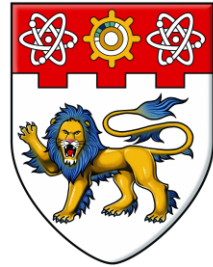**Web-based Argumentation**

Kenrick

Supervisor: Professor Miao Chun Yan
Examiner: Assistant Professor Bo An

School of Computer Science and Engineering
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Web-based Argumentation

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Kenrick

School of Computer Science and Engineering
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Abstract

Assumption-Based Argumentation (ABA) is an argumentation framework that has been proposed in the late 20th century. Since then, there was still no solver implemented in a programming language which is easy to setup and no solver have been interfaced to the web, which impedes the interests of the public. This project aims to implement an ABA solver in a modern programming language that performs reasonably well and interface it to the web for easier access by the public. This project has demonstrated the novelty of development of an ABA solver, that computes *conflict-free*, *stable*, *admissible*, *grounded*, *ideal*, and *complete* semantics, in Python programming language which can be used via an easy-to-use web interface for visualization of the argument and dispute trees. Experiments were conducted to determine the project's best configurations and to compare this project with *proxdd*, a state-of-the-art ABA solver, which has no web interface and computes less number of semantics. From the results of the experiments, this project's best configuration is achieved by utilizing "pickle" technique and tree caching technique. Using this project's best configuration, this project achieved a lower average runtime compared to *proxdd*. On other aspect, this project encountered more cases with exceptions compared to *proxdd*, which might be caused by this project computing more semantics and hence requires more resources to do so. Hence, it can be said that this project run comparably well to the state-of-the-art ABA solver *proxdd*. Future works of this project include computational complexity analysis and efficiency analysis of algorithms implemented, implementation of more semantics in argumentation framework, and usability testing of the web interface.

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1. Introduction

One of the goals of Artificial Intelligence (AI) field is to achieve an intelligent machine. A machine can be considered as intelligent when it behaves like a human. One of the most pervasive human activities that are distinct from the other species is the ability to argue. Arguing, informally speaking, is a form of interaction among the participants to give rationales for agreeing or disagreeing with claims. This is a universal human ability and can be seen everywhere in daily human activities. Hence, it led to many studies regarding human ability to argue.

Within artificial intelligence, the field that is closely related to argumentation is Knowledge Representation (KR). This field aims to represent information about the world into a computable form to solve complicated tasks. Solving these tasks require a complicated logic to automate the deduction. These knowledges and their interactions can also be represented by argumentation.

Initially, argumentation was the study within the field of philosophy and law. After argumentation was identified as a way to study defeasible reasoning [1], which is a field of KR, it led to many studies of argumentation in terms of AI. Eventually, this led to the emergence of many argumentation frameworks. One of the earliest argumentation framework defined is the Abstract Argumentation (AA) [2], and later on, another popular argumentation framework emerged, called Assumption-Based Argumentation (ABA) [3].

AA and ABA are quite related. AA is defined using a set of arguments and attack relationships among the arguments in the set. Meanwhile, in ABA, the arguments and attacks are derived from the (deductive system) rules, assumptions, and contraries; in which ABA building blocks (the rules, assumptions, and contraries) are "at a lower level of abstraction than those of AA" [4].

ABA has been studied to be applicable in supporting many fields. Fan, et al. [5] has studied the application of ABA for decision-making in medical literature field, in which they select the most relevant research paper for each patient, given the properties

of a patient. Meanwhile, ABA has also been studied to be applied in multi-agent systems, supporting the dialogues among agents [6-8] and decision making of the agents in the system [9, 10]. In other fields, Matt, et al. [11] has studied ABA application in e-procurement, to compare and select the best suppliers of goods and services during procurement negotiation. Besides that, there is also a study by Fan and Toni [12] that studied ABA in the context of game theory, mapping games into argumentations and dialogues. Toni [13] has studied the application of ABA in ontological reasoning for the semantic web, and evaluating the exchange of information and opinions at for web-based social network.

The main goal of having AI to argue is to determine which argument is the best. Determining which argument is the "best" is quite subjective. Hence, several "semantics" have been defined over the years, for both AA and ABA. The semantics define how "good" a certain argument is compared to the other semantics. For instance, it is more desirable to have an argument that is not contradicting with itself (i.e. "conflict-free"). As stated by Toni [4], AA and ABA can be transformed into each other because they are an instance of each other. This implies that semantics defined for AA can be applied to ABA, and vice versa.

To determine whether an argument satisfies certain semantics may be computationally complicated [14-16]. Hence, many attempts have been made to create programs that efficiently compute the semantics given an argumentative framework; these programs are called *solvers*. ASPARTIX [17] is an AA solver using answer set programming (ASP) that supports a broad range of semantics. Meanwhile, jArgSemSAT [18] aims to implement AA efficiently, by re-implementing in Java ArgSemSAT which won 2nd place at the 2015 International Competition on Computational Model of Argumentation (ICCMA). TOAST [19], is another AA solver that uses ASPIC+ framework to represent the structure of arguments. Despite the abundance of AA solvers, there aren't many ABA solvers out there. Some of ABA solvers includes the tree-based solver *proxdd* [20]; and the graph-based solver *grapharg* [21], and *abagraph* [22]; all of them using Prolog language.

Having a web interface makes the project easier to access and users can try out the solver without investing time in setting up the solvers in local environments. There are

a handful of AA solvers having a web interface to the solvers, such as ASPARTIX [17] and TOAST [19]. Meanwhile, there were no ABA solver with a web interface yet.

Implementing an ABA solver in a modern high-level programming language, such as Python, will make the program more accessible to more users. Furthermore, extending the tool with a web interface will indeed make the solver even more accessible to more users. Hence, there is an urgent need to implement an ABA solver in modern language and interface it to the web so more users are made aware of ABA.

1.1. Objective and Scope

The objective of this project is to implement an ABA solver in a modern programming language that performs reasonably well to regular users and create a web interface of the ABA solver so it can be accessible by the public. The programming language Python is chosen because of it is one of the most popular programming languages [23] and because of its abundance of community-supported packages available at Python Package Index (PyPI)[1].

The scope of this project includes the understanding of ABA and its semantics, analysis of the implementation of ABA solver & its web interface, techniques employed to optimize semantics computation, and evaluation of the program performance. Semantics covered in this project includes conflict-free, admissible, complete, grounded, ideal, and stable. The definition of each semantics will be covered in the subsequent sections. This project does not do an analysis of the complexity of the semantics computation because it has been extensively studied for both AA and ABA, see [14-16].

This report is organized as follows: Chapter 1 introduces the project, including project objective, scope, and timeline. Chapter 2 discusses the background knowledge required for understanding the project, namely, defines the ABA argumentation framework, its components, and its semantics. Chapter 3 describes the methodology of the project, such as software requirements and project architecture. Chapter 4 discusses the implementation aspect of the project, in both back-end and front-end, including optimization techniques employed in the project. Experiments are designed and the results are discussed in Chapter 5. Finally, conclusions are drawn on Chapter 6 and recommendations are given in Chapter 7.

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[1] https://pypi.python.org/

1.2. Project Schedule

Expected and actual project schedules are presented in the following tables. Differences in the schedules were due to underestimation of finalizing the FYP topic as the chosen topic is quite broad. To not impact the submission deadlines, the main development time was cut by not carrying out all tasks that have been initially planned and left as future works. This also decreased the time taken for additional development and hence more time can be invested in writing the reports.

1.2.1. Expected Project Schedule

Table 1 Expected project schedule

Date period	Plan
11 Jan 2016 – 1 Feb 2016	Meet up with FYP supervisor, discussing FYP topic
1 Feb 2016 – 6 March 2016	Initial research on FYP topic
7 March 2016 – 10 April 2016	Finalization of FYP topic
10 April 2016 – 31 July 2016	Main development phase of FYP
31 July 2016 – 15 August 2016	Main testing phase of FYP
15 – 22 August 2016	Work on interim report
22 August 2016 – 18 September 2016	Additional development phase of FYP
19 September 2016 – 17 October 2016	Work on final report
17 October 2016 – 11 November 2016	Work on amended final report
12 November – 5 or 6 December 2016	Preparation for FYP oral presentation
5 or 6 December 2016	FYP oral presentation

1.2.2. Actual Project Schedule

Table 2 Actual project schedule

Date period	Plan
11 Jan 2016 – 1 Feb 2016	Meet up with FYP supervisor, discussing FYP topic
1 Feb 2016 – 21 March 2016	Initial research on FYP topic
21 March 2016 – 10 May 2016	Finalization of FYP topic
10 May 2016 – 31 July 2016	Main development phase of FYP
31 July 2016 – 15 August 2016	Main testing phase of FYP
15 – 22 August 2016	Work on interim report
22 August 2016 – 8 September 2016	Additional development phase of FYP
9 September 2016 – 17 October 2016	Work on final report
17 October 2016 – 11 November 2016	Work on amended final report
12 November – 5 December 2016	Preparation for FYP oral presentation
5 December 2016	FYP oral presentation

2. Background

The field of argumentation, which analyses the represented knowledge, has been studied extensively since the introduction of *abstract argumentation* by Dung [2] in 1995. An abstract argumentation framework, as defined by Dung [2], represents the knowledge as a set of vertices, representing arguments, and the edges, representing the attacks among arguments. A more complex form of argumentation is called structured argumentation, where an argument can derive from the support of another argument, hence it is common to represent a single argument as a tree. [24]

In 1997, Bondarenko, et al. [3] introduced the concept of assumption-based argumentation (ABA) framework, which is a well-known type of structured argumentation [25]. Simply put, an assumption-based argumentation framework consists of:

- Set of symbols.
- Set of (inference) rules, in notation of $c \leftarrow s_1, \ldots, s_m$, for $m \geq 0$; where $s_1, \ldots, s_m$, is a set (possibly empty) of symbols supporting claim c. When $m = 0$ (i.e. $s_1, \ldots, s_m$ is empty), this rule represents a ground truth.
- Set of assumptions.
- Contraries of each assumption, which defines which arguments can attack this assumption.

An argument can be represented as a tree, constructed using the set of symbols and the set of inference rules. Meanwhile, the attack relationships can be defined as a set of assumptions and contraries of the assumption. Definition of argument and attack between argument is given in subsequent sections.

For this chapter, let's define the following scenario to be used as an illustration in the examples of ABA and its representations.

Scenario 1

Andy, a student in a certain university is having a dilemma when registering modules in the upcoming semester. There are two modules conflicting in lecture timing and hence he can only register either one of them. The first module, CZ5000 is a great module, because it is being taught by a great professor, and the module is also very popular among his circle of friends. The other module, CZ6000, is also another great module because the topic is popular in the industry right now, and Andy's final year project is related to the topics taught in this module. After reading online reviews about CZ6000, Andy found out that CZ6000 popularity in the industry is no doubt true.

Since arguments are essentially a claim, supported by another claim, Scenario 1 can be formalized into the following rules:

$cz5000\_is\_great \leftarrow cz5000\_great\_prof, cz5000\_popular\_on\_friends$;
$cz6000\_is\_great \leftarrow cz6000\_popular\_in\_industry, cz6000\_related\_to\_fyp$;
$cz6000\_popular\_in\_industry \leftarrow$;

Notice that the 3rd rule (CZ6000 being popular in industry) is represented as a ground truth, meaning that the claim is no doubt hold in the scenario.

Formally, an ABA framework is a tuple $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, ^{-} \rangle$ where:

- $\langle \mathcal{L}, \mathcal{R} \rangle$ is a deductive system, where $\mathcal{L}$ is the *language* and $\mathcal{R}$ is the set of *inference rules* in the form of $s_0 \leftarrow s_1, \dots, s_m$, for $m > 0$ and $s_0, s_1, \dots, s_m \in \mathcal{L}$;
- $\mathcal{A}$, where $\mathcal{A} \subseteq \mathcal{L}$ is a non-empty set, named the *assumptions*;
- $^{-}$ is a total mapping from $\mathcal{A}$ to $\mathcal{L}$, where $\bar{a}$ is defined as the contrary of a.

The implication of this formal definition is that for every assumption that is present in the framework, it needs to have a contrary. A contrary defines which other argument can attack this assumption. The formal definition of attacks in ABA is presented in Chapter 2.2.

Using the definition of an ABA framework, Scenario 1 above can be represented as the following ABA framework:

$\mathcal{L} = \{$

$cz5000\_is\_great,$

$cz5000\_great\_prof,$

$cz5000\_popular\_on\_friends,$

$cz6000\_is\_great,$

$cz6000\_popular\_in\_industry,$

$cz6000\_related\_to\_fyp$

$\}$

$\mathcal{R} = \{$

$cz5000\_is\_great \leftarrow cz5000\_great\_prof, cz5000\_popular\_on\_friends;$

$cz6000\_is\_great \leftarrow cz6000\_popular\_in\_industry, cz6000\_related\_to\_fyp;$

$cz6000\_popular\_in\_industry \leftarrow;$

$\}$

The above ABA framework is not yet complete as the assumptions and contraries are not yet defined, as this concept will be introduced in Chapter 2.2.

2.1. Arguments in ABA

Formally [26], given a deductive system $\langle \mathcal{L}, \mathcal{R} \rangle$, with language $\mathcal{L}$ and set of (inference) rules $\mathcal{R}$, and set of assumptions $\mathcal{A} \subseteq \mathcal{L}$, an *argument* for *claim $c \in \mathcal{L}$* supported by $S \subseteq \mathcal{A}$ is a tree with nodes labelled by sentences in $\mathcal{L}$ or by symbol τ, such that:

- The root is labelled by c
- For each node N
  - If N is a leaf, then N is labelled by either an assumption or by τ
  - If N is not leaf, then there is an inference rule $l_N \leftarrow s_1, \ldots, s_m$ $(m \geq 0)$, where l_N is the label of N and
    - If m = 0, then the rule shall be $l_N \leftarrow \tau$ (i.e. child of N is τ)
    - Otherwise, N has m children, labelled by $s_1, \ldots, s_m$
- S is the set of all assumptions labelling the leaves

An argument [26] with claim c supported by a set of assumption S can also be denoted as $S \vdash c$.

Using Scenario 1, if the symbols $cz5000\_great\_prof$ and $cz5000\_popular\_on\_friends$ are defined as assumptions, the following argument tree with claim $cz5000\_is\_great$ can be constructed.

$$cz5000\_is\_great$$

$$cz5000\_great\_prof \qquad cz5000\_popular\_on\_friends$$
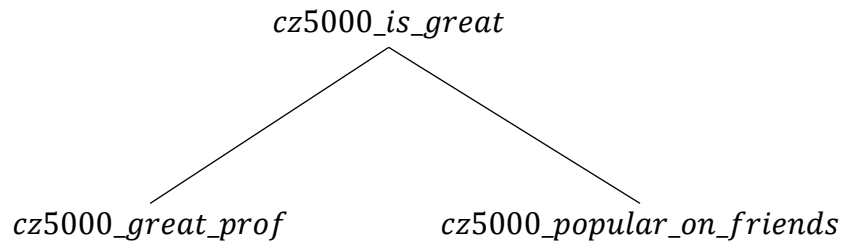
Figure 1 Argument tree for *cz5000_is_great* on Scenario 1

Also, if $cz6000\_related\_to\_fyp$ is treated as assumption, the following argument tree with claim $cz6000\_is\_great$ can be constructed.

$$cz6000\_is\_great$$

$$cz6000\_related\_to\_fyp \qquad cz6000\_popular\_in\_industry$$

$$\tau$$
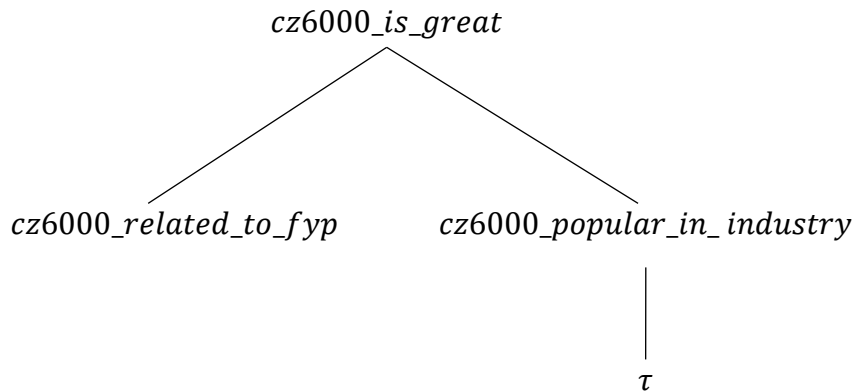
Figure 2 Argument tree for *cz6000_is_great* on Scenario 1

2.2. Attacks in ABA

Formally, an attack in ABA is defined as a relationship between two arguments X and Y, where an argument X *attacks* an argument Y (written as $X \rightsquigarrow Y$) if and only if there are some $y \in S_Y$ (member of set of all assumptions supporting Y) and $\bar{y} = X$ (contrary

of *y* is the claim of argument *X*). In other words, an argument *A* is said to be attacking another argument *B* if there exists an assumption supporting *B* which is the contrary of a sentence supporting *A*.

Going back to the recurring scenario, Andy is just informed that upon reading online reviews, he found out that the professor teaching CZ5000 is not that great as perceived by him. One review stated that the professor "conducts an extremely difficult final examination".

Taking the new information into account, one can construct the following contrary to be added to the pre-existing ABA framework.

$$\overline{cz5000\_great\_prof} \leftarrow cz5000\_exam\_is\_hard$$

Note that this does not make the current ABA argument an actual argument yet (still potential argument), as not all the argument leaves are labelled as τ or assumption yet.

By that addition of contrary, there will be an attack relationship to the argument for $cz5000\_is\_great$ from the argument for $cz5000\_exam\_is\_hard$.

2.3. Acceptability of Arguments

It is quite subjective to say whether an argument is the best argument, hence a less specific term "acceptability" is used. Whenever an argument is given, one can use ABA to determine whether it is "acceptable" or not. "Acceptability" of a claim is quite subjective, and hence can be formalized in many ways, defined as *semantics*.

There are six semantics that were implemented in this project. The formal definitions of the implemented semantics are given as follows:

1. Conflict-free: A set of arguments is conflict-free iff it does not attack itself. [22]
2. Admissible: A set of arguments is admissible iff it is conflict-free and attacks all arguments attacking it. [26]
3. Complete: A set of arguments is complete iff it is admissible and contains all arguments it can defend (by attacking every argument attacking them) [26]
4. Grounded: A set of arguments is grounded iff it is minimally (with respect to set inclusion) complete. [26]

5. Stable: A set of arguments is stable iff conflict-free and attacks every argument that does not belong to itself. [3]

6. Ideal: A set of arguments is ideal iff admissible and there are no admissible arguments attacking it. [27]

To compute the semantics, argument trees and *dispute trees* were required to be built. Informally, dispute tree can be understood as a mean to construct a winning strategy for a proponent's argument which is under dispute.[28] The proponent starts by presenting an initial argument. Then, proponents and opponents alternately attack each other's previous arguments. This continues infinitely or until there are no other arguments available to attack the proponents. In the latter case, it is said that the proponent wins the dispute. Hence, dispute tree displays the interaction of attacks among the arguments and derive whether a semantics hold based on the tree properties.

Formally, a *dispute tree*[26] for argument A is a tree $\mathcal{T}$, where:

1. Every vertex of tree $\mathcal{T}$ is either a proponent or opponent vertex (but not both), labelled by an argument.

2. Root vertex of tree $\mathcal{T}$ is a proponent vertex labelled by A.

3. For every proponent vertex V labelled by an argument B and for every argument C attacking B, there exists a child of V, which is an opponent labelled by C.

4. For every opponent vertex V labelled by an argument B, there exists exactly one child of N which is a proponent vertex V labelled by an argument attacking B.

5. There are no other vertices in tree $\mathcal{T}$ except those given by 1-4 above.

A branch of a dispute tree, i.e. a subtree, can have either finite or infinite depth. The infinite-depth tree can be caused by a circular attack. For example, in the following example, argument A attacks argument B, argument B attacks argument C, argument C attacks argument A, and later, argument A attacks argument B, and it goes on to infinity.

Example 1

$\mathcal{L} = \{a, b, c\}$
$\mathcal{R} = \{\,\}$
$\mathcal{A} = \{a, b, c\}$
$\bar{a} = b$
$\bar{b} = c$
$\bar{c} = a$

$A = \{a\} \vdash a$
$B = \{b\} \vdash b$
$C = \{c\} \vdash c$

In Example 1, arguments *A*, *B*, *C* are presented. The dispute tree of argument *A* is shown in the following figure.

Proponent (A)

Opponent (B)

Proponent (C)

Opponent (A)

Proponent (B)

∘
∘
∘
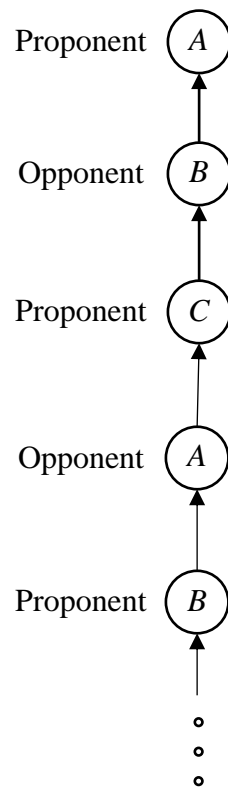
Figure 3 Illustration of infinite dispute tree in Example 1

From Figure 3, it is shown that the attacks are "circular" among argument *A*, *B*, and *C*; and will go on indefinitely. This situation illustrates an infinity dispute tree.

2.4.Computation of Acceptability

Given an ABA framework, its acceptability, defined in semantics, can be computed. In this section, the specifics of the semantics are described in more details.

2.4.1. Conflict-free

This is the simplest semantics to be computed. The real-life analogy is quite simple: it is undesirable to assert an argument that contradicts itself.

To check whether an argument is conflict-free, it is required that the argument tree has been constructed. After an argument tree is constructed, it is conflict free when the claim and assumption of all contraries do not belong to the tree.

Example 2

$\mathcal{L} = \{a, b\}$
$\mathcal{R} = \{a \leftarrow b;\}$
$\mathcal{A} = \{b\}$
$\bar{b} = a$

$A = \{b\} \vdash a$

In this example, argument A is defined as an argument with claim a supported by assumption b. Hence, one can construct an argument tree with a at its root, like in the following figure.

$$a$$

$$|$$

$$b$$

Figure 4 Argument tree of Example 2

But since argument A contains a that can attack b (because b is the contrary of a), hence it is said that argument A (with a as its claim) is not conflict-free.

2.4.2. Admissible

An argument is admissible if and only if the proponent and opponent in its dispute tree are consistent, meaning that, the proponent will always be proponent in the tree, and vice versa. A real-life example is that when arguing, a same kind of argument should

be consistent, either attacking your argument or attacking your opponent, not switching sides in subsequent attacks.

The example presented at Example 1 is not an admissible because on its dispute tree, initially argument A is labelled as a Proponent, but subsequently, it is shown that argument A is being assigned "Opponent" status.

Example 3

$\mathcal{L} = \{a, b\}$
$\mathcal{R} = \{\}$
$\mathcal{A} = \{a, b\}$
$\bar{b} = a$
$\bar{a} = b$

$A = \{a\} \vdash a$
$B = \{b\} \vdash b$

In this example, check argument A's admissibility, one need to build a dispute tree with argument A as its root argument.
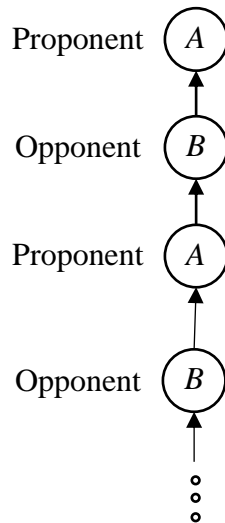
Figure 5 Illustration of dispute tree of argument A in Example 3

From the dispute tree shown in Figure 5, it is seen that while the tree is an infinite tree, the statuses of the arguments are consistent, argument A always having Proponent and argument B always having Opponent as their status. Hence, the argument A is admissible.

2.4.3. Complete

An argument is complete if and only if it is admissible, and it contains all arguments in which the attackers attacking them are attacked by this argument. An equivalent scenario is that one desires an argument that is a completely defendable argument, meaning that all assumptions supporting the parent argument, if being attacked, should be attacked by the parent argument.

Argument *A* of Example 3 is an example of a complete argument. This is because all its assumption (*a*) that can be attacked by others (argument *B*) is contained by itself (argument *A*).

2.4.4. Grounded

An argument is grounded if and only if the dispute tree is not infinite. Infinity of a tree branch is detected by tracking a history of what argument has been encountered so far. A grounded argument in real-life example is that when one can determine that the argument is the best whenever it has the final say, and not having endless attacks.

Argument *A* of Example 3 can be said as not grounded as its dispute tree, shown in Figure 5, is an infinite dispute tree.

Example 4

$\mathcal{L} = \{a, b\}$
$\mathcal{R} = \{b \leftarrow; \}$
$\mathcal{A} = \{a\}$
$\bar{a} = b$

$A = \{a\} \vdash a$
$B = \{\} \vdash b$

In this example, argument *B* is a ground truth. To illustrate, the argument trees of argument *A* and argument *B* are presented in the figure below.
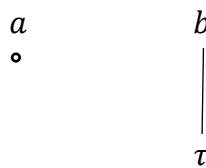
Figure 6 Argument tree of Example 4

To determine the grounded semantics, like admissible semantics, a dispute tree needs to be built. For example, to check argument *A*'s grounded semantics, one need to build a dispute tree with argument *A* as its root argument.

Proponent $\textcircled{A}$

$\uparrow$

Opponent $\textcircled{B}$
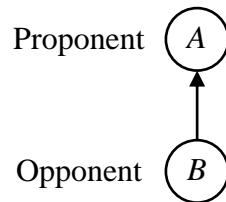
Figure 7 Illustration of dispute tree of argument A in Example 4

From Figure 7, it is shown that argument *A* is grounded because the dispute tree is a finite dispute tree.

2.4.5. Stable

An argument is stable if and only if it is conflict-free and it attacks all assumptions not present. The implication of having a stable argument is that when one has a stable argument, it can attack everyone else's argument, and hence a stable argument looks "stronger" than anyone else's arguments.

Example 5

$\mathcal{L} = \{a, b, p, q\}$
$\mathcal{R} = \{a \leftarrow p; p \leftarrow; b \leftarrow q; \}$
$\mathcal{A} = \{q\}$
$\bar{q} = p$

$A = \{\} \vdash a$
$B = \{q\} \vdash b$

In this example, stable semantics is fulfilled by argument *A* and it can be illustrated using argument trees below.

$$a \qquad b$$
$$| \qquad |$$
$$p \qquad q$$
$$|$$
$$\tau$$
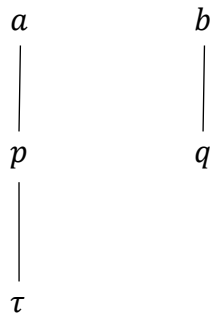
Figure 8 Argument tree of Example 5

From Figure 8, it is shown that argument *A* is conflict-free because there are no attacks from itself to members of its argument tree. Besides that, since argument *A* also attacks argument *B*, because *q* (supporting argument *B*) is the contrary of *p* (supporting argument *A*), argument *A* also fulfils stable semantics, since the argument attacks all assumptions (in the ABA) that do not present in its own argument.

2.4.6. Ideal

After the computation of admissible semantics has been carried out, the ideal semantics is computed. An ideal semantics is implemented quite straightforwardly: for each argument, get the attackers and check whether the attackers are admissible. If the attackers are admissible, then it is not an ideal semantics.

In life, ideal argument is when there are no admissible attackers; this made the argument looks stronger because the attackers are deemed "weaker" as they are not admissible.

3. Methodology

In order to follow a good software development practices, a software engineering process has been followed throughout the project as described by Bruegge and Dutoit [29]. In this report, to simplify the software engineering processes, only software requirements and software architecture were reported.

3.1. Software Requirements

3.1.1. Use Case Requirements

Use case requirements list down the overview scenario of when and how the program is being used. The use case of this project includes: computing ABA via web-interface and computing ABA via command line interface. For each use case, a detailed description is given. The use case description includes the use case name, usage frequency, priority, pre-conditions, post-conditions, flow of events, alternative flows, exceptions, etc.

Use case diagram and descriptions for each use cases are given in Appendix A and Appendix B, respectively.

3.1.2. Functional Requirements

Functional requirements of this project mainly cover the user computing an ABA framework via the web interface and computing ABA framework via the command line interface. Overall, the requirements cover the construction of argument trees, dispute trees, computing the semantics, and generating a visualization.

The detailed functional requirements are given in Appendix C.

3.1.3. Non-functional Requirements

The non-functional requirements of this projects are mainly focused on the project performance, reliability, and maintenance. Performance requirement includes the need of the project being free from critical errors and being able to respond back within a reasonable amount of time. Reliability means that the program shall be available and ready to respond at any time. The program shall be designed such that it supports easy maintenance and easy bug-fixing in the future.

The detailed non-functional requirements are given in Appendix D.

3.2. Software Architecture

In developing the project to satisfy all the software requirements, a good software architecture was designed. The project was fabricated in an object-oriented technique, where encapsulation and abstraction were applied. The other two principles, inheritance and polymorphism, were not implemented as there was no need to overcomplicate the project by implementing the whole object-oriented principles (per the KISS principle). DRY (don't repeat yourself) principle was also held in this project, where code duplication was aimed to be minimized as much as possible.

3.2.1. Class Diagram

In this project, the classes implemented and their interactions were captured in the class diagram below.
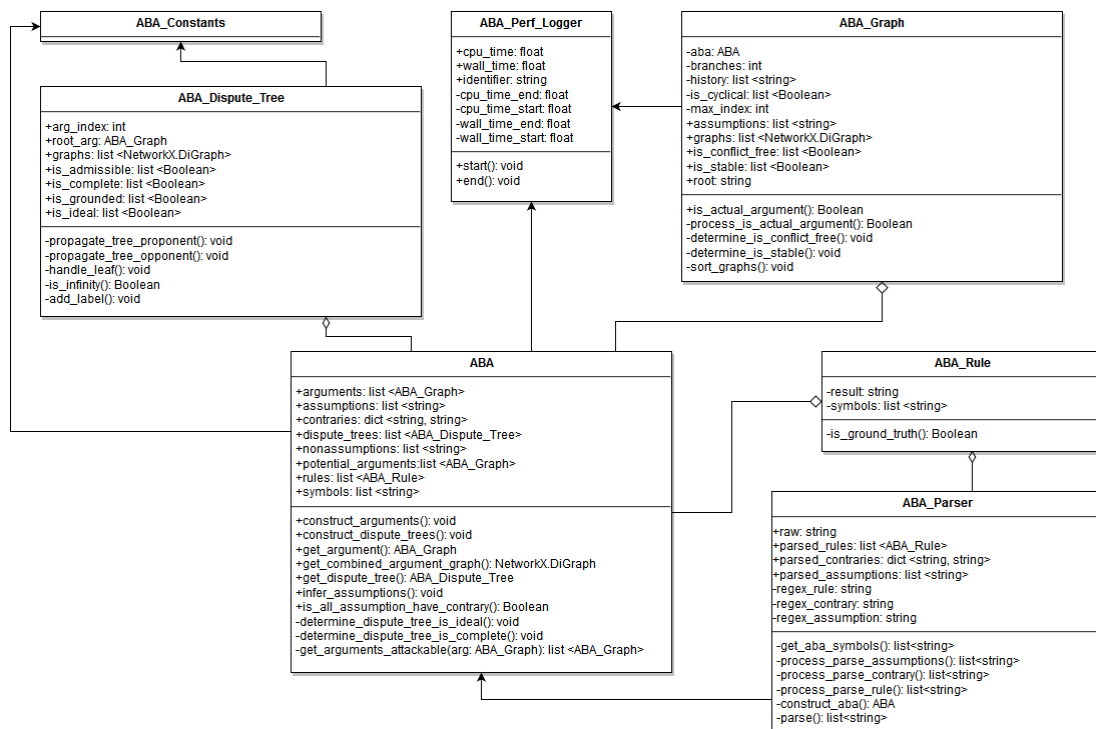
Figure 9 Class Diagram

3.2.2. Description of Classes

The description of each classes implementations is described in this section.

3.2.2.1. ABA

This is the main class, containing the properties an Assumption-Based Argumentation framework, such as symbols, (inference) rules, assumptions, and contraries. If undeclared, assumptions can be derived from the contraries previously declared.

Constructing a minimal *ABA* class starts from making an instance of *ABA* class. The first thing to do is to declare the symbols that are present in the ABA at "*symbols*" property. After that, the "*rules*" property, which is a list, shall be filled with objects that are instance of *ABA_Rule* class. Then, the "*contraries*" property, which is a dictionary, shall be filled with the ABA's contraries containing the key-value pair: the key is a string representing the assumption symbol, and value is the symbol that attacks this assumption. After these minimal declarations, one can call "*infer_assumptions*" method, to extract the assumptions from the contraries, since every key at contraries is an assumption.

After that, one can call "*construct_arguments*" method to construct the argument trees. Internally, "*construct_arguments*" will check whether all assumptions have its contrary, and will append instances of *ABA_Graph* objects to "*potential_arguments*" property; and if the object satisfies the criteria being an actual argument, it will be appended to "*arguments*" property.

"*construct_dispute_tree*" method mainly generates instances of *ABA_Dispute_Tree* and append to "*dispute_trees*" property. After the generation process has been completed, it will determine whether the objects satisfy *ideal* and *complete* semantics.

3.2.2.2. ABA_Rule

This class represents a single rule in ABA: a set of symbols (possibly empty) supporting a single symbol. This class has two public properties:

- "*symbols*", a list representing the symbols supporting the result of this rule
- "*result*", a string representing the result or claim or conclusion of this rule

If "*symbols*" is an empty list, the rule represents a ground truth. A helper public method "*is_ground_truth*" is available in this class that returns a Boolean value on whether the rule is a ground truth or not.

3.2.2.3.   ABA_Graph

This class represents arguments of the same claim symbol in ABA.

This class constructor requires an *ABA* object and a string representing argument claim symbol, in which the argument tree is to be constructed. The class constructor will call the construction of the argument trees, extraction of assumption set of each argument, and conflict-free and stable semantics computation for each argument.

This class contains the following public properties, which are available for usage after the class has been instantiated:

- "*root*", a string, representing the root of the argument trees.
- "*graphs*", a list containing *Networkx DiGraph* objects, each object representing an argument with the same root symbol.
- "*assumptions*", a list of list containing the assumption set for each argument.
- "*is_conflict_free*", a list representing whether the argument (of given index) satisfies conflict-free semantics.
- "*is_stable*", a list representing whether the argument (of given index) satisfies stable semantics.

This class only contain one public method "*is_actual_argument*" that determines whether the argument (of a given index) is an actual argument.

3.2.2.4.   ABA_Dispute_Tree

This class represents dispute tree of each argument in ABA. This represents one or possibly more dispute tree generated from one *ABA_Graph* object. This dispute tree is needed to compute the grounded and admissible semantics.

The public properties of this class, in which all but two are available after class instantiation, are:

- "*graphs*", a list of *Networkx's DiGraph* objects, representing the dispute trees with the same argument root.

- "*root_arg*", an *ABA_Graph* object, representing the argument at the root of dispute tree.

- "*arg_index*", an integer, representing the argument tree's index at the *ABA_Graph* object. Since an *ABA_Graph* object might have more than one argument, it is required to have a tracking integer to point which argument that is currently being used for constructing the dispute tree.

- "*is_grounded*", a list representing whether the dispute tree (of given index) satisfies grounded semantics.

- "*is_admissible*", a list representing whether the dispute tree (of given index) satisfies admissible semantics.

- "*is_complete*", a list representing whether the dispute tree (of given index) satisfies ideal semantics. This property is externally computed at *ABA* class because it needs to know other dispute trees admissible semantics.

- "*is_ideal*", a list representing whether the dispute tree (of given index) satisfies ideal semantics. This property is externally computed at *ABA* class because it needs to know other dispute trees admissible semantics.

There are no public methods available on this class. The private methods available in this class are used to recursively construct the dispute tree, simulating the attacks between the proponent nodes and opponent nodes.

3.2.2.5. ABA_Parser

This class is a helper class to parse raw text and returns an *ABA* object. This class is meant to be the interface between the web interface and the rest of the project, as this class parses the rules from raw string and returns an *ABA* object, after handling symbols inference, assumptions inference, arguments construction, dispute tree generations, and semantics computations.

Public properties of this class are as follows:

- "*raw*", a string, containing the unparsed text of *ABA_Parser* input.

- "*parsed_rules*", a list containing *ABA_Rule* objects, representing the list of rules parsed from the raw string. Property value is available after calling "*parse*" method.

- "*parsed_contraries*", a dictionary (key-value pair), where the key is a string representing assumption and value is a string representing symbol that attacks this assumption. This property is parsed from the "*raw*" string, hence the value is available after calling "*parse*" method.

- "*parsed_assumptions*", a list of string representing the assumptions explicitly declared at the "raw" string. Assumption inference from contraries is not done here. Property value is available after calling "*parse*" method.

Public methods of this class are as follows:

- "*parse*". At a high level, this method will check for parsing errors and try to parse the "raw" property to "*parsed_rules*", "*parsed_contraries*", and "*parsed_assumptions*". List of errors encountered during parsing is returned from this method call.

- "*construct_aba*". This is a helper method to return an *ABA* object. Internally, this method will initialize an *ABA* object, and then construct its class properties, such as "*symbols*", "*rules*", "*assumptions*", and "*contraries*". It will also do symbols inference from rules, and assumption inference from contraries. After that, it, too, will call for the construction of ABA argument trees and ABA dispute trees. Finally, it will return a fully constructed *ABA* object, where the argument trees, dispute trees, and semantics are fully computed and directly usable.

3.2.2.6. ABA_Constants

This class is a helper class to store some constants used in the computations. Constants that are stored here currently includes the string for *DT_PROPONENT* (the status string for proponent dispute tree node), *DT_OPPONENT* (the status string for opponent dispute tree node), and *DT_MAX_BRANCH* (the maximum branching of a dispute tree).

3.2.2.7. ABA_Perf_Logger

This class is a helper class to perform performance logging. Logging is stored on the same file specified at the program runtime.

Public properties available on this class are:

- "*wall_time*", this contains floating point number representing the time taken, in seconds, for the process to run, as perceived by human user. The measured time is the time between calling "*start*" and "*end*" methods. The number is only available after calling "*end*" method.
- "*cpu_time*", this contains floating point number representing the time taken, in seconds, for the process to be utilized in the CPU. The measured time is the time between calling "*start*" and "*end*" methods. The number is only available after calling "*end*" method.
- "*identifier*", a string to identify the current logging case

Public methods available on this class are:

- "*start*". Internally, it will record down the current time for later usage at "*end*" method.
- "*end*". Internally, it will record down the current time and compare it to the time recorded during "*start*" method. After that, the difference between those values is stored at "*wall_time*" and "*cpu_time*" class properties. Finally, this method will write the time measured values into the log file.

4. Implementation

This project is divided into two main areas: back-end computation and front-end web interface.

4.1. Back-end

Back-end computation was implemented in Python (version 3.4) using no framework but in object-oriented programming. Test-driven development was observed from the beginning of the project, where test cases were implemented first before the actual implementation. Thirty-three test cases were implemented in Python's native unit test framework. Source code tracking and management was done using Git and is published at GitHub[2].

Computation of the semantics are mainly using the dispute tree approach as described in Dung, et al. [26] and Dung, et al. [27]. The argument trees and dispute trees are implemented using the help *Networkx*[3] (Python) library.

The following lists the overview technical implementation of each semantics. Performance evaluations will be presented in the subsequent chapter.

- Conflict-free: After an argument tree is constructed, it is conflict free when both the attacker and assumption of all contraries present in the ABA do not belong to the tree.
- Admissible: An argument is admissible if and only if the proponent and opponent status in its dispute tree are consistent throughout the tree construction, meaning that, the proponent will always be proponent in the tree, and vice versa.
- Complete: An argument is complete if and only if it is admissible, and it contains all arguments in which the attackers attacking them are attacked by this argument.

---

[2] Available at https://github.com/kenrick95/aba-web.
[3] Available at PyPI: https://pypi.python.org/pypi/networkx

- Grounded: An argument is grounded if and only if the dispute tree is not infinite. Infinity of a tree branch is detected by tracking a history of what argument has been encountered so far.

- Stable: An argument is stable if and only if it is conflict-free and it attacks all assumptions not present in itself.

- Ideal: An ideal semantics is implemented quite straightforwardly: for each argument, get the attackers and check whether the attackers are admissible. If the attackers are admissible, then return false.

This section discusses the implementation of construction of argument trees, dispute trees, and each computation of the semantics.

Note that the procedures shown here are simplified versions of what was implemented in the project and some functionalities have been stripped away so the main gist of the implementation can be understood. In the procedures shown here, it is assumed that there is at most one rule with the same claim in the ABA, meaning that there cannot be two rule supporting the same symbol (e.g. $a \leftarrow p$; and $a \leftarrow q$; does not exist) in the ABA. In the true implementation of this project, to have more than one rule supporting a same claim, recursive branching is implemented for each rule. For example, in the case of $a \leftarrow p$; and $a \leftarrow q$;, there will be two argument trees with p as its claim since it can be constructed with either $a \leftarrow p$; or $a \leftarrow q$;.

4.1.1. Argument tree

The following procedure describes the construction of an argument tree, given an ABA framework and a symbol labelling the claim of the argument.

Procedure 1.1.: Constructing argument tree

---

function constructArgumentTree (*rootSymbol*, *aba*):
Input:
    rootSymbol: a string, representing the symbol labelling the
root/claim/conclusion of the argument tree.
    aba: an ABA object, describing the properties of the ABA framework.
Output:
    An argument tree.

argumentTree = object();
argumentTree.rootSymbol = *rootSymbol*;

argumentTree.graph = NetworkX.DiGraph();
argumentTree.is_cyclic = false;
history = list ();

argumentTree.graph.addNode(*rootSymbol*);

history.append (*rootSymbol*);
expandNode (*rootSymbol*, *argumentTree*, *aba*, *history*);
history.pop ();

return *argumentTree*;

Procedure 1.1. describes the initialization of an argument tree, but the construction would not be complete without Procedure 1.2. below, which recursively expands the nodes to find the node supporters.

Procedure 1.2.: Argument tree expansion

<u>function expandNode</u> (*node*, *argumentTree*, *aba*, *history*):
Input:
  node: a string, representing the symbol that will be expanded.
  argumentTree: an argument tree
  aba: an ABA object, describing the properties of the ABA framework.
  history: a list of previously seen symbols before expanding the current node.

for *rule* in *aba*.rules **do**
  if *rule*.result == *node* **then**
    for *symbol* in *rule* **do**
      argumentTree.graph.addEdge (*node, symbol*);
      if *symbol* is not None **then**
        if *symbol* in *history* **then**
          argumentTree.is_cyclic = true;
          break;
        end if
        history.append (*symbol*);
        expandNode (*symbol*, *argumentTree*, *aba*, *history*);
        history.pop ();
      end if
    end for
  end if
end for

return *argumentTree*;

Expanding an argument tree is straightforward. Firstly, from the rules available in the ABA framework, only selects those that derives the current node symbol, i.e. the

current node symbol is the result/claim/conclusion of the rules. Using these rules, an edge is added between the node and the supporting symbols present in the rule. If the supporting symbols are not *None*, meaning that it is not ground truth, then expand it further. Before expansion, it is crucial to check whether the tree built is cyclic, because the argument tree that is being built from this process does not guarantee that it is an actual argument, hence there will be another function to check whether an argument tree is an actual argument or just a potential one. Checking whether an argument tree is cyclic can be done by maintaining a list of symbols seen so far in the node expansion, i.e. a "history". If a symbol that is about to be expanded has been seen, the expansion will be stopped, to avoid infinite recursion.

Note that this way of expansion will treat all rules of the same symbol as if they are one and all the supporting symbols in each rule are combined into one. This will make the computation wrong, as there is no concept of "or" rules in here. The way to handle this "or" rules is to "branch" out whenever there might be multiple rules having the same claim symbol. They way to "branch" out makes the subsequent procedures complicated and hence it is implemented in the project, but not shown in the report.

After argument tree construction has been completed, it is also important to check whether the tree is an actual argument or not, meaning that it abides with the definition of an argument tree. The checking is described in Procedure 1.3. and Procedure 1.4. below.

Procedure 1.3.: Determining whether an argument tree is an actual argument

function isActualArgument (*argumentTree*, *aba*):
Input:
     argumentTree: an argument tree
     aba: an ABA object, describing the properties of the ABA framework.
Output:
     Boolean value, whether the given *argumentTree* is an actual argument.

isActual = false*;*
if *argumentTree*.isCyclical **then**
     return false;
end if
return isBranchActual (*argumentTree*.rootSymbol, *argumentTree*, aba);

Procedure 1.4.: Determining whether an argument subtree is an actual argument

function isBranchActual (*node*, *argumentTree*, *aba*):
Input:
      node: the node in the argument tree that marks the root of the subtree
      argumentTree: an argument tree
      aba: an ABA object, describing the properties of the ABA framework.
Output:
      Boolean value, representing whether the given *argumentTree* is an actual
argument.

successors = argumentTree.getSuccesors(*node*);
if count (*successors*) == 0 **then**
      if (*node* is τ) or (*node* in *aba*.assumptions) **then**
            return true;
      end if
      return false;
end if
for successor in successors **do**
      successorActual = isBranchActual (*successor*, *argumentTree*, *aba*);
      if *successorActual* is false **then**
            return false;
      end if
end for

return true;

Determining whether an argument tree is an actual tree is a recursive process. First, if one argument "tree" has a cycle inside it, by definition of a tree, it is not an actual argument anymore. If an argument tree is an actual argument, the subtrees are also actual arguments. By using this lemma, recursive search for a non-actual argument can be employed. This procedure checks where all the leaves are labelled as either "τ" or assumption. If there are violation of this rule, the whole tree will not be an actual argument.

4.1.2. Dispute tree

Procedure 2.1. below constructs a dispute tree and on the process, it also computes the *complete* and *grounded* semantics. Dispute tree construction is a recursive process, where proponent nodes will be attacked by opponent nodes (Procedure 2.2.) and vice versa (Procedure 2.3.). In the tree construction, it will need to check whether the branch

has gone into an infinite branch or not (Procedure 2.4.), hence determining whether the tree is grounded or not; and whether the node status has changed during the recursion or not (Procedure 2.5.), hence determining whether the tree is admissible or not.

Procedure 2.1.: Construct dispute tree and determine *admissible* and *grounded* semantics

---

function constructDisputeTree (*rootArgument*, *aba*):
Input:
      rootArgument: an argument tree, representing the initial argument in the dispute tree.
      aba: an ABA object, describing the properties of the ABA framework.
Output:
      whether the given argument, represented by the dispute tree satisfies complete semantics in the given ABA framework.

disputeTree = object();

disputeTree.graph = NetworkX.DiGraph();
disputeTree.isGrounded = true;
disputeTree.isAdmissible = true;
history = list ();

disputeTree.graph.addNode(*rootArgument*);
addStatus (*rootArgument, disputeTree*, "Proponent");

history.append (<*rootArgument*, "Proponent">);
expandProponentNode (*rootArgument*, *disputeTree*, *aba*, *history*);
history.pop ();

---

return *disputeTree*;

Dispute tree is implemented in this project as an object consisting of a *Networkx*'s graph object (representing the tree structure; it is a technical limitation that a directed graph is used instead of tree), and two other Boolean value properties, representing whether the dispute tree is grounded and admissible. Initially, both grounded and admissible semantics are assumed to hold until found otherwise. History is a variable to keep track of previously seen arguments during the tree expansion.

Procedure 2.2.: Expand dispute tree's proponent node

---

function expandProponentNode (*node*, *disputeTree, aba, history*):
Input:
      node: an argument tree
      disputeTree: a dispute tree
      aba: an ABA object, describing the properties of the ABA framework.
      history: a list of previously seen arguments before expanding the current node

for *assumption*, *symbol* in *node*.assumptions.items() **do**
      opponentNode = aba.getArgument(*symbol*);
      if *opponentNode* is None **then**
            continue

      disputeTree.graph.addEdge (*node*, *opponentNode*);
      addStatus (*opponentNode*, "Opponent", *disputeTree*);

      if isInfinity (*opponentNode, history*) **then**
            break;
      end if

      history.append (<*opponentNode*, "Opponent">);
      expandOpponentNode (*opponentNode*, *disputeTree*, *aba*, *history*);
      history.pop ();
end for

addToCache(*node, disputeTree*);

return**;**

Expansion of a proponent node is simply getting the assumption set of that argument, and for each assumption, get the argument that attacks it. For each argument that attacks this node, i.e. the *opponentNode*s, add an edge between the proponent and opponent nodes, symbolizing an attack, and then add the status of the *opponentNode* as "Opponent" in this dispute tree. Then do a check if the tree is infinity, if not, then expand the *opponentNode*. Finally, as an optimization technique, once the expansion of the *opponentNode*s has been completed, i.e. the branch has been fully grown, add the branch to the cache.

Procedure 2.3.: Expand dispute tree's opponent node

function expandProponentNode (*node*, *disputeTree, aba*):
Input:
    node: an argument tree
    disputeTree: a dispute tree
    aba: an ABA object, describing the properties of the ABA framework.

for *assumption*, *symbol* in *node*.assumptions.items() **do**
    proponentNode = aba.getArgument(*symbol*);
    if *proponentNode* is None **then**
        continue

    if existsInCache(*proponentNode*) **then**
        cachedBranch = loadBranchFromCache(*proponentNode*);
        NetworkX.mergeGraph(*disputeTree*.graph, *cachedBranch*);
    end if

    disputeTree.graph.addEdge(*node*, *proponentNode*);
    addStatus (*proponentNode*, "Proponent", *disputeTree*);

    if isInfinity (*proponentNode, history*) **then**
        break;
    end if

    history.append (<*proponentNode*, "Proponent">);
    expandProponentNode (*proponentNode*, *disputeTree*, *aba*, *history*);
    history.pop ();

    break;
end for

return**;**

The procedure of expansion of opponent node is quite similar to that of the proponent node. The first difference is that there is exactly one proponent node that attacks this node. Another difference is the optimization technique when it is about to expand the proponent node, which attacks this opponent node, it checks the cache if there is already a branch with that proponent node has already been fully grown. If so, then the branch us copied out from the cache and merged to the current dispute tree.

Procedure 2.4.: Determining whether a branch is infinite

---

function isInfinity (*node*, *history*):
Input:
      node: an argument tree
      disputeTree: a dispute tree
      aba: an ABA object, describing the properties of the ABA framework.

isInfinity = <*node*, *status*> present in *history*;
if *isInfinity* **then**
      disputeTree.isGrounded = false;
end if

return *isInfinity*;

Determining whether a branch is infinite or not is easily done by checking whether the given tuple <*node*, *status*> has already been present in the history. If so, then it is guaranteed that the tree expansion will cause a cycle, hence an infinite branch. This is because if a given tuple <*node*, *status*> has already been present in history, the route of node expansion will be the same as those present in *history* since the attackers of the argument *node* (and the subsequent descendants) will be the same as before. By definition, when a branch is seen to be infinite, the whole tree is said to be not grounded.

Procedure 2.5.: Add a status to a node, either "Proponent" or "Opponent"

---

function addStatus (*node*, *status, disputeTree*):
Input:
      node: an argument tree
      status: either "Proponent" or "Opponent"
      disputeTree: a dispute tree

if *disputeTree*.nodes[*node*].status != *status* **then**
      disputeTree.isAdmissible = false;
end if
disputeTree.nodes[*node*].status = *status*;

return;

Whenever there are new arguments being added to the dispute tree, a status is being assigned to them, they are either a proponent node or opponent node, but never both. Hence, this can be implemented by a dictionary (key-value pair) data structure, where the key is the argument (can be represented by a node) and the value is the status of the node (a string "Proponent" or "Opponent"). When the key has already existed and

the value being written attempts to change the value to a different one, the dispute tree is being marked as not admissible.

Since a branch of a dispute tree can be either finite or infinite, it is essential to check whether a branch has gone into infinity, i.e. a "cycle" of attacks. Since a tree structure does not permit a cycle, the project employed a workaround by implementing the tree not as using tree data structure but using directed graph data structure. A cycle of attacks can be easily detected during the construction of the dispute tree by maintaining a stack of previously seen arguments (named "history"), that is an argument is pushed into the stack when expanding the node and popped when the expansion has finished. This way, whenever a new argument is being pushed into the history and is previously seen, it is said that infinity has occurred. Since the program main goal of dispute tree in the context of this project is to determine whether an argument is admissible or grounded, it can terminate from computation, because an infinity branch makes the argument in dispute tree, by definition, not grounded.

4.1.3. Conflict-free

Determining whether an argument satisfies a conflict free argument is very simple, with the help from *Networkx* graph library. The following shows the pseudocode for determining whether a graph is conflict-free

---

Procedure 3: Determining whether an argument satisfies conflict-free semantics in a given ABA framework

---

function isConflictFree (*argumentTree*, *aba*):
Input:
       argumentTree: an argument tree.
       aba: an ABA object, describing the properties of the ABA framework.
Output:
       whether the given argument tree is conflict-free in the given ABA
framework.

conflictFree = true
for (*assumption*, *attacker*) in *aba.contraries*.items()
       if *attacker* in nodes(*argumentTree*)
       and *assumption* in nodes(*argumentTree*) **then**
           conflictFree = false
           break
       end if

end for
return *conflictFree*;

An argument, represented by the argument tree, is being assumed as *conflict-free* until being found otherwise. The implementation of this project is simply getting the list of contraries of the ABA framework, and for each contrary (assumption-attacker pair), if both attacker and assumption belong to this argument tree, the argument tree is marked as not conflict free.

4.1.4. Admissible

Admissibility of an argument is determined from its dispute tree during its construction phase, as described in Procedure 2.1. to Procedure 2.5. Initially, a dispute tree is assumed to be *admissible* until proven otherwise, i.e. it is henceforth determined as not admissible if and only if an argument is seen to have both proponent and opponent labelling that argument. (Procedure 2.4.)

4.1.5. Complete

The pseudocode, given below, to determine whether an argument satisfies *complete* semantics or not is derived from its formal definition: An argument is complete if and only if it is admissible, and it contains all arguments in which the attackers attacking them are attacked by this argument.

Procedure 4: Determining whether an argument satisfies complete semantics in a given ABA framework

---

function isComplete (*disputeTree*, *aba*):
Input:
      disputeTree: a dispute tree.
      aba: an ABA object, describing the properties of the ABA framework.
Output:
      whether the given argument, represented by the dispute tree satisfies complete semantics in the given ABA framework.

complete = false
if isAdmissible (*disputeTree*, *aba*) **then**
      complete = true
      if not isGrounded (*disputeTree*, *aba*) **then**
            attackablesByRoot = getArgumentsAttackable (*disputeTree*.
rootArgument, *aba*)

            defendableArguments = []

```
                for attackable in attackablesByRoot do
                        defendables = getArgumentsAttackable (attackable, aba))
                        defendableArguments.extend(defendables)
                end for

                allInArgument = true
                for argument in defendableArguments do
                        if argument.claim not in
nodes(disputeTree.rootArgument.tree) then
                                allInArgument = false
                                break
                end for
                complete = allInArgument;
return complete;
```

Since determining this depends on the knowledge of *admissible* semantics, hence it can only be computed only when the dispute tree has been fully constructed and admissibility semantics have been determined. Meanwhile, Craven and Toni [22] mentioned that if an argument has satisfied *grounded* semantics, it is guaranteed that it also satisfies *complete* semantics. Because at the dispute tree, both *admissible* and *grounded* semantics are determined, one can use these two pieces of knowledge to optimize the computation.

Proceeding to compute the complete semantics, first, the procedure gets a list of all arguments that can be attacked by the root (*attackablesByRoot*). Then, it constructs another list, which all members of *attackablesByRoot* can attack (*defendableArguments*). After that, it is said the root argument of this dispute tree is *complete* if and only if all members of *defendableArguments* are inside the argument tree of dispute tree's root argument.

4.1.6. Grounded

The *grounded* semantics of an argument is determined from its dispute tree during its construction phase, as described in Procedure 2.1. to Procedure 2.5. Initially, like admissible semantics, a dispute tree is assumed to be *grounded* until proven otherwise, i.e. it is henceforth determined as not *grounded* if and only if the *grounded* tree become an infinite dispute tree, that is a "cycle" is found in the tree. (Procedure 2.5.)

4.1.7. Stable

The following procedure determines whether an argument satisfies *stable* semantics, given an ABA framework and its argument tree.

Procedure 5: Determining whether an argument satisfies stable semantics in a given ABA framework

---

function isStable (*argumentTree*, *aba*):
Input:
    argumentTree: an argument tree.
    aba: an ABA object, describing the properties of the ABA framework.
Output:
    whether the given argument satisfies stable semantics in the given ABA
framework.

stable = false
if isConflictFree (*argumentTree*, *aba*) **then**
    stable = true
    for (*assumption, attacker*) in *aba*.contraries.items() **do**
        if *assumption* not in nodes(*argumentTree*) **then**
            if *attacker* not in nodes(*argumentTree*) **then**
                stable = false
                break
            end if
        end if
    end for
return *stable*;

An argument satisfies *stable* semantics iff it satisfies these two conditions:

1. The given argument is *conflict-free*. This is computed from the function *isConflictFree* from section 4.1.3

2. The given argument attacks all other arguments not supporting itself. The logic is simply iterating over the contraries (assumption-attacker pair), where if there are assumptions that are not a member of nodes in the argument tree, then the attacker of those assumptions must be a member of nodes in the argument tree, otherwise, the argument is said to be not *stable*.

4.1.8. Ideal

The following procedure determines whether an argument satisfies *ideal* semantics, given an ABA framework and its dispute tree.

Procedure 5: Determining whether an argument satisfies stable semantics in a given ABA framework

function isIdeal (*disputeTree*, *aba*):
Input:
      disputeTree: a dispute tree.
      aba: an ABA object, describing the properties of the ABA framework.
Output:
      whether the given argument, represented by the given dispute tree, satisfies ideal semantics in the given ABA framework.

ideal = false
if isAdmissible (*disputeTree.rootArgument*, *aba*) **then**
      ideal = true
      for *node* in nodes(*disputeTree*) **do**
            if *node*.status is "Opponent" **then**
                opponentDisputeTree = getDisputeTree (*node*, *aba*);
                if isAdmissible (*opponentDisputeTree*, *aba*) **then**
                    ideal = false;
                    break;
                end if
            end if
      end for
return *ideal*;

For an argument to satisfy the *ideal* semantics, by definition in [27], the dispute tree needs to satisfy the following requirements:

1. The dispute tree is *admissible*. This information is computed during the construction of dispute tree, see section 4.1.2 and 4.1.4, and hence the values can be used in this case.

2. There is no opponent in the dispute tree that satisfies *admissible* semantics. This is done by simply iterating over the nodes present in the dispute tree and checking the opponent nodes, whether these nodes are admissible or not. If there exists an opponent node that is *admissible*, it is said that the current dispute tree is not *ideal*.

4.2.Front-end

Front-end computation was implemented in Hypertext Mark-up Language (HTML), JavaScript (JS), and Cascading Style Sheet (CSS) with Flask (Python) micro-service as the connector from the web interface to the back-end. The web interface contains:

- Input area: the user should input using a simple Prolog-like syntax to define the ABA inference rules. (Figure 10)

- Visualization output: output is rendered using HTML's Scalable Vector Graphics (SVG) using D3.js library for both argument trees (Figure 10) and dispute trees (Figure 11). The back-end returns the argument trees and dispute trees in JSON format to the front-end using the help of *jsonpickle* (Python) library.

- Help page: listing the project features, input syntax, and limitations. This help page is served to guide users in using the project.
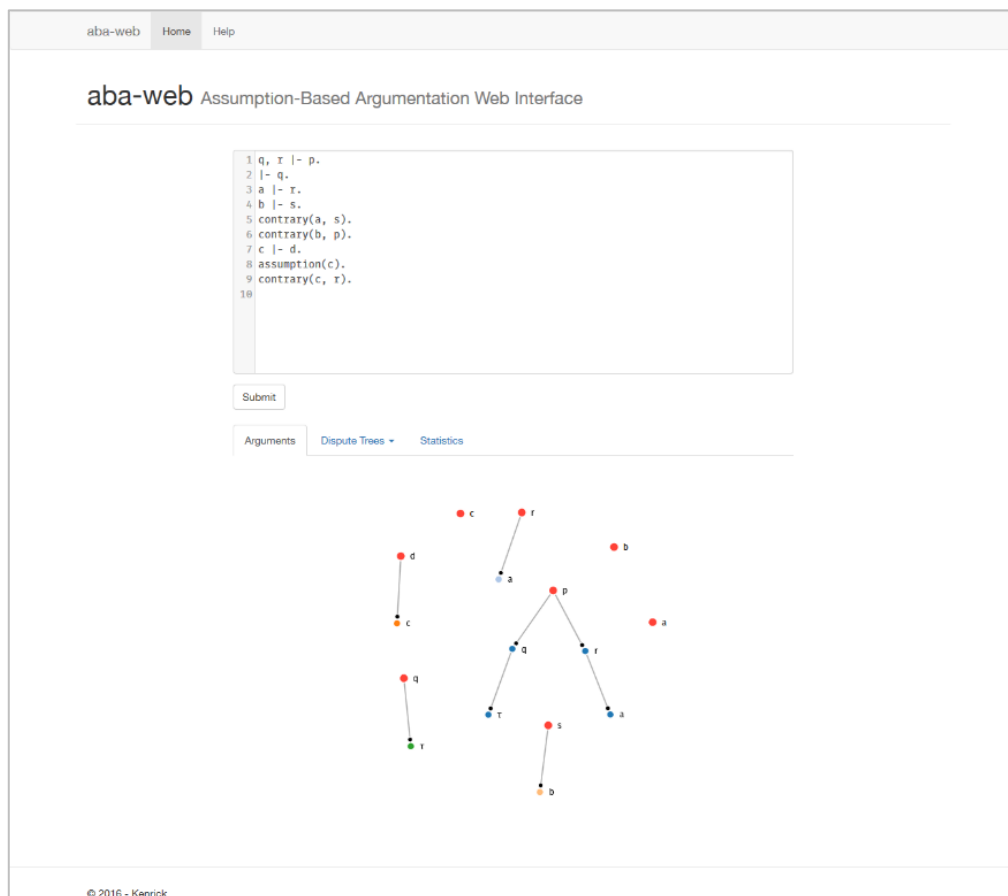
Figure 10 Project web interface, showing the input area and argument trees
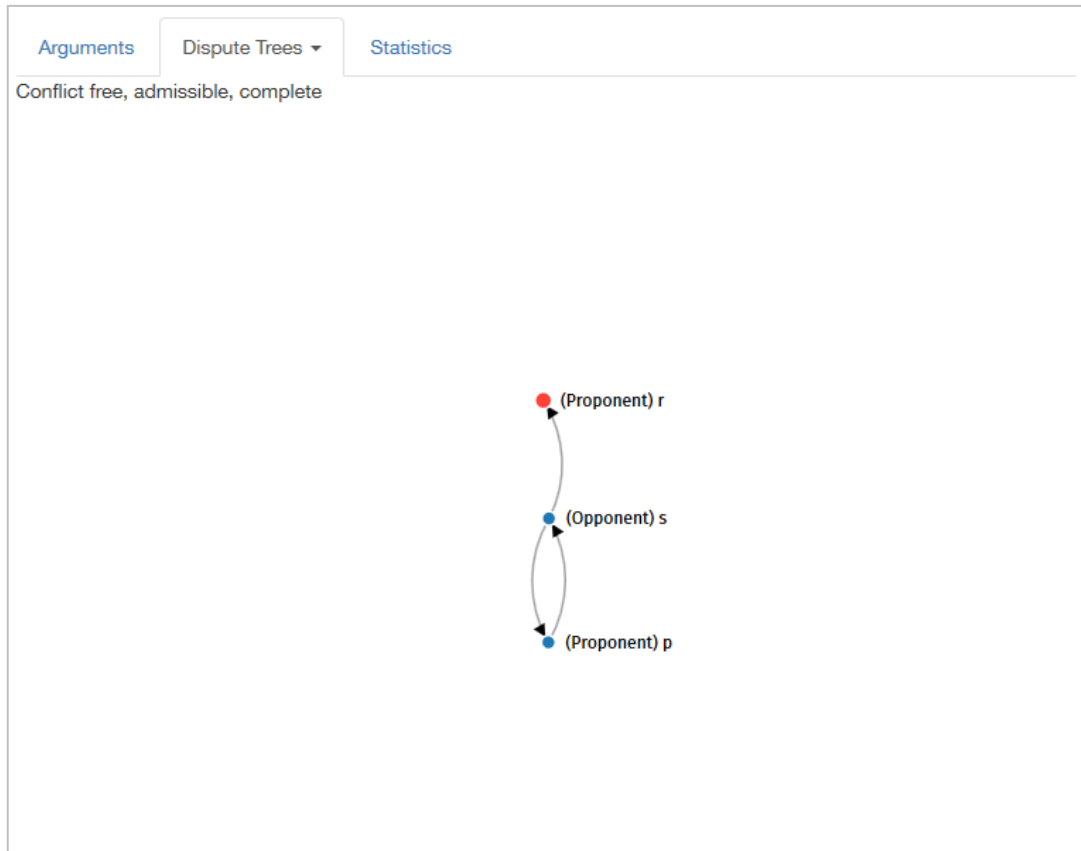
Figure 11 Visualization of the dispute tree at project web interface.

4.2.1. Syntax for Input

The syntax for input area at the web interface and for *ABA_Parser* class consists of lines of expressions, where each line can only be a single type of expression. There are three types of expression supported in the project, namely:

- Rule [4]

```
supporting |- claim.
```

Supporting symbols (`supporting`) are comma-separated symbols, meanwhile `claim` can only contain one symbol. A symbol is a string of continuous characters (lowercase alphabets, uppercase alphabets, and numeric digits are allowed). For each rule, every symbol present in the rule must be present in order for that argument to be supported. Meanwhile, if there are multiple rules present to support

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[4] Please note that this syntax is different from the usual notation for defining an argument. In the formal definition, to define a sentence, one need to use the notation "$s_0 \leftarrow s_1, \dots, s_m$"; meanwhile the symbol "⊢" is only used for defining an argument where the left hand side is a set of assumptions supporting the claim symbol at right hand side.

the same claim, the argument is supported when there are at least one rule is presented. For example, when there are the following rules:

```
a, b, c |- p.
d, e |- p.
f, g |- q.
```

This means that p can be supported by either "*a, b, c*" or "*d, e*" or both. Meanwhile, q can only be supported by "*f, g*". For instance, for the first rule, a, b, and c need to be present in order for the rule to be present.

- Contrary:

```
contrary(a, b).
```

This expression means the assumption *a* can be attacked by argument with *b* on its claim. This also implicitly declares a as an assumption.

- Assumption:

```
assumption(a).
```

This expression explicitly states that *a* is an assumption. Every assumption needs to have its contrary. This is useful when declaring an argument with no symbols supporting it, i.e. the root itself is an assumption.

```
 1  q, r |- p.
 2  |- q.
 3  a |- r.
 4  b |- s.
 5  contrary(a, s).
 6  contrary(b, p).
 7  c |- d.
 8  assumption(c).
 9  contrary(c, r).
10
```

Submit

Figure 12 Input box at aba-web web interface.

4.2.2. Drawing Argument Trees

Argument trees are drawn using D3.js library. The root node of argument is drawn slightly bigger and with a different colour (red) than the rest of the nodes. For each other nodes supporting an argument, the colours used are the same inside the same argument tree. To determine the position of the nodes within the tree, there is an internal variable tracking the node's depth and hence could be used to determine which node shall be drawn at the top or bottom of the tree, so the tree structure is more visible. The edges are drawn from supported nodes to supporting nodes, and since is directional, a black dot is drawn near the supporting nodes (i.e. symbols that are at LHS of the inference rules).
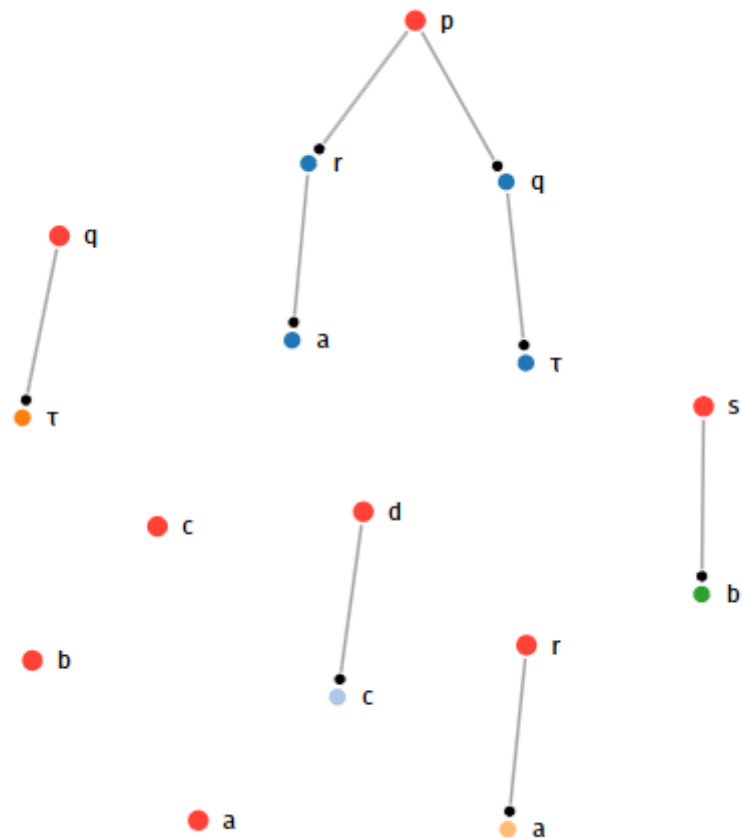
Figure 13 Argument trees drawn at aba-web's web interface.

4.2.3. Drawing Dispute Trees

Dispute trees are drawn using D3.js library, similar to drawing argument trees, but the edges are specified to have an arrowhead, to represent attacks. The edges are drawn in a curvy arc because if not, the arrows will overlap to other edges and will not be visible to the user.
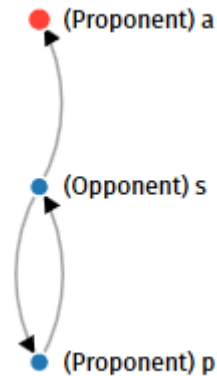
Figure 14 Dispute tree drawn at aba-web's web interface.

4.2.4. Others

One of the innovations present at front-end is lazy rendering technique, where the visualization is rendered only when one request to see it. After switching to other elements, the old visualization rendering is removed, freeing up the computer's memory used for rendering the elements.

Some simple statistics containing several metrics of program run is being collected and presented to the user. The statistics include:

1. Number of symbols
2. Number of potential arguments
3. Number of actual arguments
4. Number of assumptions
5. Number of arguments satisfying the following semantics:
    5.1. Conflict-free
    5.2. Admissible
    5.3. Complete

5.4. Grounded

5.5. Ideal

5.6. Stable

6. Overall runtime, as perceived by user (wall time)

7. Process runtime, as perceived by server's CPU (CPU time)

Figure 15 Statistics of a program run.

4.3. Optimization Techniques

Dispute trees were cached using a simple key-value dictionary during the tree generation phase. The process of storing to cache and loading from cache were shown at Procedure 2.3. and 2.4. respectively. The performance boost of this technique is discussed at Chapter 5.

Dispute tree generation was stopped when there is a tree that satisfies grounded semantics are found. Since if a grounded dispute tree is found, in practice, there is no need to find other dispute trees anymore since the value of the argument semantics (grounded) will not change anymore.
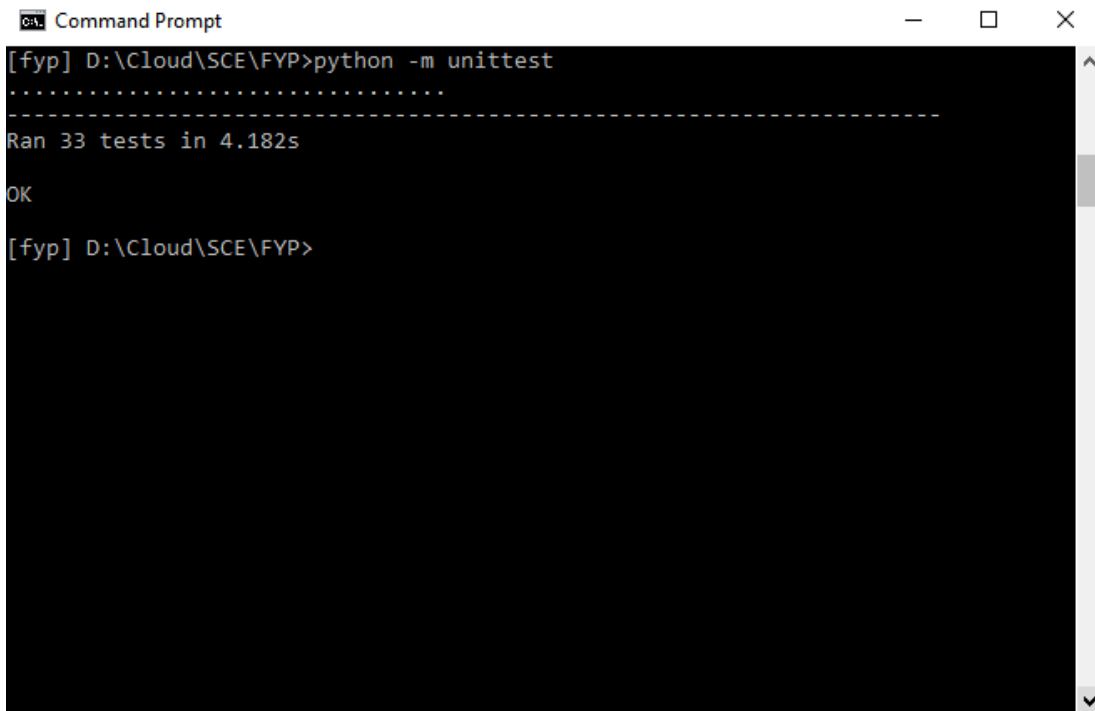
Minor performance speedup was also observed when debugging output is disabled. This was due to the reduction of the need to write output to disk, which may be the bottleneck, depending on the speed of the disk I/O.

Speedup was also observed when changing the method of copying subtrees/branches of a dispute tree during branching. Traditionally, copying an object from one variable to another variable is done by replication of the original pointer to the destination variable. Hence, when a change in the destination variable is observed, the change will be reflected on the original variable. Most of the times, when copying an object, this is not what the user wanted. Hence, Python has a "deep copy" method from its standard library "copy", where it traverses the variable fields and naively replicates the field and values from one variable to another. Meanwhile, Python has another engineering technique that results in the same effect: the "pickle" technique. This "pickle" technique is implemented by calling Python's standard "pickle" library, where it dumps a Python object into a binary form in which this can be easily written into disk. But instead writing it to disk, it can be used to deep-copy an object. The performance evaluation of both methods is discussed at Chapter 5.

4.4. Others

4.4.1. Unit testing

Test cases were written in Python native `unittest` framework to test the correctness of the program. Besides basic tests to verify the correctness of each component, complex test cases were also implemented to verify the correctness of program as a whole. Some test cases are sourced from examples present in Craven and Toni [22]. Running unit test could be carried out using command prompt, as shown in Figure 16.

Figure 16 Running unit tests at local environment.

To detect if there were any error present when committing the codes, *CircleCI* service was utilized to do the unit testing on the cloud whenever new commits were published to the GitHub repository. Figure 17 shows the list of recent commits being tested and successfully passed the test cases.
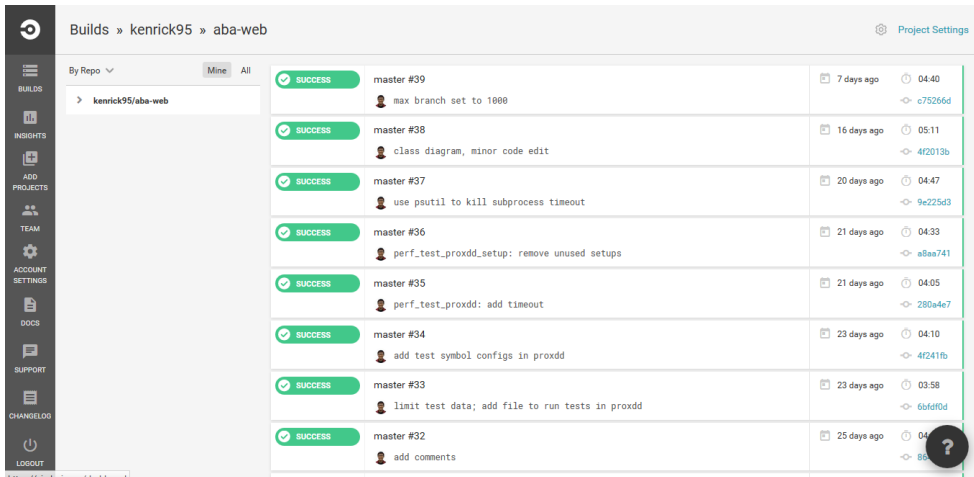
Figure 17 CircleCI unit testing on every commit pushed to GitHub.

4.4.2. Deployment

After completing the implementation of back-end and front-end, the project was configured, published, and hosted at Microsoft Azure cloud service (dashboard shown at Figure 18). The server was configured to connect to GitHub and the project will be built and updated automatically whenever there are new commits being published to GitHub repository.
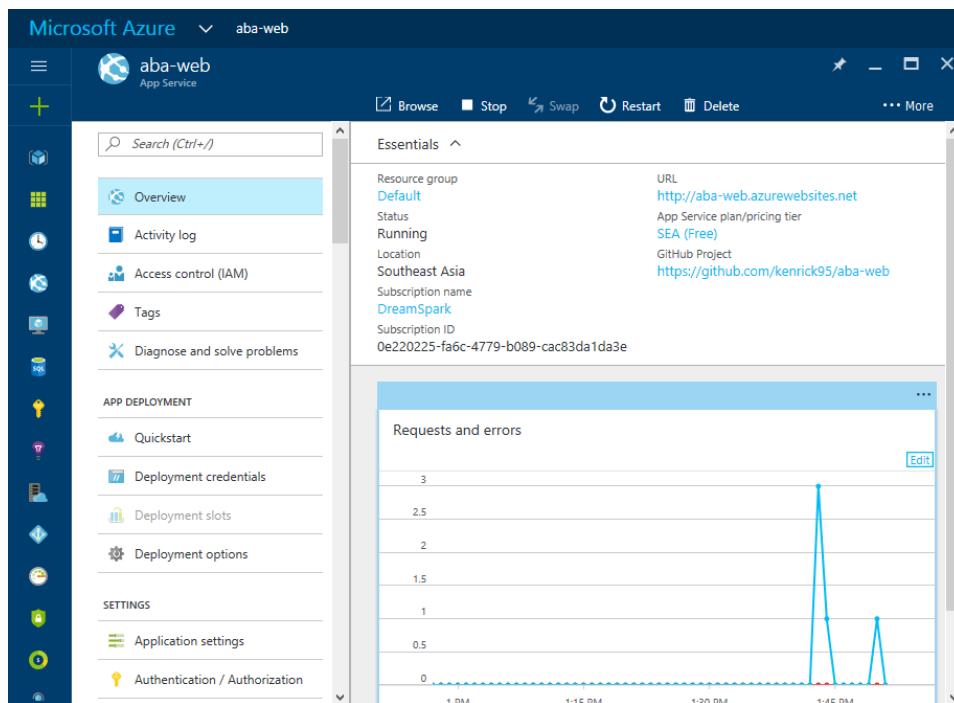
Figure 18 Microsoft Azure dashboard of *aba-web* project.

5. Experiments

5.1. Experiment Design

In evaluating the performance of this project, Toni's Prolog-based *proxdd*[20] was chosen to be compared against because it is the state-of-the-art ABA solver (that computes grounded, admissible, and ideal semantics) and its implementation of solver by representing arguments as trees is similar to the one implemented in this project.

Experiments were conducted on ASUS S46CB notebook computer with Intel Core i7-3537U (2.0 GHz) dual-core processor and 12 GB RAM, running 64-bit Windows 10 Home (Anniversary Update, version 1607, build 14393.321). Python version used is 3.4.5 and Prolog program used is SICStus Prolog 4.3.3. *proxdd* was wrapped in a Python program to record and limit the execution time.

Throughout this chapter, this project will be referred as *aba-web*. Few configurations of *aba-web* were also being compared to answer the following questions:

- Which object copying method is better when branching argument/dispute tree: "pickle" or traditional "copy"?
- What is the effect of dispute tree caching on overall performance?

In this experiment, when referring *aba-web* with "pickle", that means that the "pickle" technique was used; and when referring *aba-web* without "pickle", that means that traditional "copy" method was used.

In comparing among these configurations of *aba-web* and *proxdd*, information that are collected includes:

- the number of successful runs,
- the number of program termination due to runtime error,
- the number of program termination due to memory limit exceeded,
- the number of program termination due to time limit exceeded (timeout error), and
- the average time of successful run.

Time measured was total time taken, as perceived by human, for the program to run from the start until the end, i.e. wall time or wall-clock time; and not the total time the program is being processed in the CPU, i.e. CPU time. Although wall-clock time will be influenced by other programs running in the background, it was being used in the experiment because of technical limitation of not being able to measure the CPU time of *proxdd*, since it was run on another separate process that is being wrapped under a Python program.

In some cases, the experiment could exit due to exceeding memory limit or time limit set by the wrapper program. For *aba-web*, memory limit was arbitrarily set to 5 GB. For *proxdd*, the memory limit was managed by SICStus Prolog (unknown amount). For both program, the time limit was set to 120 seconds.

Test cases used were obtained from Craven and Toni [22], to have a fair comparison with their experiments. They generated the test cases using their Prolog program and published them at Craven's personal website.[5] There were 680 experiment cases in total that they used in their paper. The test cases varied in terms of presence of cyclic arguments, the number of arguments, the number of symbols, the number of assumptions, etc. Ninety-six (96) test cases are selected from the 680 test cases due to the time constraint of running the whole experiment in this project because they reported running the experiments for more than 1,500 hours (nearly 2 months). Since the test cases are randomly generated, it can be said that the 96 test cases represent the 680 test cases available.

At *proxdd*, experiments were conducted individually for each symbol of the test case. After that, the metrics collected were aggregated for each test case. Meanwhile, *aba-web* run the semantics computation for all symbols in one run, hence metrics produced were already aggregated.

---

[5] http://robertcraven.org/proarg/experiments.html

5.2. Results

Different configurations of *aba-web* were compared against Toni's *proxdd*. After running the experiments, taking several hours for each experiment, the results collected were analysed in this section. It should be noted that multiple exceptions could occur during a single run.

Detailed experiment results summary and results per test cases can be found in the Appendix G.

Figure 19 shows the number cases that raised exception across experiments.
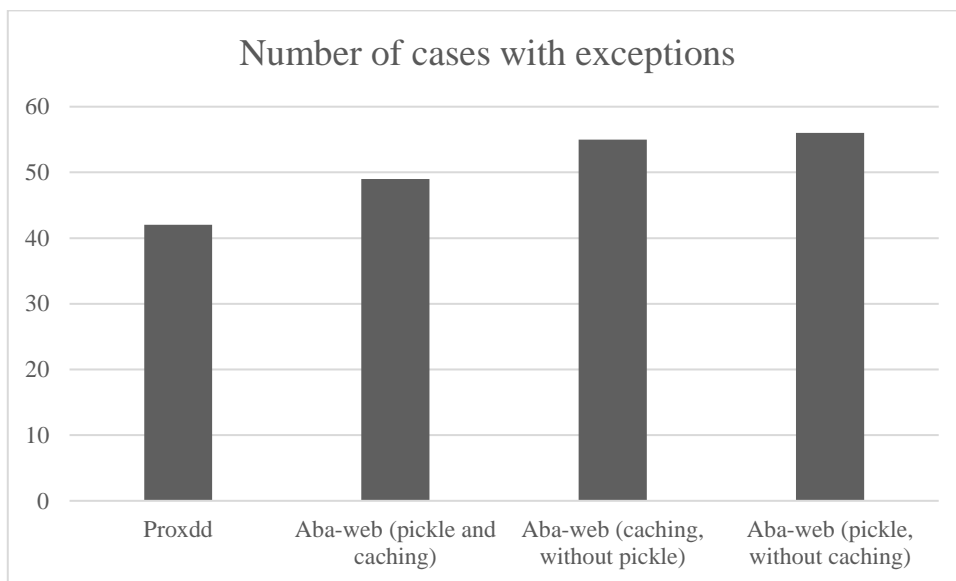
Figure 19 Total number of cases with exceptions across experiments

From the data shown in Figure 19, all *aba-web* experiments had more cases with exceptions (49, 55, and 56 cases) compared to that of *proxdd* (42 cases). This might be caused by *aba-web* computing more semantics compared to *proxdd* and hence requiring more resources, and because of that, *aba-web* is more prone to raise an exception when resource limit is exceeded. Meanwhile, for *aba-web*, enabling "pickle" and caching technique minimized the number of cases with exception. Hence, enabling "pickle" and caching technique has a positive effect on the *aba-web*'s overall performance.

Figure 20 shows the number of cases across the experiments that raised runtime exception. This experiment could not detect whether *proxdd* has raised runtime exception due to technical limitation; and if runtime exception has occurred, it will be reported as timeout exception instead. Meanwhile, runtime exceptions in *aba-web* were caught when tree branching was cut due to the tree branching limit (set to 1,000 branches), or when Python's internal maximum recursion depth is reached (using its default value: 1,000).
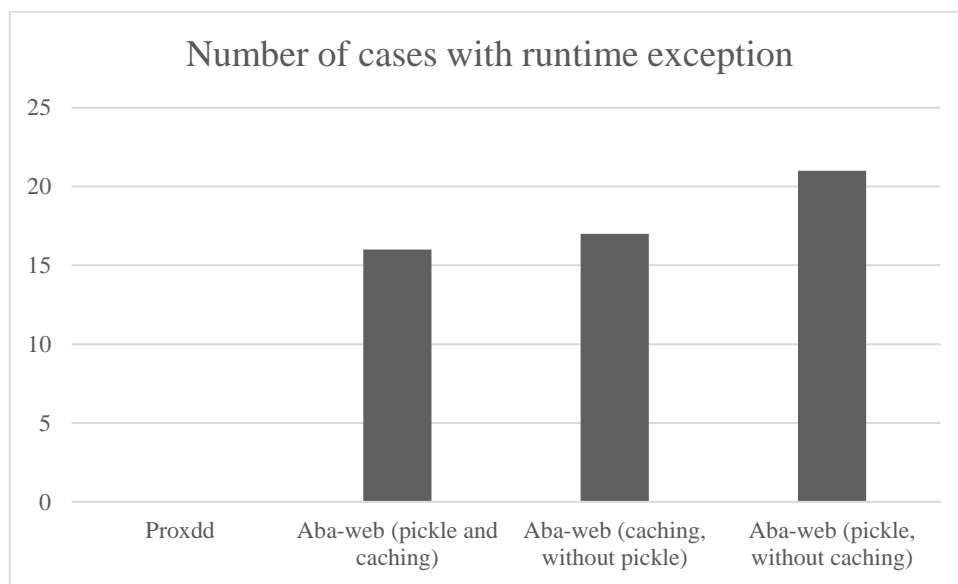
Figure 20 Total number of cases with runtime exception across experiments

From Figure 20, since this experiment could not detect whether *proxdd* has reported runtime exception or not, this section only compares the different configurations of *aba-web*. Comparing the different configurations of *aba-web*, it was shown that using "pickle" and caching technique yielded the lowest number of cases with runtime exceptions (16 cases). Usage of caching technique showed that the number of cases with runtime exceptions dropped from 21 to 16 (23.08% reduction). This might be caused by cache hit when enabling the caching technique, because without it, continuing recursive tree expansion might raise Python's maximum recursion depth exception.

Figure 21 shows the number of cases across the experiments that raised timeout exception. The time limit set for each case is 120 seconds.
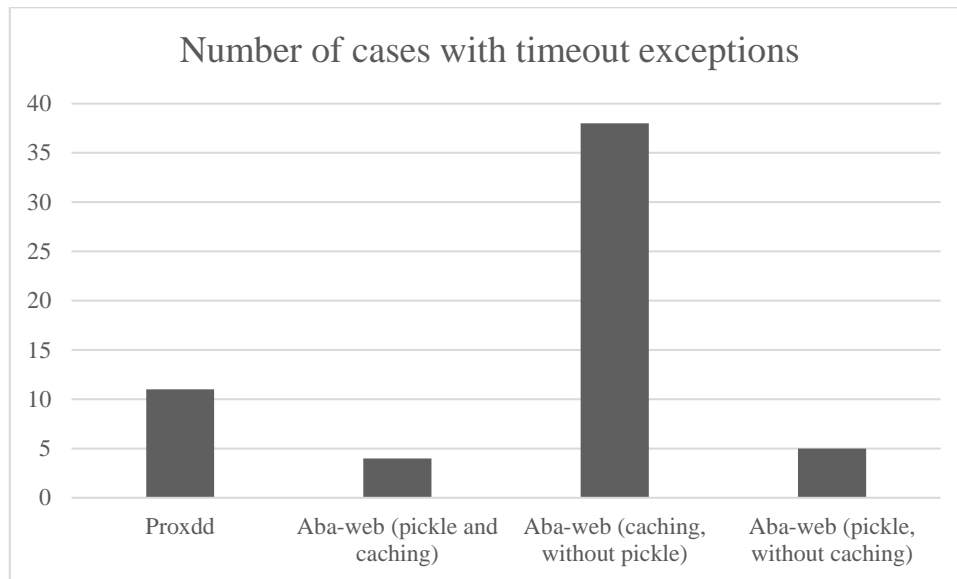
Figure 21 Total number of cases with timeout exception across experiments

From Figure 21, it is shown that using "pickle" technique, *aba-web* has significantly lower number of cases with timeout exceptions (4 cases) compared to itself not using "pickle" (38 cases), which shows the effectiveness of the "pickle" technique in speeding up the computations. With tree caching, *aba-web* performed slightly better (4 cases) compared to itself without tree caching (5 cases), hence tree caching only improves the program performance by a little amount, which might be due to a low number of cache hit. Meanwhile, *aba-web* with pickle performs better (4 cases) compared to *proxdd* (11 cases with timeout exceptions), probably because runtime exceptions are combined into timeout exceptions.

Figure 22 shows the number of cases across the experiments that raised memory limit exceeded exception. The memory limit set for *aba-web* experiments is 5 GB, and for *proxdd* is the memory limit set by SICStus Prolog program.
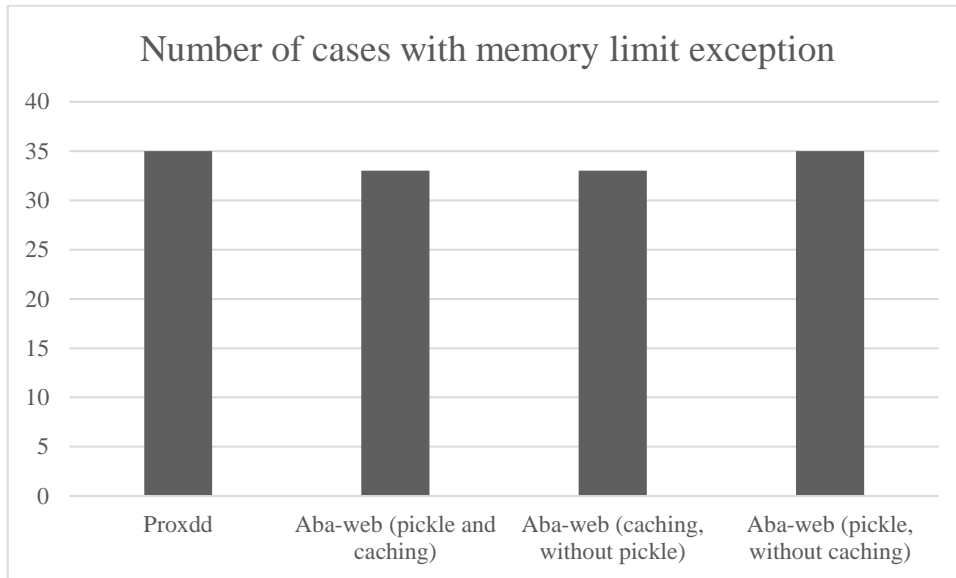
Figure 22 Total number of cases with memory limit exception across experiments

From the data in Figure 22, the number of cases with memory limit exceptions was nearly the same across these programs, ranging from 33 to 35 cases. This result was unexpected, especially in *aba-web* with caching enabled, because theoretically, implementing cache causes more memory being used and hence more prone to memory limit exception. This might be caused by the caching technique not significantly affect the memory consumption, since majority of memory consumption came from elsewhere. This might be true, since without caching, the tree recursion will go deeper and hence more prone to runtime or timeout exceptions.

Figure 23 shows the total runtime of all 96 cases across experiments, including those when the programs run for very long but died due to exceptions being raised.
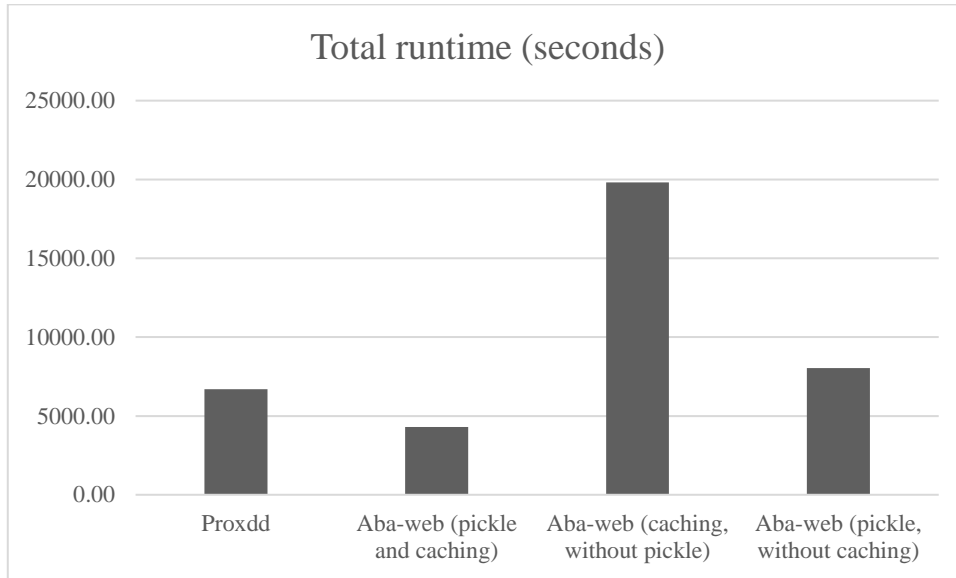
Figure 23 Total runtime in seconds across experiments

From results shown in Figure 23, it is observed that the total running time of the program differs a lot, where *aba-web* (with "pickle" technique & caching technique enabled) performed faster than *proxdd* (requiring 35.70% less runtime). Across *aba-web* configurations, it is shown that *aba-web*, with "pickle" and caching enabled, performed the best compared to that when "pickle" technique was disabled (78.27% reduction of runtime) and when caching is disabled (46.51% reduction of runtime).

In the experiments of *aba-web*, the program wasn't directly killed when the time limit has been exceeded, hence the long total runtime, especially in *aba-web* without "pickle", where there were the most number of cases with timeout exceptions. To compare the performance of these programs, the cases that will produce exception need to be ignored, which was done in Figure 24.

Figure 24 shows the average runtime of cases across experiments which did not produce any exceptions during the runtime.
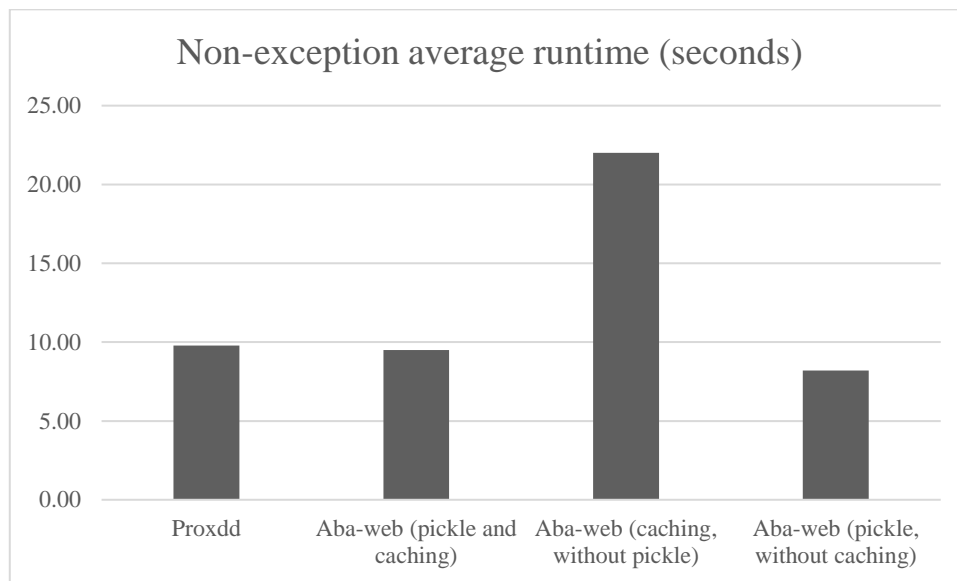
Figure 24 Average total runtime of cases without exceptions, in seconds, across experiments.

From results shown in Figure 24, *aba-web* (pickle and caching), and *aba-web* (pickle but without caching) on average run slightly (2.9% and 16.24%, respectively) faster than *proxdd*.

On *aba-web* itself, it is shown that "pickle" technique reduces the average runtime by 56.83% (from 22.01 seconds to 12.51 seconds). This shows that using "pickle" technique is much faster than without it (i.e. traditional "copy" technique). Meanwhile, caching technique unexpectedly increased the average runtime by a small amount 15.85% (from 8.2 seconds to 9.5 seconds). This might be caused by the overhead caused by constructing the cache while not being used in the end.

From the results presented, it can be said that *aba-web* run faster to *proxdd* in terms of average, but slightly inferior in terms of number of cases with exceptions produced. Hence it can be concluded that *aba-web* can run almost as well as the state-of-the-art ABA solver *proxdd*.

6. Conclusions

The objective of this project is to implement an Assumption-Based Argumentation (ABA) solver in a modern programming language that performs well to users and create a web interface of the ABA solver so it can be accessible by the public.

This project has demonstrated the novelty of development of an ABA solver in Python with a simple-to-use web interface. At the web interface, the user can describe an ABA framework using a Prolog-like syntax to define inference rules, assumptions, and contraries. Visualization of the arguments and dispute trees are also available in the web interface. Besides that, the project can also be used as a standalone package via command line interface, where it can be interfaced to other projects.

The report has introduced and explained the ABA concepts, such as arguments, attacks, argument trees, dispute trees, and its semantics. The report has also discussed the methodology of this project, laying out the software requirements and software architecture of the project.

The project implemented ABA solver that constructs argument trees, dispute trees, and computes several semantics, such as conflict-free, stable, admissible, grounded, ideal, and complete. The implementation specifics of the project, including back-end, front-end, optimiazation techniques, unit testing, and deployment, were also discussed in the report.

Experiments were designed and conducted in such a way that this project can be compared to *proxdd*, a state-of-the-art tree-based ABA solver by Toni [20], by sourcing and sampling the test cases from Craven and Toni [22] where those test cases were used by them to compare their new approach against *proxdd*.

From the experiment results, in the best configurations of this project, this project run slightly superior to *proxdd* in terms of average runtime of cases where no exceptions were raised (running 3.05% faster than *proxdd*). On the other hand, this project seemed to run somewhat inferior compared to *proxdd* in terms of number of cases with exceptions, where exceptions occurred in 16.67% more cases than *proxdd*. These observations might be because this project computes more semantics and because of

that, requires more resources to accomplish these tasks, and hence this project is more prone to exceptions being raised when resource limit was encountered.

Meanwhile, to determine the best project configurations, there were few configurations that were experimented. These experiments were conducted to determine whether to use "pickle" or traditional "copy" method and whether tree caching has an impact on the overall performance of the program.

From the results of the experiments, it can be clearly seen that this project's best configuration is by employing "pickle" technique (compared to using the traditional "copy" method) and tree caching technique. This configuration yielded the least number of cases with exceptions, where it occurred in 49 out of the 96 experiment cases (51.04%). Besides that, this configuration also produced the least number of cases with memory, timeout, and runtime exceptions (occurred in 33, 4, and 16 out of the 96 experiment cases, respectively). The only trade-off seen was that the configuration only run slower than when tree caching is disabled, where this configuration took 13.65% more time to run, in terms of average time taken for cases without any exceptions.

There were several future works that can be worked on after this project has been completed. Firstly, the scope of this project did not cover the computational complexity analyses as they might have been analysed by other researchers, but analysing the procedures applied in this project will be beneficial to improve its efficiency. After improving the performance of the performance by implementing the algorithms that are the most efficient, this project could be considered to enter the International Competition on Computational Model of Argumentation (ICCMA) to be evaluated against all top-performing argumentation solver.

Besides that, it may be good to implement the other semantics that has been defined over the years by the researchers in argumentation field, for example, "preferred" semantics. This will, in turn, make this project become a universal ABA solver that can be reused and extended in researches in the field of argumentation.

Moreover, a usability testing on the web interface might uncover usability issues so the web interface's user-friendliness could be improved even to users that did not have prior knowledge of argumentation field. This might include an interactive introduction, tutorial, and help page on educating the first-time user to utilize the ABA solver.

Finally, this project could be investigated for usage on multiple disciplines. For example, in medical field, doctors could be trained to utilize an ABA solver in this simple syntax instead of operating traditional solver program in command line. Furthermore, this project could be assessed for commercial usage since commercialization is one way quickly to gain public interest in the field. This can be done by generating more real-life application and impact of this project.

By building an ABA solver in a modern programming language with a web interface[6], the field of argumentation is expected to gain more public interest in turn applied to more real-life scenarios.

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[6] The web interface of this project is available on the URL: https://aba-web.azurewebsites.net/

7. Recommendations

From the conclusions stated in the previous chapter, the following are the recommendations for future work on improving this project eventually contributing to the field of argumentation.

1. Analyse computational complexity of the argument tree generation, dispute tree generation, and semantics computations.
2. If applicable, implement a more efficient algorithm for generating argument trees, generating dispute trees, and computation of the semantics.
3. Consider entering the International Competition on Computational Model of Argumentation (ICCMA).
4. Implement computation of other semantics, for example, "preferred" semantics.
5. Conduct usability testing on the web interface and improve the usability based on feedbacks.
6. Investigate the application of the project for multi-disciplinary research purposes by building on top of this project.
7. Assess the project's commercial value by generating more real-life examples of application and impact of this project.

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Appendices

Appendix A: Use Case Diagram
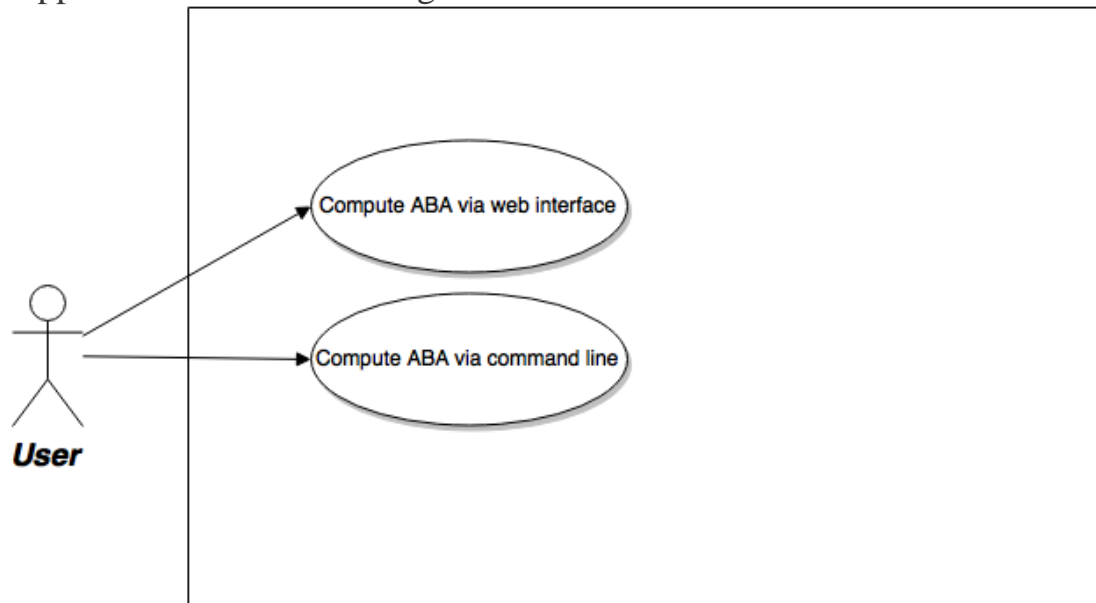
Figure 25 Use case diagram

Appendix B: Use Case Descriptions

Use Case ID:	1
Use Case Name:	Compute ABA via web interface

Actor:	User
Description:	The server computes ABA semantics and return the visualization to user.
Preconditions:	1. User has an ABA framework 2. User intends to compute the ABA semantics
Post Conditions:	1. ABA argument graph is computed 2. ABA dispute trees are computed 3. Runtime statistics are measured
Priority:	High
Frequency of Use:	Multiple times per user

Flow of Events:	1. User inputs the ABA framework description using Prolog-like syntax in the input box
	1.1. An ABA framework description contains: Rule, Assumptions, and Contraries.
	1.2. The Prolog-like syntax is described in the subsequent section.
	2. User selects "Submit"
	3. Server computes the ABA
	3.1. Server parses the ABA input
	3.2. Server constructs the ABA argument trees
	3.3. Server constructs the ABA dispute trees
	3.4. Server determines the semantics of each ABA dispute trees
	4. Server returns to the User:
	4.1. Visual representation of ABA argument trees
	4.2. Visual representation of ABA dispute trees
	4.3. Overall statistics involved in computation of ABA argument trees and dispute trees.
Alternative Flows:	-

Exceptions:	3.1.1. If ABA input contains any error,
	      3.1.1.1. Server shall terminate the computation
	      3.1.1.2. Server shall return the error message to the user

Includes:	-
Special Requirements:	-
Assumptions:	-
Notes and Issues:	-

Use Case ID:	2
Use Case Name:	Compute ABA via command line

Actor:	User
Description:	User loads ABA and manually computes ABA via command line
Preconditions:	1. User has an ABA framework 2. User intends to compute the ABA semantics 3. User has knowledge in command line interface 4. User has the latest source code of the project 5. User has set up the project dependencies 6. User has working knowledge in interactive command line Python
Post Conditions:	1. ABA semantics are computed
Priority:	Low
Frequency of Use:	Multiple times per user
Flow of Events:	1. User runs interactive command line Python 2. User imports ABA classes in the command line 3. User constructs an ABA_Parser, passing in as textual ABA representation in Prolog-like syntax as the constructor parameter 4. User calls function that handles parsing of textual input 5. User calls function that constructs and returns an ABA object 6. User accesses the ABA semantics computed at the returned ABA objects
Alternative Flows:	-
Exceptions:	4.1. If ABA input contains any parsing error, 4.1.1. Program shall terminate the computation

	4.1.2. Program shall return the error message to the user
Includes:	-
Special Requirements:	-
Assumptions:	-
Notes and Issues:	-

Appendix C: Functional Requirements

The functional requirements of this project are:

1. User computes ABA via web interface

    1.1. The web interface provides an easy-to-discover input box.

    1.2. The web interface shall contain a help page.

        1.2.1. The help page shall describe the overview of the ABA solver

        1.2.2. The help page shall explain the input syntax for describing an ABA framework

        1.2.3. The help page shall mention the limitations of the ABA solver

    1.3. After submission of the input, the user shall not wait for more than a reasonable amount of time to get back the result.

    1.4. The result of the submission shall be displayed in an interactive graph, including:

        1.4.1. Argument trees

            1.4.1.1. All tree roots shall be coloured consistently and differently from the non-root nodes, i.e. using the colour red.

            1.4.1.2. All nodes shall be labelled clearly with descriptive text when user hovers its mouse above the node.

                1.4.1.2.1. Text description of node shall contain the node symbol, whether it is root of the tree, and what node it is supporting.

            1.4.1.3. All edges of tree nodes shall be labelled clearly on which node is supporting which other nodes

                1.4.1.3.1. Nodes that are supporting other nodes shall have its edge labelled with a black dot near them.

        1.4.2. Dispute trees of each actual arguments

            1.4.2.1. Result shall contain whether the dispute tree satisfies the following semantics:

                1.4.2.1.1. Conflict-free

                1.4.2.1.2. Admissible

                1.4.2.1.3. Complete

                1.4.2.1.4. Grounded

                1.4.2.1.5. Ideal

          1.4.2.1.6.   Stable

       1.4.2.2.   All tree roots shall be coloured consistently and differently from the non-root nodes, i.e. using the colour red.

       1.4.2.3.   All nodes shall be labelled clearly with descriptive text when the user hovers its mouse above the node.

          1.4.2.3.1.   Text description of node shall contain the node symbol and a list of assumptions supporting the node symbol.

       1.4.2.4.   All nodes shall be labelled clearly whether it is proponent or opponent nodes.

       1.4.2.5.   All edges of tree nodes shall be labelled clearly on which node is attacking which other nodes.

          1.4.2.5.1.   Nodes that are being attacked by other nodes shall have its edge labelled with a black arrow pointing towards them.

1.5. The web interface shall contain statistics of running the computation, including:

    1.5.1.   Number of symbols

    1.5.2.   Number of potential arguments

    1.5.3.   Number of actual arguments

    1.5.4.   Number of assumptions

    1.5.5.   Number of arguments satisfying the following semantics:

       1.5.5.1.   Conflict-free

       1.5.5.2.   Admissible

       1.5.5.3.   Complete

       1.5.5.4.   Grounded

       1.5.5.5.   Ideal

       1.5.5.6.   Stable

    1.5.6.   Overall runtime, as perceived by user (wall time)

    1.5.7.   Process runtime, as perceived by server's CPU (CPU time)

2. User computes ABA via command line interface

   2.1. Command line interface shall provide access to all *aba-web* classes' public methods

2.2. User shall mainly be using ABA_Parser class to compute the semantics of an ABA framework

2.3. Construction of ABA Dispute Tree shall be terminated if tree branching exceeds 1000 branches.

2.4. Computation process shall be terminated if it exceeds 5 GB usage of RAM

2.5. Time taken, in terms of wall time and CPU time, to run the following procedures shall be logged:

    2.5.1. Constructing arguments

    2.5.2. Constructing dispute tree

    2.5.3. Determining conflict-free semantics

    2.5.4. Determining stable semantics

    2.5.5. Determining admissible semantics

    2.5.6. Determining grounded semantics

    2.5.7. Determining ideal semantics

    2.5.8. Determining complete semantics

Appendix D: Non-functional Requirements

The non-functional requirements of this projects are:

1. Performance

   1.1. The program should be free from critical errors

   1.2. The program should be able to compute semantics within a reasonable time limit

   1.3. The server should be able to respond back to the program in a reasonable time limit.

2. Reliability

   2.1. The program and server must be available and ready at all time

   2.2. The server should be able to respond to requests sent by users at all time

3. Maintenance

   3.1. The program should be designed to provide easy maintenance in the future

   3.2. The program should be designed to provide the developers easy access to isolate and fix bugs.

Appendix E: Program Listing

Detailed program listing is available on GitHub at the following URL:

https://github.com/kenrick95/aba-web

Web interface of the ABA solver is available at the following URL:

https://aba-web.azurewebsites.net/

Appendix F: Summary of Experiment Results

Table 3 Summarized experiment results, comparing performance of *proxdd* and *aba-web* in different configurations

	Proxdd	**Aba-web (pickle and caching)**	**Aba-web (caching, without pickle)**	**Aba-web (pickle, without caching)**
Number of cases with exceptions	42	49	55	56
Number of cases with timeout exception	11	4	38	5
Number of cases with runtime exception	0	16	17	21
Number of cases with memory limit exception	35	33	33	35
Total runtime	6691.82s	4303.03s	19802.98s	8044.75s
Number of cases without exceptions	54	47	41	40
Non-exception total runtime	528.40s	446.27s	902.41s	327.97s
Non-exception average runtime	9.7852s	9.4952s	22.0100s	8.1992s

Appendix G: Detailed Performance Evaluation Results

Proxdd

	Wall time (s)	CPU time (s)	Exception
exp_acyclic_depvary_step1_batch_yyy01	0	8.717462755	
exp_acyclic_depvary_step1_batch_yyy02	0.046875	12.19307845	
exp_acyclic_depvary_step1_batch_yyy03	0.015625	8.168678952	
exp_acyclic_depvary_step1_batch_yyy04	0	8.569151884	
exp_acyclic_depvary_step2_batch_yyy01	0.046875	8.346992245	
exp_acyclic_depvary_step2_batch_yyy02	0.046875	9.852543855	
exp_acyclic_depvary_step2_batch_yyy03	0.09375	8.630505733	
exp_acyclic_depvary_step2_batch_yyy04	0.015625	8.202013244	
exp_acyclic_depvary_step3_batch_yyy01	0.015625	8.771516542	
exp_acyclic_depvary_step3_batch_yyy02	0.015625	8.136476085	
exp_acyclic_depvary_step3_batch_yyy03	0.015625	7.586231203	
exp_acyclic_depvary_step3_batch_yyy04	0.015625	7.78426517	
exp_acyclic_indvary1_step1_batch_yyy01	0.03125	8.218891402	
exp_acyclic_indvary1_step1_batch_yyy02	0.015625	8.099757787	
exp_acyclic_indvary1_step1_batch_yyy03	0.0625	9.131568598	
exp_acyclic_indvary1_step1_batch_yyy04	0.046875	7.992655601	
exp_acyclic_indvary1_step2_batch_yyy01	0.28125	138.123259	Timeout
exp_acyclic_indvary1_step2_batch_yyy02	0.4375	247.0993161	Timeout
exp_acyclic_indvary1_step2_batch_yyy03	0.453125	247.6446793	Timeout
exp_acyclic_indvary1_step2_batch_yyy04	0.609375	372.9890577	Timeout
exp_acyclic_indvary1_step3_batch_yyy01	0.03125	7.858438258	
exp_acyclic_indvary1_step3_batch_yyy02	0	8.601849031	
exp_acyclic_indvary1_step3_batch_yyy03	0.03125	8.633582252	
exp_acyclic_indvary1_step3_batch_yyy04	0	15.96179763	
exp_acyclic_indvary2_step1_batch_yyy01	0.03125	9.897907524	
exp_acyclic_indvary2_step1_batch_yyy02	0.0625	9.947594083	
exp_acyclic_indvary2_step1_batch_yyy03	0.0625	9.741281349	
exp_acyclic_indvary2_step1_batch_yyy04	0.046875	9.270853124	
exp_acyclic_indvary2_step2_batch_yyy01	0.203125	130.5303177	Timeout
exp_acyclic_indvary2_step2_batch_yyy02	0.0625	7.665009216	
exp_acyclic_indvary2_step2_batch_yyy03	0.046875	8.734523599	
exp_acyclic_indvary2_step2_batch_yyy04	0.0625	13.26822737	
exp_acyclic_indvary2_step3_batch_yyy01	0.03125	44.56378501	
exp_acyclic_indvary2_step3_batch_yyy02	0.5	248.0138751	Timeout
exp_acyclic_indvary2_step3_batch_yyy03	0.046875	15.14618104	
exp_acyclic_indvary2_step3_batch_yyy04	0.03125	8.512307718	
exp_acyclic_indvary3_step1_batch_yyy01	0.03125	8.006946594	
exp_acyclic_indvary3_step1_batch_yyy02	0.046875	8.324383485	
exp_acyclic_indvary3_step1_batch_yyy03	0.015625	11.31103425	
exp_acyclic_indvary3_step1_batch_yyy04	0.015625	9.143283919	

exp_acyclic_indvary3_step2_batch_yyy01	0.015625	8.170720523	
exp_acyclic_indvary3_step2_batch_yyy02	0.015625	8.327150053	
exp_acyclic_indvary3_step2_batch_yyy03	0.015625	10.60674215	
exp_acyclic_indvary3_step2_batch_yyy04	0.015625	8.496664847	
exp_acyclic_indvary3_step3_batch_yyy01	0.015625	7.860538945	
exp_acyclic_indvary3_step3_batch_yyy02	0.03125	8.617873286	
exp_acyclic_indvary3_step3_batch_yyy03	0.046875	11.90138924	
exp_acyclic_indvary3_step3_batch_yyy04	0.046875	8.181719468	
exp_cycles_depvary_step1_batch_yyy01	0.046875	8.326565047	
exp_cycles_depvary_step1_batch_yyy02	0.046875	8.895699688	
exp_cycles_depvary_step1_batch_yyy03	0.046875	372.9101093	Memory
exp_cycles_depvary_step1_batch_yyy04	0.109375	10.80053656	
exp_cycles_depvary_step2_batch_yyy01	0.015625	89.69940719	Memory
exp_cycles_depvary_step2_batch_yyy02	0.0625	8.37160768	
exp_cycles_depvary_step2_batch_yyy03	0	8.420186217	
exp_cycles_depvary_step2_batch_yyy04	0.046875	163.1644415	Memory
exp_cycles_depvary_step3_batch_yyy01	0.046875	7.85542373	
exp_cycles_depvary_step3_batch_yyy02	0.265625	278.323856	Memory & timeout
exp_cycles_depvary_step3_batch_yyy03	0.015625	120.944674	Memory
exp_cycles_depvary_step3_batch_yyy04	0.171875	200.9195515	Memory & timeout
exp_cycles_indvary1_step1_batch_yyy01	0.0625	171.2657461	Memory
exp_cycles_indvary1_step1_batch_yyy02	0.015625	7.794103134	
exp_cycles_indvary1_step1_batch_yyy03	0.03125	22.67873614	Memory
exp_cycles_indvary1_step1_batch_yyy04	0.015625	23.71227611	Memory
exp_cycles_indvary1_step2_batch_yyy01	0.015625	160.088974	Memory
exp_cycles_indvary1_step2_batch_yyy02	0.015625	130.1264415	Memory
exp_cycles_indvary1_step2_batch_yyy03	0.046875	81.35193791	Memory
exp_cycles_indvary1_step2_batch_yyy04	0.015625	50.13301818	Memory
exp_cycles_indvary1_step3_batch_yyy01	0	100.7704315	Memory
exp_cycles_indvary1_step3_batch_yyy02	0	106.6274694	Memory
exp_cycles_indvary1_step3_batch_yyy03	0.03125	113.2693576	Memory
exp_cycles_indvary1_step3_batch_yyy04	0.046875	75.1178934	Memory
exp_cycles_indvary2_step1_batch_yyy01	0.5625	415.6599929	Memory & timeout
exp_cycles_indvary2_step1_batch_yyy02	0.046875	51.63815926	Memory
exp_cycles_indvary2_step1_batch_yyy03	0.21875	378.0968126	Memory & timeout
exp_cycles_indvary2_step1_batch_yyy04	0.03125	72.47039374	Memory
exp_cycles_indvary2_step2_batch_yyy01	0.015625	38.72996753	Memory
exp_cycles_indvary2_step2_batch_yyy02	0.03125	58.22308087	Memory
exp_cycles_indvary2_step2_batch_yyy03	0.015625	20.01747589	Memory
exp_cycles_indvary2_step2_batch_yyy04	0.046875	13.23939865	

exp_cycles_indvary2_step3_batch_yyy01	0.03125	59.13658775	Memory
exp_cycles_indvary2_step3_batch_yyy02	0.015625	7.367167788	
exp_cycles_indvary2_step3_batch_yyy03	0.03125	35.1359231	Memory
exp_cycles_indvary2_step3_batch_yyy04	0.015625	36.83035753	Memory
exp_cycles_indvary3_step1_batch_yyy01	0.015625	7.38438874	
exp_cycles_indvary3_step1_batch_yyy02	0.015625	7.485642912	
exp_cycles_indvary3_step1_batch_yyy03	0	7.307152681	
exp_cycles_indvary3_step1_batch_yyy04	0.25	127.1881184	Timeout
exp_cycles_indvary3_step2_batch_yyy01	0.046875	144.5085054	Memory
exp_cycles_indvary3_step2_batch_yyy02	0.015625	218.1926696	Memory
exp_cycles_indvary3_step2_batch_yyy03	0.015625	99.964143	Memory
exp_cycles_indvary3_step2_batch_yyy04	0	248.7579206	Memory
exp_cycles_indvary3_step3_batch_yyy01	0	129.962507	Memory
exp_cycles_indvary3_step3_batch_yyy02	0.015625	189.7426505	Memory
exp_cycles_indvary3_step3_batch_yyy03	0.015625	40.60401212	Memory
exp_cycles_indvary3_step3_batch_yyy04	0	153.0573504	Memory

Aba-web (Pickle and cache)

	Wall time (s)	CPU time (s)	Exception
exp_acyclic_depvary_step1_batch_yyy01	0.013523705	0.015625	
exp_acyclic_depvary_step1_batch_yyy02	0.010115068	0.015625	
exp_acyclic_depvary_step1_batch_yyy03	0.013694075	0.015625	
exp_acyclic_depvary_step1_batch_yyy04	0.012209596	0.015625	
exp_acyclic_depvary_step2_batch_yyy01	0.024073524	0.015625	
exp_acyclic_depvary_step2_batch_yyy02	0.034669734	0.03125	
exp_acyclic_depvary_step2_batch_yyy03	0.12995721	0.140625	
exp_acyclic_depvary_step2_batch_yyy04	0.030694154	0.03125	
exp_acyclic_depvary_step3_batch_yyy01	0.196115476	0.1875	
exp_acyclic_depvary_step3_batch_yyy02	0.157563763	0.171875	
exp_acyclic_depvary_step3_batch_yyy03	0.197419732	0.1875	
exp_acyclic_depvary_step3_batch_yyy04	0.304010352	0.3125	
exp_acyclic_indvary1_step1_batch_yyy01	9.18278431	8.96875	Runtime
exp_acyclic_indvary1_step1_batch_yyy02	6.449580048	6.359375	Runtime
exp_acyclic_indvary1_step1_batch_yyy03	11.56034535	11.5625	Runtime
exp_acyclic_indvary1_step1_batch_yyy04	37.09550095	37.09375	
exp_acyclic_indvary1_step2_batch_yyy01	154.562382	154.484375	Memory & timeout
exp_acyclic_indvary1_step2_batch_yyy02	1144.231452	1143.515625	Memory & timeout
exp_acyclic_indvary1_step2_batch_yyy03	316.0586287	315.765625	Memory & timeout
exp_acyclic_indvary1_step2_batch_yyy04	346.6438691	346.4375	Runtime & timeout
exp_acyclic_indvary1_step3_batch_yyy01	1.829362885	1.828125	Runtime
exp_acyclic_indvary1_step3_batch_yyy02	0.585583966	0.59375	
exp_acyclic_indvary1_step3_batch_yyy03	9.28768847	9.296875	
exp_acyclic_indvary1_step3_batch_yyy04	4.955407327	4.953125	Runtime
exp_acyclic_indvary2_step1_batch_yyy01	2.058593415	2.046875	
exp_acyclic_indvary2_step1_batch_yyy02	0.317141179	0.328125	
exp_acyclic_indvary2_step1_batch_yyy03	9.772487952	9.78125	
exp_acyclic_indvary2_step1_batch_yyy04	5.149235735	5.140625	Runtime
exp_acyclic_indvary2_step2_batch_yyy01	52.8785457	52.875	
exp_acyclic_indvary2_step2_batch_yyy02	76.11856744	76.0625	Memory
exp_acyclic_indvary2_step2_batch_yyy03	76.69856368	76.59375	Memory
exp_acyclic_indvary2_step2_batch_yyy04	75.0070562	74.78125	Memory
exp_acyclic_indvary2_step3_batch_yyy01	5.170090699	5.171875	Memory
exp_acyclic_indvary2_step3_batch_yyy02	60.42786584	60.375	Memory
exp_acyclic_indvary2_step3_batch_yyy03	67.36587816	67.296875	Memory
exp_acyclic_indvary2_step3_batch_yyy04	64.88359852	64.8125	Memory
exp_acyclic_indvary3_step1_batch_yyy01	0.097791303	0.109375	
exp_acyclic_indvary3_step1_batch_yyy02	0.062898651	0.0625	
exp_acyclic_indvary3_step1_batch_yyy03	0.07002136	0.078125	

exp_acyclic_indvary3_step1_batch_yyy04	0.052853784	0.0625	
exp_acyclic_indvary3_step2_batch_yyy01	0.315343464	0.3125	
exp_acyclic_indvary3_step2_batch_yyy02	0.477033472	0.484375	
exp_acyclic_indvary3_step2_batch_yyy03	20.27807138	20.1875	
exp_acyclic_indvary3_step2_batch_yyy04	0.982323777	0.984375	
exp_acyclic_indvary3_step3_batch_yyy01	24.2120256	24.21875	
exp_acyclic_indvary3_step3_batch_yyy02	48.4700877	48.4375	
exp_acyclic_indvary3_step3_batch_yyy03	47.0217335	47.03125	
exp_acyclic_indvary3_step3_batch_yyy04	99.68006516	99.125	
exp_cycles_depvary_step1_batch_yyy01	0.011494451	0.015625	
exp_cycles_depvary_step1_batch_yyy02	0.013124669	0.015625	
exp_cycles_depvary_step1_batch_yyy03	0.036522049	0.046875	
exp_cycles_depvary_step1_batch_yyy04	0.012900108	0.015625	
exp_cycles_depvary_step2_batch_yyy01	0.015194975	0.015625	Runtime
exp_cycles_depvary_step2_batch_yyy02	0.047197491	0.046875	
exp_cycles_depvary_step2_batch_yyy03	0.023367822	0.03125	Runtime
exp_cycles_depvary_step2_batch_yyy04	0.080197597	0.078125	
exp_cycles_depvary_step3_batch_yyy01	25.64668244	25.640625	
exp_cycles_depvary_step3_batch_yyy02	52.71346553	52.6875	Memory
exp_cycles_depvary_step3_batch_yyy03	10.34591035	10.34375	
exp_cycles_depvary_step3_batch_yyy04	8.324258551	8.25	
exp_cycles_indvary1_step1_batch_yyy01	8.914319354	8.796875	Runtime
exp_cycles_indvary1_step1_batch_yyy02	0.095706628	0.09375	Runtime
exp_cycles_indvary1_step1_batch_yyy03	11.03535573	11.03125	Runtime
exp_cycles_indvary1_step1_batch_yyy04	9.239433041	9.21875	
exp_cycles_indvary1_step2_batch_yyy01	6.558330059	6.5625	Runtime
exp_cycles_indvary1_step2_batch_yyy02	52.05045095	52.046875	Memory
exp_cycles_indvary1_step2_batch_yyy03	0.665531139	0.65625	Runtime
exp_cycles_indvary1_step2_batch_yyy04	51.83307819	51.84375	Memory
exp_cycles_indvary1_step3_batch_yyy01	48.11114094	48.09375	Memory
exp_cycles_indvary1_step3_batch_yyy02	18.88910989	18.90625	
exp_cycles_indvary1_step3_batch_yyy03	48.27523379	48.265625	Memory
exp_cycles_indvary1_step3_batch_yyy04	31.48268279	31.4375	Runtime
exp_cycles_indvary2_step1_batch_yyy01	52.69033418	52.640625	Memory
exp_cycles_indvary2_step1_batch_yyy02	28.31878659	28.328125	Runtime
exp_cycles_indvary2_step1_batch_yyy03	54.55117451	54.515625	Memory
exp_cycles_indvary2_step1_batch_yyy04	7.880503524	7.875	
exp_cycles_indvary2_step2_batch_yyy01	47.13945566	47.09375	Memory
exp_cycles_indvary2_step2_batch_yyy02	43.99903607	43.9375	Memory
exp_cycles_indvary2_step2_batch_yyy03	46.53313989	46.453125	Memory
exp_cycles_indvary2_step2_batch_yyy04	43.49448267	43.421875	Memory
exp_cycles_indvary2_step3_batch_yyy01	42.39867916	42.296875	Memory
exp_cycles_indvary2_step3_batch_yyy02	43.04498391	43	Memory

exp_cycles_indvary2_step3_batch_yyy03	42.51174344	42.421875	Memory
exp_cycles_indvary2_step3_batch_yyy04	43.48903164	43.5	Memory
exp_cycles_indvary3_step1_batch_yyy01	0.254123884	0.25	
exp_cycles_indvary3_step1_batch_yyy02	7.87021357	7.796875	
exp_cycles_indvary3_step1_batch_yyy03	0.194615807	0.1875	
exp_cycles_indvary3_step1_batch_yyy04	2.588143214	2.59375	
exp_cycles_indvary3_step2_batch_yyy01	70.25482712	70.21875	Memory
exp_cycles_indvary3_step2_batch_yyy02	7.231557008	7.234375	Memory
exp_cycles_indvary3_step2_batch_yyy03	70.63879081	70.5	Memory
exp_cycles_indvary3_step2_batch_yyy04	63.33033769	63.328125	Memory
exp_cycles_indvary3_step3_batch_yyy01	104.9427568	104.921875	Memory
exp_cycles_indvary3_step3_batch_yyy02	85.08031172	84.984375	Memory
exp_cycles_indvary3_step3_batch_yyy03	109.4636567	109.421875	Memory
exp_cycles_indvary3_step3_batch_yyy04	119.5763803	119.46875	Memory

Aba-web (No pickle and cache)

	Wall time (s)	CPU time (s)	Exception
exp_acyclic_depvary_step1_batch_yyy01	0.013839802	0	
exp_acyclic_depvary_step1_batch_yyy02	0.013725264	0	
exp_acyclic_depvary_step1_batch_yyy03	0.018488238	0.03125	
exp_acyclic_depvary_step1_batch_yyy04	0.02204959	0.015625	
exp_acyclic_depvary_step2_batch_yyy01	0.043877903	0.046875	
exp_acyclic_depvary_step2_batch_yyy02	0.092252757	0.09375	
exp_acyclic_depvary_step2_batch_yyy03	0.117446599	0.109375	
exp_acyclic_depvary_step2_batch_yyy04	0.088802659	0.078125	
exp_acyclic_depvary_step3_batch_yyy01	1.630324734	1.453125	
exp_acyclic_depvary_step3_batch_yyy02	1.504347723	1.421875	
exp_acyclic_depvary_step3_batch_yyy03	1.705245717	1.640625	
exp_acyclic_depvary_step3_batch_yyy04	1.137852425	1.125	
exp_acyclic_indvary1_step1_batch_yyy01	13.80269209	13.28125	Runtime
exp_acyclic_indvary1_step1_batch_yyy02	7.424194529	7.375	Runtime
exp_acyclic_indvary1_step1_batch_yyy03	17.90438993	17.8125	
exp_acyclic_indvary1_step1_batch_yyy04	33.56632017	33.421875	Runtime
exp_acyclic_indvary1_step2_batch_yyy01	272.329284	270.921875	Memory & timeout
exp_acyclic_indvary1_step2_batch_yyy02	2122.368454	2114.46875	Memory & timeout
exp_acyclic_indvary1_step2_batch_yyy03	914.3815474	872.96875	Memory & timeout
exp_acyclic_indvary1_step2_batch_yyy04	330.050572	329.40625	Runtime & timeout
exp_acyclic_indvary1_step3_batch_yyy01	12.18143516	11.921875	
exp_acyclic_indvary1_step3_batch_yyy02	4.106505963	4.09375	
exp_acyclic_indvary1_step3_batch_yyy03	52.07730658	52.03125	
exp_acyclic_indvary1_step3_batch_yyy04	14.38501638	14.375	Runtime
exp_acyclic_indvary2_step1_batch_yyy01	12.52045612	12.515625	
exp_acyclic_indvary2_step1_batch_yyy02	1.637435942	1.640625	
exp_acyclic_indvary2_step1_batch_yyy03	62.10012468	62.03125	
exp_acyclic_indvary2_step1_batch_yyy04	11.92700851	11.90625	
exp_acyclic_indvary2_step2_batch_yyy01	324.8199992	324.53125	
exp_acyclic_indvary2_step2_batch_yyy02	375.0289687	374.875	Memory & timeout
exp_acyclic_indvary2_step2_batch_yyy03	449.0996357	447.828125	Memory & timeout
exp_acyclic_indvary2_step2_batch_yyy04	30.71486527	30.71875	Memory
exp_acyclic_indvary2_step3_batch_yyy01	12.11011904	12.109375	Memory
exp_acyclic_indvary2_step3_batch_yyy02	13.07575436	13.0625	Memory
exp_acyclic_indvary2_step3_batch_yyy03	14.00717812	14.015625	Memory
exp_acyclic_indvary2_step3_batch_yyy04	612.3102826	589.9375	Memory & timeout
exp_acyclic_indvary3_step1_batch_yyy01	0.391439948	0.390625	

exp_acyclic_indvary3_step1_batch_yyy02	0.27996164	0.28125	
exp_acyclic_indvary3_step1_batch_yyy03	0.370393284	0.34375	
exp_acyclic_indvary3_step1_batch_yyy04	0.176443928	0.15625	
exp_acyclic_indvary3_step2_batch_yyy01	3.009582601	2.921875	
exp_acyclic_indvary3_step2_batch_yyy02	3.5367669	3.46875	
exp_acyclic_indvary3_step2_batch_yyy03	189.6481771	180.328125	Timeout
exp_acyclic_indvary3_step2_batch_yyy04	11.97307741	11.234375	
exp_acyclic_indvary3_step3_batch_yyy01	354.9011549	344.0625	Timeout
exp_acyclic_indvary3_step3_batch_yyy02	562.9825295	555.703125	Timeout
exp_acyclic_indvary3_step3_batch_yyy03	514.2050107	509.703125	Timeout
exp_acyclic_indvary3_step3_batch_yyy04	950.6512335	940.984375	Timeout
exp_cycles_depvary_step1_batch_yyy01	0.027032608	0.03125	
exp_cycles_depvary_step1_batch_yyy02	0.02655434	0.03125	
exp_cycles_depvary_step1_batch_yyy03	0.106482973	0.109375	
exp_cycles_depvary_step1_batch_yyy04	0.025445087	0.015625	
exp_cycles_depvary_step2_batch_yyy01	0.092876353	0.09375	Runtime
exp_cycles_depvary_step2_batch_yyy02	0.172957293	0.171875	
exp_cycles_depvary_step2_batch_yyy03	0.061566018	0.0625	Runtime
exp_cycles_depvary_step2_batch_yyy04	0.435894646	0.4375	
exp_cycles_depvary_step3_batch_yyy01	175.4016851	172.59375	Timeout
exp_cycles_depvary_step3_batch_yyy02	421.075742	412.609375	Memory & timeout
exp_cycles_depvary_step3_batch_yyy03	81.54591147	80.40625	
exp_cycles_depvary_step3_batch_yyy04	58.2971953	57.796875	
exp_cycles_indvary1_step1_batch_yyy01	20.0047757	19.859375	Runtime
exp_cycles_indvary1_step1_batch_yyy02	0.333843349	0.328125	Runtime
exp_cycles_indvary1_step1_batch_yyy03	18.73090469	18.546875	Runtime
exp_cycles_indvary1_step1_batch_yyy04	13.45408566	13.390625	
exp_cycles_indvary1_step2_batch_yyy01	111.018808	110.328125	Runtime
exp_cycles_indvary1_step2_batch_yyy02	390.6238527	387.234375	Memory & timeout
exp_cycles_indvary1_step2_batch_yyy03	43.48690182	41.890625	Runtime
exp_cycles_indvary1_step2_batch_yyy04	416.0816036	411.296875	Memory & timeout
exp_cycles_indvary1_step3_batch_yyy01	377.5164493	376.640625	Memory & timeout
exp_cycles_indvary1_step3_batch_yyy02	11.65868951	11.65625	Runtime
exp_cycles_indvary1_step3_batch_yyy03	450.0705616	423.03125	Memory & timeout
exp_cycles_indvary1_step3_batch_yyy04	366.2375796	360.9375	Runtime & timeout
exp_cycles_indvary2_step1_batch_yyy01	30.8657915	30.4375	Memory
exp_cycles_indvary2_step1_batch_yyy02	550.327317	538.09375	Memory & timeout
exp_cycles_indvary2_step1_batch_yyy03	532.485801	515.9375	Memory & timeout

exp_cycles_indvary2_step1_batch_yyy04	46.49705239	44.53125	Runtime
exp_cycles_indvary2_step2_batch_yyy01	388.0164577	379.328125	Memory & timeout
exp_cycles_indvary2_step2_batch_yyy02	393.050634	384.40625	Memory & timeout
exp_cycles_indvary2_step2_batch_yyy03	428.6728049	416.359375	Memory & timeout
exp_cycles_indvary2_step2_batch_yyy04	446.2884895	433.609375	Memory & timeout
exp_cycles_indvary2_step3_batch_yyy01	589.34546	556.859375	Memory & timeout
exp_cycles_indvary2_step3_batch_yyy02	404.4377012	391.921875	Memory & timeout
exp_cycles_indvary2_step3_batch_yyy03	397.7047183	383.796875	Memory & timeout
exp_cycles_indvary2_step3_batch_yyy04	361.1104872	355.765625	Memory & timeout
exp_cycles_indvary3_step1_batch_yyy01	0.910930533	0.90625	
exp_cycles_indvary3_step1_batch_yyy02	45.81873241	45.0625	
exp_cycles_indvary3_step1_batch_yyy03	0.788313763	0.78125	
exp_cycles_indvary3_step1_batch_yyy04	12.05009947	11.75	Runtime
exp_cycles_indvary3_step2_batch_yyy01	197.4267437	192.15625	Runtime & timeout
exp_cycles_indvary3_step2_batch_yyy02	467.8784945	461.0625	Memory & timeout
exp_cycles_indvary3_step2_batch_yyy03	476.7613046	475.78125	Memory & timeout
exp_cycles_indvary3_step2_batch_yyy04	463.1522997	462.140625	Memory & timeout
exp_cycles_indvary3_step3_batch_yyy01	656.3492615	649.828125	Memory & timeout
exp_cycles_indvary3_step3_batch_yyy02	531.8614243	531.046875	Memory & timeout
exp_cycles_indvary3_step3_batch_yyy03	515.3057859	514.828125	Memory & timeout
exp_cycles_indvary3_step3_batch_yyy04	596.9302604	596.140625	Memory & timeout

Aba-web (Pickle and no cache)

	Wall time (s)	CPU time (s)	Exception
exp_acyclic_depvary_step1_batch_yyy01	0.01319609	0.015625	
exp_acyclic_depvary_step1_batch_yyy02	0.0099685	0.015625	
exp_acyclic_depvary_step1_batch_yyy03	0.010903278	0	
exp_acyclic_depvary_step1_batch_yyy04	0.01190374	0	
exp_acyclic_depvary_step2_batch_yyy01	0.024984882	0.015625	
exp_acyclic_depvary_step2_batch_yyy02	0.039461827	0.046875	
exp_acyclic_depvary_step2_batch_yyy03	0.07115724	0.078125	
exp_acyclic_depvary_step2_batch_yyy04	0.023005715	0.015625	
exp_acyclic_depvary_step3_batch_yyy01	0.160948046	0.15625	
exp_acyclic_depvary_step3_batch_yyy02	0.165098509	0.171875	
exp_acyclic_depvary_step3_batch_yyy03	0.214614637	0.203125	
exp_acyclic_depvary_step3_batch_yyy04	0.191707039	0.203125	
exp_acyclic_indvary1_step1_batch_yyy01	6.449963524	6.4375	runtime
exp_acyclic_indvary1_step1_batch_yyy02	3.197325558	3.203125	runtime
exp_acyclic_indvary1_step1_batch_yyy03	14.95068667	14.921875	
exp_acyclic_indvary1_step1_batch_yyy04	7.222392957	7.21875	runtime
exp_acyclic_indvary1_step2_batch_yyy01	149.4031561	149.0625	memory & timeout
exp_acyclic_indvary1_step2_batch_yyy02	1853.777154	1833.421875	memory & timeout
exp_acyclic_indvary1_step2_batch_yyy03	285.873713	282.796875	memory & timeout
exp_acyclic_indvary1_step2_batch_yyy04	3380.536731	3350.703125	runtime & timeout
exp_acyclic_indvary1_step3_batch_yyy01	1.801212953	1.796875	
exp_acyclic_indvary1_step3_batch_yyy02	0.444739935	0.4375	runtime
exp_acyclic_indvary1_step3_batch_yyy03	1.133093146	1.125	runtime
exp_acyclic_indvary1_step3_batch_yyy04	0.233652165	0.234375	runtime
exp_acyclic_indvary2_step1_batch_yyy01	0.254460311	0.25	runtime
exp_acyclic_indvary2_step1_batch_yyy02	0.337710135	0.34375	
exp_acyclic_indvary2_step1_batch_yyy03	6.655553882	6.578125	runtime
exp_acyclic_indvary2_step1_batch_yyy04	0.151024704	0.140625	runtime
exp_acyclic_indvary2_step2_batch_yyy01	0.153349949	0.140625	runtime
exp_acyclic_indvary2_step2_batch_yyy02	109.6607554	104.78125	memory
exp_acyclic_indvary2_step2_batch_yyy03	93.16198087	86.984375	memory
exp_acyclic_indvary2_step2_batch_yyy04	87.64037179	85.71875	memory
exp_acyclic_indvary2_step3_batch_yyy01	78.6211754	77.890625	memory
exp_acyclic_indvary2_step3_batch_yyy02	76.99444429	74.5625	memory
exp_acyclic_indvary2_step3_batch_yyy03	67.36950803	67.03125	memory
exp_acyclic_indvary2_step3_batch_yyy04	62.42616777	62.140625	memory
exp_acyclic_indvary3_step1_batch_yyy01	0.09431276	0.078125	
exp_acyclic_indvary3_step1_batch_yyy02	0.070244192	0.078125	
exp_acyclic_indvary3_step1_batch_yyy03	0.073528844	0.0625	

exp_acyclic_indvary3_step1_batch_yyy04	0.061393159	0.0625	
exp_acyclic_indvary3_step2_batch_yyy01	0.299489218	0.296875	
exp_acyclic_indvary3_step2_batch_yyy02	0.409904207	0.40625	
exp_acyclic_indvary3_step2_batch_yyy03	18.69383269	18.515625	
exp_acyclic_indvary3_step2_batch_yyy04	0.959979047	0.953125	
exp_acyclic_indvary3_step3_batch_yyy01	26.19981083	26.078125	
exp_acyclic_indvary3_step3_batch_yyy02	55.32143699	55.03125	
exp_acyclic_indvary3_step3_batch_yyy03	48.28090328	48	
exp_acyclic_indvary3_step3_batch_yyy04	94.88177878	94.46875	
exp_cycles_depvary_step1_batch_yyy01	0.011142612	0.015625	
exp_cycles_depvary_step1_batch_yyy02	0.013251917	0.015625	
exp_cycles_depvary_step1_batch_yyy03	0.055356312	0.0625	
exp_cycles_depvary_step1_batch_yyy04	0.012901735	0.015625	
exp_cycles_depvary_step2_batch_yyy01	0.026800237	0.03125	runtime
exp_cycles_depvary_step2_batch_yyy02	0.036835649	0.03125	runtime
exp_cycles_depvary_step2_batch_yyy03	0.0251302	0.015625	runtime
exp_cycles_depvary_step2_batch_yyy04	0.08595108	0.09375	
exp_cycles_depvary_step3_batch_yyy01	6.345723137	6.296875	memory
exp_cycles_depvary_step3_batch_yyy02	0.609710108	0.609375	memory
exp_cycles_depvary_step3_batch_yyy03	0.861785133	0.84375	memory
exp_cycles_depvary_step3_batch_yyy04	14.57454326	14.5	
exp_cycles_indvary1_step1_batch_yyy01	5.913476641	5.875	
exp_cycles_indvary1_step1_batch_yyy02	0.074881131	0.078125	runtime
exp_cycles_indvary1_step1_batch_yyy03	11.52084632	11.421875	runtime
exp_cycles_indvary1_step1_batch_yyy04	7.467165789	7.4375	runtime
exp_cycles_indvary1_step2_batch_yyy01	8.984435566	8.9375	runtime
exp_cycles_indvary1_step2_batch_yyy02	63.82037248	63.296875	memory
exp_cycles_indvary1_step2_batch_yyy03	4.923920531	4.921875	runtime
exp_cycles_indvary1_step2_batch_yyy04	55.04461273	54.765625	memory
exp_cycles_indvary1_step3_batch_yyy01	51.7399106	51.40625	memory
exp_cycles_indvary1_step3_batch_yyy02	26.91493197	26.78125	
exp_cycles_indvary1_step3_batch_yyy03	47.22915553	47	memory
exp_cycles_indvary1_step3_batch_yyy04	49.89344482	49.421875	memory
exp_cycles_indvary2_step1_batch_yyy01	47.87894284	47.734375	memory
exp_cycles_indvary2_step1_batch_yyy02	26.95778558	26.734375	runtime
exp_cycles_indvary2_step1_batch_yyy03	53.04542148	52.75	memory
exp_cycles_indvary2_step1_batch_yyy04	7.953339951	7.90625	
exp_cycles_indvary2_step2_batch_yyy01	45.44846039	45.15625	memory
exp_cycles_indvary2_step2_batch_yyy02	45.42555608	45.25	memory
exp_cycles_indvary2_step2_batch_yyy03	42.637643	42.453125	memory
exp_cycles_indvary2_step2_batch_yyy04	44.78569869	44.609375	memory
exp_cycles_indvary2_step3_batch_yyy01	45.72322501	45.5625	memory
exp_cycles_indvary2_step3_batch_yyy02	45.00073074	44.859375	memory

exp_cycles_indvary2_step3_batch_yyy03	44.89937246	44.71875	memory
exp_cycles_indvary2_step3_batch_yyy04	44.40590031	44.203125	memory
exp_cycles_indvary3_step1_batch_yyy01	0.209175023	0.21875	
exp_cycles_indvary3_step1_batch_yyy02	7.024880597	6.984375	
exp_cycles_indvary3_step1_batch_yyy03	0.203629991	0.203125	
exp_cycles_indvary3_step1_batch_yyy04	1.622971467	1.59375	
exp_cycles_indvary3_step2_batch_yyy01	57.07060546	56.734375	runtime
exp_cycles_indvary3_step2_batch_yyy02	3.187962514	3.1875	memory
exp_cycles_indvary3_step2_batch_yyy03	66.60766608	66.3125	memory
exp_cycles_indvary3_step2_batch_yyy04	67.3013091	66.40625	memory
exp_cycles_indvary3_step3_batch_yyy01	128.0351968	126.203125	memory & timeout
exp_cycles_indvary3_step3_batch_yyy02	106.0845602	104.828125	memory
exp_cycles_indvary3_step3_batch_yyy03	110.5838849	109.828125	memory
exp_cycles_indvary3_step3_batch_yyy04	111.7377426	110.875	memory