
        k = k + 1;
    }
    return buf.reverse().toString();
}
### intToString()

{{ P: x > 0 }}

```java
String intToString(int x) {
    StringBuilder buf = new StringBuilder();
    int k = 0, y = x;
    {{ Inv: P and buf stores the lowest k digits of x in reverse order and y = x / 10^k }}
    while (y != 0) {
        char ch = (char) (y % 10 + '0');
        buf.append(ch);
        y = y / 10;
        k = k + 1;
    }
    return buf.reverse().toString();
}
```
```java
{{ P: x > 0 }}
String intToString(int x) {
    StringBuilder buf = new StringBuilder();
    int k = 0, y = x;
    {{ Inv: P and buf stores the lowest k digits of x in reverse order and y = x / 10^k }}
    while (y != 0) {
        char ch = (char) (y % 10 + '0');
        buf.append(ch);
        y = y / 10;
        k = k + 1;
    }
    {{ buf stores the digits of x in reverse order }}
    return buf.reverse().toString();
}
```

Why does this hold?
intToString() solution

{{ P: x > 0 }}

String intToString(int x) {
    StringBuilder buf = new StringBuilder();
    int k = 0, y = x;
    {{ Inv: P and buf stores the lowest k digits of x in reverse order and y = x / 10^k }}
    while (y != 0) {
        char ch = (char) (y % 10 + '0');
        buf.append(ch);
        y = y / 10;
        k = k + 1;
    }
    {{ buf stores the digits of x in reverse order }}
    return buf.reverse().toString();
}