PROMETHEUS AI
Phase 1

Sean Stappas
260639512

ECSE-498: Honours Thesis I

Supervised by: Prof. Joseph Vybihal

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Abstract

Prometheus AI is a model of the human brain with the goal of controlling multiple robots in a swarm environment. This could be useful in environments hazardous for humans, such as the aftermath of a nuclear power disaster, or in outer space. The model consists of four layers: the Neural Network (NN), the Knowledge Node Network (KNN), the Expert System (ES), and the Meta Reasoner (META). The NN classifies the signals coming from the robots' sensors and sends formatted tags to the KNN. The KNN represents memory and can initiate cascaded activation of memories in the form of tags, which are passed on to the ES. The ES is a simple logic reasoner and provides a recommendation for an action to the Meta Reasoner. The META represents high-level thinking and makes an intelligent decision for what the robots should do. The assigned task this semester was to implement prototypes of the KNN and ES layers in Java. This was achieved using specific design criteria and extensive feedback from the project supervisor, Prof. Vybihal. Personal design criteria included using object-oriented programming principles, optimizing the system for speed and space efficiency, and maximizing code readability. Tests were created in TestNG and extensive documentation was written in Javadoc [1].

Acknowledgments

Elsa Riachi worked on the other two layers of the Prometheus AI (NN and META) in parallel with my work. She also doing this project as part of an Honours Thesis. We have had many discussions on the design of the system and how our components should fit together.

[1]The Javadoc can be found here: `http://cs.mcgill.ca/~sstapp/prometheus/index.html`.

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Abbreviations

NN	Neural Network
KNN	Knowledge Node Network
ES	Expert System
META	Meta Reasoner
OOP	Object-Oriented Programming

1 Introduction

The goal of this project is to create an artificial intelligence system to control multiple robots. Applications for this type of system include robots in hazardous environments, such as in outer space (Mars, Moon, etc.), in nuclear plants after a nuclear disaster, and in military zones.

The structure of the system is inspired from the functionality of the human brain, and is composed of the following four layers (in order of increasing abstraction): the Neural Network (NN), the Knowledge Node Network (KNN), the Expert System (ES), and the Meta Reasoner (META), as can be seen in Figure 1. These will be described in Section 2.

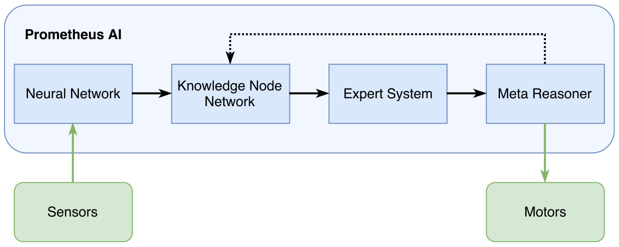


Figure 1: Prometheus AI model.

2 Background

2.1 Neural Network

The NN layer consists of a network of neurons with a similar structure to neurons in the human brain. In the context of this project, it is the interface between the robots' sensors and the rest of the AI system. Informational tags are generated by this layer based on observations that the robots make in their environment. These tags are passed onto the KNN.

The NN layer is based around the perceptron. A simple model of the perceptron can be seen in Figure 2.

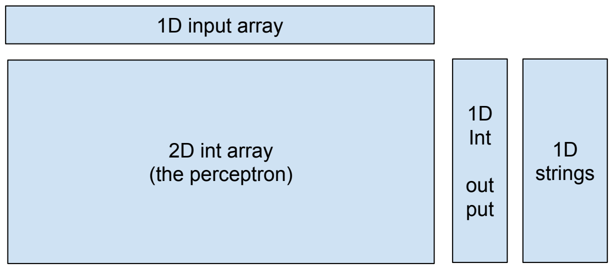


Figure 2: High-level model of the perceptron of the NN. [1]

2.2 Knowledge Node Network

The KNN layer represents memory in the human brain. It takes in the tags provided by the NN and outputs tags based on its knowledge of the environment. These output tags can be simple facts, such as "I see a wall", or can be recommendations for future actions such "turn left". These tags are passed on to the next layer, the Expert System (ES).

The KNN is based around the Knowledge Node, which is an abstract structure representing a memory and its connections to other memories. A simple model of a Knowledge Node can be seen in Figure 3.

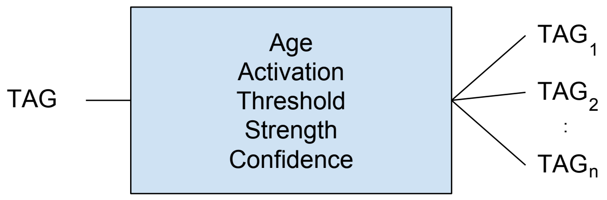


Figure 3: High-level model of the Knowledge Node of the KNN. [2]

The KNN has three main ways of thinking: forwards, backwards, and lambda. Forwards thinking is the simplest, and can be seen in Figure 4.

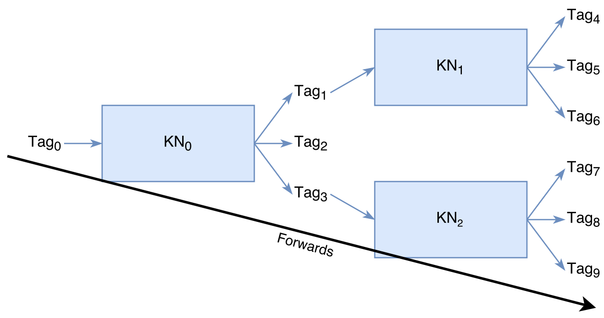


Figure 4: Thinking forwards in the KNN.

Thinking backwards starts at the output tags of Knowledge Nodes, and works backwards, as seen in Figure 5.

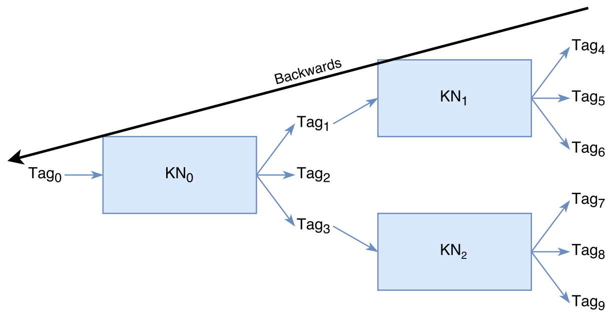


Figure 5: Thinking backwards in the KNN.

Lambda thinking uses a combination of forwards and backwards, and can be seen in Figure 6. This type of thinking occurs in humans when using analogical reasoning to solve problems [3].

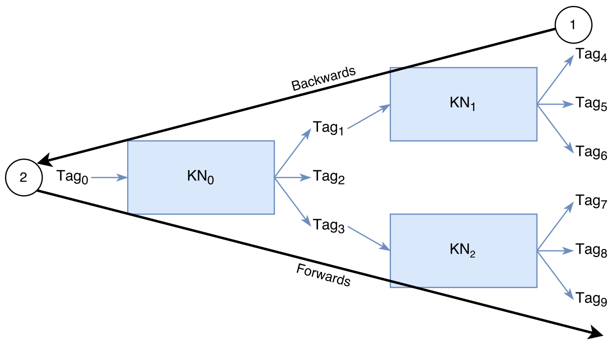


Figure 6: Lambda thinking in the KNN.

2.3 Expert System

The ES layer is a basic logic reasoner. It is not aware of its current reality, or any context. It takes in the tags provided by the KNN and interprets them as either facts, recommendations or rules.

Facts are simple calculus predicates showing that something is true. For example, the fact (A) represents that A itself is true or observed, $(A = 1)$ means that A is equal to 1, $(A > 1)$ represents that A is greater than 1, etc. As a more concrete example, a fact can represent a certain measurement, like $(distance = 5)$ representing the robot's distance from a wall as measured by one of its sensors.

Recommendations represent suggestions for actions to be taken by a robot. For example, $(\#turn\_left)$ is a recommendation for a robot to turn left, if it sees a wall directly in front of it and must avoid it, for example. These are recommendations and not commands because the META can decide whether or not to actually take that action.

Rules are a many-to-many structure with facts or recommendations as inputs and outputs. The output tags only become true when all the input tags are true. In this way, a rule represent a logical AND of all its input tags.

The runtime of the ES consists of the following general steps [4]:

1. Reset
2. Add facts and rules
3. Think
4. Send recommendations to META

These recommendations are passed on to the final layer, the Meta Reasoner (META).

2.4 Meta Reasoner

The META layer represents high-level reasoning in human brains. It is aware of its environment and context, and makes decisions based on what it believes to be right. It is paranoid, and constantly checks whether the tags reported by the rest of the AI system make sense based on its expected view of the world. If it decides to make a decision, it sends a command to the actuators of the robots to decide how to move. If it is not happy with the recommendation(s) from the ES, it may initiate another think cycle in the KNN to generate new recommendations(s).

With this full description of the Prometheus AI model, the system with labeled input and output can be seen in Figure 7.

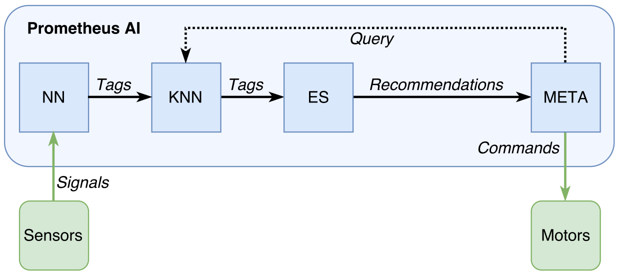


Figure 7: Prometheus AI model with labeled input and output.

3 Problem

The assigned task was to construct two out of the four layers listed in Section 2: the Expert System (ES), and the Knowledge Node Network (KNN). The other two layers are to be completed by another Honours Thesis student.

As a deliverable for the end of this first semester, it was required to complete a prototype of these two layers, with basic versions of the functionality described in Section 2. This was to be done entirely in Java.

4 Design

4.1 Efficiency (Space & Time)

A very important consideration when designing the system is speed. Since the robots may have to react very quickly to stimulus in the environment, the reasoning in the AI must be as fast as possible. This is especially true in the hazardous environments for which this system could be useful for, as specified in Section 1. An example of a design choice that was made to improve speed is the use of Java Sets for most of the collections in the ES and KNN layers. The original specifications mentioned using ArrayLists, but, since there is no specific iteration order necessary for most operations in the ES and KNN, these collections were changed to Sets.

When designing every algorithm in the system, the first criterion in mind is speed. Indeed, for the `think()` methods of the ES and KNN, it was important to think about the right way to leverage all the available data structures to maximize speed.

4.2 Object Oriented Design

Another important choice is to leverage object-oriented design as much as possible. Object-oriented programming (OOP) allows extensive planning before even beginning to write code, which can identify any flaws in the initial design. It also allows the code to be very clean and reusable. Since Java is the programming language chosen for the project, OOP is also the natural way to proceed. To follow OOP, the ES and KNN will be designed around Java classes and the methods associated with those classes. OOP principles such as polymorphism and encapsulation will be followed closely.

4.2.1 Abstraction

One important design aspect is that the system should be as abstract as possible, while still performing its desired task. For instance, the system should be general enough to perform under simulations, as well as in real-life environments. It should also ideally be able to perform in vastly different environments, with different tasks.

One example of making use of abstraction is the choice to create a `PrometheusLayer` interface for both the ES and KNN, since they share some functionality, like the ability to think.

4.2.2 Encapsulation

Each layer of the system has unique, localized functionality that does not need to be visible from the rest of the system. For instance, the intricacies of the `think()` method in the ES and KNN layers do not need to be known to the rest of the system.

4.2.3 Polymorphism

Many methods in the system can have different functionality depending on context. For instance, the `think()` method in the KNN and ES layers can take an optional number of think cycles to specify a threshold for quiescence.

4.3 Implementation in Java

The details of the specific design choices for the tags, ES and KNN will now be discussed.

4.3.1 Tags

The entire system revolves around tags passed from layer to layer. For this reason, a lot of thought was put into the proper design of these tags. To leverage OOP principles and readability, it was decided to implement these tags with a `Tag` class in Java, with `Fact`, `Rule` and `Recommendation` subclasses.

The tags described in Section 2 need to be as general as possible. A natural choice for this structure would be a Java `String`, which would be relatively simple to pass around the system. However, these tags represent various concepts; each tag can either be a fact, a recommendation, or a rule. If implemented as `String`s, the tags would have to be encoded on creation to represent each concept and decoded on use to retrieve the important information. This seems like a bad use of the OOP principles of Java. For this reason, the tags are instead implemented using a `Tag` Java class, with `Recommendation`, `Fact`, and `Rule` subclasses. This should also make manipulating the Tags faster, while incurring a slight memory overhead. To store these Tags in a database, they can be converted to JSON format. On read from the database, they can be easily decoded.

The `Tag` class itself was made abstract. This means that an object may not be directly instantiated as a `Tag`, but must be instantiated as one of its subclasses. This makes sense, since a tag *must* be one of the three types: rule, recommendation or fact.

All of these classes were placed inside the `tags` package. A UML diagram of the `tags` package can be seen in Figure 9 of the Appendix.

4.3.2 Knowledge Node Network

All code relating directly to the KNN was placed in the `knn` package of the project. A UML diagram of the `knn` package can be seen in Figure 10 of the Appendix.

The KNN layer is based around the `KnowledgeNodeNetwork` Java class.

4.3.3 Expert System

All code relating directly to the ES was placed in the `es` package of the project. A UML diagram of the `es` package can be seen in Figure 11 of the Appendix.

The ES layer is based around the `ExpertSystem` Java class.

4.4 Testing

All tests on the system were conducted using the TestNG framework in Java, which provides a simple and intuitive way to create assertions in tests. These tests were placed in the `test` package of the project. A UML diagram of the `test` package can be seen in Figure 12 of the Appendix.

4.4.1 Unit Tests

Unit tests were generated for the KNN and ES.

4.4.2 Integration Tests

Integration tests were made to test the combined functionality of the KNN and ES.

The test setup for the `testKNN()` method can be seen in Figure 8.

The test setup for the `testES()` method can be seen in Table 1.

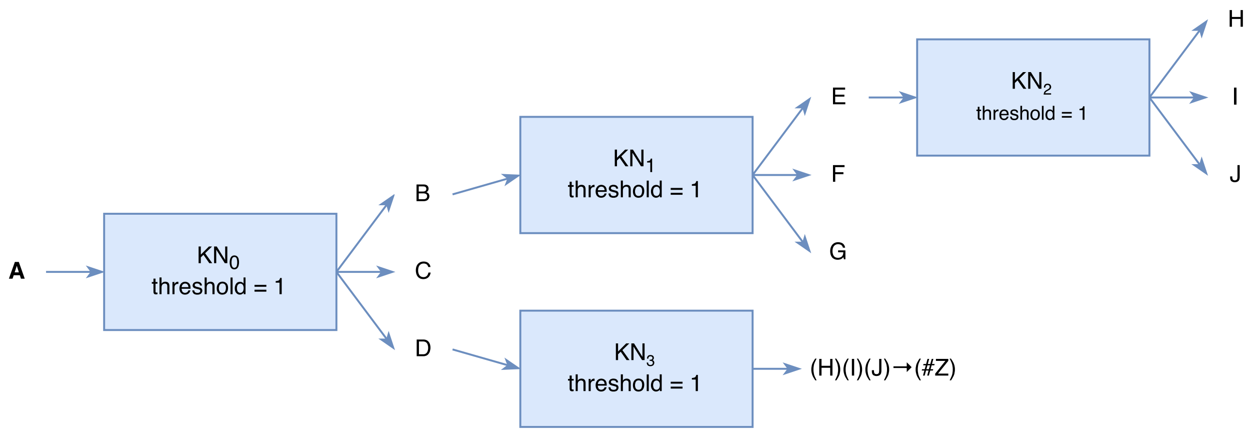


Figure 8: Setup for the `testKNN()` method. Every node has a `threshold` value of 1 to simplify the activation.

Ready Rules	Active Rules	Active Facts	Active Recommendations
$(A)(B) \to (D)$ $(D)(B) \to (E)$ $(D)(E) \to (F)$ $(G)(A) \to (H)$ $(\#X)(\#Y) \to (\#Z)$		$(A), (B)$	$(\#X), (\#Y)$
⋮	⋮	⋮	⋮
$(G)(A) \to (H)$	$(A)(B) \to (D)$ $(D)(B) \to (E)$ $(D)(E) \to (F)$ $(\#X)(\#Y) \to (\#Z)$	$(A), (B),$ $(D), (E)$ (F)	$(\#X), (\#Y), (\#Z)$

Table 1: Test setup for `testES()`. Middle activation steps omitted.

The `testKNNandES()` method has the same setup as `testKNN()` in Figure 8, except the output active Tags are passed on to the ES. The resulting setup and activation can be seen in Table 2.

4.5 Documentation

Proper documentation of the source code is very important. This is to ensure that anyone wanting to work with the code which was designed has an easy time doing so. Also, for anyone wanting to understand how the system works, documentation is essential. This documentation was achieved through Javadoc and UML diagrams.

4.5.1 Javadoc

Extensive Javadoc was generated for the entire code base. This can be found here: `http://cs.mcgill.ca/~sstapp/prometheus/index.html`.

4.5.2 UML

UML diagrams of every package in the code base were created.

Ready Rules	Active Rules	Active Facts	Active Recommendations
$(H)(I)(J) \rightarrow (\#Z)$		$(B),(C),(D)$ $(E),(F),(G)$ $(H),(I),(J)$	
	$(H)(I)(J) \rightarrow (\#Z)$	$(B),(C),(D)$ $(E),(F),(G)$ $(H),(I),(J)$	$(\#Z)$

Table 2: Test setup and activation for the ES portion of `testKNNandES()`.

5 Plan for Next Semester

The plan for next semester is to finalize the two layers that were started this semester, and to test them on the robots available in Prof. Vybihal's lab.

5.1 Finalization

5.1.1 Knowledge Node Network

Many complex features of the KNN layer are still to be implemented, such as backwards and lambda thinking, confidence, aging...

5.1.2 Expert System

Some features of the ES layer are still to be implemented, such as more complex Fact checking.

5.2 Integration

One very important task left to be done is to integrate the two layers described in this report (ES and KNN) with the other layers developed separately (NN and META). Ideally, the layers should be able to work together, but there will surely be some conflicts at the interface of the layers. These will have to be resolved when the time comes.

5.3 Testing

5.3.1 Simulation

Once all the layers are functioning together, they can be tested. The first and easiest way to test would be in a simulated environment. One simulator that may be used is Simbad, which is a Java 3D robot simulator [5]. This can allow for some early debugging and fixes.

5.3.2 Physical

One the simulation testing is completed and working properly, the system can be tested in the lab. Prof. Vybihal's lab has multiple robots with ultrasonic sensors, and these will be the test subjects of this phase.

6 Impact on Society and the Environment

6.1 Use of Non-renewable Resources

As a purely software-oriented project, there are no physical materials needed to construct this system.

6.2 Environmental Benefits

The system could be used as a tool to control robots in dangerous environments such as nuclear plants after a radioactive disaster. Indeed, the system could coordinate robots to help contain the damage faster than humans could, thus limiting the risk on the environment.

6.3 Safety and Risk

It is critical that, once this system is completed, it is used in an ethical way, and for the right purposes.

One example of use that may cause ethical concern is in a military setting, where an AI system like the one described here could be used in a battlefield in place of soldiers.

In the very long term, there are concerns with the possibility that an AI system might achieve intelligence and awareness close to a human. If such an AI were to obtain "consciousness" in its own way, should that entity be entitled to its own rights, like humans do?

6.4 Benefits to Society

Going back to the example use case in a radioactive disaster, the system could be used to send robots in an area that would otherwise be very dangerous for humans. This would therefore help prevent the unnecessary loss of life in cleaning up these leaks.

7 Conclusion

This semester, prototypes of the Expert System (ES) and Knowledge Node Network (KNN) layers of the AI model were completed in Java. These prototypes were tested individually and together, with positive results.

The main goal for next semester is to finalize the entire system, implementing more complex features that were omitted for this prototype stage.

A UML Diagrams

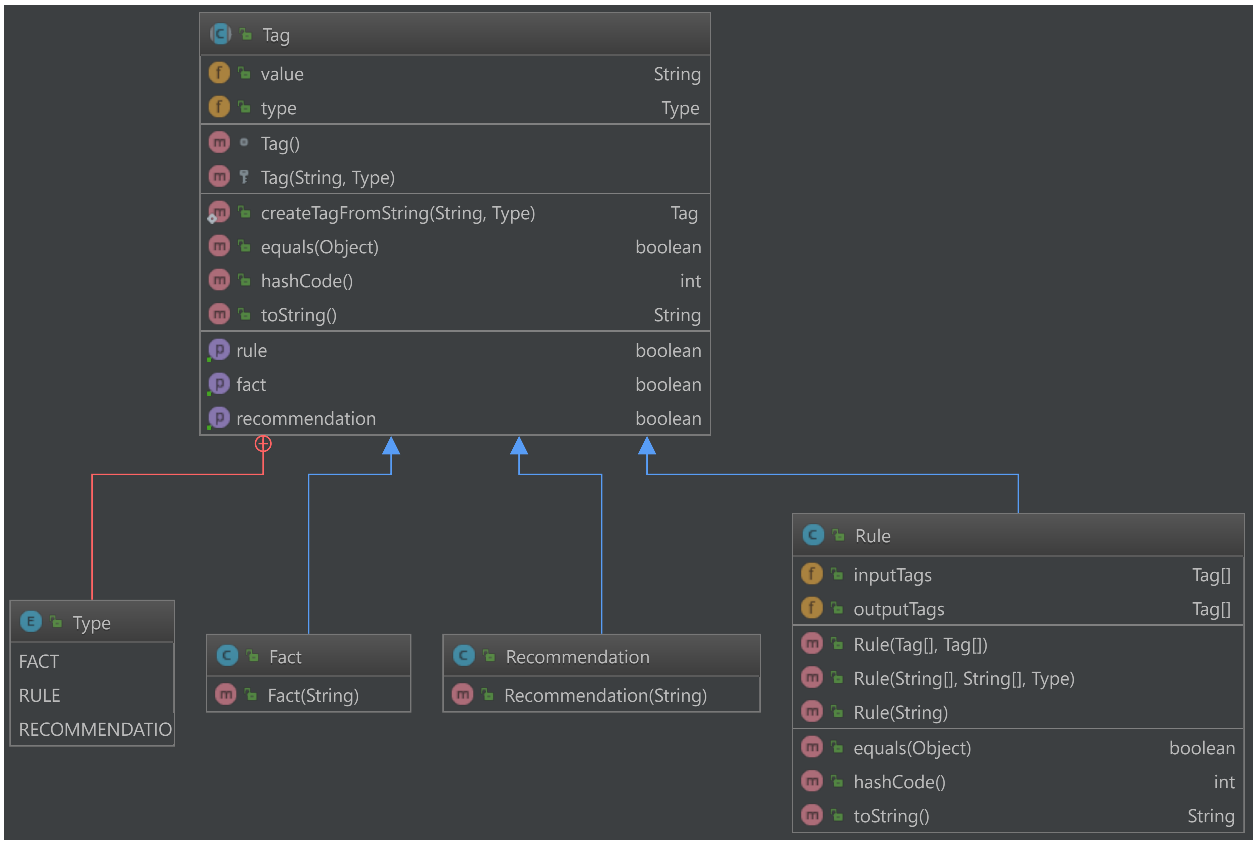


Figure 9: UML diagram of the `tags` package.

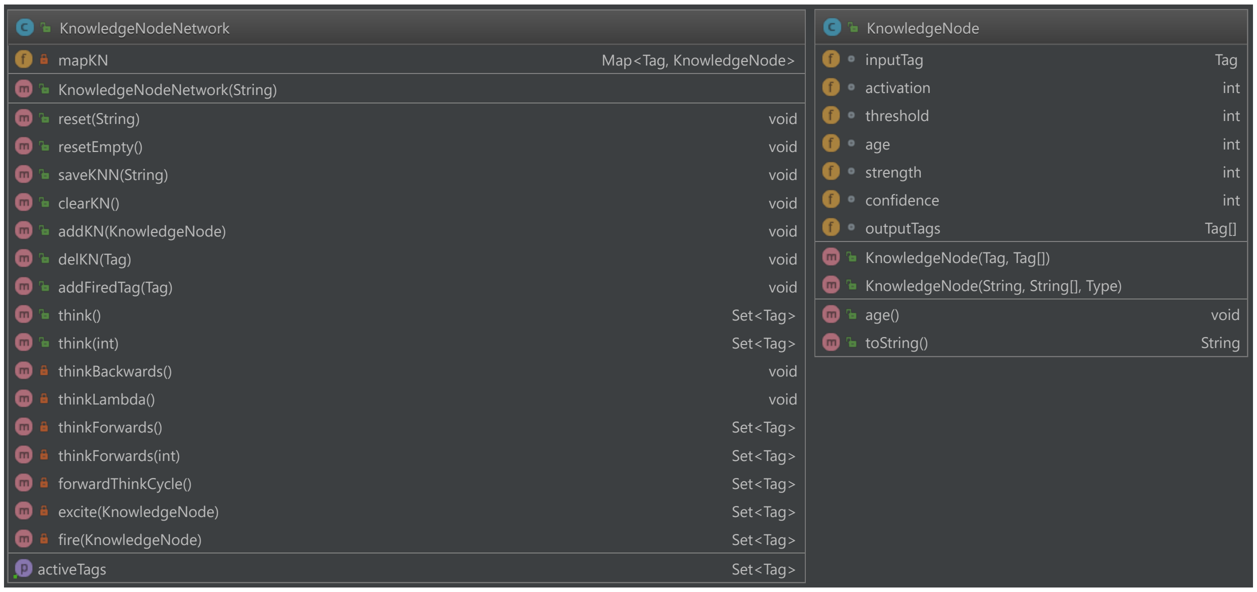
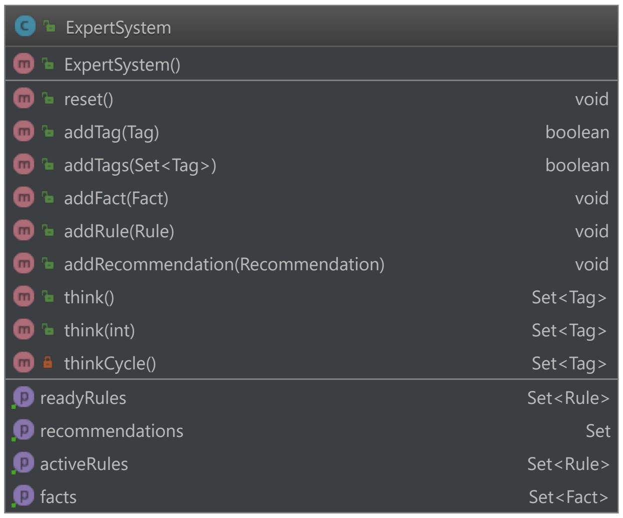
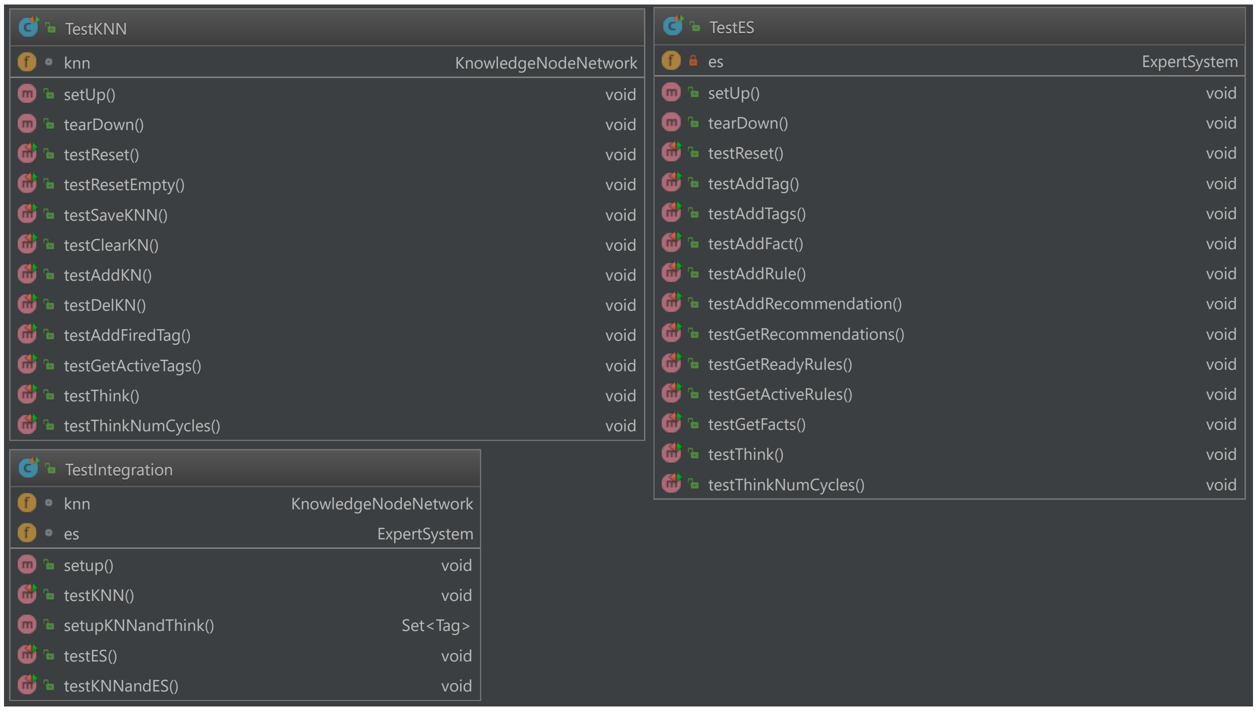


Figure 10: UML diagram of the `knn` package.



ExpertSystem	
ExpertSystem()	
reset()	void
addTag(Tag)	boolean
addTags(Set<Tag>)	boolean
addFact(Fact)	void
addRule(Rule)	void
addRecommendation(Recommendation)	void
think()	Set<Tag>
think(int)	Set<Tag>
thinkCycle()	Set<Tag>
readyRules	Set<Rule>
recommendations	Set
activeRules	Set<Rule>
facts	Set<Fact>

Figure 11: UML diagram of the `es` *package.*



TestKNN	
knn	KnowledgeNodeNetwork
setUp()	void
tearDown()	void
testReset()	void
testResetEmpty()	void
testSaveKNN()	void
testClearKN()	void
testAddKN()	void
testDelKN()	void
testAddFiredTag()	void
testGetActiveTags()	void
testThink()	void
testThinkNumCycles()	void

TestIntegration	
knn	KnowledgeNodeNetwork
es	ExpertSystem
setup()	void
testKNN()	void
setupKNNandThink()	Set<Tag>
testES()	void
testKNNandES()	void

TestES	
es	ExpertSystem
setUp()	void
tearDown()	void
testReset()	void
testAddTag()	void
testAddTags()	void
testAddFact()	void
testAddRule()	void
testAddRecommendation()	void
testGetRecommendations()	void
testGetReadyRules()	void
testGetActiveRules()	void
testGetFacts()	void
testThink()	void
testThinkNumCycles()	void

Figure 12: UML diagram of the `test` *package.*

References

[1] J. Vybihal, “Perceptron learning,” 2016.

[2] ——, “Knowledge nodes,” 2017.

[3] J. Vybihal and T. R. Shultz, “Search in analogical reasoning,” 1990.

[4] J. Vybihal, “Expert systems,” 2016.

[5] “Simbad 3d robot simulator,” http://simbad.sourceforge.net/index.php, (Accessed on 03/27/2017).