Deductive, Inductive and Abductive Reasoning over Natural Language Text: A Case Study with Adaptations, Behaviors and Variations in Organisms

by

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ABSTRACT

Question answering is a challenging problem and a long term goal of Artificial Intelligence. There are many approaches proposed to solve this problem, including end to end machine learning systems, Information Retrieval based approaches and Textual Entailment. Despite being popular, these methods find difficulty in solving problems that require multi level reasoning and combining independent pieces of knowledge, for example, a question like "What adaptation is necessary in intertidal ecosystems but not in reef ecosystems?", requires the system to consider qualities, behaviour or features of an organism living in an intertidal ecosystem and compare with that of an organism in a reef ecosystem to find the answer. The proposed solution is to solve a genre of questions, which is questions based on "Adaptation, Variation and Behavior in Organisms", where there are various different independent sets of knowledge required for answering questions along with reasoning. This method is implemented using Answer Set Programming and Natural Language Inference (which is based on machine learning) for finding which of the given options is more probable to be the answer by matching it with the knowledge base. To evaluate this approach, a dataset of questions and a knowledge base in the domain of "Adaptation, Variation and Behavior in Organisms" is created.

To my family.

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INTRODUCTION

A Natural Language can be understood as any language that has evolved through time by human use and repetition without prior planning. Humans interact mainly in Natural Language and even though there are underlying rules of the use of natural language such as grammar, there are infinite ways of expressing a single idea or a thought in Natural Language which makes it diverse and complex. Hence, processing Natural Language is a very important task in Artificial Intelligence as the ability to understand and generate Natural Language is a sign of Intelligence. Natural Language Processing is a sub-field in Artificial Intelligence that deals with the tasks like understanding and generating Natural Language. Natural Language Understanding is a subtopic in Natural Language Processing that deals with understanding and analyzing the Natural Language text. And to test whether a system (or a human) understands a text presented to it (or him/her) is through asking questions about the text.

Question answering is a topic in Natural Language Understanding that concerns with building systems that can predict an answer to the question presented to it in Human Natural Language. The first few known automatic question answering systems are BASEBALL (Green Jr *et al.* (1961)) in the year 1961 and LUNAR (Woods (1972)) in the year 1972. Since then, there have been various different approaches proposed to aid the task of Question Answering. The recent solvers use methods like textual entailment (Khot *et al.* (2018a)), information retrieval (Chen *et al.* (2017)), word matching and machine learning models to solve the task of question answering. To move towards this very important goal and encourage researchers to work on the task of question answering, there are a lot of different challenges and datasets like Winograd Schema Challenge(Levesque (2011a)), The Stanford Question Answering Dataset or SQuAD (Rajpurkar *et al.* (2016a)), Large-scale ReAding Comprehension Dataset From Examinations or RACE (Lai *et al.* (2017b)) and AI2 Reasoning Challenge or ARC (Clark *et al.* (2018a)) and AristoClark (2015) that have been proposed. Each dataset aims to encourage solving a different type of task, like SQuAD aims to solve a task that requires the system to find an answer from the passage presented to it along with the question (Reading comprehension), ARC and Aristo aim to solve questions that require science knowledge to answer questions. As this field is moving at a very fast pace, solving a task is leading to creation of more datasets that aim to solve a different task that couldn't be solved by the previous system. The next section describes the question answering task and the goals of this thesis.

1.1 Motivation

Despite being one of popular topics in Natural Language Processing, there still are challenges faced by current question answering solvers in answering questions that require multiple different pieces of knowledge to predict an answer to the question presented to it. Combining pieces of knowledge to find an answer is very effortless for human beings but is very challenging for the system to reason with different sets of information. There are various different challenges and datasets created that require knowledge to answer a question. For example, consider an example from the winograd schema challenge (Levesque (2011a)).

The trophy would not fit in the brown suitcase because it was too big (small). What was too big (small)?   ANSWER 0 the trophy   ANSWER 1 the suitcase

In this question, the system would require the knowledge about how an object being big would affect it fitting into a container, or a container being small would affect an object fitting into it. The missing knowledge that is require for this question would be "Object1 is big may cause Object1 does not fit in object2". Without this knowledge it would be difficult for the system or a human to be able to answer the question.

Consider an example in the field of science- "What adaptation does a fish have that helps it survive in a freshwater ecosystem?"- the system would need knowledge regarding the body parts and the organs of fish and also features and properties of freshwater ecosystem to find the most probable answer. The system would require to combine these different sets of information or knowledge to predict an answer to the question. Along with the ecosystem or environment information, the system (or even the human) needs to know the entities required by the fish to survive (like oxygen, water, sunlight, etc.), organs and behaviors of the organism that are used to obtain these entities, and the functions of the organs and behaviors. The system would have to find a link between entities that a fish would require to survive, and whether the ecosystem can provide the entity or not. If not, how the fish would have to evolve to overcome it or obtain in some other way.

Humans use already learnt knowledge through reading or experience to answer questions presented to them, and combine different pieces of knowledge to answer using reasoning and if the knowledge required to answer the question is unavailable, humans find the most probable answer by looking for clues in the question and relating the clues with the answer. The quality to combine different unrelated pieces of knowledge, or to find relation between question statement and answer options is effortless for humans. One of the major tasks of the thesis is to create questions that are easy for humans to solve given the knowledge about the question, but can be challenging for existing systems to solve and creating a reasoning system that uses knowledge and combines different unrelated information to find answers to the questions. There are various types of questions that a human can solve effortlessly given the knowledge about the entities present in the questions which could be challenging for the system.

Consider another example from science,

What adaptation is required in intertidal ecosystem but not in reef ecosystem?

1. the ability to live in salt water
2. the ability to use oxygen in respiration
3. the ability to cope with daily dry periods
4. the ability to blend into the surroundings

For a human to answer this question, information about intertidal and reef ecosystem needs to be provided or the human must already have the information like the description of the ecosystem and their properties to be able to use this information to reason in order to find the most probable answer.

To answer a question like this, the person needs to know information about the ecosystems mentioned in the question. The information the human would require is - intertidal ecosystem is the area where the ocean meets the land between high and low tides and during low tides, there is less or no water and during high tides this area might be submerged in water and the coral reef ecosystem is where coral reefs live which isn't near the shore and is always underwater or the fish would die. As long as the human has this information with him/her, the question can be answered by a human. But a machine can find difficulties in solving this problem because answering this question requires a multiple steps which comes naturally to humans. In this case, the series or steps can be:

- Finding the qualities required to survive in intertidal ecosystem.
- Finding the qualities required to survive in reef ecosystem.
- Checking which of the qualities aren't required for survival in reef ecosystem but is required in Intertidal ecosystem.
- Comparing the final set of qualities with the options.

These aren't the only steps to reach the answer, there can be many other reasoning methods a human can use to reach the right answer. With the help of reasoning and knowledge, even if it is not intuitive, a human would find it easy to answer the question, given the knowledge.

For example:

What adaptation is most useful when an animal has to catch and eat a prey in deep caves?

1. the ability to move quickly
2. sharp teeth to pierce through the meat
3. strong arms for strength to catch it
4. the ability to see in the dark

In this question, one only has to relate the deep caves to darkness and necessity to see in the dark to answer the question. All the options could be the answer if the environment is not taken into consideration, but when the environment is considered, we can deduce that the animal would require the ability to be able to see in the dark. The other options may or may not be necessary but the ability to see in the dark has more priority over the other mentioned adaptations.

As discussed earlier, there are datasets and challenges that have already been proposed to encourage researchers to work on the question answering task like The Stanford Question Answering Dataset (SQuAD), Large-scale ReAding Comprehension Dataset From Examinations (RACE), Aristo and AI2 Reasoning Challenge (ARC). These datasets have questions and a knowledge paragraph or a corpus is provided to help find the answer to the questions. Stanford Question Answering Dataset (SQuAD) Rajpurkar *et al.* (2018) is a dataset in which a paragraph along with the question is provided which contains the answer to the question. In RACE dataset, the questions are provided with a passage as well and the task that it aims to solve is reading comprehension. The questions in the RACE dataset have been collected from Engish exams for middle and high school Chinese students and created by english experts.

Aristo is a challenge that includes solving school level science multiple choice questions. ARC is a challenge by Allen AI that also aims to solve science based multiple choice question. There are two subsets of the AI2 Reasoning challenge question dataset:

a. Easy set

b. Challenge set

Challenge set contains questions that requires additional external knowledge to answer the questions. The data set (both easy and challenge) has 7787 questions and a set of 14M sentences relevant to the question answering task. The challenge set of ARC contains 2590 questions sourced from various different topics in science.
An example of ARC challenge set question:

> George wants to warm his hands quickly by rubbing them. Which skin surface will produce the most heat?
>
> 1. dry palms
> 2. wet palms
> 3. palms covered with oil
> 4. palms covered with lotion

In this question, the information about friction is missing. Rubbing palms causes friction which in turn causes heat and that a dry surface would create more friction than a surface covered with water, oil or lotion.

1.2 Goals of this work

One of the goals of the thesis work is to solve challenging questions that require additional knowledge. To achieve this goal, difficult questions that requires additional knowledge and information related to the topics on which the questions are based is required. And as it was observed that the questions in the domain of science require external knowledge to find the answer, a topic from science- "Adaptations, Behavior and Variations in Organisms" was chosen to create more difficult questions that require additional knowledge find answer to the question and collect knowledge that would help in answering the questions.

In summary, the goals of the thesis are:

1. Create a QA dataset in the domain of "Adaptations, Behavior and Variations in Organisms" that contain:
   (a) Questions that require additional knowledge to find the answer
   (b) Well defined set of knowledge that can be used for reasoning
2. Evaluate the Performance of existing models
3. Develop easy-to-deploy KR inspired model

The next section contains the contributions made in order to reach the mentioned goals.

1.3 Contribution

This thesis work is an attempt to solve questions that require additional knowledge in the domain of "Adaptations, Variations and reasoning in Organisms" using domain knowledge and reasoning. The contributions made towards these goals are as follows:

- Creation of dataset of questions that require reasoning and knowledge.
- Creation of knowledge base.
- A reasoning model to combine different pieces of knowledge to answer the presented question.
- Evaluated performance of the existing models

1.4 Structure

This section defines the structure of the thesis document. The brief explanation of what each of the chapters contain is as follows:

- **Chapter 2**: The Chapter contains details of the related QA datasets and Question answering systems.
- **Chapter 3**: The Chapter contains the higher level details of the steps taken in this work to achieve the goals mentioned in the current chapter (Section 1.2)
- **Chapter 4**: The Chapter contains details of the analysis done on the initial 44 questions to understand what information or knowledge is required to create the challenging QA dataset.
- **Chapter 5**: The Chapter contains details of the steps taken to create the Knowledge Base and a dataset of questions.
- **Chapter 6**: The Chapter contains detailed information about the steps in reasoning model.
- **Chapter 7**: The Chapter contains details about the baselines, experimentation and results of the experimention

- **Chapter 8**: This chapter contains the conclusion and the future directions of the work.

Chapter 2

RELATED WORK

Question answering is an important topic in NLP. Many Question Answering datasets and challenges have been proposed to move towards the goal of achieving a human level accuracy. The current chapter aims to discuss related QA datasets and approaches that have been implemented to move towards this goal. The chapter is divided into two sections, the first section (Section 2.1) includes some of the related Question Answering challenges and datasets that have been proposed and the second section (Section 2.2) includes some of the work that is related to this work.

2.1 Challenges and Datasets

Challenges encourage researchers to improve the existing systems or propose a different approach for solving a task. In the past few years, QA datasets and challenges in the field of Science and Mathematics such as Rajpurkar *et al.* (2016b) and Clark *et al.* (2018a) (AI2 Reasoning Challenge) have been proposed.

2.1.1 AI2 Reasoning Challenge (ARC)

ARC is a challenge that requires powerful set of knowledge and reasoning in answering a science multiple choice question presented by ARC. There are two subsets of the AI2 Reasoning challenge question dataset:

a. Easy set

b. Challenge set

Challenge set contains questions that aren't answered correctly by information retrieval or a word co-occurrence algorithm. The data set has 7787 questions and a set of 14M sentences relevant to the question answering task out of which 2590 are a part of challenge set. An example from the easy set:

> Which factor will most likely cause a person to develop a fever?
>
> A. a leg muscle relaxing after exercise
>
> B. a bacterial population in the bloodstream
>
> C. several viral particles on the skin
>
> D. carbohydrates being digested in the stomach

The questions in the easy set can be solved either by IR based or word co-occurrence algorithm.

An example from the challenge set:

> A ship leaks a large amount of oil near a coastal area. Which statement describes how the oil most likely will affect the coastal habitat?
>
> A. Fish reproduction rates will increase.
>
> B. Water birds will be unable to use their wings.
>
> C. Water plants will be exposed to more sunlight.
>
> D Coastal plants will have access to more nutrients.

ARC aims at solving questions that require common-sense knowledge and reasoning and deeper understanding of text. As mentioned in the previous chapter, the goal of this work is to build a system that uses different sets of knowledge and combines them to find an answer. There are many other datasets that aim at solving QA tasks like reading comprehension (SQuAD (Rajpurkar *et al.* (2016b)) and RACE (Lai *et al.* (2017a)))

2.2 Related Approaches

One approach to solve QA is Khot *et al.* (2017) which is an information extraction model. In this model, tuples of the form (subject, predicate, objects) with 0 or more objects using a text corpus are created and given a question and answer choices, the most relevant tuples are selected from the set of tuples to get the most probable answer of the question. To do the same, tf-idf score is used to find the most relevant tuples by using the question as the query and the tuple as the document. Also, the information or the tuples is gained on the fly during the testing to handle the domains not covered during training. Elastic search query is used to gain on the fly information which then is converted into a tuple if there isn't an already existing tuple. The question answering problem in this paper is viewed as a graph problem, searching for a path that best connects the question asked to the most probable answer from the given choices.

Another approach which is used to solve the problem of question answering is Semantic ILP by Khashabi *et al.* (2017) which generates semantic graphs of the given question using various natural language processing modules to find the best possible answer to the question. The paper treats question answering as a sub optimal graph problem with inputs being the question asked, list of the answer options and the paragraphs as knowledge snippets to model a support graph. To find the optimal support graph and maximize the objective function, inductive logic programming (ILP) is used.

Among the many solutions to question answering, the closest to our work is Mitra *et al.* (2019). In this approach, answer set programming and textual entailment is used to find the solution in life cycle domain. Since the domain in Mitra *et al.* (2019) is life cycle, the reasoning required to find the answers of the question is different as the knowledge pertaining only to the organism is required to answer the question, which is not in the case for questions in Adaptation, behaviour and variation in organisms. In this domain, there are information pertaining the organisms and the ecosystem required to solve the problem. There can be phrases describing adaptations and ecosystems which makes it harder for the text search instead of the actual term. For example, instead of describing an adaptation as "several folds on the skin" in chuckwallas, which is a type of lizard that lives in rocky areas of desert, it can be described in many other ways as it is a natural language phrase. This makes the questions in Adaptations, Variations and Behavior in Organisms challenging to solve. Just like in Mitra *et al.* (2019), this work uses external modules for Natural Language Inference to determine the truthfulness of the hypothesis generated.

Chapter 3

OVERVIEW OF THE APPROACH

In the previous chapters, the existing datasets, challenges and Question answering models were discussed along with the motivation for this work. In this chapter, the steps taken to move towards the goals mentioned in Chapter 1 will be discussed in brief. The details of these steps will be described in the next few chapters.
The three major steps that were taken to achieve these goals are:

1. Analysing existing Questions
2. Dataset Creation
   (a) Knowledge Base Creation
   (b) Question Creation
3. Reasoning Model Creation

The Figure 1 contains the flow of the steps that were taken to move towards the goal mentioned in Chapter 1. As it can be seen, there are four components, and these components will be discussed in the later chapters in detail. A brief introduction to all the components is given in this chapter.

3.1 Analysing Existing Questions

To start with, 44 questions relating to the topic of "Adaptations, Behaviors and Variations in Organisms" were collected from ARC challenge set and Science textbooks. The aim of this part is to collect information from the already existing questions to help in the further process of creating questions and knowledge base and

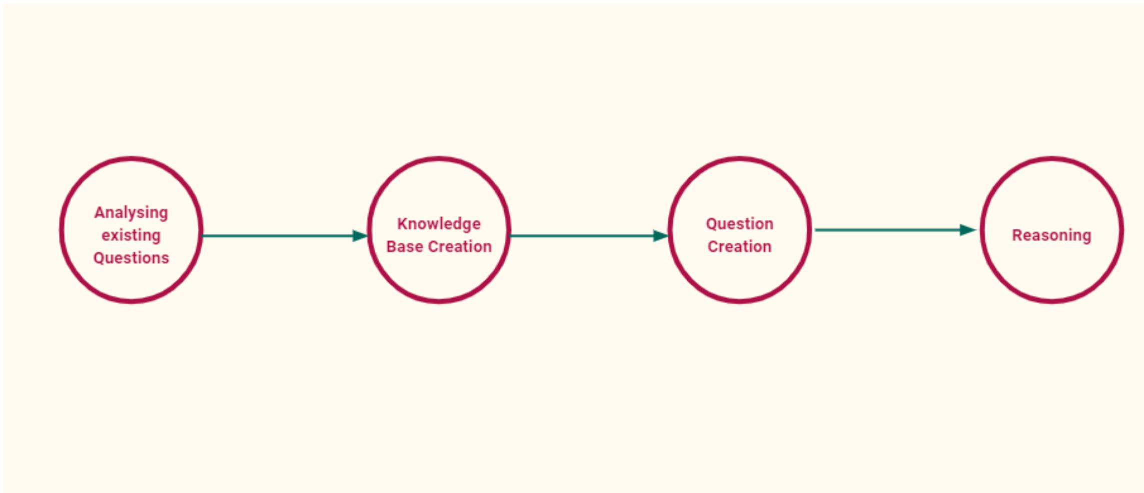

Figure 1: Overview of the Steps

creating a reasoning model. These questions were analysed to find what information would be required to create more similar question in this topic, knowledge that would be required to solve these questions and how the questions can be made challenging for the already existing systems. Analysis of these questions resulted in questions being divided into 8 categories based on the information present in the question stem and the information present in the answer options. Each category requires a different reasoning model and different sets of knowledge to create questions. The detailed explanation of the analysis of the initial questions is present in Chapter 4.

3.2 Dataset Creation

After the analysis of the initial questions, an idea of what the knowledge base should contain in order to answer the 8 types of questions was obtained. Dataset creation has two parts in it: Knowledge Base creation and Question Creation.

3.2.1 Knowledge Base Creation

Knowledge Base needs to contain information that can help with reasoning to be able to answer questions in the field of "Adaptations, Behaviors and Variations in Organisms". The following are the information that the knowledge base needs to contain:

- Ecosystem Information
- Organism Information
- Adaptation Information

These details are later combined to find the answer. These information are also important in Question Creation as the Question Creator needs to know the information regarding the ecosystem, organism and adaptation along with the question types and instructions on how to create challenging questions in order to create the questions. The details collection of these information is present in Chapter 5, Section 5.1. Appendix B contains the information about the website from which the data has been collected and Appendix C contains the examples of the information stored in the Knowledge Base. A brief discussion of question creation is present in the next subsection.

3.2.2 Question Creation

In the previous subsection, the creation of knowledge base was discussed and the creation of the knowledge base helps in reasoning as well as question creation. One of the goals of this work is to create a Question Answering dataset in the field of "Adaptations, Behaviors and Variations in Organisms" that requires external knowledge. The questions are in Natural Language and were crowd sourced to create a Question Answering Dataset. A knowledge paragraph of a particular adaptation was provided to the question creators from which they could get the information about the adaptation, organism and the environment along with instructions on how to make the questions challenging and types of questions. The knowledge paragraph provided to the question creator for the question creation task includes the organism's name, the ecosystem or environment information and information about the adaptation. A total of 1303 questions were created over the span of one month with the help of lab mates. More details on steps taken to create questions is discussed in Section 5.2 of Chapter 5.

3.3 Reasoning Model

One of the goals of this work is to create a reasoning model that uses external knowledge along with the information present in the question to find answers to questions that requires external knowledge. As mentioned in the previous sections, the questions have been categorized into 8 types and these different types of questions require a different reasoning model as the information provided by the question and options for each type is different and the information from the Knowledge Base. There are two major steps in the reasoning model:

1. Identification of the Ecosystem
2. Textual Entailment (Generate and Validate)

The generate and validate functions in the textual entailment step is similar to the functions in Mitra *et al.* (2019). The generate function generates natural language sentences using a template and the validate function takes a premise hypothesis pair and returns a textual entailment score based on which the ASP rules find the most probable answer to the question. The entire reasoning model has been described in detail in Chapter 6.

In this chapter, an overview of the steps taken towards the goals of creation of QA dataset and reasoning model was discussed. The next chapter includes details of the Analysis of the initial questions.

Chapter 4

ANALYSING EXISTING QUESTIONS

In the previous chapters, a number of challenges and datasets were discussed along with various methodologies, each dataset aiming to solve a particular task that would help the AI system get closer to the goal of understanding Natural Language as well as humans do. The task this thesis aims to solve, as previously mentioned, is finding answers to the question that requires combination of different pieces of knowledge to find the answer. In order move towards that, a set of goals were defined which included - Creation of Question Answering dataset, Creation of reasoning models, creation of a reasoning model, testing the questions created on other models. To start, there were 44 questions collected from ARC and middle school science textbooks in the domain of "Adaptation, Behaviors and Variation in Organisms". Analysis of these initial existing questions were done in order to create a map of how to get more questions in the domain of "Adaptations, Behaviors and Variations in Organisms" and to know what knowledge would be required to be in the Knowledge Base to answer these questions. The flowchart of how the analysis of the questions looked like is given in Figure 2.

In this chapter, the details of the analysis of the initial 44 questions will be discussed in the sections. The section 4.1 contains details about the type of information present in the existing questions.

4.1 Information in the Questions

Analysis of question includes recognising the information are present in the question and the information are present in the answer options. Using this information,

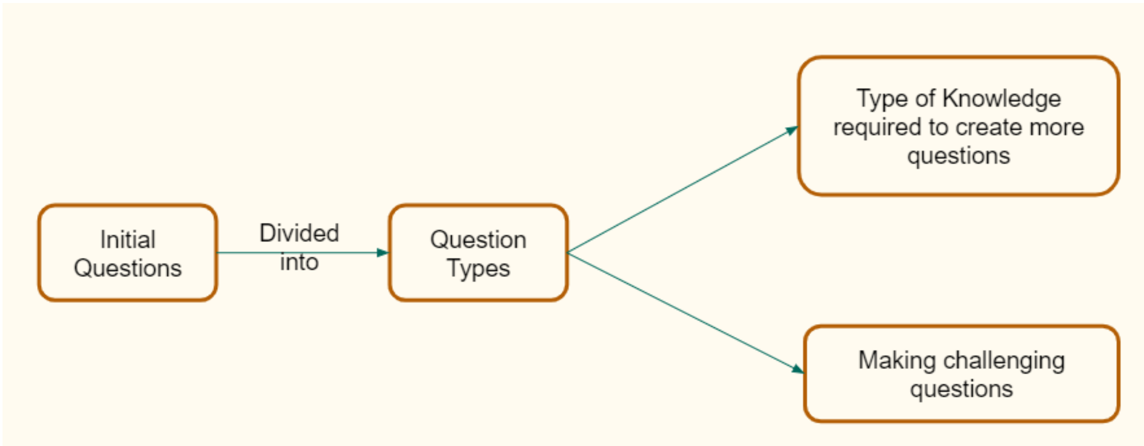

Figure 2: Flowchart of the Analysis

a step by step procedure can be created to create more questions in the domain of "Adaptations, Behaviors and Variations in Organisms". From this point on wards, whenever "Adaptation" is mentioned, it refers to "Adaptation, Behaviors and/or Variations".

In this section, the analysis of knowledge required to create more questions and knowledge required to answer those questions are discussed.

Consider an example:

A tropical rain forest contains many tall trees. Smaller plants with large leaves grow at the base of the trees. The large leaves are most likely an adaptation of the plant due to which condition?

A lack of sunlight

B lack of oxygen

C lack of water

D lack of food

Looking at the example, it can be observed that the question contains the environment information("the base of trees in the tropical rain forest"), the organism name ("smaller plants")and the adaptation ("larger leaves"). And the options contain the possible reasons for the adaptation ("larger leaves"). To create more questions of this type, the properties such as ecosystem or environment information, organism information and adaptation information has to be given to the question creator to generate more questions of this type where the adaptation, organism name and the environment information is present in the question and the options contain possible answer options. To answer this question, the system would require to combine different sets of information like the ecosystem information and organism information to find the answer.

Consider another example:

What adaptation is required in intertidal ecosystem but not in reef ecosystem?

A the ability to live in salt water

B the ability to use oxygen in respiration

C the ability to cope with daily dry periods

D the ability to blend into the surroundings

In this question, there are two ecosystem names present. The first ecosystem mentioned is the "intertidal" ecosystem and the second is the "reef" ecosystem. And the answer options contains information about adaptations that is required by organisms in first ecosystem and not the second. To create this type of questions the question creator would require the ecosystem information along with the properties of the ecosystems. All the questions were analysed in a similar way and were grouped together in different question types. The types of questions will be discussed in the next section.

4.2 Question Types

The questions were categorised into 8 types based on the information present in the question and the options. These eight types of questions require different sets of knowledge and reasoning to answer the questions. The categorization also helps in the question creation stage, as it would make it easier for the question creator to know what information goes in the question and what information goes in the answer. The eight types of questions are described as follows:

TYPE 1 Information present in the question:

(a) Question Stem- Organism, Ecosystem, Adaptation

(b) Options- Reason for adaptation

Following is an example of this category:
A tropical rain forest contains many tall trees. Smaller plants with large leaves grow at the base of the tall trees. The large leaves are most likely an adaptation of the plant due to which condition?
(A) lack of sunlight (B) lack of oxygen (C) lack of water (D) lack of food

TYPE 2 Information present in the question:

(a) Question Stem- Organism, Ecosystem, Adaptation

(b) Options- Purpose for adaptation

The brown fur of the arctic hare that lives in arctic region turns white in winter. How does this color change most likely help the arctic hare?

(A) It helps the animal save water. (B) It helps the animal hide from predators. (C) It helps keep the animal cool. (D) It helps protect the animal from disease.

TYPE 3 Information present in the question:

(a) Question Stem- Organism, Ecosystem, Adaptation

(b) Options- not Purpose/Reason for adaptation

Following is an example of this category:

The brown fur of the arctic hare that lives in arctic region turns white in winter. Which of the following does not explain how this color change helps?

(A) It helps the animal save water. (B) It helps the animal hide from predators.

TYPE 4 Information present in the question:

(a) Question Stem- Organism, Ecosystem, reason/purpose of Adaptation

(b) Options- Adaptation

Following is an example of this category: *A tuna is an ocean fish that is well adapted to catching small, fast-moving prey. Which of the following adaptations most helps a tuna swim fast to catch its prey?*

(A) large fins (B) sharp teeth (C) small gills (D) tough scales

TYPE 5 Information present in the question:

(a) Question Stem- Organism, Ecosystem, reason/purpose of Adaptation

(b) Options- Not the adaptation

Following is an example of this category:

Small mammals have many adaptations that keep them warm in winter. Which would not help conserve heat?

(A) running (B) hibernating (C) huddling in a group (D) growing thicker fur

TYPE 6 Information present in the question:

(a) Question Stem- Two Ecosystems

(b) Options- Adaptation in Ecosystem 1 and not in Ecosystem 2

Following is an example of this category:

What adaptation is necessary in intertidal ecosystems but not in reef ecosystems?

(A) the ability to live in salt water (B) the ability to use oxygen in respiration (C) the ability to cope with daily dry periods (D) the ability to blend into the surroundings

TYPE 7 Information present in the question:

(a) Question Stem- Adaptation

(b) Options- Ecosystem that requires the adaptation mentioned in the question

Following is an example of this category:

In which of the following habitats would an animal have to be hiding during the *day time?*

(A) Deep caves (B) Base of rainforest (C) Desert (D) Rainforest canopy

TYPE 8 Information present in the question:

(a) Question Stem- Adaptation

(b) Options- Not the Ecosystem that requires this adaptation

Following is an example of this category:

In which of the following habitats would an animal not require to be able to see in the dark?

(A) Deep caves (B) Base of rainforest (C) Deep sea (D) Rainforest canopy

As it can be observed, these 8 categories differ in the type of information that is present in the question and the options. These 8 categories give us information on how to further create more questions and what information has to be present in the knowledge paragraph that is provided to create the question in order to create the question. As the aim of the dataset creation is not only to create questions but to create questions that are difficult for systems to reason with. Analysis of these questions also give an idea about how to make the questions more and more difficult.The aim of the dataset creation is to create difficult questions that is difficult for the machine to solve but can be solved by humans, given the domain knowledge base. The next section contains details on how to make the questions more challenging for the system.

4.3 Making Questions More Challenging

Creation of questions requires information relating to the domain in which the questions are created. This information is also necessary in the reasoning stage.

The aim of this work is not to create questions that can be solved by look up, but rather requires combining different sets of information. To achieve that, there were observations made looking at the already existing questions and five instructions were derived from the existing questions:

- Ecosystem described in the question
- Options that could be the correct answer given any other scenario.
- Options overlap with the knowledge statements.
- Options overlap with each other
- (Only for type 6 questions) Adaptation that is required in both mentioned ecosystem

The explanation of each instruction about how to make the questions more challenging, is given in the subsections. The first four instructions apply to all the types of questions but the last one applies only to type 6 question.

4.3.1 Ecosystem described in the question

Instead of having the name of the ecosystem in the question, the ecosystem can be described to make the question more challenging. This would require the reasoning system to combine the information of the organism and the ecosystem information while the time of reasoning. To create a link between the ecosystem or the environment causing an adaptation in an organism, ecosystem name is an important entity for reasoning.
Consider an example

A tropical rain forest contains many tall trees. Smaller plants with large leaves grow at the base of the trees. The large leaves are most likely an adaptation of the plant due to which condition?

A lack of sunlight

B lack of oxygen

C lack of water

D lack of food

In this example, the ecosystem or the environment is the base of the trees in a tropical rain forest. To answer this question, the system (or the human) would require to know that the base of the trees in a tropical rain forest is the forest floor layer of the rain forest and would have to know the properties of forest floor layer like the abundance of humidity and less available sunlight.

4.3.2 Options that could be the correct answer in any other scenario

In order to make the questions more challenging, few of the options could be correct if a part of the question is changed. If the organism is changed in the question or the ecosystem is changed in the question, there is a possibility that another option could be the right option. This would make it harder for the information retrieval system and the end to end machine learning systems as there can be information about the other options in a different in the textual corpus or knowledge base.
Consider the example:

A tropical rain forest contains many tall trees. Smaller plants with large leaves grow at the base of the trees. The large leaves are most likely an adaptation of the plant due to which condition?

A lack of sunlight

B lack of oxygen

C lack of water

D lack of food

In this example, if the environment mentioned is changed, maybe to the areas with high alleviation (Alpine tundra) where there is less available oxygen, the answer might change to lack of oxygen. Since leaves are used to absorb both sunlight and oxygen and there is less available sunlight in the base of rain forest, the answer is the lack of sunlight. But in the case of any other environment where there is very little oxygen available, the answer would change. There can be questions created where different organisms in the same environment have different adaptations. For example, in a hot and dry desert, a plant has small or no leaves and an animal would have some other ability to cope with excessive heat.

4.3.3 Options overlap with knowledge statement

To create questions, there are knowledge paragraphs provided to the question creators to get information about the ecosystems, organisms and the adaptations of the organisms in the ecosystem. And these knowledge paragraphs are also used in reasoning to find the answer given these knowledge paragraph. So to make the question more challenging, if all the options have words that are present in the knowledge paragraph, it would be difficult for systems like word vector similarity to find the right answer to the question.

Consider the example:

Some Mammals huddle during the cooler times of the year. Which of the following is not a purpose of this behavioral adaptation?

A To stay cool

B To stay warm

C To avoid losing energy

Knowledge Paragraph (searched on the web to indicate the meaning as the questions initially collected didn't have paragraphs associated with them):

"Many small mammals huddle together to keep warm when it gets cold. It now turns out that this huddling behaviour changes the composition of bacteria in the animals guts and it does so in a way that slows down their metabolism and helps them preserve energy."

As it can be observed, the words cool, warm and energy are present in the knowledge paragraph that is present. This could make it challenging for the existing solvers like word vector similarity (The explanation of how word vector similarity for question answering works is given in section X) as the words present in the options are also present in knowledge paragraphs.

4.3.4 Options overlap with each other

To make existing systems struggle with finding the right answer choice, the options can be made difficult by containing similar words, so that the options look very similar to each other. Consider the example:

> Thorny devil has tiny folds on its skin that overlap, creating tube-like structures. How does the skin of thorny devil help it survive?
>
> A It helps them to absorb water from dry sand
>
> B It helps them to absorb water from moist sand

In the given example, the options are similar except for one word that is different. To answer this question, the system would have to understand the importance of "dry" and "moist", and the properties of the ecosystem, which in this case is desert and the organisms' body parts and behaviors.

4.3.5 Adaptation required in both ecosystems

This instruction applies only to the type 6 questions. As in this type, the answer is adaptation that is required in ecosystem 1 and not in 2. So to make the answer options more challenging, an option where the adaptation is required by both the ecosystem can be included. This option can also confuse a human being. Including options like this would confuse the system (or a human) as it would require the system to consider the properties of both the ecosystems. Ignoring either of the ecosystems or changing one of the ecosystems in the question could lead to a wrong answer.
Consider the example:

What adaptation is required in intertidal ecosystem but not in reef ecosystem? A the ability to live in salt water B the ability to use oxygen in respiration C the ability to cope with daily dry periods D the ability to blend into the surroundings

In this example, it can be seen that both intertidal and reef ecosystems are aquatic ecosystems, more specifically marine ecosystems. Organisms in both ecosystems require the ability to live in salt water as marine ecosystems have saline water, and both would require to have the ability to use oxygen in respiration. Only when the system understands that the intertidal ecosystem is sometimes underwater and sometimes not, and the reef ecosystem is completely and always underwater, the ability to cope with daily dry periods will be chosen unless there are phrases in the knowledge corpus which state the difference between all the ecosystems.

The summary of the types of questions created and the information that can be extracted from the question is given in table 3.1.

Question Type	Extracted Information from Stem	Options
TYPE 1	1. Adaptation 2. Environment 3. Organism	Reason
TYPE 2	1. Adaptation 2. Environment 3. Organism	Purpose
TYPE 3	1. Adaptation 2. Environment 3. Organism	Not the Purpose or the Reason
TYPE 4	1. Reason/Purpose 2. Environment 3. Organism	Adaptation
TYPE 5	1. Reason/Purpose 2. Environment 3. Organism	not the adaptation that is required
TYPE 6	1. Ecosystem 1 2. Ecosystem 2	Adaptation required in Ecosystem 1 but not in Ecosystem 2
TYPE 7	1. Adaptation	Ecosystem
TYPE 8	1. Adaptation	Ecosystem that doesn't require this adaptation

Table 4.1: Types of Questions and information in the questions

Chapter 5

DATASET CREATION

In the previous chapters, analysis of already existing questions to find the information that is required to create more questions and knowledge base was discussed. Based on this information provided by the analysis, more knowledge paragraphs were gathered in order to help with the question creation and reasoning. This chapter aims to focus on two parts:

1. Knowledge Base Creation
2. Question Creation

Knowledge Base contains information that is required to answer the questions in the domain of "Adaptations, Behaviors and Variations in Organisms". The contents and the steps taken to collect the information to create the Knowledge Base is explained in detail in Section 5.1.

The questions were crowd sourced by providing the information that is required to create the questions along with the instructions on how to make the questions more difficult. The details about the question creation and the information provided to the question creators in order to create more questions of each type is explained in Section 5.2.

5.1 Knowledge Base Creation

In Chapter 4, the questions were divided into 8 categories or types and each type requires different sets of knowledge to do the reasoning. To create the KB, the steps taken are shown in Figure 3. In this topic of “Adaptations, Behaviors and Variations”, the information regarding the ecosystem and the organisms need to be present in the Knowledge Base. The knowledge base information is stored in the form of ASP code.

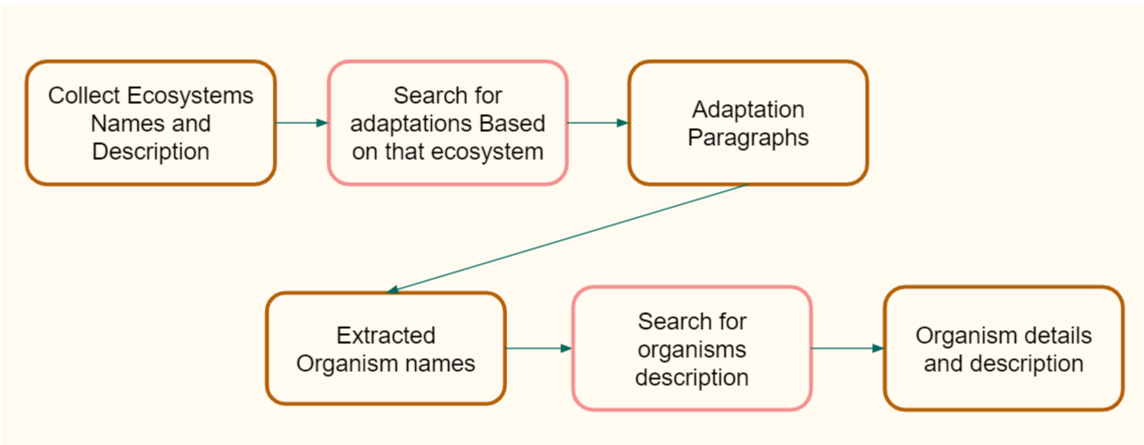

Figure 3: Knowledge Base Creation Steps

There are three categories of information that were collected to be stored in the Knowledge Base:

1. Ecosystem description and properties
2. Organisms, body parts and function of the body parts
3. Paragraphs relating to adaptation

These are the information that needs to be present in the knowledge base to answer question and the information provided to the Question Creators to create more questions of the 8 types. In order to collect this information, the following steps were taken:

1. Collect Ecosystem List, Description and Properties
2. Collect Adaptation Paragraphs based on Ecosystem

3. Collect Organism information

The details of the collection and steps are mentioned in the subsequent subsections - 5.1.1, 5.1.2 and 5.1.3.

5.1.1 Ecosystem Information Collection

The first step to collecting information about the ecosystem is to collect the list of ecosystem. There is a list of ecosystems and biomes at the bottom of the wikipedia page (Wikipedia contributors (2019)) from where the list of ecosystems were collected. The screenshot of the list of ecosystems that are present on the wikipedia page is shown in Figure 4

V · T · E	Biogeographic regionalisations [hide]		
Biomes	Terrestrial biomes	Polar/montane	Tundra · Taiga · Montane grasslands and shrublands
		Temperate	Coniferous forests · Broadleaf and mixed forests · Deciduous forests · Grasslands, savannas, and shrublands
		Tropical and subtropical	Coniferous forests · Moist broadleaf forests · Dry broadleaf forests · Grasslands, savannas, and shrublands
		Dry	Mediterranean forests, woodlands, and scrub · Deserts and xeric shrublands
		Wet	Flooded grasslands and savannas · Riparian · Wetland · Mangrove
	Aquatic biomes		Pond · Littoral · Intertidal · Mangroves · Kelp forests · Coral reefs · Neritic zone · Pelagic zone · Benthic zone · Hydrothermal vents · Cold seeps · Demersal zone
	Other biomes		Endolithic zone
Biogeographic realms	Terrestrial		Afrotropical · Antarctic · Australasian · Indomalayan · Nearctic · Neotropical · Oceanian · Palearctic
	Marine		Arctic · Tropical Atlantic · Central Indo-Pacific · Western Indo-Pacific · Temperate Northern Pacific · Tropical Eastern Pacific · Southern Ocean
	Subdivisions		Biogeographic provinces · Bioregions · Ecoregions (Lists of ecoregions · Global 200 ecoregions)
See also	Ecological land classification · Floristic kingdoms · Vegetation classifications · Zoogeographic regions		

Figure 4: List of Ecosystems (Wikipedia contributors (2019))

Using the list of ecosystem, the properties and descriptions were searched for on the internet. The template for the web search is as follows:

<ecosystem name> description

Many websites were used to get these information, such as wikipedia (Wikipedia contributors (2019)), information publically available on National Geographic website (rainforest description was from Christina Nunez (2019)) and other educational

Ecosystem	Description
Tropical Rainforest Canopy	tropical evergreen forest canopy is canopy refers to the upper layer or habitat zone, formed by mature tree crowns and including other biological organisms
Benthic Zone	benthic zone, ocean floor, bottom of lake, deep sea and sea floor is the lowest level of a body of water such as an ocean, lake, or stream, including the sediment surface and some sub-surface layers
Lagoons	estuary or lagoon is partially enclosed coastal body of brackish water with one or more rivers or streams flowing into it, and with a free connection to the open sea

Table 5.1: Ecosystem and Description

websites such as study.com. This information is stored in ASP format. Examples of entires that are present in the knowledge base is given in Table 5.1. More examples of ecosystem descriptions in the knowledge base in present in the appendix.

While this information wasn't sufficient to answer all the types of questions, more information about the ecosystem were required to be able to reason like the properties of the ecosystem such as availability or unavailability of entities that are key to survival of organisms, such as sunlight. All this information was collected by manually going through the information about the ecosystem and collecting data about them. They also were stored in the ASP format. The example of the data is shown in the table 5.2. This information was very much necessary when there has to be a connection between the organism and the ecosystem or between two ecosystems.
In summary, in this subsection, the collection of ecosystem related information was

```
adaptation("the thorny devil", "sandplain and sandridge desert", "not
only does their spiny armor protect them from predators, it also helps
them absorb water in their arid habitat. there are hygroscopic
(moisure-attracting) grooves between their thorns. they obtain water
from the dew that condenses on their bodies overnight, during rare
rainfalls, or by brushing up against dew-coated grass. any water that
gets into the grooves between its thorns is drawn by capillary action
to its mouth, allowing the thorny dragon to suck water from all over
its body.").
adaptation("pyxie frog", "dry savanna, moist savanna, subtropical or
tropical dry shrubland", "it digs holes so it can go dormant during
the dry season. it makes a dry, watertight cocoon for itself, which
prevents the evaporation of body fluids. it loses approximately half
of the water that a frog without a cocoon would lose. the frogs can
survive for several months in dry soil by absorbing water stored in
the bladder. once the rainy season starts, the moisture will seep into
the ground and soak the cocoon. after it softens enough to split open,
the frog eats it. ").
```

Figure 5: Adaptation KB in ASP

Ecosystem	Property	Entity required for survival
Tropical Rainforest Canopy	abundance	sunlight
Benthic Zone	lacks	sunlight
salt marsh	abundance	salt

Table 5.2: Ecosystem Properties

described. Using this information, adaptation paragraphs would be searched on the web. In the next subsection, collection of the adaptation knowledge paragraphs would be described in detail.

5.1.2 Adaptation Paragraphs Collection

In Section 5.1.1, the collection of adaptation related information was described in detail. Using the information that was collected in that section, the Adaptation Paragraphs would be collected. As the adaptations are based on the ecosystem and the environments that the organisms are living in, the list of ecosystems were collected first and then adaptations in each of those ecosystems were looked for on the web. The templates for web searches are mentioned in the Table 5.3. Using these tem-

Templates	Examples
"adaptations in <ecosystem>"	"adaptations in rain forest"
"plant adaptations in <ecosystem>"	"plant adaptations in rain forest"
"animal adaptations in <ecosystem>"	"animal adaptations in rain forest"

Table 5.3: Templates and Examples to search for Adaptation Paragraphs on the web

plates, a lot of adaptation information and paragraphs were gathered. All adaptation paragraphs were specific to a particular organism or a set of organisms. These organisms were identified and a list of organisms were made in parallel with the adaptation paragraphs, so that the organism details can be gathered easily (Subsection 5.1.3). Adaptation paragraphs examples are given in 5.4. These paragraphs were collected from various different websites that are mentioned in the Appendix B.

5.1.3 Organism Related Information Collection

In the previous subsections, ecosystem and adaptation related information were collected. While collecting the adaptation paragraphs, a list of organisms were made as mention in Subsection 5.1.2. Using these organisms, a list of their body parts and their functions were made in order to help with the reasoning. These information is also stored in the knowledge base in ASP format. The examples of organisms' body parts are given in Table 5.5 and the example of functions of body parts are present in Table 5.6.

An example of how the whole Knowledge Base creation would look like is present in Figure 6.

To summarize, the total number of information collected and stored in the knowledge

Organism	Ecosystem	Adaptations
Plants	Savanna	The Savanna biomes are usually very hot so the plants that live there would have to have certain qualities about them so they are able to survive in a hot environment that has barely any rainfall each year. The plants that live in the Savanna have adapted in many different ways to put up with these harsh environments. The trees and plants have longer roots so that they have the ability to extract water from deeper into the ground.
Fennec fox	Desert	Xerocoles, having to travel long distances for food and water, are often adapted for speed, and have long limbs,feet that prevent them from sinking in the sand, and are overall slender in form. As there is little cover to protect them from predators, desert animals also use speed as a defense mechanism.

Table 5.4: Examples of Adaptation Paragraphs

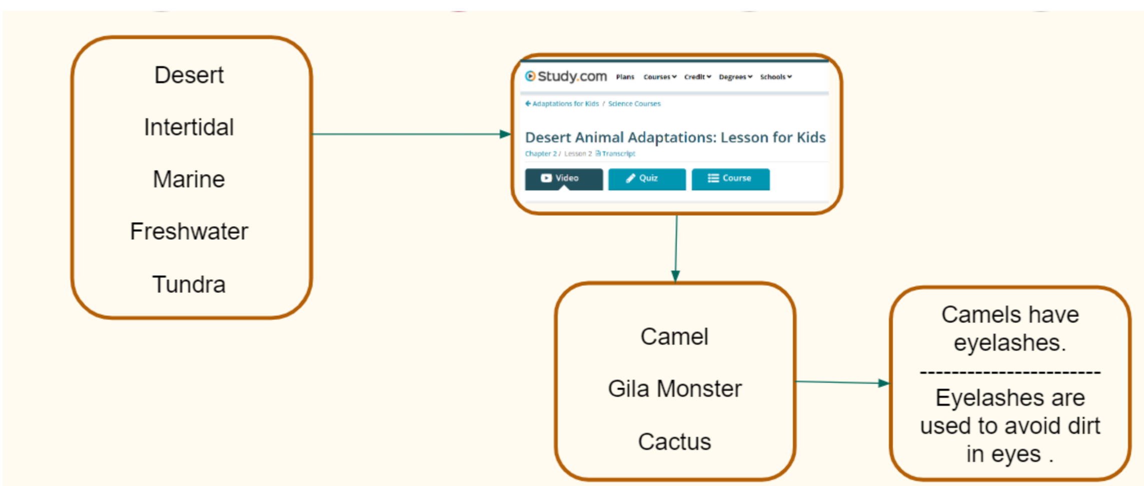

Figure 6: Knowledge Base Creation Example

Organism	Body Part
Plants	roots
Cactus	thorns
Eagles	Talons

Table 5.5: Body Parts of Organisms

Body Part / Behavior	Function
roots	consume water
teeth	gripping prey
bark	conserving water

Table 5.6: Funtions of Organisms' Body Parts

base is shown in Table 5.7

In the next section, the details of Question Creation using these knowledge paragraphs are explained.

5.2 Question Creation

As mentioned in the previous chapters, one of the goals of this work is to create dataset of questions in the field of "Adaptation, Behaviors and Variations" that re-

Type of Knowledge	Total
Adaptation Paragraphs	335
Ecosystems	38
Ecosystem Properties	262
Organisms	158
Parts/Behaviors of Organisms	93
Functions of the Parts/Behaviours	157

Table 5.7: Summary of Knowledge Base

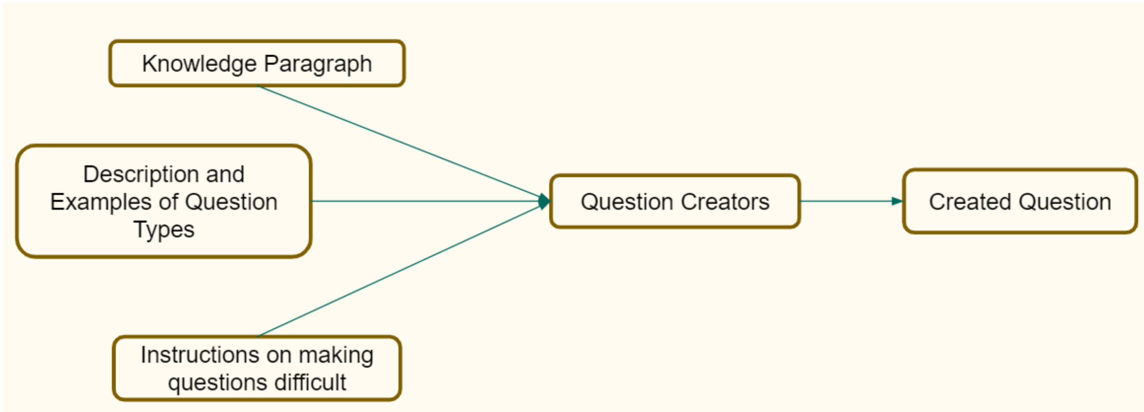

Figure 7: Question Creation Steps

quire external combining information to answer the question. In order to achieve this goal, an step by step algorithm was created. The questions were crowd sourced and to create the questions a knowledge paragraph from the Knowledge Base, instructions on how to make the questions difficult and description and example of the 8 question types were provided. Each question can have 2-4 answer options. The flow of the question creation is shown in Figure 7.

The example of the flow is mentioned in Figure 8. A total of 1303 questions were created in this procedure. For each question type, there is a different set of information present in the question and a different type of answer choice, the questions were created keeping that in mind.

All the 8 questions types differ from each other when it comes to the type of information present in the questions and answer options. Table **??** contains the question types and the information contained in the question and the answer options. The Question types can further be divided into two categories based on the knowledge paragraphs that would be required to create the questions. The first category would contain questions of type 1 to 5 and the second category would contain questions of type 6 to 8. Question types 1-5 require one paragraph from the adaptation KB

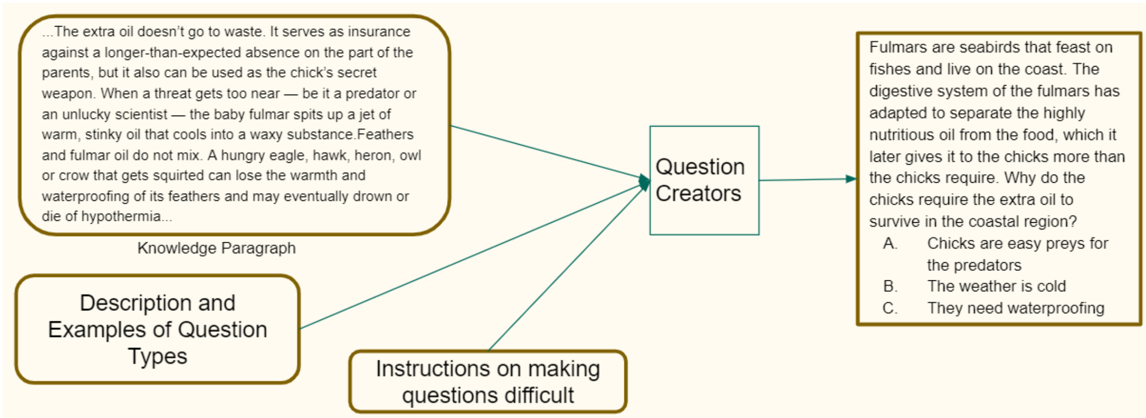

Figure 8: Question Creation Example

and one paragraph from the ecosystem KB while question types 6 would require two paragraphs from the ecosystem KB (About two different ecosystems) and all the adaptations relating to those two ecosystems. Question types 7 and 8 would require one paragraph from the ecosystem KB and all the Adaptation KB paragraphs relating to the ecosystem chosen from ecosystem KB. Even though there are two categories based on the information given to the creators from the KB, all types of questions are different, and reasoning of each type is different.

5.2.1 Question Creation for Type 1-5

Questions of type 1-5 can be created using the same knowledge paragraph, hence this subsection includes description of question types 1-5, provided the knowledge paragraph.

Given a Knowledge Paragraph, the question creator should identify the environment, the organism, the adaptation and the reason for the adaptation. and then create a question. Consider the knowledge paragraph from the knowledge base mentioned in Table 5.8.

The following information can be identified from the paragraph:

Fulmars	Marine	Fulmars are birds that live in interidal or marine environments. After swallowing a fish, an adult fulmars digestive system separates the oil from the protein, and shunts the oil into a storage gland called the proventriculus. Mom or dad then returns to the nest and regurgitates this reddish-orange, highly nutritious oil for the chick. The parents hedge their bets though and pump their chick full of more oil than it needs to survive.The extra oil doesnt go to waste. It serves as insurance against a longer-than-expected absence on the part of the parents, but it also can be used as the chicks secret weapon. When a threat gets too near be it a predator or an unlucky scientist the baby fulmar spits up a jet of warm, stinky oil that cools into a waxy substance. Feathers and fulmar oil do not mix. A hungry eagle, hawk, heron, owl or crow that gets squirted can lose the warmth and waterproofing of its feathers and may eventually drown or die of hypothermia.

Table 5.8: Adaptation KB Paragraph for Question Creation[Type 1-5]

- Organism- Fulmar chicks
- Ecosystem- Marine or Intertidal
- Adaptation or Behaviour or variation - spits up a jet of warm, stinky oil
- Purpose- Protection from predators
- Reason- Predators prey on smaller defenseless chicks

As it can be observed, the purpose and reason is implied from the knowledge paragraph, it is not explicitly present in the paragraph. This makes the questions more challenging. There can be five types of questions that can be derived from this paragraph which are Types 1-5. Table 5.9 contains five questions that were created using the knowledge paragraph about fulmars that is mentioned above and the ecosystem KB that contains the descriptions of all the ecosystem.

Type	Question
Type 1	Fulmars are seabirds that feast on fishes and live on the coast. The digestive system of the fulmars has adapted to separate the highly nutritious oil from the food, which it later gives it to the chicks more than the chicks require. Why do the chicks require the extra oil to survive in the coastal region? A. Chicks are easy preys for the predators B. The weather is cold C. They need waterproofing

Type 2	Fulmars are seabirds that feast on fishes and live on the coast. The digestive system of the fulmars has adapted to separate the highly nutritious oil from the food, which it later gives it to the chicks more than the chicks require. How does the extra oil help the chicks survive in the coastal region? A. Defence from predators B. Helps stay warm by insulating feathers C. Helps make the feathers waterproof
Type 3	Fulmars are seabirds that feast on fishes and live on the coast. The digestive system of the fulmars has adapted to separate the highly nutritious oil from the food, which it later gives it to the chicks more than the chicks require. Which of the following is not a purpose to have extra oil to survive in the coastal region? A. To waterproof the feathers B. To defend itself from predators

Type 4	Fulmars are seabirds that feast on fishes and live on the coast. A lot of predators prey on small chicks as they look defenseless when their parents aren't present. What adaptation or behavior helps fulmar chicks to survive this environment? A. Spitting oil B. Swallowing highly nutritious oil C. Claws
Type 5	Fulmars are seabirds that feast on fishes and live on the coast. A lot of predators prey on small chicks as they look defenceless when their parents aren't present. What adaptation does not help fulmar chicks to survive this environment? A. Swallowing highly nutritious oil B. Spitting oil

Table 5.9: Examples of Created Questions [TYPE 1-5]

As it can be observed from the examples created, using one knowledge paragraph, five questions in total, one of each type (Type 1-5) can be created. Question creators were provided with one knowledge paragraph and the Ecosystem KB to create 5 questions- one of each type in Question Types 1-5.

Ecosystem	Description
Alpine tundra	Alpine tundra is a type of natural region or biome that does not contain trees because it is at high elevation. As the latitude of a location approaches the poles, the threshold elevation for alpine tundra gets lower until it reaches sea level, and alpine tundra merges with polar tundra.
Arctic Tundra	Arctic tundra is located in the northern hemisphere, encircling the north pole and extending south to the coniferous forests of the taiga. The arctic is known for its cold, desert-like conditions.

Table 5.10: Ecosystem KB Example for Question Creation [Type 6-8]

5.2.2 Question Creation for Type 6-8

To create questions 6-8, a lot of information needs to be provided to the question creators. Information of all the collected adaptations paragraphs from the KB, and the description of ecosystems from the ecosystem KB have to be provided to create the rest of the question types (Type 6-8).

Table 5.10 contains information about two ecosystems, Alpine and Arctic Tundra. Using only this information, questions of Type 6-8 can be created. But along with this the entire Adaptation KB was provided to the question creators to create questions. With the KB, the instructions on how to make the questions difficult and examples of existing questions were provided for the question creation.

Type	Question
Type 6	Which adaptation would be required for an organism to survive in high in the mountains and not in arctic tundra? A. Ability to live on high altitudes B. Ability to live on permafrost C. Ability to survive with less water D. Ability to use oxygen in respiration
Type 7	In which of the following ecosystem does an organism require the ability to live on high altitudes? A. Mountainous regions B. Underwater regions C. Freshwater regions D. Valleys of mountains
Type 8	In which of the following ecosystem does an organism not require the ability to live on high altitudes? A. Mountainous regions B. Arctic Tundra

Table 5.11: Examples of Created Questions [TYPE 6-8]

In this section, the details and steps of the Question Creation were discussed. Following this procedure, a total of 1303 questions has been created using the KB that was created in the previous section.

In this Chapter, the steps of Dataset Creation (Knowledge Base and Question Answering Dataset) has been discussed in detail. The next step is to create a reasoning model that would combine different pieces of information mentioned in the question and answer options to find the answer to the given question. The details of the reasoning model has been discussed in the Chapter 6.

Chapter 6

REASONING MODEL

In the previous chapters, using the analysis done on the initial questions, a Knowledge Base on the topic of "Adaptations, Behaviors and Variations in Organisms" was created and using the created Knowledge Base, more questions were created. In this chapter, the details of the reasoning model will be discussed. Reasoning is used to find the answer to the question given the knowledge base. The reasoning model is different for each question type and even though the basic reasoning steps or flow is the same for all questions, the Textual Entailment part of the reasoning differs. The flow chart of the reasoning model is given in Figure 9.

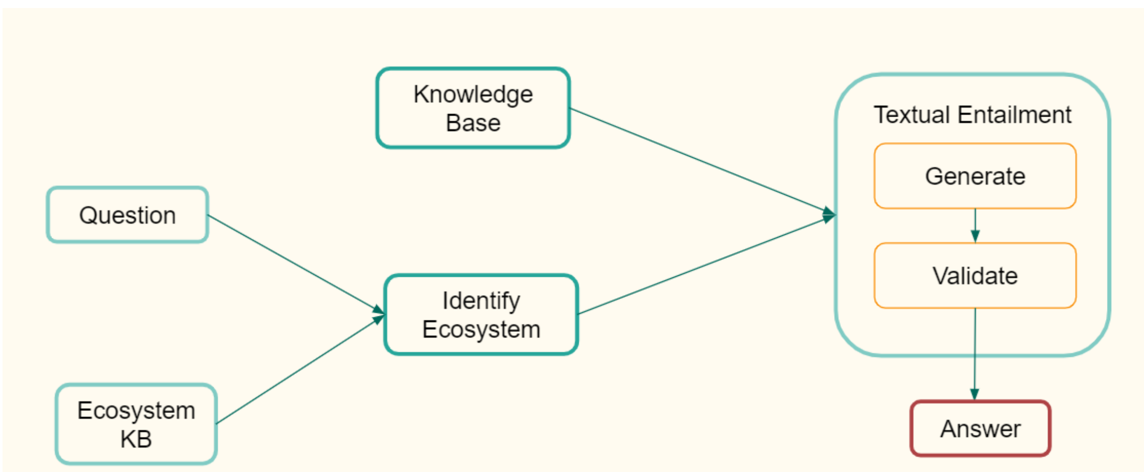

Figure 9: Reasoning Model

The Section 6.1 explains the question represented in ASP format. Since the reasoning for all question types are different, questions are represented with different predicates. As ecosystem is present in all question types, identifying what ecosystem the question is talking about is common to all question types. Section 6.2 explains the part of

Question Type	Question Representation
TYPE 1	qFindReason(Organism, Environment, Adaptation).
TYPE 2	qFindPurpose(Organism, Environment, Adaptation).
TYPE 3	qNotFindPurpose(Organism, Environment, Adaptation).
TYPE 4	qFindAdaptation(Organism, Environment, Reason/Purpose).
TYPE 5	qFindNotAdaptation (Organism, Environment, Reason/Purpose).
TYPE 6	qFindDifference(Ecosystem1, Ecosystem2).
TYPE 7	qFindHabitat(Adaptation).
TYPE 8	qFindNotHabitat(Adaptation).

Table 6.1: Questions Representation

identifying the ecosystem or environment the question is describing. The last Section, Section 6.3 describes the textual entailment part of the reasoning.

6.1 Question Representation in ASP

In this section, the Question Representation in ASP is discussed. Since the reasoning is done using Answer Set Programming, the question requires to be represented in ASP format. As mentioned earlier, the question types differ in the information present in the question stem and the type of answer options. Hence, the reasoning model is different for each type of question, and therefore each question type has to be represented with a different predicate, so that the system can identify which sets of rules can be applied.

Table 6.1 shows the question representation in ASP format for each type of question. The answer options are represented using `Options(X,D)` predicate where X is the option number and D is the option value.

Consider an example of the type 1:

> A tropical rain forest contains many tall trees. Smaller plants with large leaves grow at the base of the trees. The large leaves are most likely an adaptation of the plant due to which condition?
>
> A lack of sunlight
>
> B lack of oxygen
>
> C lack of water
>
> D lack of food

The question would be representation as:

```
qFindReason("Small Plants", "Base of the trees tropical rain forest","large leaves").
options(1,"lack of sunlight").
options(2,"lack of oxygen").
options(3,"lack of water").
options(4,"lack of food").
```

The option representation is the same in all types of questions, only the question predicate is different. The next two sections aim at discussing the reasoning part of the model as the question representation has been discussed in the current section.

6.2 Identify the Ecosystem

Identifying the ecosystem is the part of the reasoning model that is common to all the Question Types. Identifying ecosystem is crucial as with the ecosystem name, the reasoning system can obtain properties of the ecosystem from the KB to use this information. Therefore the first step in the reasoning model is to identify the Ecosystem. Ecosystem is identified using textual entailment with premise being the description of ecosystems in the KB and hypothesis being the description of the ecosystem in the question. The rule for identifying the ecosystem is as follows:

```
maxSim(E,E1,V) :- qFindReason(O,E,A), def_eco(E1, Desc),
V=@entail(E,Desc).
```

qFindReason is the predicate that contains the information from the question. def_eco is a predicate from the KB that contains description about the ecosystem. E1 in def_eco indicates the name of the ecosystem and Desc indicates the description of the ecosystem E1. This rule is finding the entailment score V where the description of ecosystem (Desc) is the premise and the ecosystem information from the question (E) is the premise. If the ecosystem extracted from the question is the name of the ecosystem, then the value of V is 1. Therefore, maxSim is a predicate that indicates how much each ecosystem in the KB entails the ecosystem mentioned in the question, where E is the ecosystem mentioned in the question, E1 is the ecosystem from the ecosystem KB and V is the entailment score. The next section describes the next step in the reasoning model which is textual entailment.

6.3 Textual Entailment

As the ecosystem identification part has been discussed in the previous section, the aim of this section is to explain how the different entities from the KB are combined to convert it into a textual entailment problem. There are two sub-parts in this part of reasoning- generate and validate. The information from the question and the Knowledge Base are combined in the generate function to generate premise and hypothesis pairs and the validate function takes these pairs and returns an entailment score. The generate and validate functions are explained in detail in the subsections 6.3.1 and 6.3.2. The template for premise generation is

6.3.1 Generate

The Generate function is the part of the reasoning that is different for all types of questions. The generate function creates hypothesis by combining information in the question with the answer options by filling in a text template. The template varies for each type of question. Table 6.2 contains templates for every question type. The generate function takes the information present in the question along with the options to generate hypotheses. The premise is either extracted from the KB or generated using the different sets of values from the Knowledge Base. The template for premise generation is common to all the Question Types. The templates for premise is as follows : `"<Organism> in <ecosystem> requires <adaptation> due to <Ecosystem property from KB>"`.

6.3.2 Validate

The Validate function is basically an entailment function that takes a premise-hypothesis pair and returns an entailment score. An entailment score is computed for every premise-hypothesis pair which is then combined in ASP.
The rule that includes generate and validate function:

```
findReason(O,E,A,D,V) :- options(X,D), qFindReason(O,E,A),
adaptation(O,E,Adaptation_Paragraph), Hypothesis=@hyp_reason(O,E,A,D),
V=@entail(Hypothesis,Adaptation_Paragraph).
```

In this rule, hyp_reason is the generation function that is generating a hypothesis using the information from the question and the answer option and entail is the

Question Type	Hypothesis Template	Number of Hypothesis Generated
Type 1	$< organism >$ in $< ecosystem >$ have $< adaptation >$ due to $< option >$	= Number of options
Type 2	$< organism >$ requires $< adaptation >$ for $< option >$ purpose in $< ecosystem >$	= Number of options
Type 3	$< organism >$ requires $< adaptation >$ for $< option >$ purpose in $< ecosystem >$ AND $< organism >$ in $< ecosystem >$ have $< adaptation >$ due to $< option >$	= Number of options * 2
Type 4 and 5	$< organism >$ requires $< option >$ for $< purpose/reason >$ purpose in $< ecosystem >$ AND $< organism >$ in $< ecosystem >$ have $< option >$ due to $< purpose/reason >$	= Number of options * 2
Type 6	Organisms in $< Ecosystem1 >$ require $< option >$ AND Organisms in $< Ecosystem2 >$ require $< Options >$	= Number of options * 2
Type 7 and 8	Organisms in $< Option >$ require $< Adaptation >$	= Number of options

Table 6.2: Hypothesis Generation Template

validation function that computes and returns the entailment score.

Consider an example:

Penguins are birds which live at arctic places with strong flippers and aerodynamics body. Why do they have such strong flippers and aerodynamic body?

A. To swim fast

B. To float on water

C. To stay underwater

Hypothesis generated using the information mentioned in the question are as follows:

- <Penguins> in <Tundra> has <strong flippers and aerodynamic body> because <To swim fast>
- <Penguins> in <Tundra> has <strong flippers and aerodynamic body> because <To float on water>
- <Penguins> in <Tundra> has <strong flippers and aerodynamic body> because <To stay underwater>

The premise in this case would be:

1. "At sea, emperor penguins glide through the water with great speed and agility. Their aerodynamic bodies and strong flippers make them excellent swimmers, reaching speeds of 3.4 m/s (7.6 mph). They can dive deeper than any other bird as deep as 565 m (1850 ft.) and they can stay under for more than 20 minutes."

2. Penguins in Tundra use large flippers to move faster

All the premise-hypothesis pairs would be sent to the validation function to compute entailment score which then gets combined in the ASP code. This is illustrated in Figure 10. As it can be observed, all the premise and hypothesis pairs that are

Figure 10: Premise-Hypothesis Pair

generated are sent to the validation function. When it it returned, the system has scores for all the pairs of hypothesis and premise. And these scores are evaluated (this is based on the question type) and one of the option is picked as the right answer. In most question types, the option with the highest entailment score is selected as the right answer. The ASP code to all the 8 types are given the Appendix A

Chapter 7

EXPERIMENTS AND RESULTS

In the previous chapters, goals, analysis and methodology of creation of QA dataset and reasoning models were discussed, so in this Chapter, the experimentation of the created model along with the baseline models on the created QA dataset will be discussed.

The QA dataset contains 1303 multiple choice questions (with 2, 3 or 4 options) in total including all categories of questions in the domain of Adaptations, Behavior and Variation. These questions were tested on three baseline models along with the method mentioned in the thesis to evaluate the performance of the system implemented. The three baselines are - Textual entailment, Word vector Similarity and Information retrieval based model. The Word Vector Similarity and Information Retrieval models are provided in the Aristo mini QA solver. The textual entailment model was implemented taking Khot *et al.* (2018b) as the reference. These baseline models have been explained in detail in Section 7.1. The experimental setup is explained in Section 7.2 and the final results are discussed in Section 7.1.

7.1 Baselines

The Questions Dataset has been tested on three baseline models:

- Textual entailment using Decomposition Attention Model (Parikh *et al.* (2016a)) as used in Khot *et al.* (2018b), by creating a hypothesis with the question and answer options and validating it with a premise.
- Word Vector Similarity

- Information Retrieval based solver

7.1.1 Word Vector Similarity

Word Vector similarity used word2vec to find the best possible answer to the question. As it can be seen in the flow diagram, the question statement along with each option is tokenized and their word vectors are created. To find the similarity, the average of word vectors of all words in the question is computed and average of word vectors of the options is computed separately. The cosine similarity of both the average values is computed and the answer option which gets the maximum cosine similarity score is chosen as the answer. So if there are four options to a question, there will be 4 cosine similarity scores as each score would represent the similarity between the question and each answer option.
There are three experiments done with word vector similarity.

1. Word2vec model trained on Aristo-mini corpus

2. Word2vec model trained on the KB created in this thesis

3. Word2vec model trained on Aristo-mini corpus+ the KB created in this thesis

The aristo-mini corpus contains:

- Simple Wiki (1.1M lines)

- Simple Wiktionary (32k lines)

- Web (50k lines)

The input and output is in JSONL format. The input is the entire question stem and the answer options in jsonl format. The confidence value for each option is returned as an output.

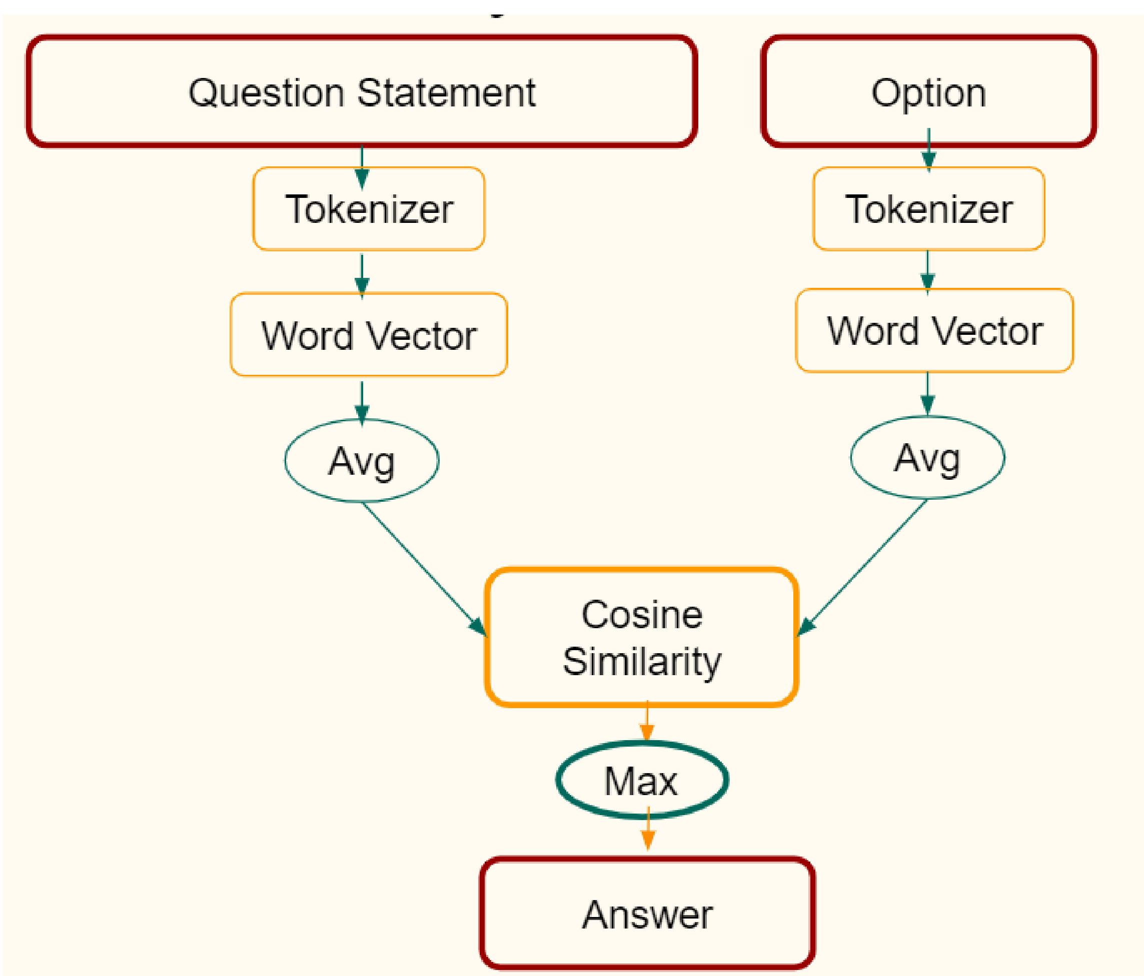

Figure 11: Word Vector Similarity Flow Chart

7.1.2 Information Retrieval based solver

The IR based solver is another model used as a baseline for this work. The IR based solver that is used in this work is provided by aristo-mini which is a question answering system provided to quickly evaluate Aristo Science Questions. As shown in Figure 12, the IR based solver uses elasticsearch index to score the choices. The question with options is taken as an input by the IR solver. The IR solver sends the question statement with each option statement as a query to the ElasticSearch which contains the aristomini corpus. Elasticsearch returns a confidence score for

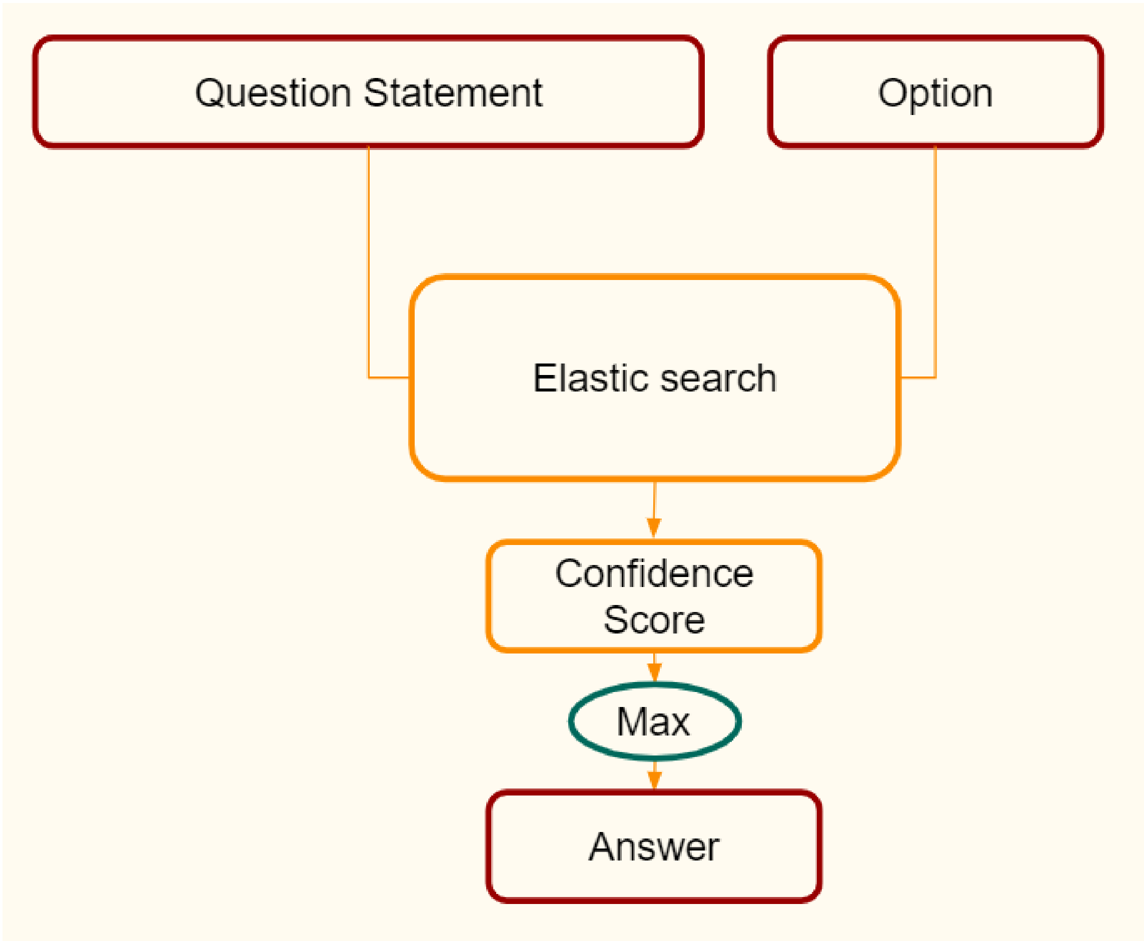

Figure 12: IR based solver Flow Chart

each answer option. The answer option that has the maximum confidence score is chosen as the right answer. The input and output format is jsonl. There are three experiments done with IR based model as well.

1. Elasticsearch with Aristo-mini corpus

2. Elasticsearch with the KB created in this thesis

3. Elasticsearch with Aristo-mini corpus + the KB created in this thesis

7.1.3 Textual Entailment

Textual entailment model was also chosen as a baseline to this work. The textual entailment model was implemented taking Khot *et al.* (2018b) as the reference using Decomposition Attention Model (Parikh *et al.* (2016b)) for entailment. As mentioned in the Figure 13, The hypothesis and the option would be together used to create a hypothesis (just like in Khot *et al.* (2018b)). To use this model as a baseline, every question was presented with a paragraph from the KB that could be used as a premise. A hypothesis is generated for every answer option. The premise along with the generated hypothesis was given to an entailment function which returns a confidence score. The option that gets the maximum confidence score is chosen as the answer. Example of hypothesis created is shown in Figure 14 for the following question:

> Penguins are birds which live at arctic places with strong flippers and aerodynamics body. Why do they have such strong flippers and aerodynamic body?
>
> A. To swim fast
>
> B. To float on water
>
> C. To stay underwater

7.2 Experimental Setup

For Textual Entailment in the baseline model as well as our model, Decomposition Attention Model (Parikh *et al.* (2016b)) was used. There were three corpus used to train the word2vec model and to insert into elastic search:

1. Aristo-mini corpus

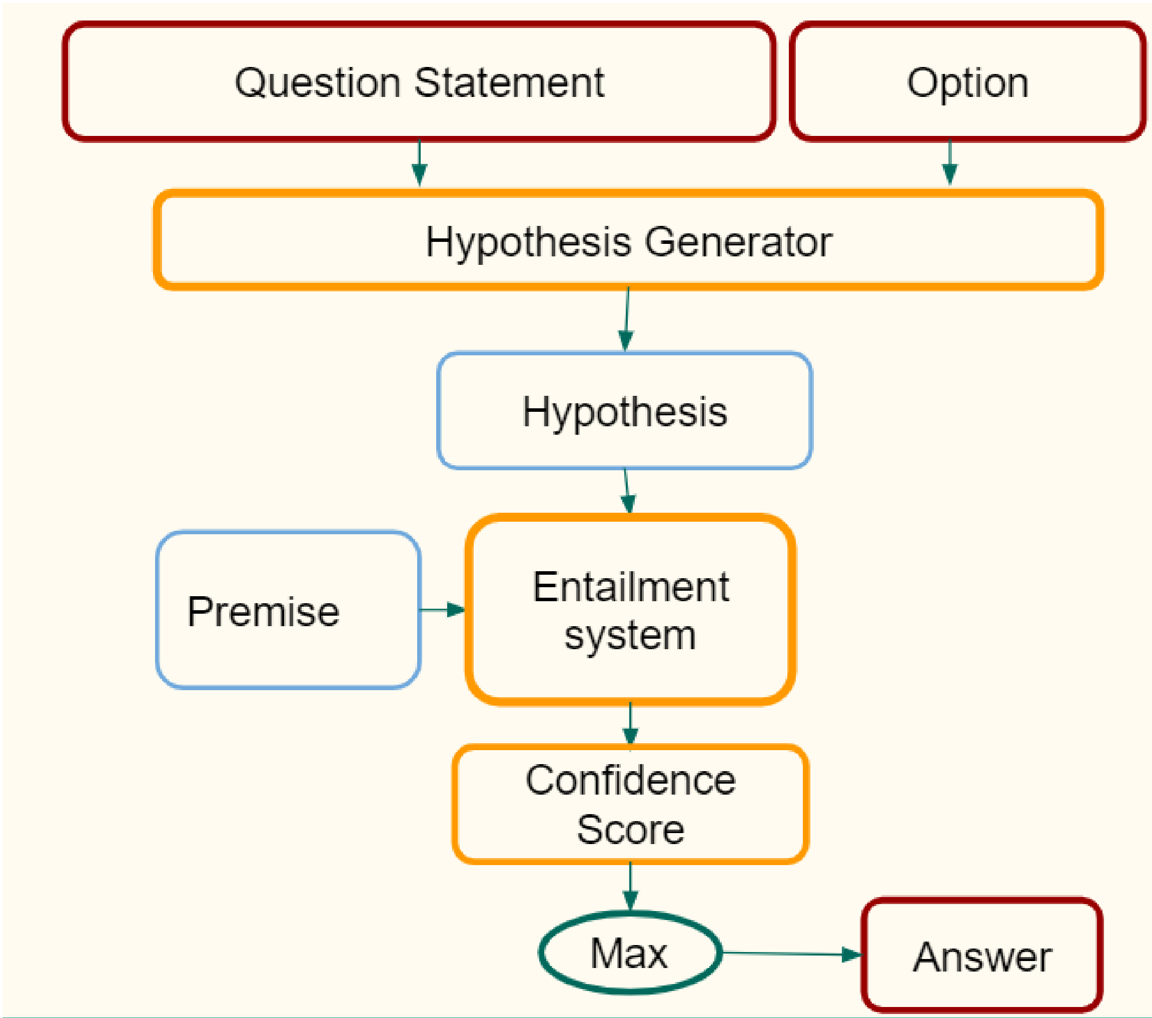

Figure 13: Textual Entailment Flow Chart

2. the KB created in this work

3. the KB created in this work + Aristo-mini corpus

These models were tested using the QA dataset created in this work. The results are described in the next section.

```
A. penguins are birds which live at artic places wit
h strong flippers and aerodynamics body.  they have
such strong flippers and aerodynamic body because to
 swim fast .
B. penguins are birds which live at artic places wit
h strong flippers and aerodynamics body.  they have
such strong flippers and aerodynamic body because to
 float on water .
C. penguins are birds which live at artic places wit
h strong flippers and aerodynamics body.  they have
such strong flippers and aerodynamic body because to
 stay underwater .
```

Figure 14: Generated Hypothesis

7.3 Results

The results of the experimentation done is shown in Table **??**. The first three results are the results of experimentation on the Information retrieval baseline model. The next three are the results of experimentation on the Word Vector Similarity model. Textual entailment system was provided with the exact paragraph from which contained the answer to the question, which was not in the case of the rest of the models, hence textual entailment system did slightly better. The last row is the result of the experimentation done with our system.

The reasoning system created in this work creates multiple premises from the information present in the knowledge base that can be used for the entailment. And the model combines different sets of knowledge to find the answer, unlike the textual entailment model which takes in only one premise. The systems find it difficult to solve questions that require an external knowledge to answer the question.

System	Accuracy (%)
Text Search with Aristo-mini corpus	41.44
Text Search with KB	43.44
Text Search with Aristo-mini corpus and KB	43.90
Word Vector Similarity with Aristo-mini corpus	42.30
Word Vector Similarity with KB	44.59
Word Vector Similarity with Aristo-mini corpus and KB	41.98
Textual entailment	46.21
Our system	52.82

Table 7.1: Experimentation Results

Chapter 8

CONCLUSION AND FUTURE DIRECTIONS

In this work, a QA dataset of 1303 questions that require using multiple sets of knowledge for finding the answer is presented along with the well defined knowledge base that can be used for the reasoning in the domain of "Adaptation, Behavior and Variation in Organisms". A method of reasoning that would combine different natural language texts to answer the presented question has been presented. However there is a very good scope for further improvements with as the accuracy being only 52.82% when compared to the human accuracy. The future direction would include expanding the Question dataset and the Knowledge Base over the other fields of science and to work on creating a better model as there is a very high scope of improvement.

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APPENDIX A

ANSWER SET PROGRAMMING IN CLINGO

A.1 ASP for type 1 question

Line	Code
1	eco(E):-qFindReason(O,E,A).
2	qFindReasonFromOptions(O,E,A,V):-V="1", qFindReason(O,E,A), ecosystem(E).
3	qFindReasonFromOptions(O,E,A,V):-V="1", qFindReason(O,E1,A), other_name(E,E1), ecosystem(E).
4	qFindReasonFromOptions(O,E1,A,V):-V="1", qFindReason(O,E,A), E="", def_eco(E1,X).
5	qFindReasonFromOptions(O,E1,A,V):-qFindReason(O,E,A), maxSim(E,E1,V,X), not ecosystem(E).
6	maxSim(E,E1,V,X):-eco(E), def_eco(E1, Desc), V=@ent(E,Desc).
7	ans(X):- conf(X,V), V==#maxV1:conf(X1,V1).
8	conf(X,V):- options(X,D), findReason(O,E,A,D,V).
9	findReason(O,E,A,D,V):-options(X,D), qFindReasonFromOptions(O,E,A,Vx), adaptation(O,E,Adapt), Hyp=@hyp_reason(O,E,A,D), Vy=@ent(Hyp,Adapt), V=@mul(Vx,Vy).
10	findReason(O,E,A,D,V):-options(X,D), qFindReasonFromOptions(O,E,A,Vx), lacks(E,L), H_L=@hyp_lack(L), usedFor(O,Ad,Purp), H_B=@hypMoreOrLarge(Ad), Hyp1=@hyp_reason(O,E,A,D), Hyp2=@hyp_reason(O,E,H_B,H_L), Hyp3=@hyp_reason(O,E,H_B,Purp), V1=@ent(Hyp1,Hyp2), V2=@ent(Hyp2,Hyp3), Vy=@mul(V1,V2), V=@mul(Vx,Vy).

11	findReason(O,E,A,D,V):-options(X,D), qFindReasonFromOptions(O,E,A,Vx), abundance(E,L), H_L=@hyp_abun(L), usedFor(O,Ad,Purp), H_B=@hypSmall(Ad), Hyp1=@hyp_reason(O,E,H_B,H_L), Hyp2=@hyp_reason(O,E,A,D), Hyp3=@hyp_reason(O,E,H_B,Purp), V1=@ent(Hyp1,Hyp2), V2=@ent(Hyp2,Hyp3), Vy=@mul(V1,V2), V=@mul(Vx,Vy).

Table A.1: Asp Rules for Type 1 Questions

A.2 ASP for Type 2 Questions

Line	Code
1	eco(E):-qFindPurpose(O,E,A).
2	qFindPurposeFromOptions(O,E,A,V):-V="1",qFindPurpose(O,E,A), ecosystem(E).
3	qFindPurposeFromOptions(O,E1,A,V):-V="1",qFindPurpose(O,E,A), ecosystem(E1), other_name(E1,E).
4	qFindPurposeFromOptions(O,E1,A,V):-V="1",qFindPurpose(O,E,A), E="", def_eco(E1,X).
5	qFindPurposeFromOptions(O,E1,A,V):-qFindPurpose(O,E,A), maxSim(E,E1,V,X), not ecosystem(E).
6	maxSim(E,E1,V,1):-eco(E), def_eco(E1, Desc), V=@ent(E,Desc).
7	ans(X):- conf(X,V), V==#max{V1:conf(X1,V1)}.
8	conf(X,V):- options(X,D), qFindPurposeFromOptions(O,E,A), findPurpose(O,E,A,D,V).

9	findPurpose(O,E,A,D,V):-options(X,D), qFindPurposeFromOptions(O,E,A,Vx), adaptation(O,E,Adapt), Hyp=@hyp_purpose(O,E,A,D), Vy=@ent(Hyp,Adapt), V=@mul(Vx,Vy).
10	findPurpose(O,E,A,D,V):-options(X,D), qFindPurposeFromOptions(O,E,A,Vx), property(E,L), H_L=@hyp_purp(L), usedFor(O,Ad,Purp), H_B=Ad, Hyp1=@hyp_purpose(O,E,A,D), Hyp2=@hyp_purpose(O,E,H_B,H_L), Hyp3=@hyp_purpose(O,E,H_B,Purp), V1=@ent(Hyp1,Hyp2), V2=@ent(Hyp2,Hyp3), Vy=@mul(V1,V2), V=@mul(Vx,Vy).

Table A.2: Asp Rules for Type 2 Questions

A.3 ASP for Type 3 Questions

Line	Code
1	eco(E):-qNotFindPurpose(O,E,A).
2	qNotFindPurposeFromOptions(O,E,A,V) :- V="1", qNotFindPurpose(O,E,A), ecosystem(E).
3	qNotFindPurposeFromOptions(O,E1,A,V):- V="1",qNotFindPurpose(O,E,A), E="", def_eco(E1,X).
4	qNotFindPurposeFromOptions(O,E1,A,V):- V="1",qNotFindPurpose(O,E,A), maxSim(E,E1,V,X), not ecosystem(E).
5	ans(X):- conf(X,V), V==#minV1:conf(X1,V1).
6	conf(X,V):- options(X,D), notFindPurpose(O,E,A,D,V), V==#max{V1:notFindPurpose(O1,E1,A1,D,V1)}.

7	notFindPurpose(O,E,A,D,V):-options(X,D), qNotFindPurposeFromOptions(O,E,A,Vx), adaptation(O,E,Adapt), Hyp=@hyp_purpose(O,E,A,D), Vy=@ent(Hyp,Adapt), V=@mul(Vx,Vy).
8	notFindPurpose(O,E,A,D,V):-options(X,D), qNotFindPurposeFromOptions(O,E,A,Vx), property(E,L), H_L=@hyp_purp(L), usedFor(O,Ad,Purp), H_B=Ad, Hyp1=@hyp_purpose(O,E,A,D), Hyp2 = @hyp_purpose(O,E,H_B,H_L), Hyp3 = @hyp_purpose(O,E,H_B,Purp), V1=@ent(Hyp1,Hyp2), V2=@ent(Hyp2,Hyp3), Vy=@mul(V1,V2), V=@mul(Vx,Vy).
9	maxSim(E,E1,V,1):-eco(E), def_eco(E1, Desc), V=@ent(E,Desc).

Table A.3: Asp Rules for Type 3 Questions

A.4 ASP for Type 4 Questions

Line	Code
1	eco(E):-qFindAdaptation(O,E,A).
2	qFindAdaptationFromOptions(O,E,A,V):-V = “1”,qFindAdaptation(O,E,A), ecosystem(E).
3	qFindAdaptationFromOptions(O,E1,A,V):-V = “1”,qFindAdaptation(O,E,A), E = “”, def_eco(E1,X).
4	qFindAdaptationFromOptions(O,E1,A,V):-V = “1”,qFindAdaptation(O,E,A), other_name(E1,E), ecosystem(E1).
5	qFindAdaptationFromOptions(O,E1,A,V) :- qFindAdaptation(O,E,A), maxSim(E,E1,V,X), not ecosystem(E).

6	maxSim(E,E1,V,1):-eco(E), def_eco(E1, Desc), V = @ent(E,Desc).
7	ans(X):- conf(X,V), V = = #max{V1:conf(X1,V1)}.
8	conf(X,V):- options(X,D), V = #max{V1:findAdaptation(O1,E1,A1,D,V1)}, findAdaptation(O,E,A,D,V).
9	findAdaptation(O,E,A,D,V):-options(X,D), qFindAdaptationFromOptions(O,E,A,Vx), adaptation(O,E,Adapt), Hyp = @hyp_purpose(O,E,A,D), Vy = @ent(Hyp,Adapt),V = @mul(Vx,Vy).
10	findAdaptation(O,E,A,D,V):-options(X,D), qFindAdaptationFromOptions(O,E,A,Vx), property(E,L), H_L = @hyp_purp(L), usedFor(O,Ad,Purp), H_B = Ad, Hyp1 = @hyp_purpose(O,E,A,D), Hyp2 = @hyp_purpose(O,E,H_L,H_B), Hyp3 = @hyp_purpose(O,E,Purp,H_B), V1 = @ent(Hyp1,Hyp2), V2 = @ent(Hyp2,Hyp3), Vy = @mul(V1,V2), V = @mul(Vx,Vy).
11	findAdaptation(O,E,A,D,V):-options(X,D), qFindAdaptationFromOptions(O,E,A,Vx), adaptation(O,E,Adapt), Hyp = @hyp_reason(O,E,A,D), Vy = @ent(Hyp,Adapt),V = @mul(Vx,Vy).
12	findAdaptation(O,E,A,D,V):-options(X,D), qFindAdaptationFromOptions(O,E,A,Vx), property(E,L), H_L = @hyp_purp(L), usedFor(O,Ad,Purp), H_B = Ad, Hyp1 = @hyp_reason(O,E,A,D), Hyp2 = @hyp_reason(O,E,H_L,H_B), Hyp3 = @hyp_reason(O,E,Purp,H_B), V1 = @ent(Hyp1,Hyp2), V2 = @ent(Hyp2,Hyp3), Vy = @mul(V1,V2), V = @mul(Vx,Vy).

Table A.4: Asp Rules for Type 4 Questions

A.5 ASP for Type 5 Questions

Line	Code
1	eco(E):-qFindNotAdaptation(O,E,A).
2	qFindNotAdaptationFromOptions(O,E,A,V):- qFindNotAdaptation(O,E,A), ecosystem(E),V="1".
3	qFindNotAdaptationFromOptions(O,E1,A,V):- qFindNotAdaptation(O,E,A), E="", def_eco(E1,X),V="1".
4	qFindNotAdaptationFromOptions(O,E,A,V):- qFindNotAdaptation(O,E1,A), other_name(E,E1), ecosystem(E),V="1".
5	qFindNotAdaptationFromOptions(O,E1,A,V):- qFindNotAdaptation(O,E,A), maxSim(E,E1,V,X), not ecosystem(E).
6	maxSim(E,E1,V,1):-eco(E), def_eco(E1, Desc), V=@ent(E,Desc).
7	ans(X):- conf(X,V), V==#min{V1:conf(X1,V1)}.
8	conf(X,V):- options(X,D), V=#max{V1: findNotAdaptation(O1,E1,A1,D,V1)}, findNotAdaptation(O,E,A,D,V).
9	findNotAdaptation(O,E,A,D,V):-options(X,D), qFindNotAdaptationFromOptions(O,E,A,Vx), adaptation(O,E,Adapt), Hyp=@hyp_purpose(O,E,A,D), Vy=@ent(Hyp,Adapt),V=@mul(Vx,Vy).
10	findNotAdaptation(O,E,A,D,V):-options(X,D), qFindNotAdaptationFromOptions(O,E,A,Vx), property(E,L), H_L= @hyp_purp(L), usedFor(O,Ad,Purp), H_B=Ad, Hyp1= @hyp_purpose(O,E,A,D), Hyp2= @hyp_purpose(O,E,H_L,H_B), Hyp3= @hyp_purpose(O,E,Purp,H_B), V1=@ent(Hyp1,Hyp2), V2=@ent(Hyp2,Hyp3), Vy=@mul(V1,V2),V=@mul(Vx,Vy).

11	findNotAdaptation(O,E,A,D,V):-options(X,D), qFindNotAdaptationFromOptions(O,E,A,Vx), adaptation(O,E,Adapt), Hyp=@hyp_reason(O,E,A,D), Vy=@ent(Hyp,Adapt),V=@mul(Vx,Vy).
12	findNotAdaptation(O,E,A,D,V):-options(X,D), qFindNotAdaptationFromOptions(O,E,A,Vx), property(E,L), H_L=@hyp_purp(L), usedFor(O,Ad,Purp), H_B=Ad, Hyp1=@hyp_reason(O,E,A,D), Hyp2=@hyp_reason(O,E,H_L,H_B), Hyp3=@hyp_reason(O,E,Purp,H_B), V1=@ent(Hyp1,Hyp2), V2=@ent(Hyp2,Hyp3), Vy=@mul(V1,V2),V=@mul(Vx,Vy).

Table A.5: Asp Rules for Type 5 Questions

A.6 ASP for type 6 questions

Line	Code
1	eco(E1;E2) :- qFindDifference(E1,E2).
2	qDifference(E_1,E_2) :- qFindDifference(E1,E2), maxSim_Eco(E1,E_1,Vx,K), maxSim_Eco(E2,E_2,Vy,L), E_1 != E_2.
3	maxSim_Eco(E,E_1,V) :- eco(E), def_eco(E_1,D), V=@ent(E,D), not ecosystem(E).
4	maxSim_Eco(E,E,V):- eco(E), ecosystem(E), V="1".
5	maxSim_Eco(E,D,V,1):-maxSim_Eco(E,D,V), V==#max{V1:maxSim_Eco(E,D1,V1)}.
6	maxSim_Eco(E,D,V,2):-maxSim_Eco(E,D,V), maxSim_Eco(E,Dx,V2,1), V==#max{V1:maxSim_Eco(E,D1,V1), V1 < V2}.

7	ecosystemBasedAdapt_1(Eco,Desc):- qDifference(Eco,Eco1), adaptation(Org,Eco,Desc).
8	ecosystemBasedAdapt_2(Eco,Desc):- qDifference(Eco1,Eco), adaptation(Org,Eco,Desc).
9	diff(E1,E2,D,V):-ecosystemBasedAdapt_1(E1,Desc1), ecosystemBasedAdapt_2(E2,Desc2),options(X,D),H1=@hyp(E1,D), H2=@hyp(E2,D), V1=@ent(H1,Desc1), V2=@ent(H2,Desc2), V=@divide(V1,V2).
10	diff(E1,E2,D,V):-qDifference(E1,E2),property(E1,P1), property(E2,P2), options(X,D), V1=@ent_req(D,P1), V2=@ent_req(D,P2), V=@divide(V1,V2).
11	diff(E1,E2,D):- diff(E1,E2,D,V), V==#max{V1: diff(E1x,E2x, D1x, V1)}.
12	ans(X):-qDifference(E1, E2), options(X,D), diff(E1,E2,D).

Table A.6: Asp Rules for Type 6 Questions

A.7 ASP for Type 7 Questions

Line number	ASP Code
1	eco(E):-options(X,E).
2	maxSim_Eco(E,E1,V):- eco(E), def_eco(E1,D), not other_name(E_1,E),V=@ent(E,D), not ecosystem(E), ecosystem(E_1).
3	maxSim_Eco(E,E,V):- eco(E), ecosystem(E), V="1".
4	maxSim_Eco(E1,E,V):- ecosystem(E), other_name(E,E1), eco(E1), V="1".
5	conf(X,V):-habit(Adapt,D,V), qFindHabit(Adapt).
6	ans(X):-conf(X,V), V==#max{V1:conf(X1,V1)}.
7	ecosystemBasedAdapt(E1,Desc):- maxSim_Eco(Eco,E1,V), adaptation(Org,E1,Desc).
8	habit(AdaptationD,V):-maxSim_Eco(D,E1,V1), ecosystemBasedAdapt(E1,Desc), qFindHabit(Adaptation),options(X,D),H=@hyp(E1,Adaptation), V2=@ent(H,Desc), V=@mul(V1,V2).
9	habit(Adapt,D,V):-qFindHabit(Adapt),property(E1,P1), maxSim_Eco(D,E1,V1), options(X,D), V2=@ent_req(Adapt,P1), V=@mul(V1,V2).

Table A.7: ASP Rules for TYPE 7 Questions

A.8 ASP for Type 8 Questions

Line number	ASP Code
1	eco(E):-options(X, E).
2	maxSim_Eco(E, E1, V):- eco(E), def_eco(E1, D), not other_name(E_1, E), V=@ent(E, D), not ecosystem(E), ecosystem(E_1).
3	maxSim_Eco(E, E, V):- eco(E), ecosystem(E), V="1".
4	maxSim_Eco(E1, E, V):- ecosystem(E), other_name(E, E1), eco(E1), V="1".
5	conf(X, V):-nHabit(Adapt, D, V), options(X, D), qFindNotHabitat(Adapt), V==#max{V1:habit(Adapt1, D, V1)}.
6	ans(X):-conf(X, V), V==#min{V1:conf(X1, V1)}.
7	ecosystemBasedAdapt(E1, Desc):- maxSim_Eco(Eco, E1, V), adaptation(Org, E1, Desc).
8	nHabit(Adaptation, D, V):-maxSim_Eco(D, E1, V1), ecosystemBasedAdapt(E1, Desc), qFindNotHabitat(Adaptation), options(X, D), H=@hyp(E1, Adaptation), V2=@ent(H, Desc), V=@mul(V1, V2).
9	nHabit(Adapt, D, V):-qFindNotHabitat(Adapt), property(E1, P1), maxSim_Eco(D, E1, V1), options(X, D), V2=@ent_req(Adapt, P1), V=@mul(V1, V2).

Table A.8: ASP Rules for TYPE 8 Questions

APPENDIX B

WEBSITES AND TEMPLATES USED FOR KNOWLEDGE BASE CREATION

B.1 Knowledge related to Ecosystem

- Wikipedia
- https://www.dkfindout.com/us/
- https://www.nationalgeographic.org/
- https://sciencing.com
- https://ucmp.berkeley.edu/exhibits/
- http://www.mbgnet.net
- study.com
- https://askabiologist.asu.edu

B.2 Knowledge related to Adaptation

- Wikipedia
- http://kids.nceas.ucsb.edu/
- https://www.coolantarctica.com/
- https://asknature.org/
- https://www.dkfindout.com/us/
- https://www.nationalgeographic.org/
- https://sciencing.com
- https://ucmp.berkeley.edu/exhibits/

- http://www.mbgnet.net
- study.com
- http://www.srl.caltech.edu/personnel/krubal/rainforest/serve_home.html
- https://askabiologist.asu.edu
- https://www.livescience.com/
- http://mentalfloss.com/article/57204/20-amazing-animal-adaptations-living-desert
- quizlet.com
- http://www.primaryhomeworkhelp.co.uk/adaptations/
- http://www.factsfornow.scholastic.com/

APPENDIX C

KNOWLEDGE BASE EXAMPLES

C.1 Adaptation, Behaviour and Variation in Organisms KB

There is a total of 335 KB Paragraphs on this topic. Few of them are mentioned heree as examples:

- adaptation("southern desert horned lizard", "desert", "the southern desert horned lizard, when sufficiently threatened, is capable of squirting blood from his eyes and the blood is very distasteful to predators, who may drop the lizard and let him escape if any of the blood gets in their mouth. north american desert horned lizards have a wide range of predators within their habitat. one unusual defense mechanism involves the flooding of their ocular sinuses, tissues found below their eye, with blood. when a horned lizard feels threatened by a predator, its final defense response is to shoot blood from these flooded sinuses and out its eye sockets. as a result, the predator is often frightened and flees. the lizard also uses this mechanism to remove foreign particles from the surface of its eyes.").

- adaptation("fennec fox", "desert", "the fennec fox of north africa has large ears ,serve a dual purpose,: they are great for listening for bugs to eat that may be moving around underground, but they are also loaded with blood vessels, allowing the animals to dissipate excess body heat.").

- adaptation("fennec fox", "desert", "xerocoles, having to travel long distances for food and water, are often adapted for speed, and have long limbs,feet that prevent them from sinking in the sand, and are overall slender in form. as there is little cover to protect them from predators, desert animals also use speed as a defense mechanism.”).

- adaptation(“fennec fox”, “desert”, “fennec foxes also have thick fur on the soles of their feet, which insulate against the hot sand of the desert. this extra fur on the soles of their feet also affords them excellent traction in the loose sand.”).

- adaptation(“camel”, “desert”, “a camel’s hump does not hold water at all - it actually stores fat. the camel uses it as nourishment when food is scarce. if a camel uses the fat inside thehump, the hump will become limp and droop down. with proper food and rest the hump will return to normal.”).

- adaptation(“camel”, “desert”, “camel’s ears are covered with hair, even on the inside. the hair helps keep out sand or dust that might blow into the animal’s ears.”).

- adaptation(“camel”, “desert”, “the long beautiful eyelashes in camels help it in blowing sand out of eyes. the long eyelashes also protect camels from direct sun rays. long eyelashes are practically important in a desert environment to keep some visibility.”).

- adaptation(“camel”, “desert”, “camels can even close their nostrils to stop them inhaling sand. the nostrils can open and close.”).

- adaptation(“camel”, “desert”, “when the camel exhales, water vapor becomes trapped in their nostrils and is reabsorbed into the body as a means to conserve water. camels eating green herbage can ingest sufficient moisture in milder conditions to maintain their bodies’ hydrated state without the need for drinking.”).

- adaptation(“camel”, “desert”, “the colour of their bodies helps them to blend into their environment. (camouflage)”).

- adaptation(“camel”, “desert”, “camels have thick lips which let them forage for thorny plants without feeling pain other animals can,t eat.”).

- adaptation(“camel”, “desert”, “camels feet are wide so they can walk on sand more easily. their huge feet help them to walk on sand without sinking into it.”).

- adaptation(“gila monster”, “desert”, “gila monsters are carnivores, which means they eat meat. since they are on the lazy side, they tend to prefer easy prey, such as eggs and newborn mammals. these animals don’t even chew their food and can even swallow small eggs whole. gilas may also eat frogs, rodents, insects, lizards, worms and carrion.if they can’t get out of their burrow to forage, no problem. gilas store fat in their tails and can go for months without food. they especially use this trait during the winter and will stay inside all season long.”).

- adaptation(“peccary”, “desert”, “the peccary, or javelina, has a tough mouth and specialized digestive system which enables it to chomp down on prickly pear cactus pads (one of their favorite foods) without feeling the effects of the plant,s thousands of tiny spines. the jaws and tusks of peccaries are adapted for crushing hard seeds and slicing into plant roots. as an added bonus, using cactus as a food source is a great way to supplement water intake as the spiny succulents are absolutely loaded with the stuff. ").

- adaptation("sand grouse", "desert", "this bird, found mainly in the deserts of asia and north africa, has specialized feathers on its belly that are able to soak up small quantities of water. males of the species will use these feathers like a sponge to carry water back to their nests, which they then share with their female counterparts and offspring.").

- adaptation("dorcas gazelle", "desert", "though they will drink water when it is available, this small species of north african antelope can get all of the water it needs from the food in its diet. when water is unavailable, the dorcas gazelle can concentrate its urine into uric acid, which can be described as ,a white pellet, instead of the hydraulically expensive liquid waste. ").

- adaptation("penguins", "tundra", "external fur and feathers are the most efficient insulators on a weight for weight basis, but can be ruffled by wind and are much less useful when wet. penguins have to keep high body temperatures to remain active. they have thick skin and lots of fat (blubber) under their skin to keep warm in cold weather. they also huddle together with their friends to keep warm.").

- adaptation("penguins", "tundra", "penguins have two areas where their body is very poorly insulated and where they can lose a lot of heat, these are their flippers and their feet. the solution is quite elegant. the muscles that operate feet and flippers are not located in the feet and flippers, that way for most of the group, where their feathers end, instead of all of them having to face the biting wind and relentless cold, most of them have another warm penguin to shield them instead.").

- adaptation("penguins", "tundra", "penguins have two areas where their body is very poorly insulated and where they can lose a lot of heat, these are their flippers and their feet. the solution is quite elegant. the muscles that operate feet and flippers are not located in the feet and flippers, but deeper in the warmer regions of the penguins body. the feet and flippers are moved by tendons that pass through them and attach to the bones of the toes, ankle, and wrist like a sort of remote operation by wire or string. this means that it doesn't matter much if the feet and flippers get really cold as they can still be operated normally by muscles in regions that are at normal body temperature and so still fully functional.").

- adaptation("penguins", "tundra", "feet pulled in when swimming - like an aircraft pulling in its landing gear to reduce air resistance, penguins pull their feet close to their bodies when swimming for maximum streamlining and drag reduction. however when needed they can be used like a water-brake, stuck out at the right moment, a penguin can use its feet to make a 180, turn in 1/5th of a second.").

- adaptation("small penguins", "tundra", "smaller penguins 'bounce' - small size means less kinetic energy if the penguins are thrown around and so less damage. the smaller penguin species can come out of crashing waves and rough seas on inhospitable, difficult rocky shores without being smashed to pieces precisely because they are small and so don't have so much kinetic energy if bashed against a rock, an inherent toughness and blubber padding helps too.").

- adaptation("coniferous trees", "boreal forest", "coniferous trees are particularly well suited to the harsh boreal climate. their conical shapes reduce snow buildup on branches in winter, so that they do not break under the snow load as in boreal forests there can be harsh winters").