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**Leveraging NLP Techniques for  
Ambiguity Analysis: The AmbiTRUS Tool**

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## **KEYWORDS**

Agile Software Engineering

Ambiguity

Requirements Engineering

Requirements Quality

Software Engineering

User Stories

# CONTENTS

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1. INTRODUCTION.....	1
2. SOFTWARE DEVELOPMENT METHODOLOGY.....	2
3. SOFTWARE REQUIREMENTS AND SPECIFICATIONS.....	2
3.1 Functional Requirements .....	3
3.2 Non-functional Requirements.....	3
4. SOFTWARE DESIGN .....	3
4.1 ARCHITECTURE AND TECHNOLOGY OF AMBITRUS TOOL.....	3
4.2 THE AMBIGUITY ANALYSIS PIPELINE.....	5
4.2.1 Preprocessing .....	6
4.2.2 Syntactic Analysis .....	7
• Well-formedness analysis .....	8
• Atomicity analysis .....	9
4.2.3 Lexical Analysis .....	10
• Preciseness analysis .....	11
• Consistency analysis .....	12
4.2.4 Semantic Analysis.....	13
• Conciseness analysis .....	14
• Conceptual soundness analysis.....	15
• Uniqueness analysis.....	16
5. CONCLUSIONS.....	17
6. FUTURE WORK.....	17
7. REFERENCES.....	18
APPENDIX A PSEUDOCODE FOR CHUNKING PROCESS .....	24
APPENDIX B PSEUDOCODE FOR WELL-FORMEDNESS ANALYSIS .....	25
APPENDIX C PSEUDOCODE FOR ATOMICITY ANALYSIS.....	26
APPENDIX D PSEUDOCODE FOR PRECISENESS ANALYSIS.....	28
APPENDIX E PSEUDOCODE FOR CONSISTENCY ANALYSIS .....	32
APPENDIX F PSEUDOCODE FOR CONCISENESS ANALYSIS .....	35
APPENDIX G PSEUDOCODE FOR CONCEPTUAL SOUNDNESS ANALYSIS.....	38
APPENDIX H PSEUDOCODE FOR UNIQUENESS ANALYSIS.....	41

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## 1. INTRODUCTION

This report details the technical aspects in the development of AmbiTRUS (Ambiguity Tracking and Resolution for User Stories) tool, specifically tailored to implement the AmbiTRUS framework. The AmbiTRUS tool employs Natural Language Processing (NLP) techniques for ambiguity analysis within a set of user stories, aligning with quality criteria established within the AmbiTRUS framework (“Technical Report: The AmbiTRUS Analysis Framework” 2024). The primary objective of this report is to offer comprehensive technical insights, focusing on the NLP techniques underpinning each quality criterion, and facilitating a clear understanding of the AmbiTRUS tool functionality.

Industries have recognized the value of translating quality guidelines into a Computer-Aided Software Engineering (CASE) tool. This not only enhances software development efficiency and resource management but also ensures system robustness and reliability (Alzayed and Al-Hunaiyyan 2021; Koh and Chua 2023; Luisa et al. 2004; Osama et al. 2020; Sonbol et al. 2022; Zhao et al. 2021). However, the study presented in (Fernández et al. 2017) revealed that only 16% of companies in Europe and the US utilized automated techniques for requirements analysis, despite the known inefficiencies and error-proneness of manual analysis processes (Dalpiaz et al. 2018; Koh and Chua 2023; Riaz et al. 2019).

On the other hand, the adoption of NLP-based techniques has proven effective in enhancing problem understanding and user expectations. These techniques analyze textual requirements documents to pinpoint linguistic issues (Ezzini et al. 2022; Fantechi et al. 2023), classify functional aspects of the requirements (Dalpiaz, Dell’Anna, et al. 2019; Kocerka et al. 2022), and identify similarities between them (Alhoshan et al. 2022; Dalpiaz, van der Schalk, et al. 2019).

In this context, the AmbiTRUS tool has been developed to address these challenges. By leveraging NLP techniques, the tool efficiently detects and resolves potential ambiguity in user stories by validating against the AmbiTRUS quality criteria. Recognizing the subjective nature of ambiguity, the tool offers semi-automatic analysis, empowering users to select relevant criteria and validate results before implementation.

Moreover, the tool incorporates a machine-learning-based recommendation system and an automatic calculation feature to enhance the effectiveness of ambiguity analysis. These features not only enhance the tool’s performance but also facilitate an examination of the alignment between tool-generated recommendations and user opinions. Consequently, a thorough evaluation of how well the tool meets user expectations.

This report will discuss the methodology used in the development of the AmbiTRUS tool, NLP techniques that support the validation of the quality criteria, and the practical implementation of the AmbiTRUS in analyzing ambiguity in user stories.

## 2. SOFTWARE DEVELOPMENT METHODOLOGY

The tool development started with the careful selection of relevant NLP techniques. The selection process involved a thorough review of the literature on identifying user story ambiguity using NLP. The outcome of this review was translated into a set of tool functionalities that was then implemented within a Jupyter Notebook. These functionalities were tested using an open-source dataset sourced from <https://data.mendeley.com/datasets/7zbk8zsd8y/1>, encompassing over 1000 user stories from 23 domains (Dalpiaz, van der Schalk, et al. 2019). Based on the test results, the tool functionalities underwent iterative review to ensure alignment with the AmbiTRUS quality criteria.

Next, to enhance usability and encourage user adoption, we transformed the previously defined Jupyter Notebook tool functionalities into a more user-friendly web application. A web-based tool that facilitates a more comfortable analysis of user stories was developed utilizing the Django framework. Additionally, the tool functionality was expanded by incorporating a user feedback mechanism. Users were provided with the opportunity to express their opinions on the recommendations provided by the tool for rewriting user stories identified as potentially ambiguous. To assist users in this process, a glossary was integrated to assist users in the selection of standard terminology for rewriting user stories. This iterative approach aimed to ensure that the tool is not only effective but also user-friendly, increasing user satisfaction and engagement.

The development of the tool adopted a Design Science approach (Hevner et al. 2004), with iterative improvements based on feedback obtained during the empirical usability testing conducted between September and November 2023 (Figure 1).

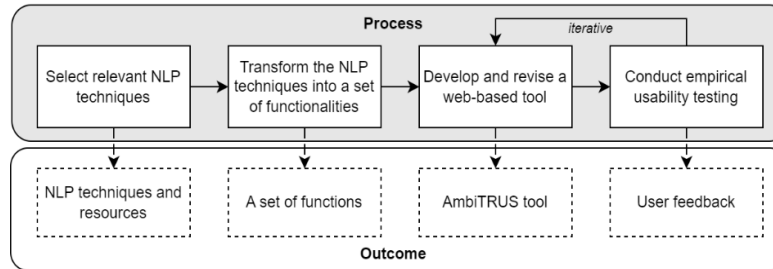


Figure 1. The development process of AmbiTRUS tool-based method

## 3. SOFTWARE REQUIREMENTS AND SPECIFICATIONS

AmbiTRUS tool is designed with a primary focus on analyzing ambiguity in a set of user stories. The tool's development is driven by the following objectives:

- Analyzing ambiguity in a set of user stories
- Refining user stories that are flagged as “potentially ambiguous”

- Evaluating level of agreement with the results generated by the tool
- Customizing quality criteria that users wish to analyze

These objectives have been broken down into software requirements, which further have been broken down into functional and non-functional requirements.

### 3.1 Functional Requirements

- The AmbiTRUS must capable of performing a thorough examination of ambiguity presents in user stories in accordance with the AmbiTRUS framework quality criteria.
- The AmbiTRUS must capable of providing recommendations for the purpose of user stories refinement for those that are identified as “potentially ambiguous”.

### 3.2 Non-functional Requirements

- The AmbiTRUS tool should enable users to assess their level of agreement with the outcomes generated by the tool to evaluate the analysis and refinement results.
- The AmbiTRUS tool should provide flexibility and customization to select quality criteria that users wish to analyze.

## 4. SOFTWARE DESIGN

### 4.1 ARCHITECTURE AND TECHNOLOGY OF AMBITRUS TOOL

The AmbiTRUS tool has two versions. Version 1.0 focuses on identifying ambiguity issues in the *WHO* and *WHAT* segments while excluding the *WHY* segment. This version analyzes potential ambiguity and provides results based on the entire set of quality criteria outlined in the AmbiTRUS framework. Version 1.1, on the other hand, includes the *WHY* segment, recognizing that syntactic ambiguity in this segment could affect understanding (Wautelet et al. 2017). Version 1.1 also streamlines the analysis process and reduces the time users spend reviewing results by using a hierarchical method. This new approach decreases the notification of “potential ambiguity” in user stories from multiple notifications to a single notification, as it requires user stories to meet the earlier criteria before moving to the next level of analysis (Figure 2).

Regardless of the versions, the tool operates through four main stages: preprocessor, analyzer, enhancer, and report generator (Figure 3). The **preprocessor** prepares user stories for analysis by splitting them into *WHO*, *WHAT*, and *WHY* segments.



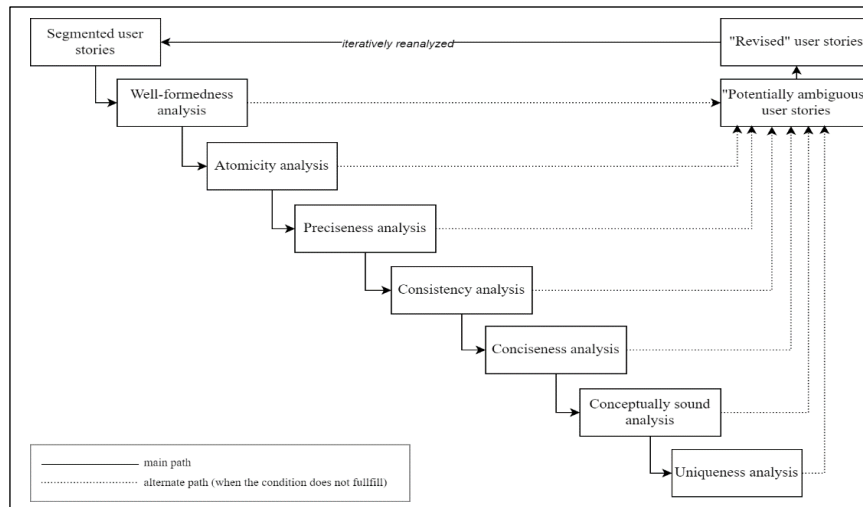


Figure 2. Hierarchical analysis procedure that is used in the AmbiTRUS tool Version 1.1.

The **analyzer** initiates the process by allowing users to choose the quality criteria they wish to assess. Once the criteria are selected, the analyzer employs a variety of NLP tools and techniques associated with the chosen criteria. This process identifies potential ambiguities in user stories and generates results accordingly.

The **enhancer** uses the analyzer results to aid users in enhancing user stories by leveraging recommendations provided by the tool to rephrase the user stories flagged as “potentially ambiguous”. The enhancer helps users improve their flagged user stories by providing recommendations for rephrasing user stories which are differently designed based on the specific criteria violated. The detailed improvement recommendations are presented in Table 1. Finally, the **report generator** allows users to download analysis results and improvements in different file formats, including .PDF, .XLS, .CSV, and .TXT.

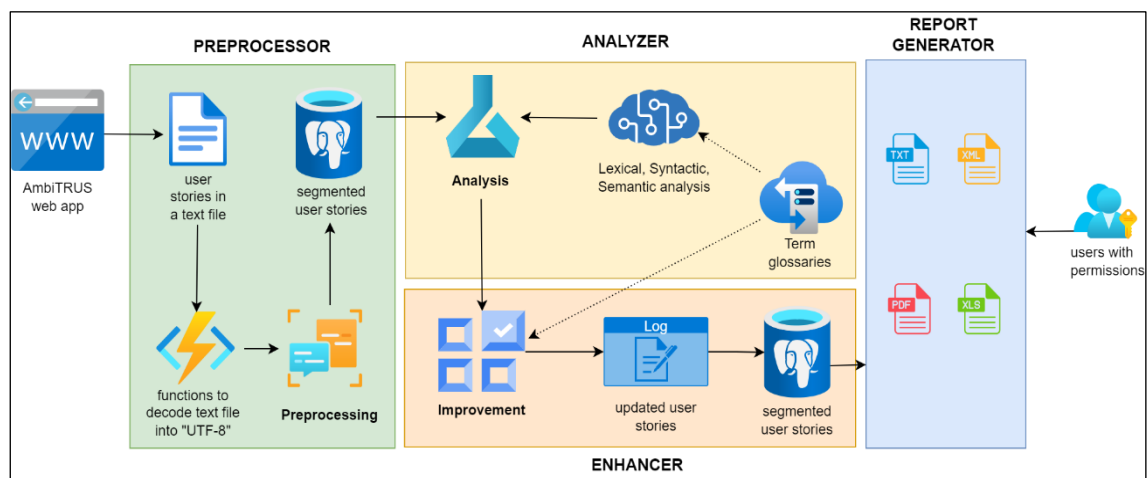


Figure 3. Components of the NLP-based tool-supported method tool: preprocessor, analyzer, enhancer, and report generator

Table 1. The expected improvement actions

Quality criteria	Action of improvement
Well-formed analysis	Rewrite user story using Connextra template, “ <i>As a [role], I want [goal], so that [benefit]</i> ”
Atomicity analysis	Split user story to remove conjunctions
Conciseness analysis	Rewrite user story to avoid subordinate clause
Preciseness analysis	Change the action in <i>WHAT/WHY</i> segment using the recommended terminology from the standard glossary
Consistent analysis	Change the role in the <i>WHO</i> segment or the actions in the <i>WHAT/WHY</i> segments using the recommended terminology
Conceptually sound analysis	Consider rewriting the user story using the recommended terminology
Uniqueness analysis	Delete one user story that has been identified as duplicate

## 4.2 THE AMBIGUITY ANALYSIS PIPELINE

An ambiguity analysis begins with an examination of the structure of the user stories to ensure their atomicity and well-formedness, as issues at this level may lead to more intricate semantic problems (Wautelet et al. 2016, 2017). Next, the tool checks the terminology used in user stories to maintain clarity and consistency (Urbieta et al. 2022). Following these processes, semantic analysis is performed to ensure that user stories express clear, consistent, and unique ideas without potentially causing ambiguities. To achieve this objective, the tool employs various NLP techniques aligned with the AmbiTRUS criteria. Figure 4 shows how the AmbiTRUS tool uses NLP technologies to identify ambiguity based on quality criteria outlined in the AmbiTRUS framework.

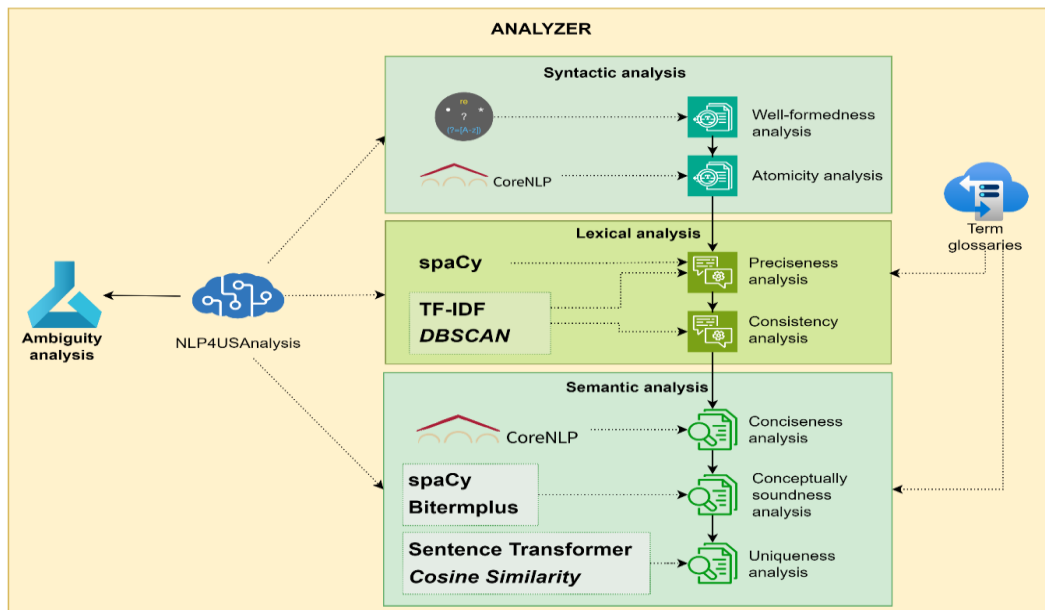


Figure 4. The pipeline of analyzer supporting AmbiTRUS tool

Our tool uses NLP techniques for basic tasks like breaking a user story sentence into tokens, analyzing the structure, and tagging Part-of-speech (POS) (Alzayed and Al-Hunaiyyan 2021; Zhao et al. 2021). We then enhanced these capabilities by integrating Machine Learning (ML) features, specifically Density-Based Spatial Clustering of Applications with Noise (DBSCAN) clustering (Deng 2020) and Biterm Topic Models (Yan et al. 2013). As a result, the tool seamlessly combines NLP and ML techniques to check for the AmbiTRUS criteria compliance. A detailed list of the NLP technologies used in the AmbiTRUS tool is outlined in Table 2.

Table 2. The criteria analysis derived from AmbiTRUS framework involving NLP

Linguistic level	Quality criteria	Library/Toolkit	Algorithm/Techniques
Syntactic	Well-formed analysis	Regular Expression	Chunking
Syntactic	Atomicity analysis	Stanford CoreNLP parser, NLTK	Tokenization, POS tagging
Lexical	Preciseness analysis	SpaCy, Scikit-learn, DBSCAN, WordNet	Tokenization, Lemmatization, DBSCAN Clustering, POS tagging
Lexical	Consistency analysis	SpaCy, Scikit-learn, DBSCAN	Tokenization, Lemmatization, DBSCAN Clustering
Semantic	Conciseness analysis	Stanford CoreNLP parser, NLTK	Tokenization, POS tagging, Dependency parsing
Semantic	Conceptually soundness analysis	SpaCy, WordNet, Bitermplus	Tokenization, Text classification, Word extraction, Dependency parsing, Biterm Topic Model
Semantic	Uniqueness analysis	Sentence Transformer	Sentence embedding, Cosine similarity, Pairwise comparison

To facilitate the improvement process, the tool is equipped with a term glossary proposed by Müter et al. (Müter et al. 2019) as a foundation for terminology classification. This glossary dynamically evolves based on user input, leveraging both the terms identified as problematic during analysis and those selected by users during the user story improvement process. If users encounter an action keyword that is not present in the glossary, they have the flexibility to add it to ensure future usability.

#### 4.2.1 Preprocessing

Preprocessing is the stage that prepares user stories for analysis. The stage consists of transforming user stories into “UTF-8” format, removing stop-words and special characters, and splitting user stories into their segments, *WHO*, *WHAT*, *WHY* (Figure 5). To remove stop-words, there are different libraries such as SpaCy (“Spacy.io” n.d.), Gensim (Řehůřek et al. n.d.), and NLTK (NLTK team n.d.). This study chooses NLTK because it is easy to use.

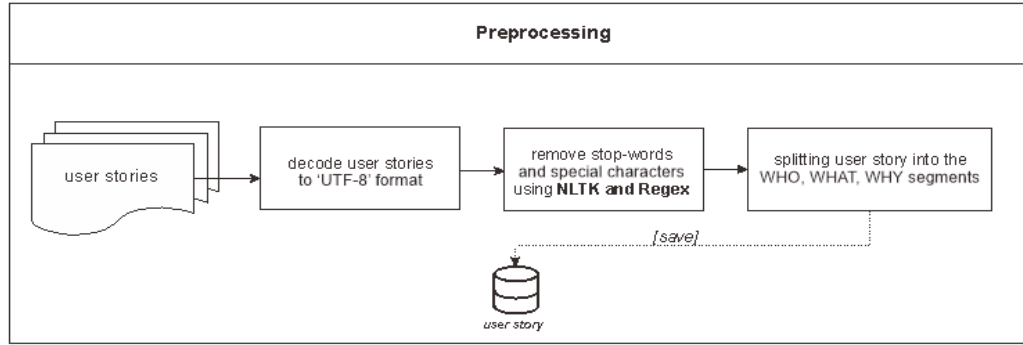


Figure 5. Activities performed in preprocessing stage.

The segmentation process focuses on splitting user stories into segments, which is known as chunking. The process iteratively reads each user story in the list using a regular expression, extracting identifiers and content related to *WHO*, *WHAT*, and *WHY* segments. As a result, a user story consists of six parts. The indicators are identified based on the list of indicators that is allowed in the Connextra template (Table 3). The full process of the chunking is presented in **Appendix A**.

Table 3. The list of supported identifiers for user story segments

Segment	Identifier
<i>WHO</i>	as an, as a, as
<i>WHAT</i>	I'm able to, I am able to, I want to, I want, I wish to, I can, I should be able to
<i>WHY</i>	so that, so, to, in order

#### 4.2.2 Syntactic Analysis

The syntactic analysis involves two parts, well-formedness analysis and atomicity analysis. In well-formedness analysis, the focus is on ensuring that user story segments are complete. This examination involves the use of regular expressions and checking for any missing segments.

In atomicity analysis, the goal is to look for coordinating conjunctions (CC) in user stories. To do this, Part-of-Speech Tagging (POS-Tagging), chunking, and dependency parsing (Sonbol et al. 2022) are used. The flow of syntactic analysis is outlined in Figure 6.

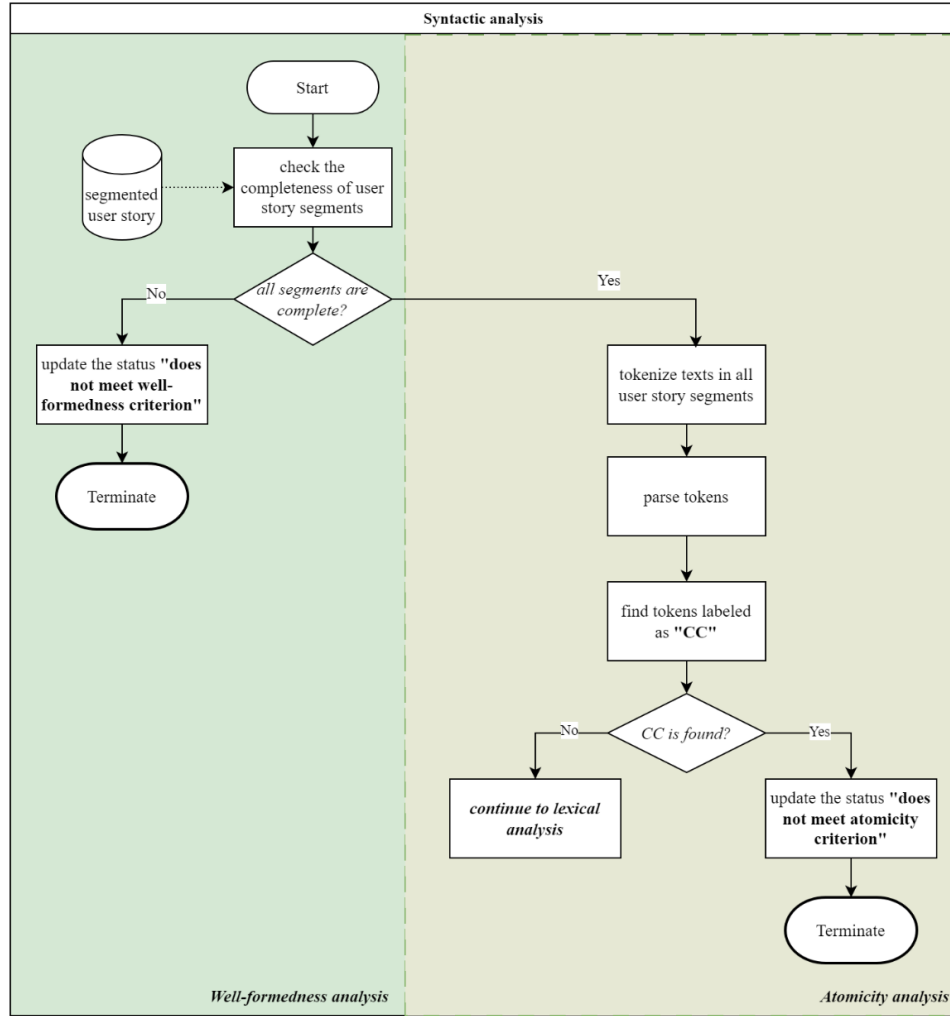


Figure 6. The outline of syntactic analysis

### • Well-formedness analysis

Well-formedness analysis is a crucial step for ensuring consistency in user stories. The analysis focuses on examining key segments of user stories, *WHO*, *WHAT*, and *WHY* segments (Gralha et al. 2022a; Murtazina and Avdeenko 2019). This analysis relies solely on the *null checking* mechanism without employing NLP techniques. The process begins by extracting various components from the user story segments. These components are then evaluated against specific conditions to assess the completeness and structural integrity of the user stories. If any components are missing or if there are syntactical errors in the structure of the user stories, the system flags them as “potentially ambiguous”. To address flagged issues, users are prompted to rewrite their user story following the Connextra template. For further reference, the algorithm of the analysis is provided in **Appendix B**, while Figure 7 illustrates the results of the well-formedness analysis.

```

Full text: as an administrator, i want to have a connection with magicdraw, so that implementation details can easily be connected to business rules.
Well-formed criteria is achieved!

Full text: as an administrator, i want to manage the format and layout of reports, so that the technical details are my responsibility.
Well-formed criteria is achieved!

Full text: i want to separate projects, so that people cannot traverse each others work.
Problem: Well-formed is not achieved ! WHO segment is not not found !
Solution: Rewrite user story in Connextra format: *As a <role>, I want <action>, so that <goal>*

Full text: administrator, i want to have branching and merging, so that i can easily make releases from the rulebase.
Problem: Well-formed is achieved ! WHO segment is not complete. WHO identifier does not found !
Solution: Rewrite user story in Connextra format: *As a <role>, I want <action>, so that <goal>*

```

Figure 7. Illustration for the well-formedness analysis

## • Atomicity analysis

Atomicity analysis ensures that each user story addresses one specific feature or function to maintain its clarity (Liskin et al. 2014; Lombriser et al. 2016). This analysis examines coordinating conjunctions (CC) in both the *WHAT* and *WHY* segments to determine if the *WHAT* segment introduces multiple functionalities needed to achieve the benefits described in the *WHY* segment (Berry and Kamsties 2004; Elallaoui et al. 2018; Gilson and Irwin 2018; Gralha et al. 2022b).

The analysis initiates by tokenizing sentences within user story segments and scrutinizing the syntactic structure of the tokens in the *WHAT* and *WHY* segments using the *Stanford CoreNLP Parser* (Group n.d.). To identify CC in these segments, the tokens undergo iterative examination until either the end of the text in the segments is reached or a CC is found (Manning et al. 2014). When a CC is found, the examination stops, shifting focus to the verb phrases preceding and following the CC. If verb phrases are identified, the atomicity analysis concludes, and the user stories are labelled as “potentially non-atomic”.

In cases where verb phrases are solely identified either before or after CC, an additional examination of the CC’s position is conducted. If CCs are present in both the *WHAT* and *WHY* segments, the user stories are labelled as “potentially non-atomic”. However, user stories are classified as “potentially atomic” when the CC is found only in either the *WHAT* or *WHY* segments and verb phrases are identified only before or after the CC. Details on this algorithm are presented in **Appendix C**, while an illustration of the atomicity analysis is shown in Figure 8.

```

Story # 64 : as an admin, i want to have a pricing plan and billing system, so that i can charge users and make my platform sustainable.
Coordinating conjunction that could trigger syntactic ambiguity: ** and **

Status: User story does not meet atomicity criterion. User story is potentially ambiguous ! It is recommended to split user story !
=====

Story # 65 : as a publisher, i want to know if this site has a pricing plan and what the prices are, so that i can work out what this will cost me in the future and have a sense that these guys are sustainable.
Coordinating conjunction that could trigger syntactic ambiguity: ** and **

Status: User story does not meet atomicity criterion. User story is potentially ambiguous ! It is recommended to split user story !
=====

```

Figure 8. Illustration for the atomicity analysis

### 4.2.3 Lexical Analysis

Lexical analysis consists of preciseness and consistency analysis. Although both use similar techniques, the goals are different. Preciseness analysis aims to detect any “noise” in user stories that could lead to “potential impreciseness”, while consistency analysis ensures that terms used in user stories are classified as “within cluster”.

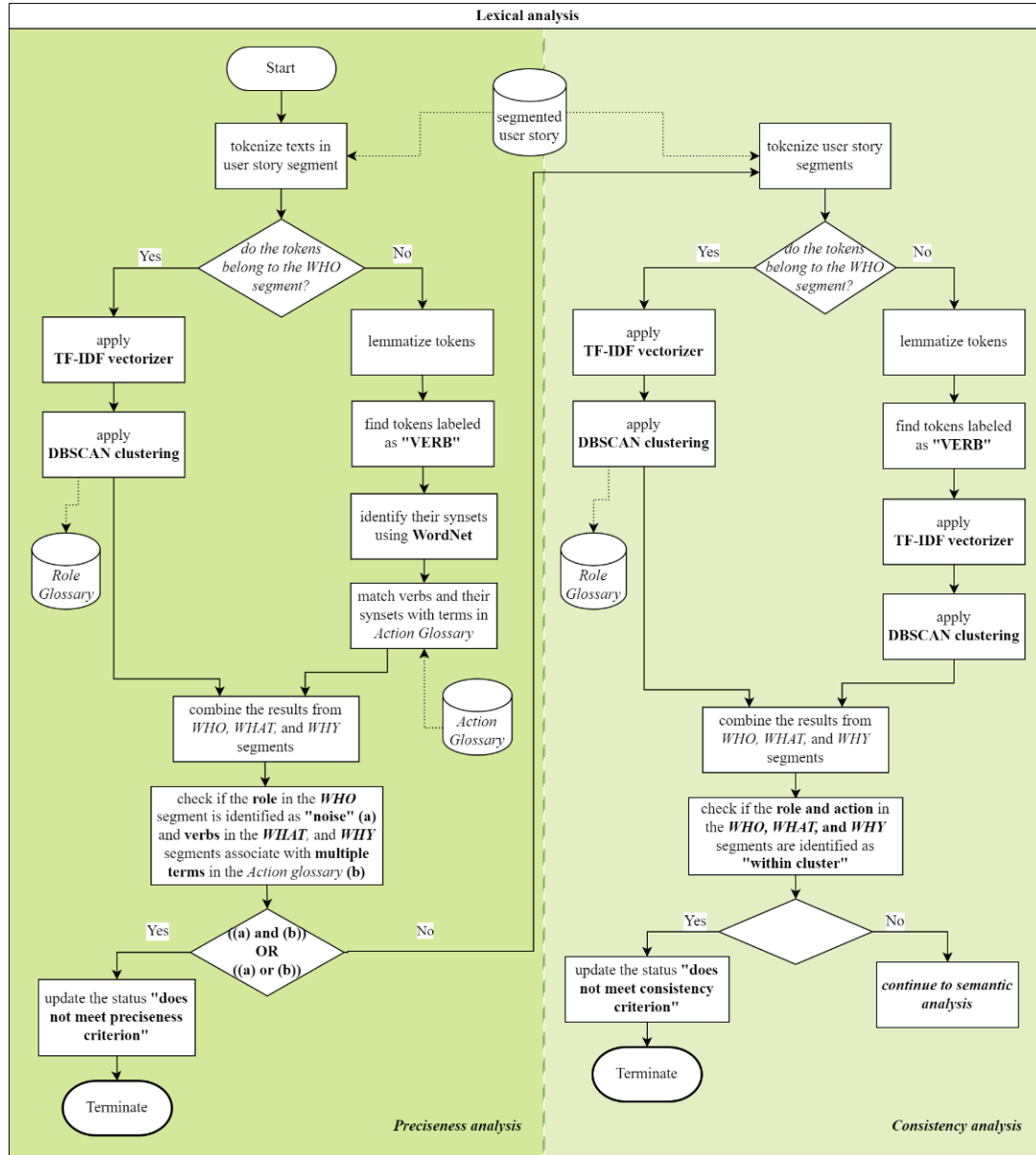


Figure 9. Illustration for preciseness and consistency analysis

The analysis uses TF-IDF to convert the *WHO* segment into vectors before employing DBSCAN clustering (Deng 2020). As a result of the clustering process, role values and the

associated cluster labels are determined. Notably, default settings of scikit-learn are applied for DBSCAN hyperparameters, including an epsilon ( $\epsilon$ ) default value of 0.5, and the minimum number of points (minPts) is set to 2.

In the *WHAT* and *WHY* segments, the SpaCy library identifies morphological features and *verbs*. However, these verbs are treated differently according to the analysis that has been conducted. Detailed procedures for preciseness and consistency analysis are illustrated in Figure 8.

## • Preciseness analysis

Preciseness analysis is conducted to ensure clarity in user stories (Müter et al. 2019; Urbietta et al. 2022). This analysis involves examining terminology within user stories. The *WHO* segment uses unique domain context for actor description, while the *WHAT* and *WHY* segments use standard terms from the glossary to represent actions. This approach prevents different interpretations of action execution by identifying frequent *nouns* in the *WHO* segment and evaluating similarities between *verbs* in the *WHAT* and *WHY* segments and the predefined terms in the standard glossary. This process aims to associate verbs with a singular term class in the glossary.

The analysis starts with tokenizing texts in user story segments, followed by different processes according to the segments. In the *WHO* segment, the tokens are vectorized using TF-IDF (Das et al. 2021; Liu et al. 2022) before being clustered using DBSCAN clustering (Murugesan et al. 2021). Instances that are identified as “noisy” by the DBSCAN clustering are classified as the candidates of “potentially imprecise” user stories.

In the *WHAT* segment, tokens undergo an iterative process. Initially, they are lemmatized to obtain the base form of the text. Subsequently, the lemmas are analyzed to determine their labels using the *SpaCy* library. If a token is identified as a *verb*, both the verb and its lemma are added to their respective lists. To precisely associate the verb with a specific action, it is mapped with the word class terminology from the **action glossary** (Table 4). When the word class is found, the verb along with its lemma is then linked to its corresponding keywords in the glossary. If no word class is identified, the lemma is compared with synsets from WordNet (Miller 1995), and similar processes are followed for classification and mapping.

Table 4. The list of the predefined terminology representing the class of actions, later referred to as the “action glossary” (Müter et al. 2019).

Keyword class	Keyword Item
Create	add, insert, create, make, build, develop, establish, generate, construct, invite
Read	view, read, display, show, retrieve, get, access, examine, browse
Update	modify, edit, change, update, revise, alter, adjust, adapt, refine, fix, improve, renew, replace
Delete	remove, delete, erase, clear, eliminate, exclude, discard, purge, drop
Merge	bind, export, integrate, link, list, offer
Validate	check, evaluate, test, verify
Search	investigate, inquire, research, search



The assessment of user story preciseness relies on the *WHO*, *WHAT*, and *WHY* segments. A user story is considered satisfactory if the *noun* or *noun phrase* in the *WHO* segment is not identified as noise in cluster analysis, and if each *verb* in both *WHAT* and *WHY* segments is associated with a single action from the **action glossary**. Otherwise, a user story is labelled “potentially imprecise” if it fails to meet both conditions. The algorithm outlining this analysis is presented in **Appendix D**, and the results are illustrated in Figure 10.

```

Story # 28 : as a consumer, i want to see some example data packages quickly, so that i get a sense of what is on this site and if it is useful to look further.
Role: consumer
Action: to see some example data packages quickly
Status: The preciseness criterion is not achieve !
Recommendation: Please change the word of action using recommended terms!

Problematic terms:
Action: ['see']

Recommended terms:
Action: ['read', 'validate']
=====

Story # 32 : as a developer, i want to use data package as a node lib in my project, so that i can depend on it using my normal dependency framework.
Role: developer
Action: to use data package as a node lib in my project
Status: The preciseness criterion is not achieve !
Recommendation: Please change the word of action !

Problematic terms:
Action: ['use']

Recommended terms:
Action: sorry, we do not have a recommendation. could you please provide me with some suggestions.
=====

Story # 38 : as a web developer, i want to be able to install multiple versions of the same datapackage separately, so that all my projects could be developed independently and deployed locally.
Role: web developer
Action: to be able to install multiple versions of the same datapackage separately
Status: The preciseness criterion might not achieve ! The role is not standard !
Recommendation: Please review the role !
Problematic terms:
Role: web developer

Recommended terms:
Role: ['publisher', 'admin', 'consumer', 'developer', 'data analyst', 'owner']
=====

Story # 54 : as a consumer, i want to search among all data packages, so that i can easily find one data package amongst all the data packages by this publisher.
Role: consumer
Action: to search among all data packages
Status: The preciseness criterion is achieved !
Recommendation: User story is fine.
Problematic terms:
Action: ['search']

Recommended terms:
Action: ['search']
=====

```

Figure 10. Illustration for preciseness analysis

## • Consistency analysis

Consistency analysis is performed to ensure that a user story uses consistent terms to describe the same actor or similar behaviour in the same set of user stories. According to the Agile Requirements Verification Framework, it is essential to maintain project-specific glossaries and abbreviations to ensure consistency and correctness in agile requirements artifacts (Heck and Zaidman 2014). This finding is similar to other studies that recommend the use of standard glossaries to describe actors and behavioural responses (Müter et al. 2019; Urbietta et al. 2022). However, although consistency analysis and preciseness analysis follow similar processes, this analysis uses the results from the DBSCAN clustering in a different way.

The analysis starts by tokenizing the *WHO*, *WHAT*, and *WHY* segments using SpaCy. Subsequently, tokens in the *WHO* segment are converted into vectors using TF-IDF vectorization (Liu et al. 2022). The vectors are then clustered using DBSCAN clustering (Murugesan et al. 2021), resulting in role values and associated cluster labels.

In the *WHAT* and *WHY* segments, tokens are iteratively lemmatized and inspected to identify *verbs*. The verbs obtained are then vectorized using TF-IDF and clustered to evaluate whether the verbs belong to any cluster labels.

The consistency analysis yields the results by considering the results of DBSCAN clustering performed in the entire user stories segments (i.e., *WHO*, *WHAT*, and *WHY*). User stories are considered non-ambiguous when the *WHO*, *WHAT*, and *WHY* segments are identified as “within cluster”. Otherwise, they are considered “potentially inconsistent”. The algorithm outlining this analysis is presented in **Appendix E**, and the anticipated results are illustrated in Figure 11.

```

Story # 11 : as an hrd manager, i want to select date and month and year, so that i can see who take days off and how long.
Role: hrd manager
Action: to select date and month and year
Status: Consistency criterion is not achieved. User role is not consistent.
User story is potentially ambiguous!
Recommendation: Change the user role using the same terminology.
Problematic terms: hrd manager
Recommendation terms:
Terms for role: {0: [' developer'], 1: [' business user'], 2: [' ruleauthor'], 3: [], 4: [' terminator'], 5: [' ruleanalys
t'], 6: [' administrator', 'administrator', '']}

-----

Story # 12 : as a ruleauthor, i want to filter the list per rulebase with a new or existing filter, so that i can quickly fi
nd what i am looking for.
Role: ruleauthor
Action: to filter the list per rulebase with a new or existing filter
Status: Consistency criterion is achieved. User story is good.
Recommendation: pass

```

Figure 11. Illustration for the consistency analysis

#### 4.2.4 Semantic Analysis

Semantic analysis focuses on comprehending user stories’ meanings. The analysis can be examined through the consistency of user stories when they are transformed into conceptual models and scrutinizing the user story description to deliver contextual information (Amna and Poels 2022).

The analysis encompasses three key aspects, which are conciseness analysis, conceptual soundness, and uniqueness analysis. Conciseness analysis aims to identify implicit meanings within user stories by examining the presence of subordinate conjunctions. While often considered as a syntactic criterion (Heck and Zaidman 2014; Lucassen et al. 2016), issues arising from the appearance of subordinate conjunction (SBAR) extend into semantics as this may prevent the establishment of clear contexts (De Araujo and Siqueira 2016; Berry and Kamsties 2004; Wautelet et al. 2017).

Conceptual soundness involves categorizing user stories into particular topics to ensure clarity and prevent user stories from being underspecified or missing (Tiwari et al. 2020).

This analysis is facilitated by the BiTerm topic model which is well-suited for short text analysis (Yan et al. 2013).

Uniqueness analysis focuses on identifying similarities between user stories to mitigate duplication. This analysis employs Sentence Transformer<sup>1</sup> and Cosine similarities to identify similar user stories by extracting linguistics annotations from user story segments. The flow of the analysis is outlined in Figure 12.

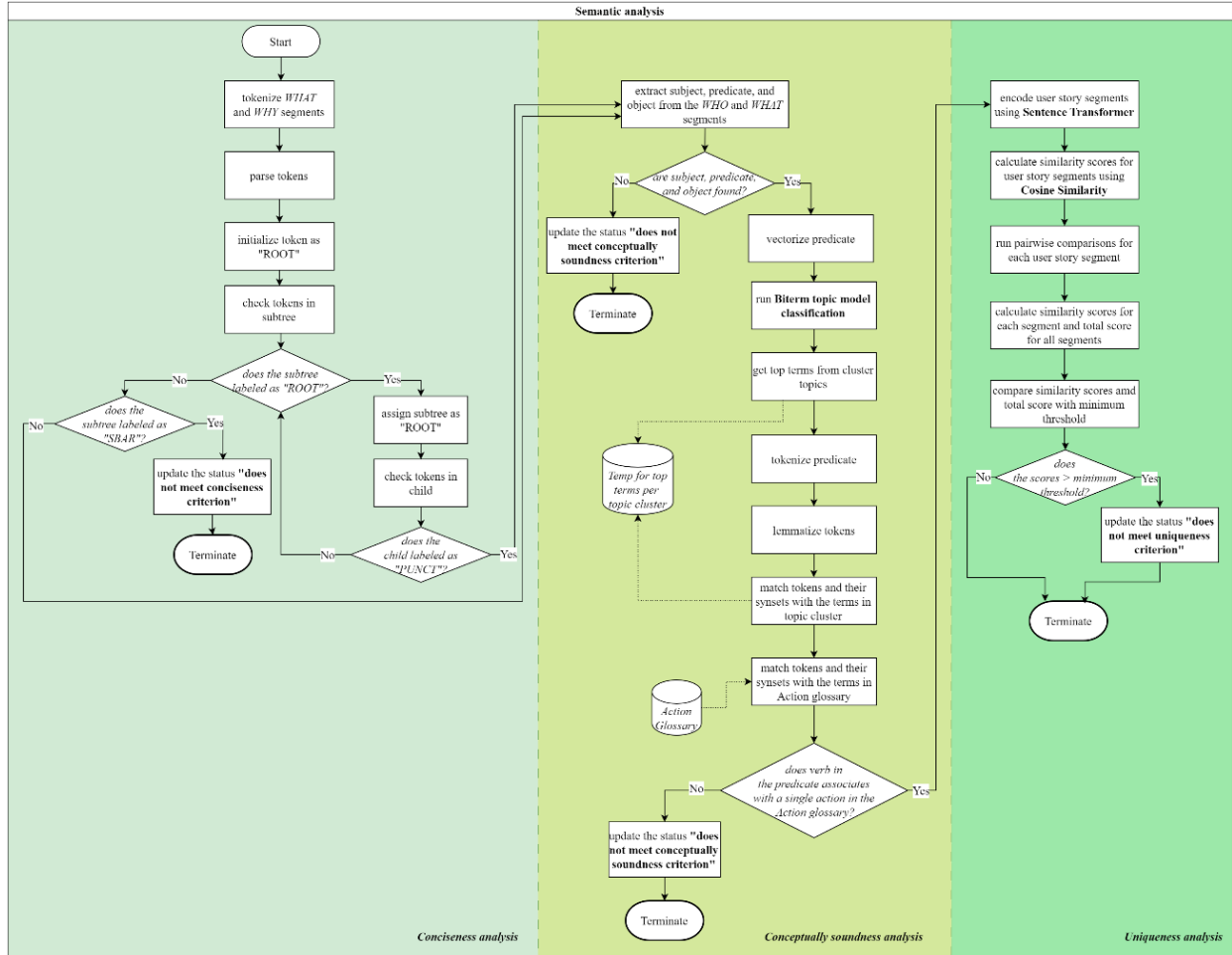


Figure 12. The outline of semantic analysis

### • Conciseness analysis

Conciseness analysis is a process for ensuring that user stories convey the expected features/objects/functionalities clearly and concisely to prevent unintentionally omitting features or functionalities (Berry 2021; Ribeiro and Berry 2020). This process examines the presence of subordinating conjunctions (SBAR) that are sometimes added to provide additional information to clarify the connections among comprehension of logical

<sup>1</sup> <https://www.sbert.net/>

relationships, general vocabulary knowledge, and reading comprehension, but which could make information in user stories less concise (Fraser et al. 2021; Lucassen et al. 2016).

The analysis is conducted specifically to user stories meeting the consistent terminology criterion. Unlike other analyses, conciseness analysis is employed in the *WHAT* and *WHY* segments of user stories, where this information is mainly presented. The analysis starts with tokenization and is followed by parsing the tokens to identify the root of the parsed *WHAT* and *WHY* segments and to identify the presence of SBAR in the sentence. These processes are performed using the *Stanford CoreNLP Parser*.

The adherence of user stories to the conciseness criterion is determined by the presence of SBAR in the *WHAT* and *WHY* segments. User stories with the SBAR in both segments are considered as “potentially ambiguous” and “do not meet the conciseness criterion”, while those having SBAR in the *WHAT* segment are considered as “does not potentially ambiguous” even though it “does not meet conciseness criterion”. This decision is motivated by the explanation of the *minimal* criterion in the QUS framework, which primarily requires the *WHO* and *WHAT* segments to be concise (Lucassen et al. 2016). The algorithm constructing conciseness criterion analysis is presented in **Appendix F**, and the illustration of the expected results is presented in Figure 13.

```

Story # 31 : as a ruleanalyst, i want to have an overview of all rulebase parts that have been reused, so that i can see wha
t the external dependencies are.

Subordinate conjunction that could trigger semantic ambiguity: ** that have been reused **
Status: User story does not meet conciseness criterion.
User story is potentially ambiguous ! It is recommended to remove subordinate conjunction !
=====
Story # 33 : as a ruleanalyst, i want to have an impact report, so that i can estimate the impact of a future change.

Status: User story meet conciseness criterion.
User story is not potentially ambiguous !
=====
Story # 34 : as a ruleanalyst, i want to see per business rule in what form and how much of it has been implemented, so that
is in known what is implemented from the rulebase.

Subordinate conjunction that could trigger semantic ambiguity: ** how much of it has been implemented **
Status: User story does not meet conciseness criterion.
User story is potentially ambiguous ! It is recommended to remove subordinate conjunction and split the user story !
=====

```

Figure 13. Illustration of the conciseness analysis

## • Conceptual soundness analysis

A thorough analysis is performed to assess whether user stories effectively communicate the necessary actions for delivering requested objects, features, or functionalities. This involves identifying *verb* and *noun phrases* in the *WHO* and *WHAT* segments, classifying user stories, and ensuring each user story expresses a single action towards one object/feature/functionality.

The SpaCy library was employed for component extraction, focusing on extracting *verb/verb phrases* and *noun/noun phrases* in *WHAT* segments representing predicates and objects. The extracted predicate was then vectorized and classified using the Biterm topic model (Yan et al. 2013). To ensure each user story represents a single action delivering one feature/functionality, the *verb/verb phrases* and their synsets in user story predicates were

examined through sentence matching using the **action glossary**. This sentence-matching process follows similar steps to the one performed in the preciseness analysis.

User stories are considered as “potentially ambiguous” and do not meet the conceptual soundness criterion when their *verb/verb phrase* is not associated with a single action from the **action glossary**. However, this problem can be resolved by referring to other user stories classified by the same topic to predict the intended actions that need to be addressed by “potentially underspecified” user stories. The illustration of the conceptual soundness analysis is depicted in Figure 14, and the algorithm is presented in **Appendix G**.

```

Story # 2 : as a publisher, i want to publish a dataset, so that i can share the dataset publicly with everyone.
Subject: publisher
Predicate: to publish
Object: a dataset
Topic # 7
Action terms: {}
Status: The user story is potentially ambiguous. It might be underspecified.
Recommendation: Rewrite the user story !
=====

Story # 23 : as a publisher, i want to show the world how my published data is, so that it immediately catches consumer's attention.
Subject: publisher
Predicate: to show how my published data is
Object: the world
Topic # 7
Action terms: {'show': ['read']}
Status: user story is fine !
=====

Story # 52 : as a consumer, i want to see a publisher's profile, so that i can discover their packages and get a sense of how active and good they are.
Subject: consumer
Predicate: to see a publisher's profile
Object: a publisher's profile
Topic # 7
Action terms: {'see': ['validate', 'read']}
Status: The user story is potentially ambiguous. It might be wrongly decode.
Recommendation: Rewrite the predicate using one of these term : ['validate', 'read']
=====

```

Figure 14. Illustration of the conceptually sound analysis

## • Uniqueness analysis

This analysis is performed to detect potential similarities among user stories. The analysis focused on examining *WHO*, *WHAT*, and *WHY* segments in user stories. The *Sentence Transformer* model, specifically “all-MiniLM-L6-v2” (“Sentence Transformer” n.d.) is employed to encode these segments, and *Cosine similarity* (Han et al. 2012) is used to compute similarity scores.

The cosine similarity metric measures the similarity between user story segments. Iterative pairwise comparisons are performed for each combination of user stories, distinctively for the three segments, resulting in similarity scores that reflect the degree of similarity between them. It is noteworthy to mention that this study adopts a uniform minimum threshold of 0.6 for all user story segments.

The chosen threshold of 0.6 serves as a critical determinant to assess adherence to the uniqueness criterion. User stories with similarity scores above this threshold is flagged as

potentially ambiguous. Importantly, users have the flexibility to independently modify this threshold in the tool, offering adaptability to specific project requirements.

Figure 15 represents the outcome of the uniqueness analysis, providing a clear depiction of the relationships between user stories. A detailed understanding of the algorithm employed in this analysis can be found in **Appendix H**.

```

Story #21: as a consumer, i want to view a data package online, so that i can get a sense of whether this is the dataset i want.
Story #23: as a consumer, i want to view the data package, so that i can get a sense of whether i want this dataset or not.
Role 1: consumer
Role 2: consumer
Similarity score in role: 1.0

Action 1: to view a data package online
Action 2: to view the data package
Similarity score in action: 0.8534

Goal 1: i can get a sense of whether this is the dataset i want.
Goal 2: i can get a sense of whether i want this dataset or not.
Similarity score in goal: 0.9299

Total similarity score: 0.9278
User stories are potentially duplicate. These are potentially ambiguous !
Please remove one user story!
=====

Story #50: as a consumer, i want to browse and find publishers, so that i can find interesting publishers and their packages.
Story #53: as a consumer, i want to search among all data packages owned by a publisher, so that i can easily find one data package amongst all the data packages by this publisher.
Role 1: consumer
Role 2: consumer
Similarity score in role: 1.0

Action 1: to browse and find publishers
Action 2: to search among all data packages owned by a publisher
Similarity score in action: 0.5202

Goal 1: i can find interesting publishers and their packages.
Goal 2: i can easily find one data package amongst all the data packages by this publisher.
Similarity score in goal: 0.4575

Total similarity score: 0.6592
User stories meet uniqueness criterion !
User stories are unique !
=====

```

Figure 15. Illustration of the uniqueness analysis

## 5. CONCLUSIONS

The development of the AmbiTRUS tool represents a significant advancement as an operationalization of the AmbiTRUS framework. It was designed to improve the framework's effectiveness and usability, and the productivity of its users, by transitioning from a manual review of user story quality criteria to a semi-automated approach. This was accomplished through the integration of various NLP technologies.

However, the AmbiTRUS tool does have limitations. Notably, the tool is restricted to a single user story template, namely Connextra template. These limitations constrain its applicability and functionality, suggesting areas for future development and improvement.

## 6. FUTURE WORK

Our study confirms the significant impact of the AmbiTRUS tool on enhancing user performance and efficiency in identifying potential ambiguity in user stories. However, it

also sheds light on certain limitations of the tool, particularly in its effectiveness, and areas for improvement.

To establish a benchmark for the AmbiTRUS tool, it is essential to evaluate a version of the tool that includes an analysis of the *WHY* segment (i.e., version 1.1). This evaluation will provide more comprehensive results regarding the effectiveness of the tool in analyzing potential ambiguity in a set of user stories. Integrating the manual glossary with an LLM such as ChatGPT could offer more improvement recommendation options. Additionally, simplifying the user interface (UI) by incorporating colour-coded highlighting can significantly improve the visualization of the review process and enhance the overall user experience.

It is essential to explore the tool’s potential to improve awareness of potential ambiguity in user stories among novice users, including requirements engineers and business analysts. Employing eye-tracking technology can offer valuable insights into the cognitive process of the tools’ users during user story ambiguity analysis. Integrating the tool into training or certification programs can help assess its impact on participant understanding and skills. Furthermore, sharing insights from our study can enrich education in requirements engineering classes, fostering a deeper understanding of ambiguity issues and practical tools for addressing them.

In conclusion, addressing the identified limitations and enhancing the AmbiTRUS tool are critical steps towards improving user efficiency, satisfaction, and awareness. By implementing these recommendations, we can further advance the capabilities and impact of the tool in addressing potential ambiguity in user stories.

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## APPENDIX A PSEUDOCODE FOR CHUNKING PROCESS

<b>Algorithm 1:</b> Function to chunk user stories into user story segments	
<b>Input:</b> User stories	
<b>Output:</b> List of user story segment	
1:	function chunk_user_stories(user_story_list):
2:	<b>user_story_segment</b> $\leftarrow$ empty list
3:	<b>for each</b> userstory_id <b>in</b> user_story_list <b>do</b>
4:	who_identifier $\leftarrow$ extract_who_identifier (userstory_id)
5:	who_content $\leftarrow$ extract_who_content (userstory_id)
6:	what_identifier $\leftarrow$ extract_what_identifier (userstory_id)
7:	what_content $\leftarrow$ extract_what_content (userstory_id)
8:	why_identifier $\leftarrow$ extract_why_identifier (userstory_id)
9:	why_content $\leftarrow$ extract_why_content(userstory_id)
10:	<b>segment_data</b> $\leftarrow$ {
11:	"userstory_id": userstory_id,
12:	"who_identifier": who_identifier,
13:	"who_content": who_content,
14:	"what_identifier": what_identifier,
15:	"what_content": what_content,
16:	"why_identifier": why_identifier,
17:	"why_content": why_content,
18:	}
19:	user_story_segments.append(segment_data)
10:	<b>end for</b>
11:	<b>return</b> user_story_segments
12:	<b>end function</b>

## APPENDIX B PSEUDOCODE FOR WELL-FORMEDNESS ANALYSIS

<b>Algorithm 2:</b> Determine violation of the well-formedness criteria in user stories	
<b>Input:</b> List of user story segment	
<b>Output:</b> IsProblem	
1:	<b>function</b> identify_ambiguity(user_story_segments):
2:	who_identifier_text $\leftarrow$ “ ”
3:	who_user_text $\leftarrow$ “ ”
4:	who_full $\leftarrow$ user_story_segment.who_full
5:	<b>if</b> who_full is not <b>None</b> <b>then</b>
6:	who_identifier_text $\leftarrow$ lower(who_full.who_identifier) <b>if</b> who_full.who_identifier is not <b>None</b> <b>else</b> “ ”
7:	who_user_text $\leftarrow$ lower(who_full.who_user) <b>if</b> who_full.who_user is not <b>None</b> <b>else</b> “ ”
8:	<b>end if</b>
9:	what_identifier_text $\leftarrow$ “ ”
10:	what_user_text $\leftarrow$ “ ”
11:	what_full $\leftarrow$ user_story_segment.what_full
12:	<b>if</b> what_full is not <b>None</b> <b>then</b>
13:	what_identifier_text $\leftarrow$ lower(what_full.what_identifier) <b>if</b> what_full.what_identifier is not <b>None</b> <b>else</b> “ ”
14:	what_user_text $\leftarrow$ lower(what_full.what_user) <b>if</b> what_full.what_user is not <b>None</b> <b>else</b> “ ”
15:	<b>end if</b>
16:	why_identifier_text $\leftarrow$ “ ”
17:	why_user_text $\leftarrow$ “ ”
18:	why_full $\leftarrow$ user_story_segment.why_full
19:	<b>if</b> why_full is not <b>None</b> <b>then</b>
20:	why_identifier_text $\leftarrow$ lower(why_full.why_identifier) <b>if</b> why_full.why_identifier is not <b>None</b> <b>else</b> “ ”
21:	why_user_text $\leftarrow$ lower(why_full.why_user) <b>if</b> why_full.why_user is not <b>None</b> <b>else</b> “ ”
22:	<b>end if</b>
23:	isProblem $\leftarrow$ False
24:	<b>if</b> (
25:	who_identifier_text is empty or who_user_text is empty
26:	what_identifier_text is empty or what_user_text is empty
27:	why_identifier_text is empty or why_user_text is empty
28:	) <b>then</b>
29:	isProblem $\leftarrow$ True
30:	<b>end if</b>
31:	<b>return</b> isProblem
32:	<b>end function</b>

## APPENDIX C PSEUDOCODE FOR ATOMICITY ANALYSIS

<b>Algorithm 3:</b> Find CC and verb after CC in WHO, WHAT and WHY segments of user stories	
<b>Input:</b> List of <i>WHO</i> , <i>WHAT</i> , and <i>WHY</i> segments	
<b>Output:</b> List of segments containing CC and the verb after CC	
1:	<b>function</b> find_cc_with_verb(who_segments, what_segments, why_segments):
2:	cc_with_verb_segments $\leftarrow$ empty list
3:	isProblem $\leftarrow$ false
4:	<b>for</b> who_segment in who_segments:
5:	who_text $\leftarrow$ who_segment["text"]
6:	cc_and_verb $\leftarrow$ find_cc_and_verb(who_text)
7:	<b>if</b> cc_and_verb:
8:	cc_with_verb_segments.append({
9:	"segment_type": "who",
10:	"segment_text": who_text,
11:	"cc_text": cc_and_verb["cc_text"],
12:	"verb_after_cc": cc_and_verb["verb_after_cc"]
13:	})
14:	<b>for</b> what_segment in what_segments:
15:	what_text $\leftarrow$ what_segment["text"]
16:	cc_and_verb_what $\leftarrow$ find_cc_and_verb(what_text)
17:	<b>if</b> cc_and_verb_what:
18:	cc_with_verb_segments.append({
19:	"segment_type": "what",
20:	"segment_text": what_text,
21:	"cc_text": cc_and_verb_what["cc_text"],
22:	"verb_after_cc": cc_and_verb_what["verb_after_cc"]
23:	})
24:	<b>for</b> why_segment in why_segments:
25:	why_text $\leftarrow$ why_segment["text"]
26:	cc_and_verb_why $\leftarrow$ find_cc_and_verb(why_text)
27:	<b>if</b> cc_and_verb_why:
28:	cc_with_verb_segments.append({
29:	"segment_type": "why",
30:	"segment_text": why_text,
31:	"cc_text": cc_and_verb_why["cc_text"],
32:	"verb_after_cc": cc_and_verb_why["verb_after_cc"]
33:	})
34:	<b>if</b> (
35:	(cc_and_verb_why["verb_after_cc"] <b>is not</b> None) <b>and</b>
36:	(cc_and_verb_why["cc_text"] == cc_and_verb_what["cc_text"])
37:	):

38:	isProblem $\leftarrow$ True
39:	return cc_with_verb_segment, isProblem

40:	<b>function</b> find_cc_and_verb(segment_text):
41:	tokens $\leftarrow$ tokenize(segment_text)
42:	parsed_sentence $\leftarrow$ parse_with_corenlp(tokens)
43:	<b>for</b> subtree <b>in</b> parsed_sentence.subtrees():
44:	<b>if</b> subtree.label() == "CC":
45:	vc_text $\leftarrow$ subtree.leaves()[0]
46:	verb_after_cc $\leftarrow$ find_verb_after_cc(subtree, parsed_sentence)
47:	<b>return</b> {"cc_text": cc_text, "verb_after_cc": verb_after_cc}
48:	<b>return</b> None
49:	
50:	<b>function</b> find_verb_after_cc(cc_subtree, parsed_sentence):
51:	<b>for</b> idx, sibling <b>in</b> enumerate(cc_subtree.rights()):
52:	<b>if</b> sibling.label().startswith("VB"):
53:	<b>return</b> sibling.leaves()[0]
54:	<b>elif</b> sibling.label() == "CC":
55:	<b>continue</b>
56:	<b>else:</b>
57:	<b>return</b> search_for_verb_below(sibling, parsed_sentence)
58:	<b>return</b> None
59:	
60:	<b>function</b> find_verb_below(subtree, parsed_sentence):
61:	<b>for</b> child <b>in</b> subtree:
62:	<b>if</b> child.label().startswith("VB"):
63:	<b>return</b> child.leaves()[0]
64:	<b>elif</b> len(list(child.subtrees())) > 0:
65:	<b>return</b> search_for_verb_below(sibling, parsed_sentence)
66:	<b>return</b> None



## APPENDIX D PSEUDOCODE FOR PRECISENESS ANALYSIS

---

### Algorithm 4: Function to determine preciseness in the *WHO* segment

---

**Input:** well\_formed\_data

---

**Output:** dic\_sub

---

```

1:  function actor_precise():
2:      role_s_values ← empty list
3:      role_s_text ← empty list
4:      userstory_values ← empty list
5:      for each item in well_formed_data do
6:          role_s_values.append(item.actor.who_action)
7:          role_s_text.append(item.userstory)
8:          userstory_values.append(item.userstory_obj)
9:      vectorizer ← create_tfidf_vectorizer(role_s_values)
10:     labels ← apply_dbscan_clustering(vectorizer)
11:     dic_sub ← group_and_print_clusters(role_s_values, role_s_text, userstory_values, labels)
12:  return dic_sub

```

---



---

### Algorithm 5: Classify Sentence Function

---

**Input:** well\_formed\_data

---

**Output:** sentence\_classifications

---

```

1:  function classify_sentence():
2:      sentence_classifications ← empty list
3:      keyword_to_sentence_class ← empty dictionary
4:      for each item in well_formed_data do
5:          text ← item.userstory
6:          action ← item.action.What_action if item.action else None
7:          doc ← create_nlp_document(action)
8:          sentence_classify ← process_sentence(doc, text, keyword_to_sentence_class)
9:          sentence_classify["isProblem"] ← calculate_is_problem(item, sentence_classify)
10:         sentence_classifications.append(sentence_classify)
11:  return sentence_classifications

```

---



---

### Algorithm 6: Helper Function - Calculate isProblem

---

**Input:** item, sentence\_classify

---

**Output:** isProblem

---

```

1:  function calculate_is_problem(item, sentence_classify):
2:      label_in_action ← item.get("action", {}).get("label", None)
3:      label_in_sentence_classify ← sentence_classify.get("label", None)

```

---

---

```

4:         if label_in_action == -1 and label_in_sentence_classify != "1":
5:             return true
6:         else if label_in_action != -1 and label_in_sentence_classify == "1":
7:             return false
8:         else:
9:             return false
10:    end function

```

---



---

**Algorithm 7: Helper Function - Process Sentence**


---

**Input:** doc, text, keyword\_to\_sentence\_class

---

**Output:** sentence\_classify

---

```

1:    function process_sentence(doc, text, keyword_to_sentence_class):
2:        sentence_class ← empty set
3:        keyword_words ← empty set
4:        prob_act ← empty list
5:        for each token in doc do
6:            if is_verb_with_ancestor(token):
7:                process_verb_token(token, prob_act, keyword_words, sentence_class,
                                   keyword_to_sentence_class)
8:            sentence_classify ← {
9:                "sentence": text,
10:               "act_action": action,
11:               "sentence_class": list(sentence_class),
12:               "keyword_words":
13:                 create_keyword_word_dict(keyword_words,
14:                                           keyword_to_sentence_class),
15:               "problem_act": prob_act,
16:               "recommended_action": [],
17:               "label": classify_label(keyword_words),
18:               "isProblem": null
19:            }
20:    return sentence_classify

```

---



---

**Algorithm 8: Helper Function - Process Verb Token**


---

**Input:** token, prob\_act, keyword\_words, sentence\_class, keyword\_to\_sentence\_class

---

**Output:** None (modifies prob\_act, keyword\_words, sentence\_class, keyword\_to\_sentence\_class)

---

```

1:    function process_verb_token (token, prob_act, keyword_words, sentence_class,
                                keyword_to_sentence_class):
2:        tok_verb ← token.text
3:        tok_process ← token.lemma_
4:        prob_act.append (tok_verb)
5:        word_class ← get_word_class (tok_process)

```

---

---

```

6:      if word_class:
7:          process_word_class      (word_class,      keyword_words,      sentence_class,
                                   keyword_to_sentence_class)
8:      else:
9:          process_synsets      (tok_process,      keyword_words,      sentence_class,
                                   keyword_to_sentence_class)
10:     end if
11: end function

```

---



---

**Algorithm 9: Helper Function - Process Word Class**


---

**Input:** word\_class, keyword\_words, sentence\_class, keyword\_to\_sentence\_class

---

**Output:** None (modifies keyword\_words, sentence\_class, keyword\_to\_sentence\_class)

---

```

1: function      process_word_class(word_class,      keyword_words,      sentence_class,
                                   keyword_to_sentence_class):
2:     sentence_class.add(word_class.keyword)
3:     keyword_words.add(word_class.text)
4:     update_keyword_to_sentence_class(word_class.text,      keyword_to_sentence_class,
                                   word_class.keyword)
5: end function

```

---



---

**Algorithm 10: Helper Function - Process Synsets**


---

**Input:** tok\_process, keyword\_words, sentence\_class, keyword\_to\_sentence\_class

---

**Output:** None (modifies keyword\_words, sentence\_class, keyword\_to\_sentence\_class)

---

```

1: function      process_synsets(tok_process,      keyword_words,      sentence_class,
                                   keyword_to_sentence_class):
2:     synsets ← get_synsets(tok_process)
3:     for each synset in synsets do
4:         synset_class ← get_synset_class(synsets)
5:         if synset_class:
6:             sentence_class.add(synset_class.keyword)
7:             keyword_words.add(tok_process)
8:             update_keyword_to_sentence_class(tok_process, keyword_to_sentence_class,
                                   synset_class.keyword)
9:         end if
10:    end for
11: end function

```

---



---

**Algorithm 11: Helper Function - Update Keyword to Sentence Class**


---

**Input:** keyword, keyword\_to\_sentence\_class, class\_keyword

---

**Output:** None (modifies keyword\_to\_sentence\_class)

---

```

1: function      update_keyword_to_sentence_class(keyword,      keyword_to_sentence_class,
                                   class_keyword):
2:     if keyword not in keyword_to_sentence_class:
3:         keyword_to_sentence_class[keyword] ← empty set()

```

---

---

4:	<b>end if</b>
5:	keyword_to_sentence_class[keyword].add(class_keyword)
6:	<b>end function</b>

---

## APPENDIX E PSEUDOCODE FOR CONSISTENCY ANALYSIS

<b>Algorithm 12: Function to ensure consistency in the <i>WHO</i> segment</b>	
<b>Input: Well-formed data</b>	
<b>Output: List of dictionaries containing consistent <i>WHO</i> segment</b>	
1:	<b>function</b> who_consistency(well_formed_data):
2:	txt = []           # List to store user story texts
3:	r_txt = []         # List to store 'who' segment
4:	dic_role = []      # List to store consistent 'who' segment
5:	userstory_list = [] # List to store user story objects
6:	<b>for</b> item <b>in</b> well_formed_data:
7:	text = item["userstory"]
8:	userstory = item["userstory_obj"]
9:	role = item["actor"].Who_action
10:	txt.append(text)
11:	r_txt.append(role)
12:	userstory_list.append(userstory)
13:	<b>end for</b>
14:	vectorizer = TfidfVectorizer()
15:	X = vectorizer.fit_transform(r_txt)
16:	dbscan = DBSCAN(eps=eps, min_samples=min_samples)
17:	labels = dbscan.fit_predict(X)
18:	grouped_role_s = defaultdict(list)
19:	role_s_lists = defaultdict(list)
20:	total_role_members = defaultdict(int)
21:	<b>for</b> role, text, label, userstory <b>in</b> zip(r_txt, txt, labels, userstory_list):
22:	grouped_role_s[label].append((role, text, userstory))
23:	<b>end for</b>
24:	<b>for</b> label, role_s_text_list <b>in</b> grouped_role_s.items():
25:	role_s_list = []
26:	<b>for</b> role, text, userstory <b>in</b> role_s_text_list:
27:	<b>if</b> role <b>not in</b> role_s_list:
28:	role_s_list.append(role)
29:	<b>end if</b>
30:	<b>end for</b>
31:	role_s_lists[label] = role_s_list
32:	total_role_members[label] = len(role_s_list)
33:	<b>if</b> label == -1:
34:	<b>for</b> role, text, userstory <b>in</b> role_s_text_list:
35:	dic_role.append({"userstory": userstory, "text": text, "actor": role, "role_cluster_label": label})
36:	<b>end for</b>

---

```

37:         else:
38:             for role, text, userstory in role_s_text_list:
39:                 dic_role.append({"userstory": userstory, "text": text, "actor": role,
                                "role_cluster_label": label})
40:             end for
41:         end if
42:     end for
43: return dic_role, role_s_lists, total_role_members

```

---



---

**Algorithm 12: Function to ensure consistency in the *WHAT* and *WHY* segments**


---

**Input: Well-formed data**


---

**Output: List of dictionaries containing consistent *WHAT* and *WHY* segments**


---

```

1: function who_consistency(well_formed_data):
2:     txt = []          # List to store user story texts
3:     a_txt = []        # List to store 'what' segment
4:     m_txt = []        # List to store 'why' segment
5:     dic = []          # List to store consistent 'what' and 'why' segments
6:     userstory_list = [] # List to store user story objects
7:     for item in well_formed_data:
8:         text = item["userstory"]
9:         userstory = item["userstory_obj"]
10:        action = item["action"].Why_action
11:        motive = item["motive"].Why_action
12:        action = action.translate(str.maketrans("", "", string.punctuation))
13:        motive = motive.translate(str.maketrans("", "", string.punctuation))
14:        words_act = word_tokenize(action)
15:        words_mot = word_tokenize(motive)
16:        lemmatized_stc_act = " ".join(lemmatizer.lemmatize(word) for word in words_act)
17:        lemmatized_stc_mot = " ".join(lemmatizer.lemmatize(word) for word in words_mot)
18:        vectorizer = TfidfVectorizer()
19:        X_act = vectorizer.fit_transform([lemmatized_stc_act])
20:        X_mot = vectorizer.fit_transform([lemmatized_stc_mot])
21:        dbscan = DBSCAN(eps=eps, min_samples=min_samples)
22:        labels_act = dbscan.fit_predict(X_act)
23:        labels_mot = dbscan.fit_predict(X_mot)
24:        status = "consistent" if labels_act[0] != -1 and labels_mot[0] != -1 else "inconsistent"
25:        dic.append({"userstory": userstory, "text": text, "action": lemmatized_stc_act,
                    "motive": lemmatized_stc_mot, "act_cluster_label": labels_act[0], "mot_cluster_label":
                    labels_mot[0], "status": status})
26:        act_s_lists = defaultdict(list)
27:        why_s_lists = defaultdict(list)
28:        total_act_members = defaultdict(int)
29:        total_why_members = defaultdict(int)

```

---

---

```

29:         for item in dic:
30:             act_cluster_label = item["act_cluster_label"]
31:             why_cluster_label = item["why_cluster_label"]
32:             act_s_lists[act_cluster_label] += role_s_lists[act_cluster_label]
33:             why_s_lists[why_cluster_label] += role_s_lists[why_cluster_label]
34:             total_act_members[act_cluster_label] = len(act_s_lists[act_cluster_label])
35:             total_why_members[why_cluster_label] = len(why_s_lists[why_cluster_label])
36:             item["isProblem"] = is_problem(total_act_members[act_cluster_label],
37:                                           total_why_members[why_cluster_label])
37:         end for
38:     end for
39:     return dic, what_s_lists, what_members, why_s_lists, total_why_members

```

---



---

**Algorithm 13: Helper Function: is\_problem**


---

**Input:** total\_role\_members, total\_act\_members, total\_why\_members

---

**Output:** None

---

```

1:     function is_problem(total_role_members, total_act_members, total_why_members):
2:         if total_role_members > 1 and total_act_members > 1 and total_why_members > 1:
3:             return True
4:         else:
5:             return False
6:         end if
7:     end function

```

---

## APPENDIX F PSEUDOCODE FOR CONCISENESS ANALYSIS

<b>Algorithm 14: Function to find SBAR in WHAT and WHY segments</b>		
<b>Input:</b> action_what_text, goal_why_text		
<b>Output:</b> SBAR_text_what, SBAR_text_why, is_Problem, userstory		
1:	<b>function</b> find_sbar(action_what_text, goal_why_text):	
2:	isProblem $\leftarrow$ False	
3:	act_sbar $\leftarrow$ empty list	
4:	goal_sbar $\leftarrow$ empty list	
5:	dependency_pairs_what $\leftarrow$ empty list	
6:	sbar_text_what $\leftarrow$ empty list	
7:	dependency_pairs_why $\leftarrow$ empty list	
8:	sbar_text_why $\leftarrow$ empty list	
9:	<b>for</b> each well_formed <b>in</b> well_formed_data <b>do</b>	
10:	index $\leftarrow$ 0	
11:	action $\leftarrow$ well_formed["action"]	
12:	goal $\leftarrow$ well_formed["goal"]	
13:	text $\leftarrow$ well_formed["userstory"]	
14:	<b>for</b> each segment <b>in</b> ["action_what_text", "goal_why_text"] <b>do</b>	
15:	<b>if</b> segment == "action_what_text" <b>then</b>	
16:	tokens_action $\leftarrow$ word_tokenize(action_what_text)	
17:	parsed_sentence_action next(self.corenlp_parser.parse(tokens_action))	$\leftarrow$
18:	root_what = None	
19:	<b>for</b> each subtree <b>in</b> parsed_sentence_action.subtrees() <b>do</b>	
20:	<b>if</b> subtree.label() == "ROOT" <b>then</b>	
21:	root_what $\leftarrow$ subtree	
22:	<b>else if</b> subtree.label() == "SBAR" <b>then</b>	
23:	sbar_text_what $\leftarrow$ subtree.leaves()	
24:	<b>end if</b>	
25:	<b>end for</b>	
26:	<b>for</b> each child <b>in</b> root_what <b>do</b>	
27:	<b>if</b> isinstance(child, Tree) <b>and</b> child.label() != "PUNCT" <b>then</b>	
28:	dependency_pairs_what.append(child[0], child.label(), root_what[0])	
	<b>else</b>	
29:	dependency_pairs.append(child, "PUNCT", root_what[0])	
30:	<b>end for</b>	
31:	new_text_what $\leftarrow$ action_what_text	
32:	<b>if</b> sbar_text_what <b>then</b>	
33:	sbar_text_joined_what $\leftarrow$ " ".join(sbar_text_what)	
34:	sbar_start_index_what action_what_text.find(sbar_text_joined_what)	$\leftarrow$



```

35:          if sbar_start_index_what >= 0 then
36:              sbar_end_index_what ← sbar_start_index_what +
                len(sbar_text_joined_what)
37:          if sbar_start_index_what == len(action_what_text) then
38:              new_text_what ←
                action_what_text[:sbar_start_index_what].strip()
39:          else
40:              new_text_what ←
                action_what_text[:sbar_start_index_what] +
                action_what_text[sbar_end_index_what:].strip()
41:          end if
42:          end if
43:      end if
44:      match_what ← re.search(r"I\s+want\s+to|I\s+want", new_text_what,
re.IGNORECASE)
45:      captured_text_what ← ""
46:      if match_what then
47:          start_index_what ← match_what.end ()
48:          comma_index_what ← new_text_what.find (",", start_index_what)
49:          if comma_index_what != -1 then
50:              captured_text_what <--
                new_text_what[start_index_what:comma_index_what]
51:          else
52:              captured_text_what <-- new_text_what[start_index_what:]
53:          end if
54:          end if
55:      else if segment == "goal_why_text" then
56:          tokens_action ← word_tokenize(action_what_text)
57:          parsed_sentence_action ←
                next(self.corenlp_parser.parse(tokens_action))
58:          root_what = None
59:          for each subtree in parsed_sentence_action.subtrees() do
60:              if subtree.label() == "ROOT" then
61:                  root_what ← subtree
62:              else if subtree.label() == "SBAR" then
63:                  sbar_text_what ← subtree.leaves()
64:              end if
65:          end for
66:          for each child in root_what do
67:              if isinstance(child, Tree) and child.label() != "PUNCT" then
68:                  dependency_pairs_what.append(child[0], child.label(),
                root_what[0])
69:              else
70:                  dependency_pairs.append(child, "PUNCT", root_what[0])
71:              end if
72:          end for

```

73:	<code>new_text_what ← action_what_text</code>	
74:	<b>if</b> <code>sbar_text_what</code> <b>then</b>	
75:	<code>sbar_text_joined_what ← " ".join(sbar_text_what)</code>	
76:	<code>sbar_start_index_what</code>	←
76:	<code>action_what_text.find(sbar_text_joined_what)</code>	
77:	<b>if</b> <code>sbar_start_index_what &gt;= 0</code> <b>then</b>	
78:	<code>sbar_end_index_what ← sbar_start_index_what +</code>	+
78:	<code>len(sbar_text_joined_what)</code>	
79:	<b>if</b> <code>sbar_start_index_what == len(action_what_text)</code> <b>then</b>	
80:	<code>new_text_what</code>	←
80:	<code>action_what_text[:sbar_start_index_what].strip()</code>	
81:	<b>else</b>	
82:	<code>new_text_what</code>	←
82:	<code>action_what_text[:sbar_start_index_what]</code>	+
82:	<code>action_what_text[sbar_end_index_what:].strip()</code>	
83:	<b>end if</b>	
84:	<b>end if</b>	
85:	<b>end if</b>	
86:	<code>match_what ← re.search(r"I\s+want\s+to I\s+want", new_text_what,</code>	
86:	<code>re.IGNORECASE)</code>	
87:	<code>captured_text_what ← ""</code>	
88:	<b>if</b> <code>match_what</code> <b>then</b>	
89:	<code>start_index_what ← match_what.end ()</code>	
90:	<code>comma_index_what ← new_text_what. find (",", start_index_what)</code>	
91:	<b>if</b> <code>comma_index_what != -1</code> <b>then</b>	
92:	<code>captured_text_what</code>	<--
92:	<code>new_text_what[start_index_what:comma_index_what]</code>	
93:	<b>else</b>	
94:	<code>captured_text_what &lt;-- new_text_what[start_index_what:]</code>	
95:	<b>end if</b>	
96:	<b>end if</b>	
97:	<b>end if</b>	
98:	<b>end for</b>	
99:	<b>if</b> <code>sbar_text_what</code> <b>or</b> <code>sbar_text_why</code> <b>then</b>	
100:	<code>isProblem ← True</code>	
101:	<b>end if</b>	
102:	<b>return</b> <code>sbar_text_what, sbar_text_why, action_what_text, goal_why_text,</code>	
102:	<code>isProblem</code>	

## APPENDIX G PSEUDOCODE FOR CONCEPTUAL SOUNDNESS ANALYSIS

<b>Algorithm 15: Function to extract subject, object, predicate from dataframes</b>	
<b>Input: well_formed_data</b>	
<b>Output: sentence_dependency</b>	
1:	<b>function</b> extract_subject_object_predicate(well_formed_data):
2:	sentence_dependency $\leftarrow$ empty list
3:	dict_sent $\leftarrow$ empty dictionary
4:	<b>for</b> each item <b>in</b> well_formed_data <b>do</b>
5:	userstory $\leftarrow$ item["userstory_obj"]
6:	text $\leftarrow$ item["userstory"]
7:	who $\leftarrow$ item["actor"].who_action <b>if</b> item["actor"] <b>else</b> None
8:	what $\leftarrow$ item["actor"].what_action <b>if</b> item["action"] <b>else</b> None
9:	why $\leftarrow$ item["actor"].why_action <b>if</b> item["motive"] <b>else</b> None
10:	index $\leftarrow$ item["index"]
11:	doc $\leftarrow$ nlp(action)
12:	subject $\leftarrow$ None
13:	predicate $\leftarrow$ None
14:	obj $\leftarrow$ None
15:	skip_next_token $\leftarrow$ False
16:	skip_next_verb $\leftarrow$ False
17:	<b>for</b> each token <b>in</b> doc <b>do</b>
18:	<b>if</b> skip_next_token <b>then</b>
19:	skip_next_token $\leftarrow$ False
20:	<b>continue</b>
21:	<b>end if</b>
22:	<b>if</b> lowercase(token.text) <b>is</b> "want to" <b>or</b> lowercase(token.text) <b>is</b> "want" <b>then</b>
23:	skip_next_token $\leftarrow$ True
24:	<b>continue</b>
25:	<b>end if</b>
26:	<b>if</b> skip_next_verb <b>and</b> token.pos_ <b>is</b> "VERB" <b>then</b>
27:	skip_next_verb $\leftarrow$ False
28:	<b>continue</b>
29:	<b>end if</b>
30:	<b>if</b> "subj" <b>is in</b> token.dep_ <b>then</b>
31:	subject $\leftarrow$ token.text
32:	<b>else if</b> "obj" <b>is in</b> token.dep_ <b>and</b> (token.pos_ <b>is</b> "PROPN" <b>or</b> token.pos_ <b>is</b> "NOUN") <b>then</b>
33:	obj $\leftarrow$ token.text
34:	<b>end if</b>
35:	<b>if</b> list(doc[token.left_edge.i : token.right_edge.i + 1].noun_chunks) <b>then</b>

```

36:         obj ← concatenate text for each chunk in doc[token.left_edge.i :
           token.right_edge.i + 1].noun_chunks
37:         else if token.pos_ is "VERB" then
38:             if predicate is None then
39:                 predicate ← token.text
40:             else
41:                 predicate ← concatenate predicate and token.text
42:             end if
43:             skip_next_verb ← True
44:         end if
45:         if token.subtree then
46:             predicate ← concatenate text for each t in token.subtree
47:         end if
48:     end for
49: end for
50: return sentence_dependency

```

---

**Algorithm 16: Function to classify topic**


---

**Input:** sentence\_dependency

---

**Output:** topic\_btm

---

```

1:  function classify_topic(sentence_dependency):
2:      topic_btm = []
3:      new_docs = []
4:      for each dic_sent in sentence_dependency:
5:          index1 = dic_sent["index"]
6:          sent = dic_sent["sentence"]
7:          subject = dic_sent["subject"]
8:          predicate = dic_sent["predicate"]
9:          obj = dic_sent["object"]
10:         if predicate is not None:
11:             doc = nlp(predicate)
12:             filtered_predicate = concatenate token.text for each token in doc if not
               token.is_stop
13:             cleaned_filtered_predicate = remove non-alphanumeric characters from
               filtered_predicate
14:             new_docs.append(cleaned_filtered_predicate)
15:         end if
16:     end for
17:     X, vocabulary, vocab_dict = btm.get_words_freqs(new_docs)
18:     docs_vec = btm.get_vectorized_docs(new_docs, vocabulary)
19:     biterms = btm.get_biterms(docs_vec)
20:     model = btm.BTM(X, vocabulary, T=8, M=20, alpha=50/7, beta=0.01)
21:     model.fit(biterms, iterations=100)
22:     p_zd = model.fit_transform(docs_vec, biterms, infer_type=u'sum_b', iterations=100)

```

---

```

23:         result = btm.get_docs_top_topic(new_docs, p_zd)
24:         for each index, doc_topic_dist in enumerate(p_zd):
25:             text = new_docs[index]
26:             cluster_topic = index of the maximum value in doc_topic_dist
27:             if text is not None and cluster_topic is not None:
28:                 matching_predicates = list of dic_sent where predicate contains text
29:                 for each dic_sent in matching_predicates:
30:                     top_words = btm.get_top_topic_words(model, words_num=10,
31:                                                         topics_idx=[cluster_topic])
32:                     word_column = top_words.columns[0]
33:                     cluster_words = top_words[word_column].tolist()
34:                     shuffle(cluster_words)
35:                     sentence_length = minimum of 5 and length of cluster_words
36:                     sentence = randomly select sentence_length words from cluster_words
37:                     cluster_sentence = concatenate words in sentence
38:                 end for
39:             end if
40:         end for
41:         return topic_btm

```

---

**Algorithm 17: Helper Function - Get word class**


---

**Input:** word

---

**Output:** word class or None

---

```

1: function get_word_class(word):
2:     for each word_class, class_keywords in keywords do
3:         if lowercase(word) is in class_keywords then
4:             return word_class
5:         return None
6:     end function

```

---



---

**Algorithm 18: Helper Function - Get synset class**


---

**Input:** synset

---

**Output:** word class or None

---

```

1: function get_synset_class(synset):
2:     for each word_class, class_keywords in keywords do
3:         for each lemma in synset.lemma_names() do
4:             if lowercase(lemma) is in class_keywords then
5:                 return word_class
6:         return None
10: end function

```

---

## APPENDIX H PSEUDOCODE FOR UNIQUENESS ANALYSIS

<b>Algorithm 19: Function to calculate similarities among user stories</b>	
<b>Input: well_formed_data</b>	
<b>Output: userstory, isProblem</b>	
1:	<b>function</b> uniqueness_criterion(well_formed_data):
2:	pair_role = []
3:	pair_action = []
4:	pair_goal = []
5:	tot_score = []
6:	isProblem = False
7:	role_user = []
8:	action_user = []
9:	goal_user = []
10:	<b>for</b> each item <b>in</b> self.well_formed_data <b>do</b>
11:	<b>append</b> item["actor"].Who_action <b>to</b> role_user <b>if</b> item["actor"] <b>is not</b> None <b>else</b> <b>append</b> None
12:	<b>append</b> item["action"].What_action <b>to</b> action_user <b>if</b> item["action"] <b>is not</b> None <b>else</b> <b>append</b> None
13:	<b>append</b> item["goal"].Why_action <b>to</b> goal_user <b>if</b> item["goal"] <b>is not</b> None <b>else</b> <b>append</b> None
14:	<b>append</b> item["userstory_obj"] <b>to</b> userstory_list
15:	<b>end for</b>
16:	role_embeddings = settings.MODEL_ST.encode(role_user)
17:	action_embeddings = settings.MODEL_ST.encode(action_user)
18:	goal_embeddings = settings.MODEL_ST.encode(goal_user)
19:	score_role = util.cos_sim(role_embeddings, role_embeddings)
20:	score_action = util.cos_sim(action_embeddings, action_embeddings)
21:	score_goal = util.cos_sim(goal_embeddings, goal_embeddings)
22:	<b>for</b> each i, j <b>in</b> itertools.combinations(range(len(self.well_formed_data)), 2) <b>do</b>
23:	<b>append</b> {'index': [i, j], 'sim_score_role': score_role[i][j]} <b>to</b> pair_role
24:	<b>end for</b>
25:	<b>for</b> each i, j <b>in</b> itertools.combinations(range(len(self.well_formed_data)), 2) <b>do</b>
26:	<b>append</b> {'index': [i, j], 'sim_score_action': score_action[i][j]} <b>to</b> pair_action
27:	<b>end for</b>
28:	<b>for</b> each i, j <b>in</b> itertools.combinations(range(len(self.well_formed_data)), 2) <b>do</b>
29:	<b>append</b> {'index': [i, j], 'sim_score_goal': score_goal[i][j]} <b>to</b> pair_goal
30:	<b>end for</b>
31:	<b>for</b> each i, j <b>in</b> itertools.combinations(range(len(self.well_formed_data)), 2) <b>do</b>
32:	<b>append</b> {'index': [i, j], 'sim_score_tot': (score_role[i][j] + score_action[i][j] + score_goal[i][j]) / 3} <b>to</b> tot_score
33:	<b>end for</b>
34:	result = zip(pair_role, pair_action, pair_goal, tot_score)

35:	<code>result = <b>sort</b> result <b>by</b> key=lambda x: x[3]['sim_score_tot'] <b>in</b> descending order</code>
36:	<code>isProblem = all(x['sim_score_role'] &gt;= 0.6 <b>and</b> x['sim_score_action'] &gt;= 0.6 <b>and</b> x['sim_score_goal'] &gt;= 0.6 for x <b>in</b> result)</code>
37:	<code><b>return</b> isProblem</code>





