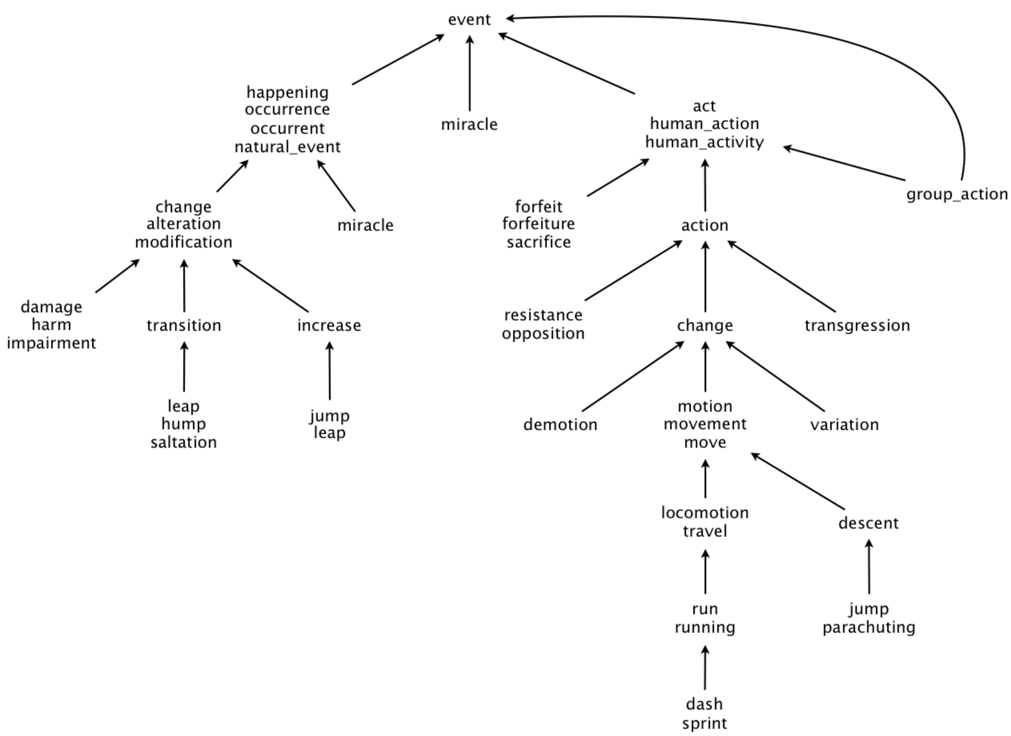
This document only contains the description of the project and the project problems. For the programming exercises on concepts related to the project, please refer to the project checklist.

Goal Find the shortest common ancestor of a digraph in WordNet, a semantic lexicon for the English language that computational linguists and cognitive scientists use extensively. For example, WordNet was a key component in IBM's Jeopardy-playing Watson computer system.

WordNet groups words into sets of synonyms called synsets. For example, {*AND circuit, AND gate*} is a synset that represents a logical gate that fires only when all of its inputs fire. WordNet also describes semantic relationships between synsets. One such relationship is the *is-a* relationship, which connects a *hyponym* (more specific synset) to a *hypernym* (more general synset). For example, the synset {*gate, logic gate*} is a hypernym of {*AND circuit, AND gate*} because an AND gate is a kind of logic gate.

The WordNet Digraph Your first task is to build the WordNet digraph: each vertex v is an integer that represents a synset, and each directed edge $v \to w$ denotes that w is a hypernym of v. The WordNet digraph is a *rooted DAG*: it is acyclic and has one vertex — the root — that is an ancestor of every other vertex. However, it is not necessarily a tree because a synset can have more than one hypernym. A small subgraph of the WordNet digraph is shown below.



The WordNet Input File Formats We now describe the two data files that you will use to create the WordNet digraph. The files are in *comma-separated values* (CSV) format: each line contains a sequence of fields, separated by commas.

- *List of synsets.* The file `synsets.txt` contains all noun synsets in WordNet, one per line. Line i of the file (counting from 0) contains the information for synset i. The first field is the *synset id*, which is always the integer i; the second field is the synonym set (or synset); and the third field is its dictionary definition (or *gloss*), which is not relevant to this assignment.

```
% more synsets.txt
  ⋮
34,AIDS acquired_immune_deficiency_syndrome,a serious (often fatal) disease of the immune system
35,ALGOL,a programming language used to express computer programs as algorithms
36,AND_circuit AND_gate,a circuit in a computer that fires only when all of its inputs fire
37,APC,a drug combination found in some over-the-counter headache remedies
38,ASCII_character,any member of the standard code for representing characters by binary numbers
39,ASCII_character_set,(computer science) 128 characters that make up the ASCII coding scheme
40,ASCII_text_file,a text file that contains only ASCII characters without special formatting
41,ASL American_sign_language,the sign language used in the United States
42,AWOL,one who is away or absent without leave
  ⋮
```

For example, line 36 implies that the synset `AND_circuit AND_gate` has an id number of 36 and it's gloss is "a circuit in a computer that fires only when all of its inputs fire". The individual nouns that constitute a synset are separated by spaces. If a noun contains more than one word, the words are connected by the underscore character.

- *List of hypernyms.* The file `hypernyms.txt` contains the hypernym relationships. Line i of the file contains the hypernyms of synset i. The first field is the synset id, which is always the integer i; subsequent fields are the id numbers of the synset's hypernyms.

```
% more hypernyms.txt
  ⋮
34,47569,48084
35,19983
36,42338
37,53717
38,28591
39,28597
40,76057
41,70206
42,18793
  ⋮
```

For example, line 36 implies that synset 36 (`AND_circuit AND_Gate`) has 42338 (`gate logic_gate`) as it only hypernym. Line 34 implies that synset 34 (`AIDS acquired_immune_deficiency_syndrome`) has two hypernyms: 47569 (`immunodeficiency`) and 56099 (`infectious_disease`).

Problem 1. (`WordNet` *Data Type*) Implement an immutable data type called `WordNet` with the following API:

WordNet	
`WordNet(String synsets, String hypernyms)`	constructs a `WordNet` object given the names of the input (synset and hypernym) files
`Iterable<String> nouns()`	returns all WordNet nouns
`boolean isNoun(String word)`	returns `true` if the given word is a WordNet noun, and `false` otherwise
`String sca(String noun1, String noun2)`	returns a synset that is a shortest common ancestor of `noun1` and `noun2`
`int distance(String noun1, String noun2)`	returns the length of the shortest ancestral path between `noun1` and `noun2`

Corner Cases

- The constructor should throw a `NullPointerException()` with the message `"synsets is null"` if *synsets* is `null` and the message `"hypernyms is null"` if *hypernyms* is `null`.
- The `isNoun()` method should throw a `NullPointerException("word is null")` if *word* is `null`.
- The `sca()` and `distance()` methods should throw a `NullPointerException()` with the message `"noun1 is null"` or `"noun2 is null"` if $noun1$ or $noun2$ is `null`. The methods should throw an `IllegalArgumentException()` with the message `"noun1 is not a noun"` or `"noun2 is not a noun"` if $noun1$ or $noun2$ is not a noun.

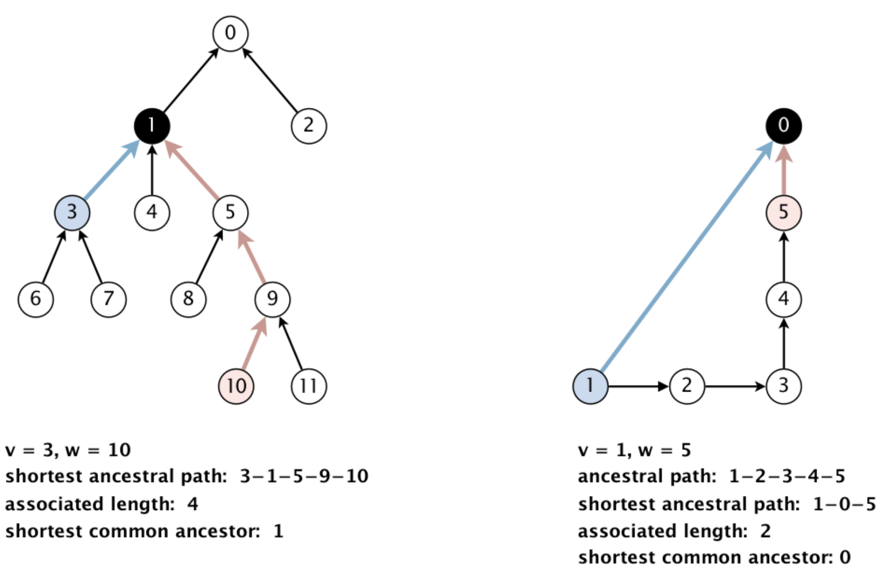
Performance Requirements

- The constructor and the `nouns()` method should run in time $T(n) \sim n$, where n is the size of the WordNet lexicon.
- The `isNoun()` method should run in time $T(n) \sim 1$.
- The `sca()` and `distance()` methods should make exactly one call to the `ancestor()` and `length()` methods in `ShortestCommonAncestor`, respectively.

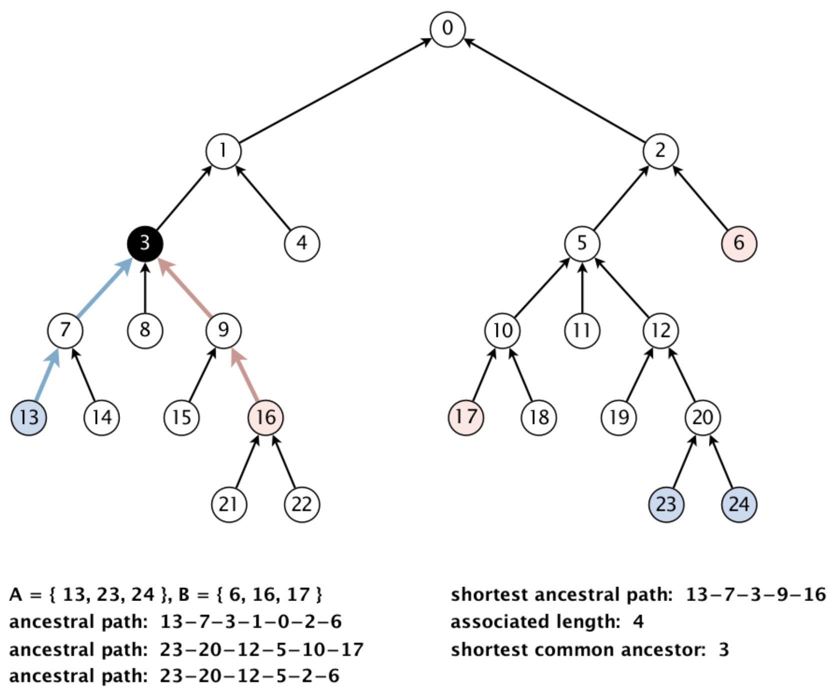
```
>_ ~/workspace/project6

$ java WordNet data/synsets.txt data/hypernyms.txt worm bird
# of nouns = 119188
isNoun(worm)? true
isNoun(bird)? true
isNoun(worm bird)? false
sca(worm, bird) = animal animate_being beast brute creature fauna
distance(worm, bird) = 5
```

Shortest Common Ancestor An *ancestral path* between two vertices v and w in a rooted DAG is a directed path from v to a common ancestor x, together with a directed path from w to the same ancestor x. A shortest ancestral path is an ancestral path of minimum total length. We refer to the common ancestor in a shortest ancestral path as a *shortest common ancestor*. Note that a shortest common ancestor always exists because the root is an ancestor of every vertex. Note also that an ancestral path is a path, but not a directed path.



We generalize the notion of shortest common ancestor to subsets of vertices. A shortest ancestral path of two subsets of vertices A and B is a shortest ancestral path over all pairs of vertices v and w, with v in A and w in B.



Problem 2. (*`ShortestCommonAncestor` Data Type*) Implement an immutable data type called `ShortestCommonAncestor` with the following API:

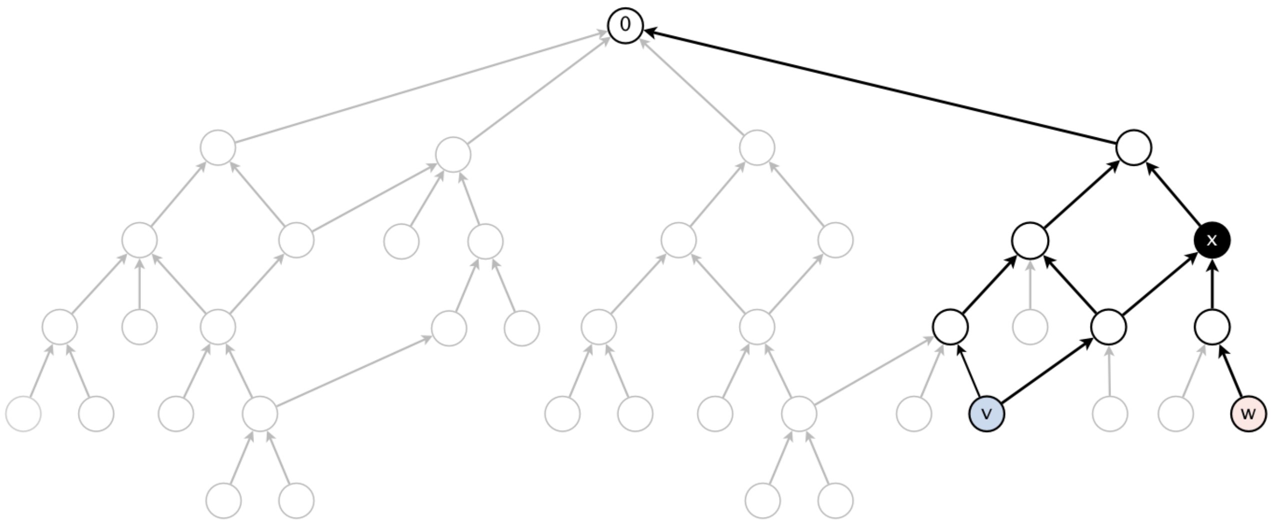
ShortestCommonAncestor	
`ShortestCommonAncestor(Digraph G)`	constructs a `ShortestCommonAncestor` object given a rooted DAG
`int length(int v, int w)`	returns length of the shortest ancestral path between vertices `v` and `w`
`int ancestor(int v, int w)`	returns a shortest common ancestor of vertices `v` and `w`
`int length(Iterable<Integer> A, Iterable<Integer> B)`	returns length of the shortest ancestral path of vertex subsets `A` and `B`
`int ancestor(Iterable<Integer> A, Iterable<Integer> B)`	returns a shortest common ancestor of vertex subsets `A` and `B`

Corner Cases

- The constructor should throw a `NullPointerException("G is null")` if G is `null`.
- The `length()` and `ancestor()` methods should throw an `IndesOutOfBoundsException()` with the message `"v is invalid"` or `"w is invalid"` if $v, w < 0$ or $v, w \geq V$, the number of vertices in G.
- The overloaded `length()` and `ancestor()` methods should throw a `NullPointerException()` with the message `"A is null"` or `"B is null"` if the vertex subset A or B is `null`. The methods should throw an `IllegalArgumentException()` with the message `"A is empty"` or `"B is empty"` if either A or B is empty.

Performance Requirements

- The constructor run in time $T(E, V) \sim 1$, where E and V are the number of edges and vertices in the digraph G, respectively.
- The methods `length()` and `ancestor()` should run in time $T(E, V) \sim E + V$. To be precise, they should run in time proportional to the number of vertices and edges reachable from the argument vertices. For example, to compute the shortest common ancestor of v and w in the digraph below, your algorithm can only examine the highlighted vertices and edges and it should not initialize any vertex-indexed arrays.



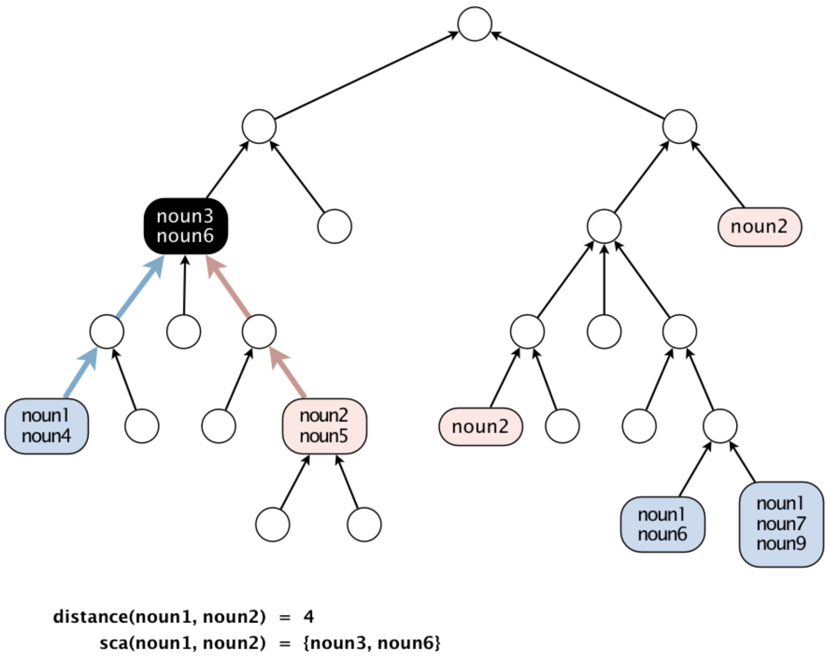

```
>_ ~/workspace/project6

$ java ShortestCommonAncestor data/digraph1.txt
3 10 8 11 6 2
<ctrl-d>
length = 4, ancestor = 1
length = 3, ancestor = 5
length = 4, ancestor = 0
```

Measuring the Semantic Relatedness of Two Nouns Semantic relatedness refers to the degree to which two concepts are related. Measuring semantic relatedness is a challenging problem. For example, you consider *George W. Bush* and *John F. Kennedy* (two U.S. presidents) to be more closely related than *George W. Bush* and *chimpanzee* (two primates). It might not be clear whether *George W. Bush* and *Eric Arthur Blair* are more related than two arbitrary people. However, both *George W. Bush* and *Eric Arthur Blair* (aka George Orwell) are famous communicators and, therefore, closely related. We define the semantic relatedness of two WordNet nouns x and y as follows:

- A is set of synsets in which x appears;
- B is set of synsets in which y appears;
- $sca(x, y)$ a shortest common ancestor of A and B; and
- $distance(x, y)$ is length of shortest ancestral path of A and B.

This is the notion of distance that you will use to implement the `distance()` and `sca()` methods in the `WordNet` data type.



Outcast Detection Given a list of WordNet nouns $x_1, x_2, \ldots, x_n$, which noun is the least related to the others? To identify an outcast, compute the sum of the distances between each noun and every other one:

$$d_i = distance(x_i, x_1) + distance(x_i, x_2) + \cdots + distance(x_i, x_n)$$

and return a noun x_i for which d_i is maximum. Note that because $distance(x_i, x_i) = 0$, it will not contribute to the sum.

Problem 3. (`Outcast` *Data Type*) Implement an immutable data type called `Outcast` with the following API:

Outcast	
`Outcast(WordNet wordnet)`	constructs an `Outcast` object given the WordNet semantic lexicon
`String outcast(String[] nouns)`	returns the outcast noun from `nouns`

You may assume that argument to `outcast()` contains only valid WordNet nouns (and that it contains at least two such nouns).

```
>_ ~/workspace/project6

$ java Outcast data/synsets.txt data/hypernyms.txt < data/outcast10.txt
cat cheetah dog wolf *albatross* horse zebra lemur orangutan chimpanzee
$ java Outcast data/synsets.txt data/hypernyms.txt < data/outcast11.txt
apple pear peach banana lime lemon blueberry strawberry mango watermelon *potato*
$ java Outcast data/synsets.txt data/hypernyms.txt < data/outcast12.txt
competition cup event fielding football level practice prestige team tournament world *mongoose*
```

Acknowledgements This project is an adaptation of the WordNet assignment developed at Princeton University by Alina Ene and Kevin Wayne.