CSE 331
Software Design & Implementation

Spring 2021

Section 4 – Graphs, Testing

Administrivia

- Done with HW4!

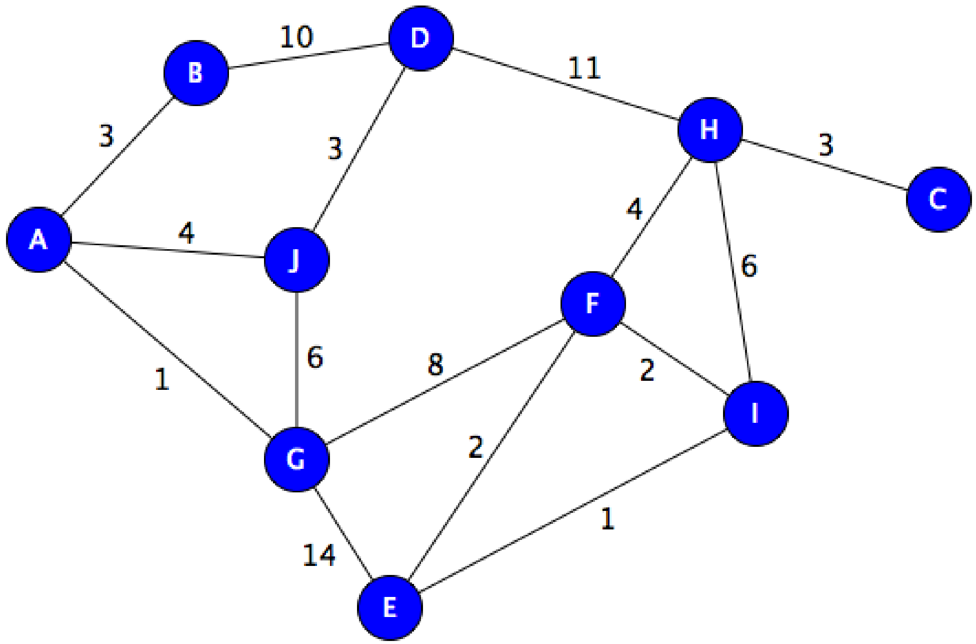
- HW5-1 and HW5-2 Spec out on the website
  - Always plan for work taking 3x longer than expected, so start early!

- Any questions?

Agenda

- Graph concepts
- Testing in practice
  - Script Testing
  - JUnit Testing
- Testing exercise

Graphs



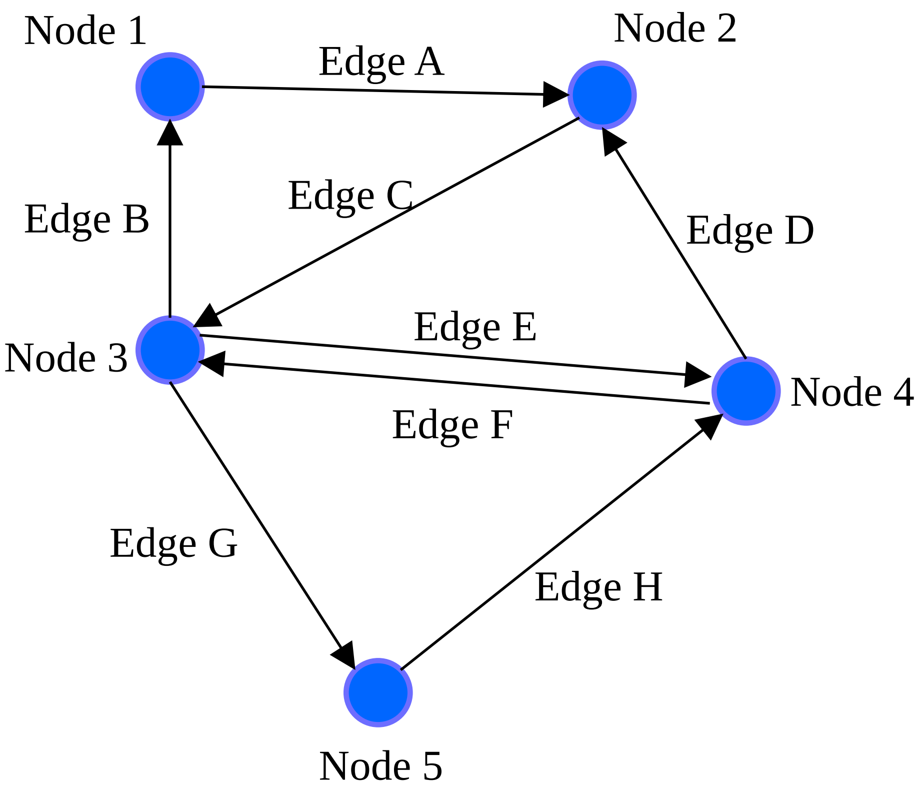
A graph represents relationships

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

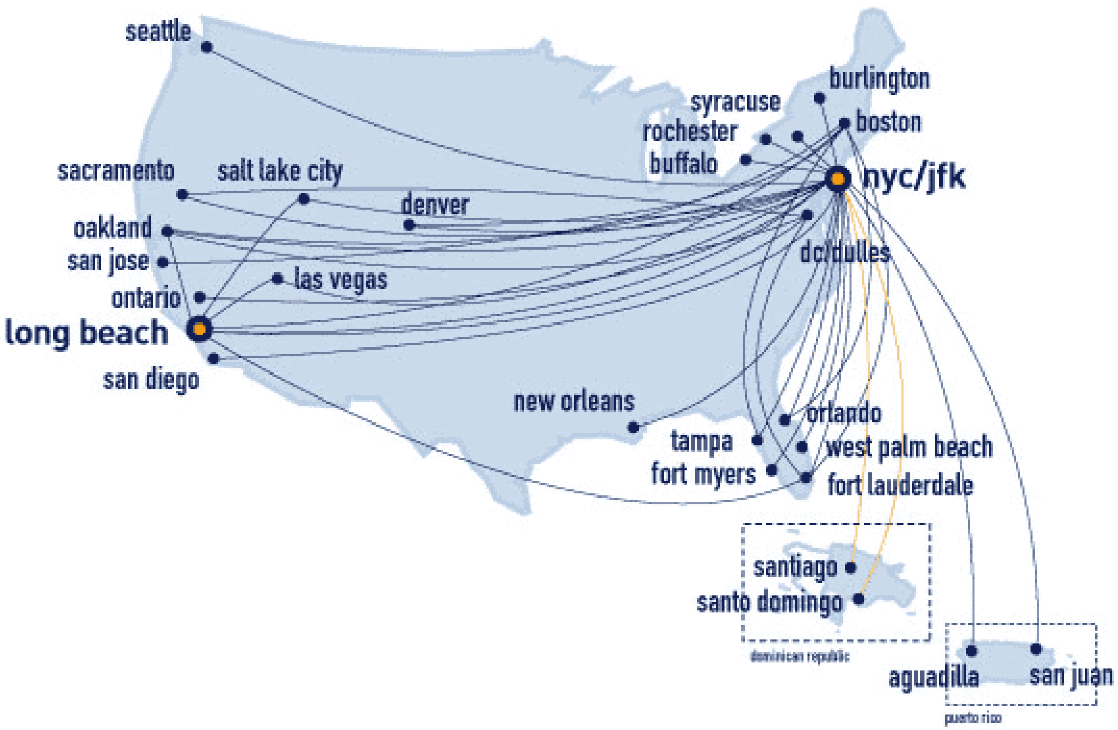
Nodes: intersections (cities)

Label: name/location

Edges: roads

Label: name/length

Example: airline flights



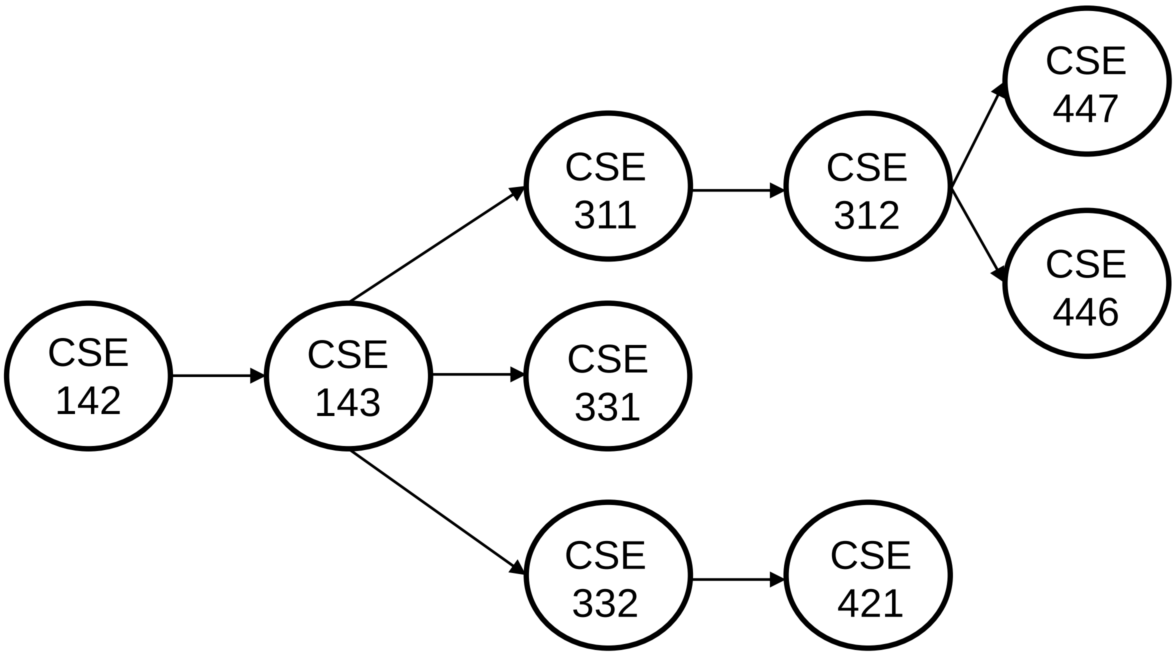
Nodes: airports

Label: airport code

Edges: flights

Label: cost/time

Example: CSE courses



Nodes: Courses

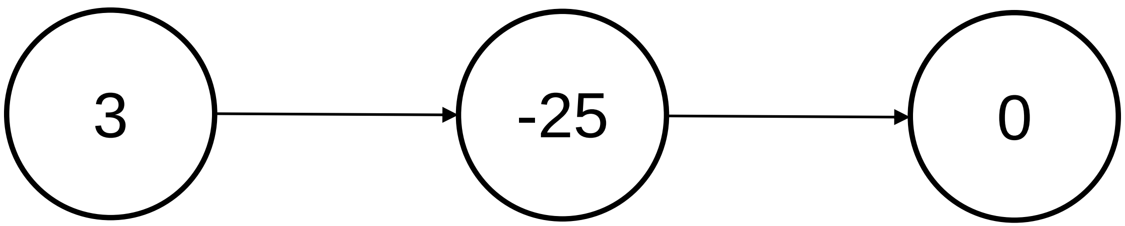
Label: Course name

Edges: pointer to next class

Label: none

You’ve used graphs before!

Singly linked Lists:



Nodes: Linked list node

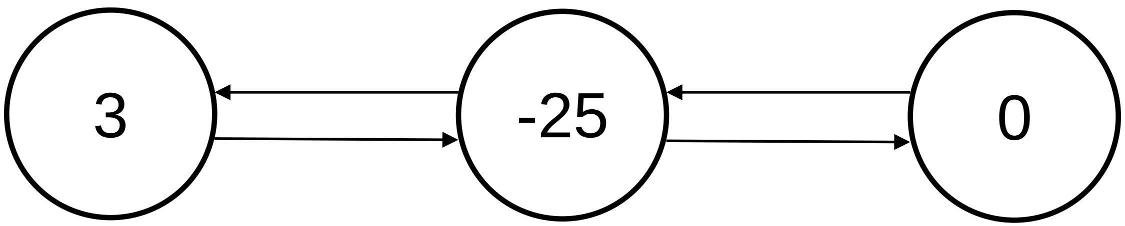
Label: integer

Edges: pointer to next node

Label: none

You’ve used graphs before!

Doubly linked Lists:



Nodes: Linked list node

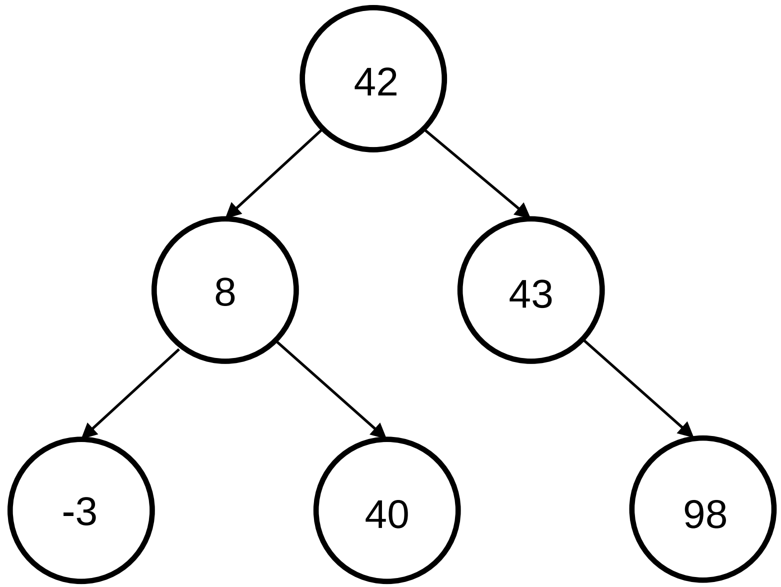
Label: integer

Edges: pointers to prev/next nodes

Label: none

You've used graphs before!

Binary trees:



Nodes: Tree node

Label: Integer

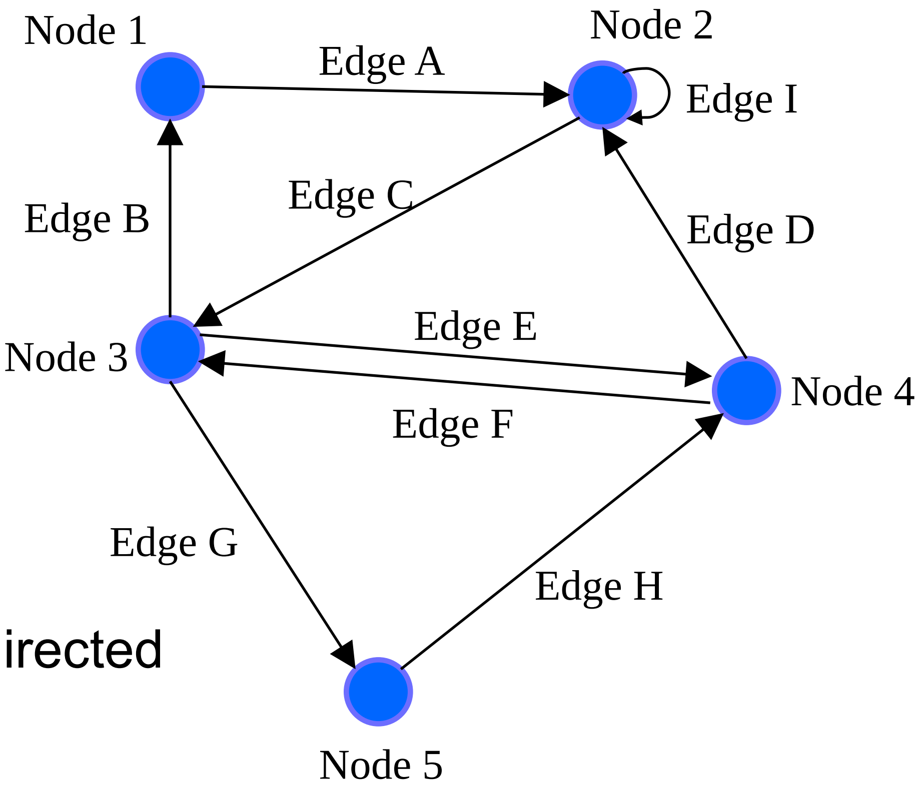
Edges: pointers to children

Label: none

An edge points from source to dest.

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

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

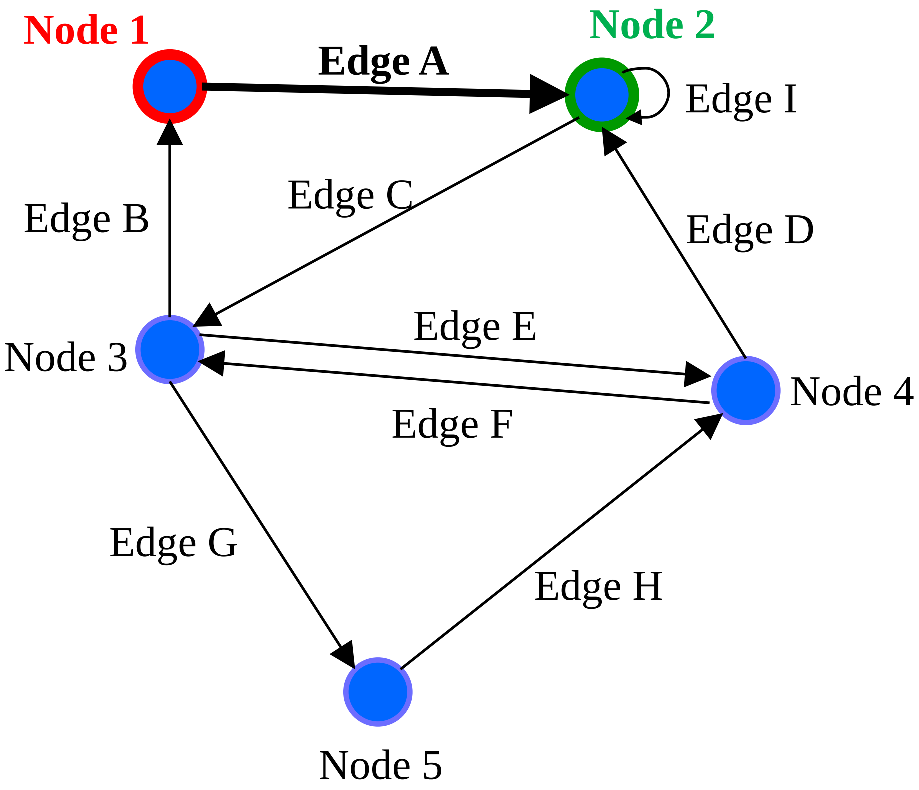


N.B.: We’re only dealing with directed graphs from here on out.

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 → Node 2.

- Outgoing from Node 1
- Incoming to Node 2

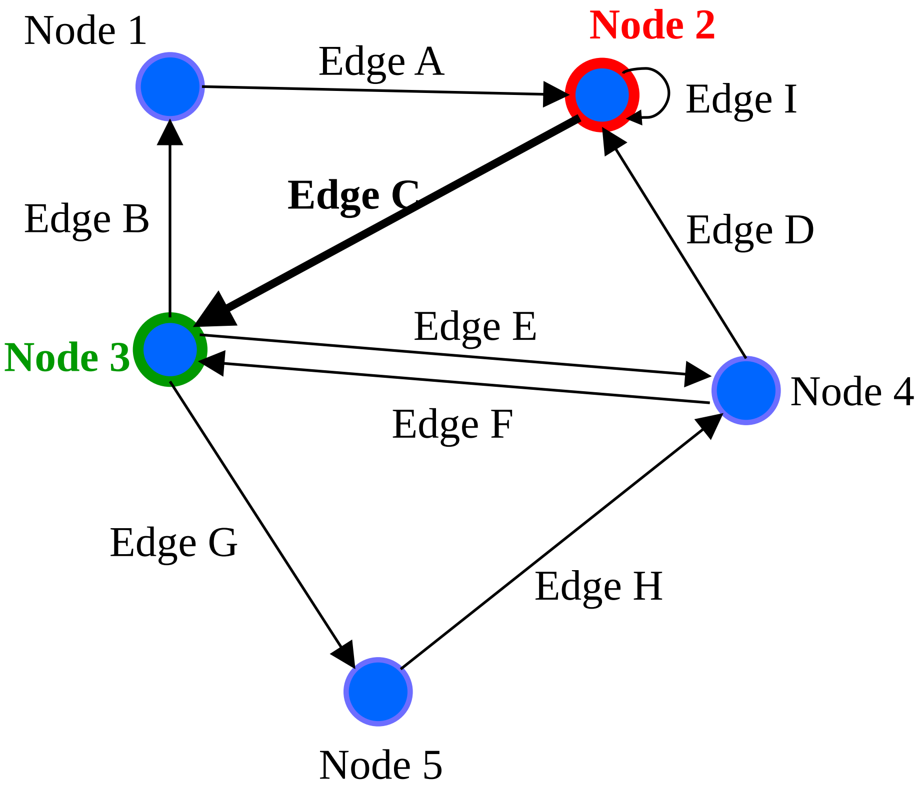
An edge points from source to dest.

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

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

Edge C is Node 2 → Node 3.

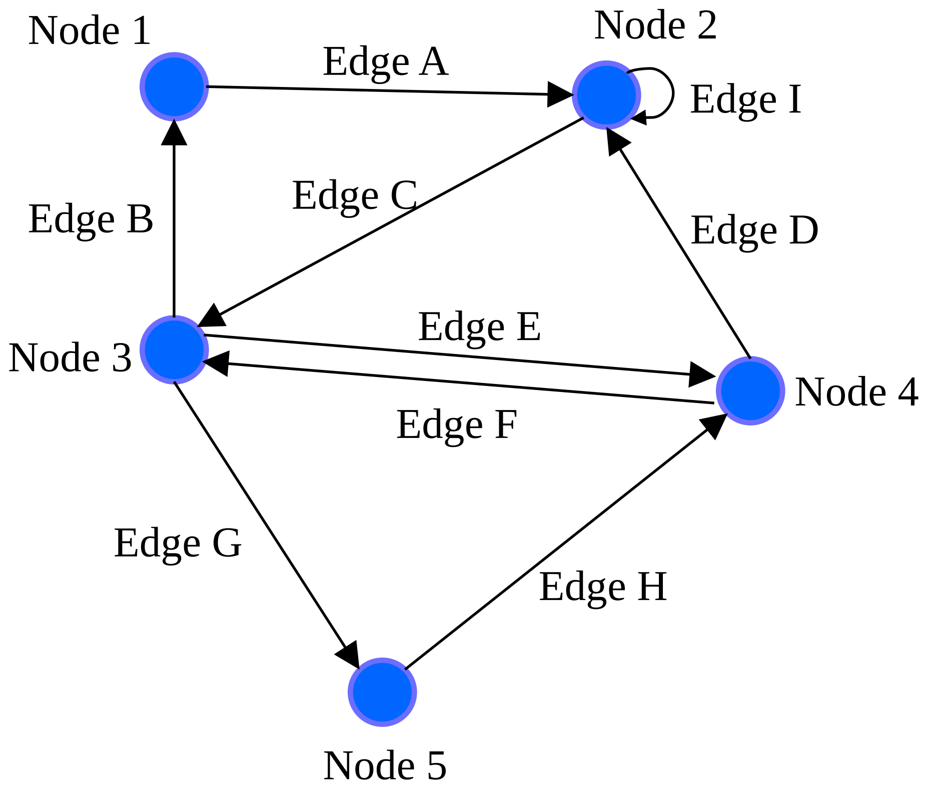
- Outgoing from Node 2
- Incoming to Node 3



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**.

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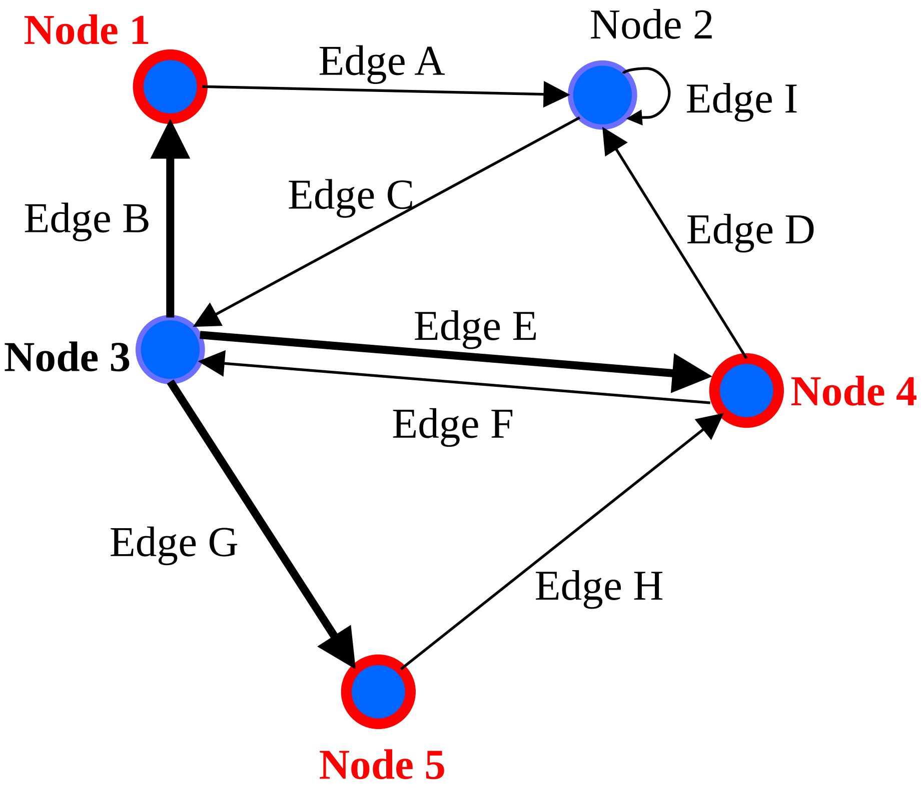


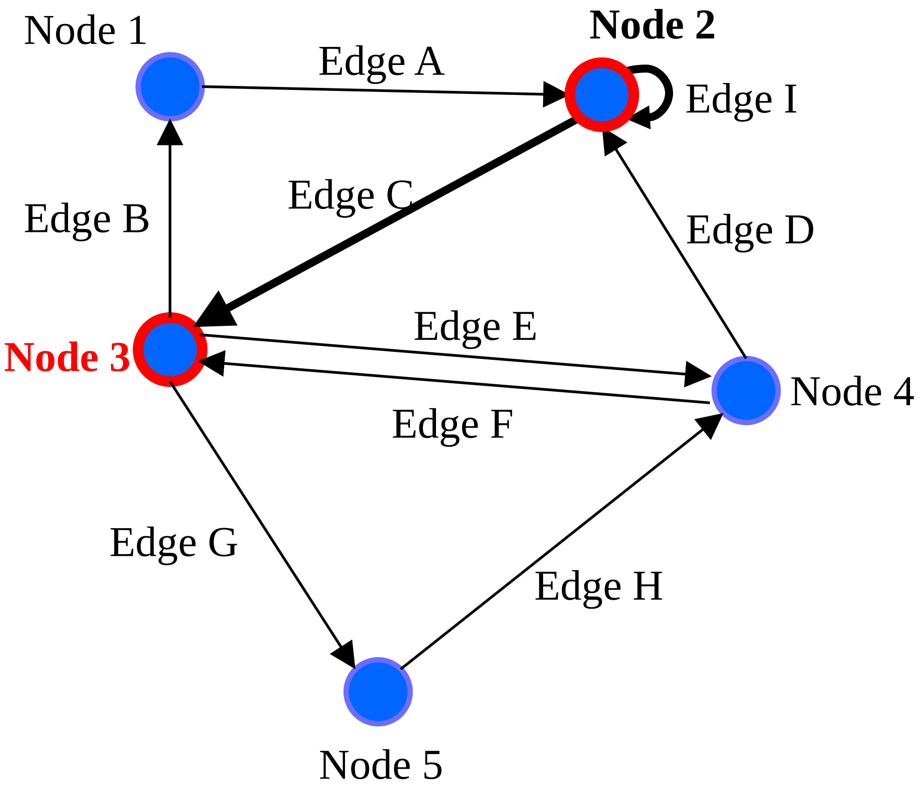
Node 3 has three children:

- Node 1
- Node 4
- Node 5

A node has children

A node's outgoing edges point to its **children**.

- Potentially empty set



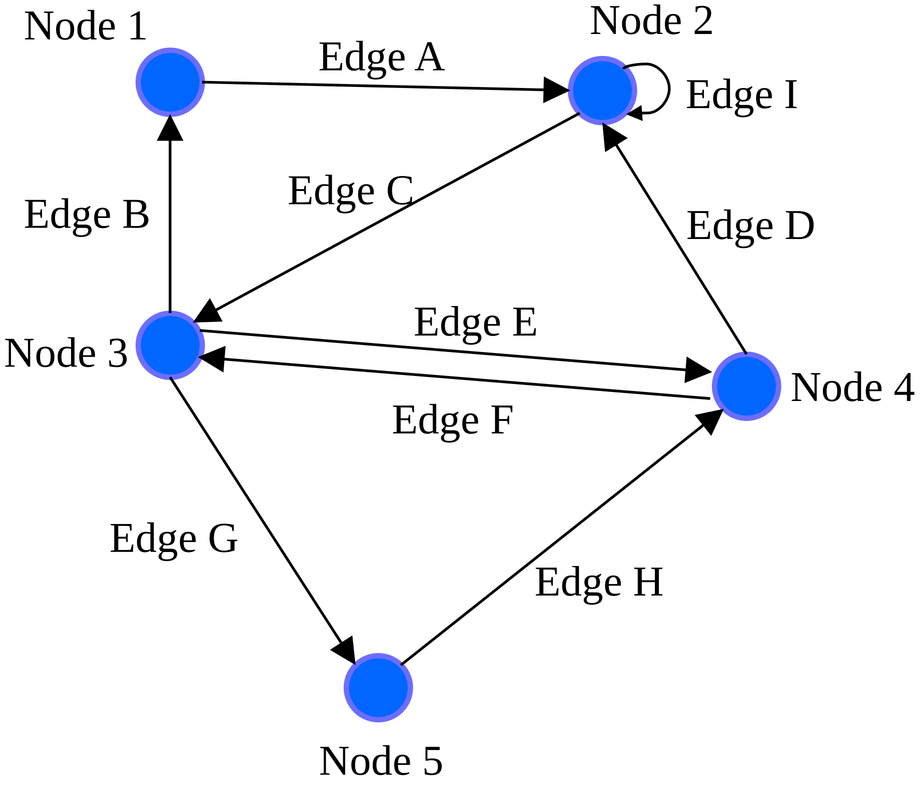
Node 2 has two children:

- Node 2
- Node 3

A node has parents

A node’s incoming edges point from its **parents**.

- Potentially empty set



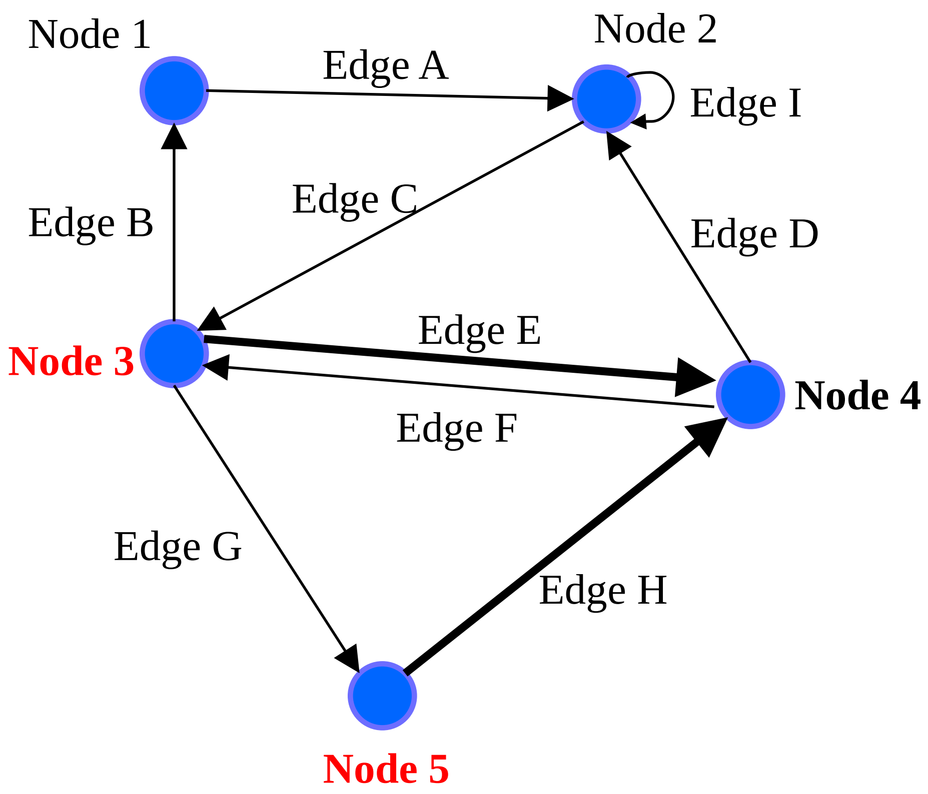
A node has parents

A node's incoming edges point from its **parents**.

- Potentially empty set

Node 4 has two parents:

- Node 3
- Node 5



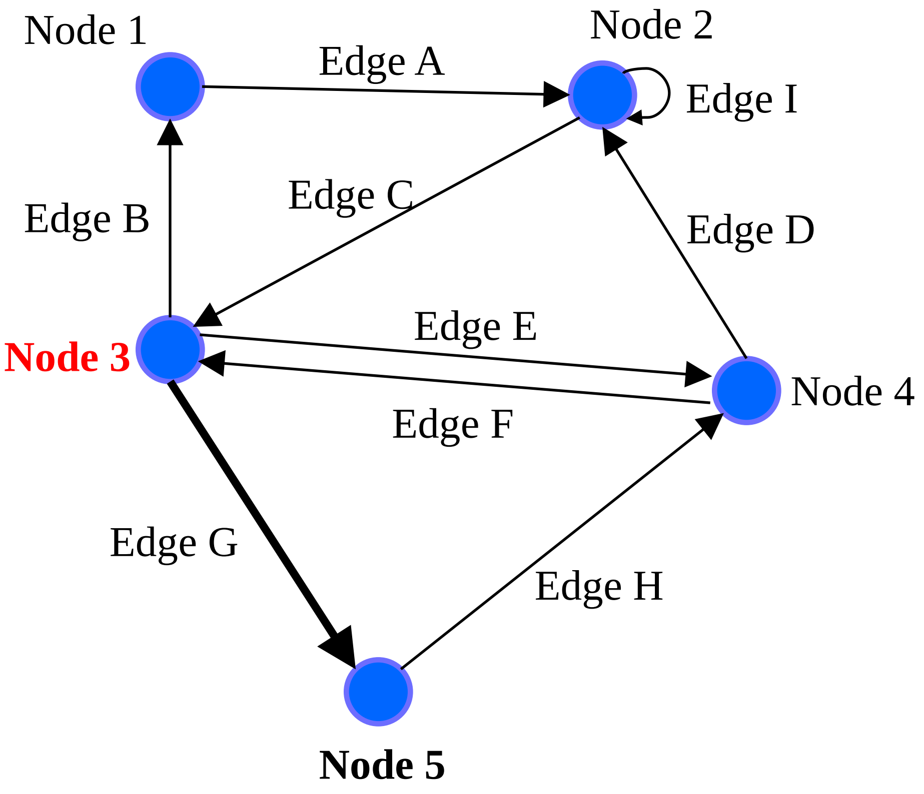
A node has parents

A node's incoming edges point from its **parents**.

- Potentially empty set

Node 5 has one parent:

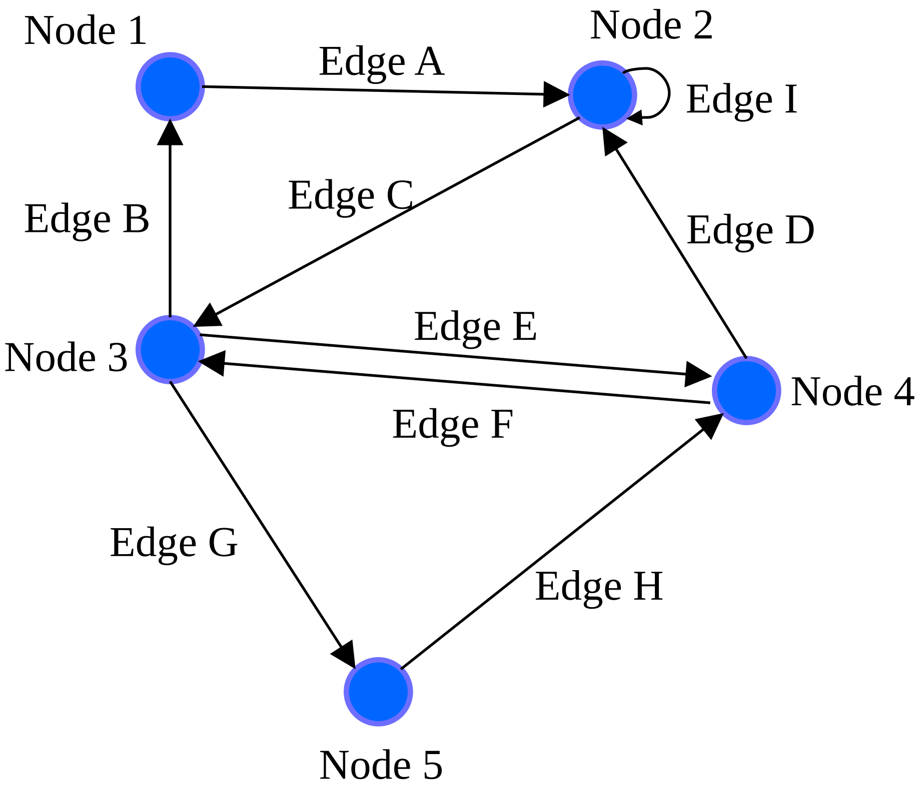
- Node 3



A node has neighbors

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

- Potentially empty set



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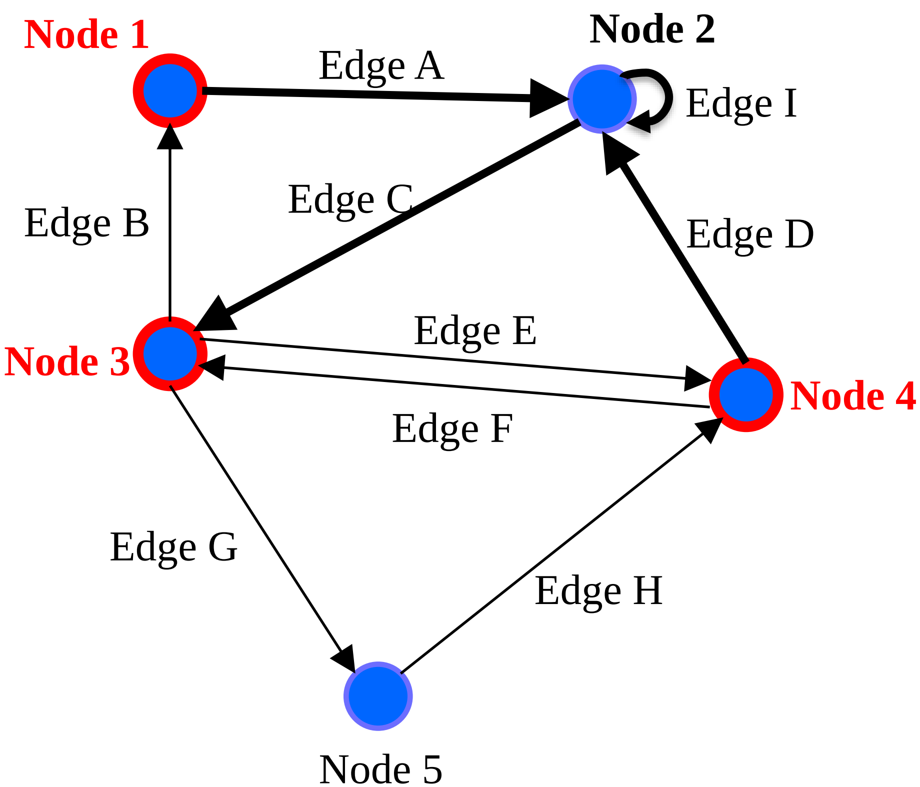


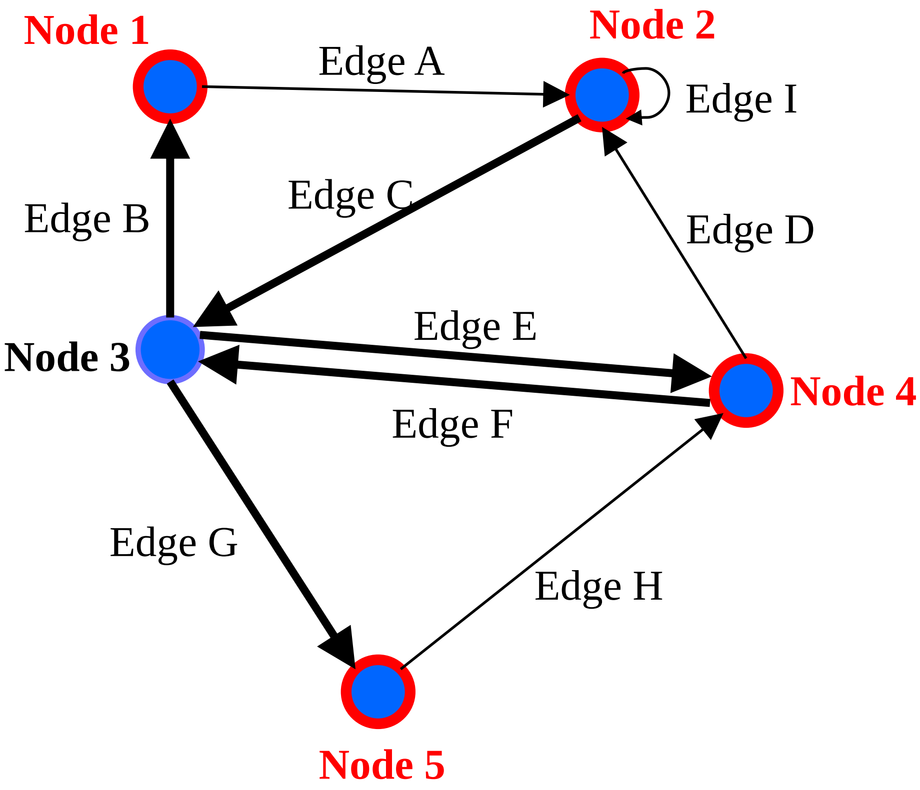
Node 2 has four neighbors:

- 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



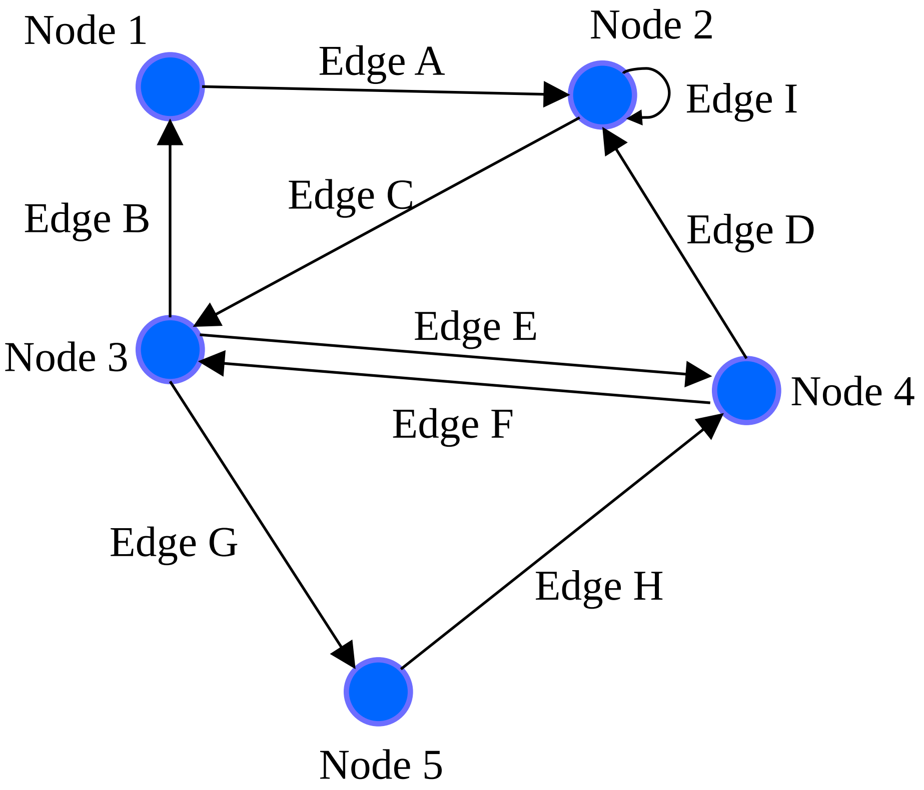
Node 3 has four neighbors:

- 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



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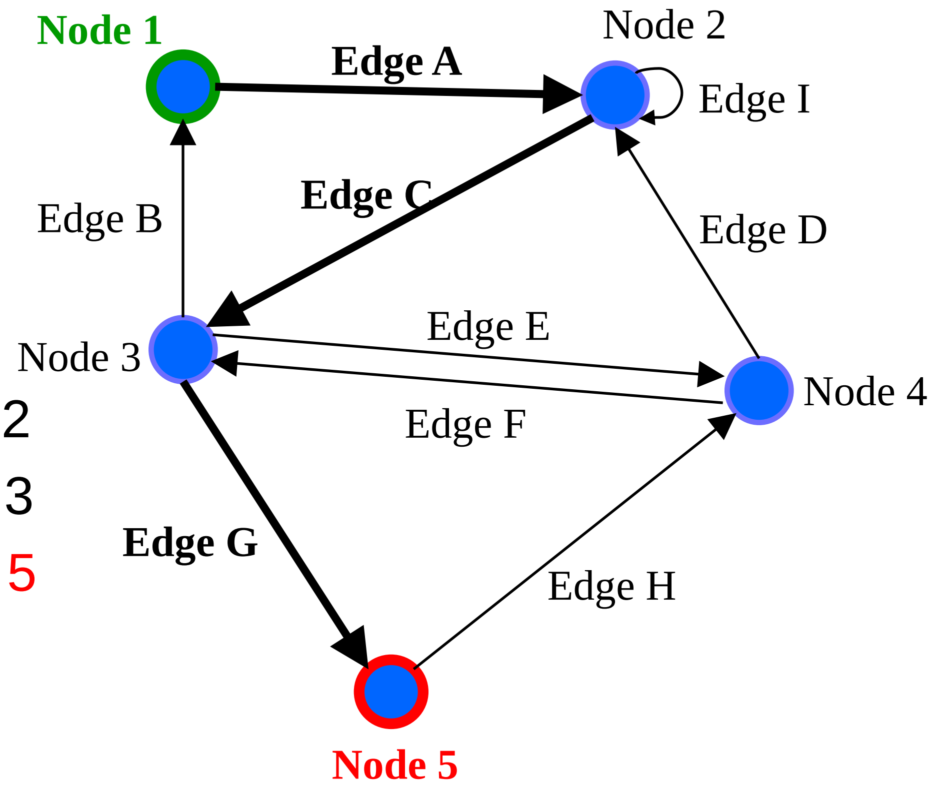

Path from Node 1 to Node 5:

1. Edge A : Node 1 → Node 2
2. Edge C : Node 2 → Node 3
3. Edge G : Node 3 → Node 5

Paths between nodes

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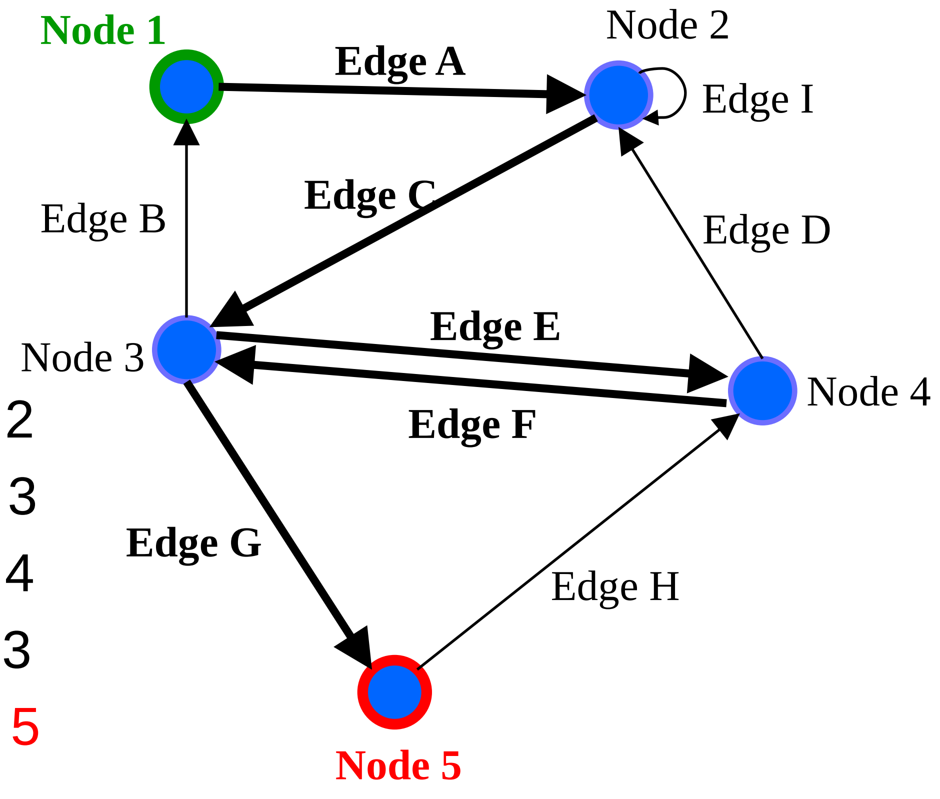

Path from Node 1 to Node 5:

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

Paths between nodes

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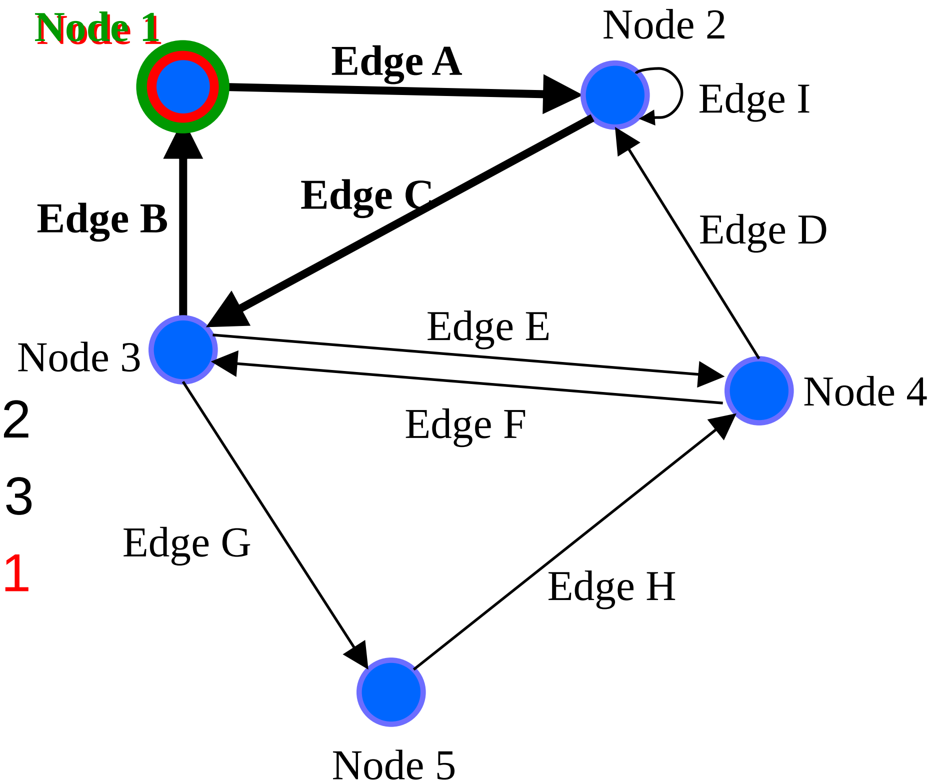

Path from Node 1 to Node 1:

1. Edge A : Node 1 → Node 2
2. Edge C : Node 2 → Node 3
3. Edge B : Node 3 → Node 1

Paths between nodes

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

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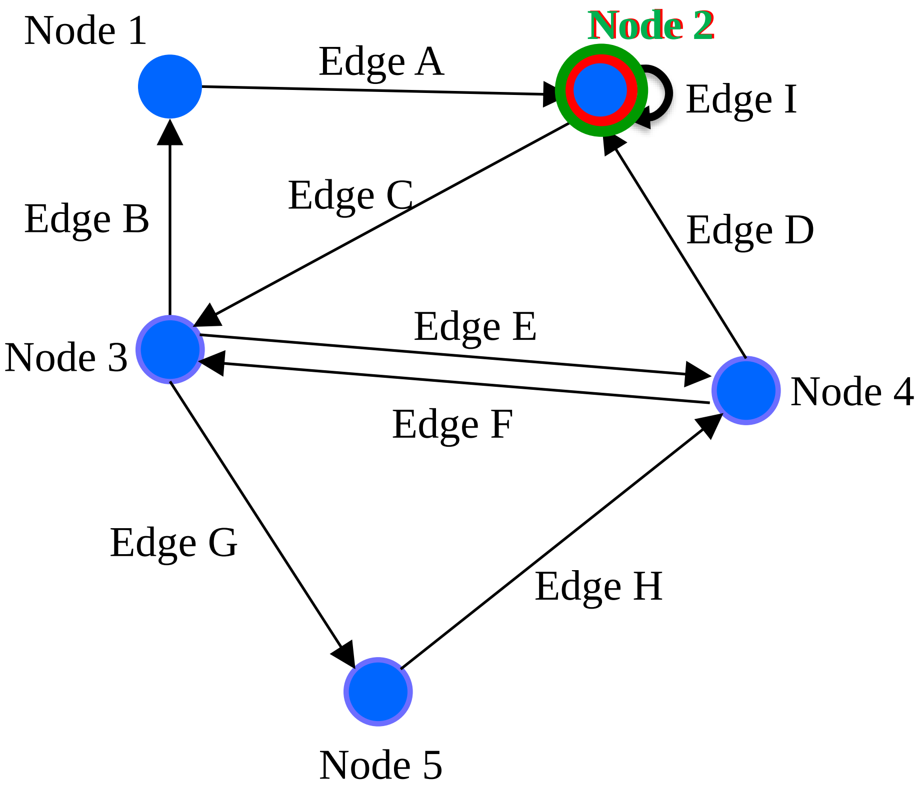
- Often want shortest



Path from Node 2 to Node 2:

1. Edge I : Node 2 → Node 2

Possible graph operations

Creators

- Construct an empty graph

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

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

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 (**`String`**s)
  - Directed: Edges have direction
  - Edges with same source and destination will have unique labels

HW5: Design before implementation

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- The exact interface of your **`Graph`** class is up to you
  - So, no given JUnit tests bundled with the starter code
  - Advice: Look ahead at HW6 and consider its likely needs
    - Will be posted before Saturday
  - Reminder: *Not a generic class.*

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- HW5 split into 2 parts
  1. **Design and specify a graph ADT**
  2. Implement that ADT specification

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

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

HW5: Testing

- The design process includes crafting a good test suite
  - Script tests and JUnit tests
- **Script Tests** (`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/`)
  - 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: 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: 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***, <u>including whitespace</u>!

Command (in *foo*.test)	Output (in *foo*.expected)
CreateGraph *name*	**created graph** *name*
AddNode *graph label*	**added node** *label* **to** *graph*
AddEdge *graph parent child label*	**added edge** *label* **from** *parent* **to** *child* **in** *graph*
ListNodes *graph*	*graph* **contains:** *label*$_{node}$ …
ListChildren *graph parent*	**the children of** *parent* **in** *graph* **are:** *child* **(***label*$_{edge}$**)** …
# *This is comment text …*	**#** *This is comment text …*

HW5: **`example.test`**

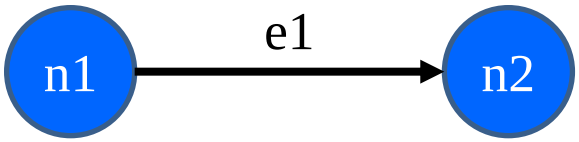
```
# Create a graph
CreateGraph graph1

# 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
```



HW5: `example.expected`

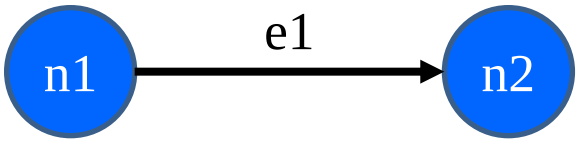
```
# Create a graph
created graph graph1

# 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)
```



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: 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`**

```
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

1. Note: Your JUnit tests will fail in hw5 part 1, because you have not implemented the actual methods yet
   – The same goes for your script tests

2. You will do that in part 2

JUnit for test authors

The following slides are included for reference and add additional material that you'll need to write tests for HW 5.

Writing tests with JUnit

Annotate a method with **`@Test`** to flag it as a JUnit test

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

/** Unit tests for my Foo ADT implementation */
public class FooTests {
  @Test
  public void testBar() {
    ... /* use JUnit assertions in here */
  }
}
```

Common JUnit assertions

JUnit's documentation has a full list, but these are the most common assertions.

Assertion	Failure condition
`assertTrue(`*`test`*`)`	*`test`* `== false`
`assertFalse(`*`test`*`)`	*`test`* `== true`
`assertEquals(`*`expected, actual`*`)`	*`expected`* and *`actual`* are not equal
`assertSame(`*`expected, actual`*`)`	*`expected`* `!=` *`actual`*
`assertNotSame(`*`expected, actual`*`)`	*`expected`* `==` *`actual`*
`assertNull(`*`value`*`)`	*`value`* `!= null`
`assertNotNull(`*`value`*`)`	*`value`* `== null`

Any JUnit assertion can also take a string to show in case of failure, *e.g.*, **`assertEquals("helpful message", expected, actual)`**.

Always* use >= 1 JUnit Assertion

- If you don't use any JUnit assertions, you are only checking that no exception/error occurs

- That's a pretty weak notion of passing a test; rarely the best test you could write

- Having more than one JUnit assertion in a test may make sense, but one is the most common scenario
  – "Each test should test one (new) thing" (most of the time)

* = Special-case coming in a couple slides 💻

JUnit assertions vs Java's assert

- Use JUnit assertions **only in JUnit test code**
  - JUnit assertions have names like **`assertEquals`**, **`assertNotNull`**, **`assertTrue`**
  - Part of JUnit framework used to report test results
    - Accessed via **`import org.junit`**….
  - **Don't** use in ordinary Java code (***never*** **`import org.junit`**…. in non-JUnit code)
- Use Java's **`assert`** statement in ordinary Java code
  - Use liberally to annotate/check "must be true" / "must not happen" / etc. conditions
  - Use in **`checkRep()`** to detect failure if problem(s) found
  - **Do not** use in JUnit tests to check test result – does not interact properly with JUnit framework to report results

Checking for a thrown exception

- Need to test that your code throws exceptions as specified
- This kind of test method fails if its body does *not* throw an exception of the named class
  - May not need any JUnit assertions inside the test method

```
@Test(expected=IndexOutOfBoundsException.class)
public void testGetEmptyList() {
  List<String> list = new ArrayList<String>();
  list.get(0);
}
```

Test ordering, setup, clean-up

JUnit does not promise to run tests in any particular order.

However, JUnit can run helper methods for common setup/cleanup

- Run before/after *each* test method in the class:

```
@Before
public void m() { ... }
@After
public void m() { ... }
```

- Run before/after *all* test methods in the class:

```
@BeforeClass
public static void m() { ... }
@AfterClass
public static void m() { ... }
```

Tips for effective testing

- Use constants instead of hard-coded values
  - Makes change easier later on
- Take advantage of assertion messages
- Give a descriptive name to each unit test (method)
  - Verbose but clear is better than short and inscrutable
  - Don’t go overboard, though :-)
- Write tests with a simple structure
  - Isolate bugs one at a time with successive assertions
  - Helps avoid bugs in your tests too!
- Aim for thorough test coverage
  - Big/small inputs, common/edge cases, exceptions, ...

Test Design Worksheet

- Work in pairs
- Give logic of the tests, not actual code
- Only test operations provided on the worksheet
- More details in lecture if additional information/review needed