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RESEARCH

Tree hole rescue: an AI approach for suicide risk detection and online suicide intervention

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Abstract

Adolescent suicide has become an important social issue of general concern. Many young people express their suicidal feelings and intentions through online social media, e.g., Twitter, Microblog. The "tree hole" is the Chinese name for places on the Web where people post secrets. It provides the possibility of using Artificial Intelligence and big data technology to detect the posts where someone express the suicidal signal from those "tree hole" social media. We have developed the Web-based intelligent agents (i.e., AI-based programs) which can monitor the "tree hole" websites in Microblog every day by using knowledge graph technology. We have organized Tree-hole Rescue Team, which consists of more than 1000 volunteers, to carry out suicide rescue intervention according to the daily monitoring notifications. From 2018 to 2023, Tree-hole Rescue Team has prevented more than 6600 suicides. A few thousands of people have been saved within those 6 years. In this paper, we present the basic technology of Web-based Tree Hole intelligent agents and elaborate how the intelligent agents can discover suicide attempts and issue corresponding monitoring notifications and how the volunteers of Tree Hole Rescue Team can conduct online suicide intervention. This research also shows that the knowledge graph approach can be used for the semantic analysis on social media

Keywords: Suicide risk detection, Online suicide intervention, Knowledge graph approach, Mental health

Introduction

Close to 800,000 people die due to suicide every year, which is one person every 40 s [1]. Suicide is a global phenomenon and occurs throughout the lifespan. It is the second leading cause of death among 15–29 year old globally [1]. The highest rates of suicide were associated with the mental disorders around the globe. Although all mental disorders carry an increased risk of suicidal ideation, suicide attempt, and suicide, major depressive disorder (MDD) is the leading cause of suicide. Up to one in 10 people affected by depression will commit suicide. Depression not only causes physical complications, e.g. suicide, but also imposes substantial economic burdens on individuals and society. Individuals living with major depressive disorder face an increased risk of having a financial crisis. Because depression has a direct (e.g. cost of health care) and indirect (e.g. lost employment) economic impact on individuals. An urgent action needed to prevent suicidal behavior and promoting mental health to decrease the costs of individual and societal levels. Suicides are preventable and preventing suicide should be a global imperative [1].

Nowadays, many young people often express their suicidal ideas and wishes through online social media. This provides the possibility of suicide rescue through the analysis of online social media using artificial intelligence and big data technology. The "tree hole" is the Chinese name for places on the Web where people post secrets for others to read. The name is inspired by an Irish tale about a man who confided his secrets to a tree. There are already thousands of tree holes on Sina Weibo, the China Webblog. Many patients of major depression patients are gathering at the Tree Holes in China. We have developed the Web-based intelligent agents with knowledge graph technology to monitor the specific "Tree Hole" websites in Microblog every day since July 27, 2018. They can detect those messages in which high-risk suicidal ideas from Microblog and

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release Tree-hole monitoring notification every day. The "Tree-hole Rescue Team" organized by us carry out suicide rescue intervention according to the daily monitoring notifications. From July 2018 till the end of 2023, we have conducted online suicide rescue action and have prevented more than 6600 suicides and have saved a few thousands of lives within those 5 years.

In order to enable intelligent agents to obtain backstage knowledge support, we constructed a "tree hole" knowledge graph. It can provide various basic knowledge related to suicide, which is used to analyze and judge the microblog information after the data acquisition. That helps to identify the people who with high-risk suicide level and sent the monitoring notification to Tree-Hole Rescue Team. The volunteers in the rescue team, under the guidance of professionals, conduct the rescue work to prevent potential suicides through online or onsite intervention. This paper presents the basic technology of the "Tree Hole" intelligent agents. We will elaborate how the intelligent agents discover suicide attempts and issue corresponding monitoring notifications, and how the suicide intervention can be conducted by the volunteers of Tree Hole Rescue Team. This research also shows that the knowledge graph approach can be used for the semantic analysis on social media.

The rest of paper is organized as follows: First we illustrate the ideas of suicidal risk grading in Section 2. In Section 3, we introduce the general architecture of Tree Hole Knowledge Graphs and show how to integrate various knowledge/data resources about the knowledge and data-sources about suicidal risk detection. Section 4 discusses the processing workflow of the tree hole intelligent agents and make the evaluation on the proposed approach. Section 6 discusses the procedure of the suicidal intervention, before concluding the paper in Section 7.

"Tree hole" and grading criteria of suicidal risks

In ancient times, people would go to the forests to find a tree hole to tell the secrets of heart without being known by others. Nowadays, people often express their heart's feelings by using online social media (e.g. Microblog). After a depression blogger committed suicide, his Microblog became a "tree hole" for others to leave secret messages without worrying about the secret leaked by the owner. There are thousands of "tree holes" on Microblog, and the largest one has accumulated more than 2.6 million pieces of messages. These "tree holes" receive a lot of information about suicide attempt every day, which provides the fundamental conditions for detecting high-risk suicides.

In order to identify those suicidal people who urgently need to be rescued, we propose a method of suicide risk grading.

First we consider the following four basic principles (or hypotheses) for suicidal risk grading:

- *Principle one (Urgency): The more urgent the suicide may occur, the more dangerous it is.* Namely we consider the urgency is the most crucial aspect of suicide. If the suicide may occur soon, it is the most dangerous situation the patient is facing.
- *Principle two (Concreteness): The more concrete a suicide is planned, the more dangerous it is.* Namely, If a concrete suicide method such as burning charcoal, jumping out building etc. has been decided to take, it is more dangerous than that in which there is no any concrete plan has been made.
- *Principle three (Desire) : The stronger the subjective desire is, the more dangerous it is.* Namely strong wish to the suicide is one of the dangerous aspects of suicides.
- Principle Four (Time Priority): Urgency has the top priority that others. Namely the time of suicide may occur is the most dangerous issue, compared it with other aspects such as concrete plan and others.

Based on the four basic principles above, we propose the following suicidal risk classification (Table 1). It is mainly due to the factors of the method certainty (i.e., concreteness) and the time urgency etc. to determine the level of suicide risk. The higher the level, the higher the risk. Specific criteria for suicide risk classification are shown in Table 1.

It is not too hard to prove that the following proposition holds:

Proposition 1 *The* 11 *Levels of Suicidal risk definition* (*Table* 1) *satisfies the four basic principles/hypotheses of suicidal risk grading.*

Tree-hole knowledge graph

As mentioned above, in order to enable intelligent agents to obtain background knowledge support, we construct the tree hole knowledge graph to provide basic knowledge related to suicide and depression, and to analyze and judge the Microblog information after capturing. A knowledge graph is the domain-specific knowledge in a systematic, structured and integrated form by using semantic technology [2, 3]. The knowledge graph can acquire and integrate a large and complex set of knowledge and data resources more easily [4]. It has become an important way for the application

Table 1 11 levels of suicidal risk definitions

Level	Definition
10	Suicide is going on
9	Suicide method has been decided. Suicide may occur in a few days
8	Suicide plan has been made. Suicide may occur in a few days
7	Suicide method has been decided. Unknown when it may be committed
6	Suicide plan has been made. Unknown when it may be committed
5	Strong wish for suicide has been expressed
4	Suicide wish has been expressed. Unknown when it may be committed
3	Strong survival pain. No suicidal desire expression
2	Survival pain has been clearly expressed. No suicidal desire expression
1	Survival pain has been expressed. No suicidal desire expression
0	No painful expression

of artificial intelligence technology. An ontology can be thought of as a specific type of knowledge graph, with a primary focus on conceptual association descriptions that transcend specific individuals. Knowledge graph and ontology have become the most important forms of knowledge expression for facing the information environment of the World Wide Web. The advantage of a knowledge graph lies in structured and organized knowledge. It's transforming knowledge into knowledge graphs by structurally describing and associating accurate and reliable information. Knowledge graphs use semantic technology standards such as the RDF/RDFS/OWL language to express knowledge. That provides specialized knowledge in specific areas. Recently the knowledge graph approach has been widely used in many applications [5, 6].

The Tree-hole knowledge graph is mainly used for the Tree-hole Agent to assess the suicide possibility that contained in social media information. Therefore, it has to cover the suicide attempt related concepts, including suicide method, suicide plan, painful expression, time description, place description, mourning pattern, and others. Since there are many ready-made ontologies (e.g. Time Ontology and Space Ontology) and related knowledge graphs (e.g. knowledge graph of depression3) available, the Tree-hole knowledge graph can be designed by combining different ontologies or knowledge graphs. The tree hole knowledge graph structure is shown in Fig. 1.

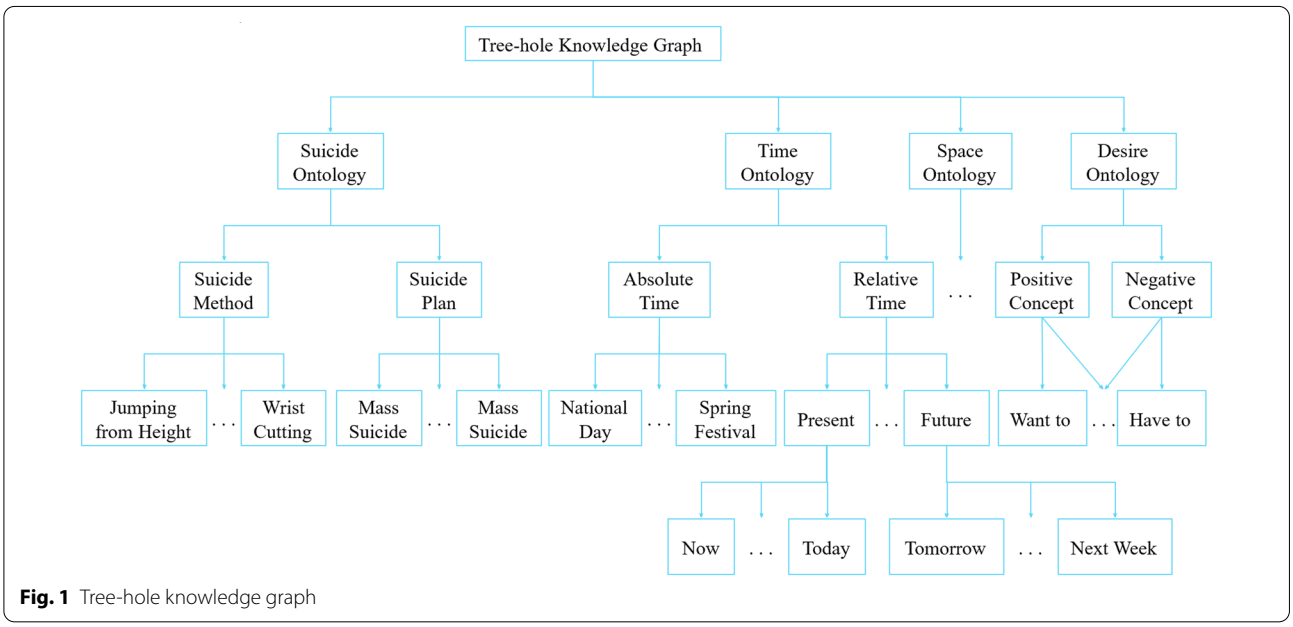

Fig. 1 Tree-hole knowledge graph

The Tree-hole knowledge graph contains several independent ontologies as we list in the following:

- *Suicide ontology*. The current Tree-hole Agent only monitors people who are at risk of suicide above level 6. Therefore, the current suicide ontology only covers the relevant concepts of risk above level 6, that is, the description of suicide methods and suicide plans. Suicide methods include hanging, drowning, wrist cutting, jumping from height, drug poisoning, carbon monoxide poisoning, etc. and suicide plans include mass suicide, suicide initiative, asking about lethal drugs for suicide, etc.
- *Time ontology*. We embed the time description of the specification (https://www.w3.org/TR/owl-time/), plus the ontology for Chinese time description. Time ontology covers absolute time concepts (such as calendar and holiday information) and relative time concepts (such as present, future, and past time descriptions).
- *Space ontology*. This ontology about the description of the related concepts of spatial geography. Because of the suicide risk classification we are currently dealing with does not cover the judgment of spatial geographic information. Therefore, in the currently implemented version of the network intelligent agent, the spatial geographic ontology is not used for the time being.
- *Desire ontology*. Desire Ontology is used to portray people's subjective wishes and related negative concepts. Such as "very want" and its negation (don't wish), "should" and its negation "should not", etc. It is mainly used to analyze the subjective suicidal wishes of a specific group of people and to exclude those who have no subjective suicidal ideations.

Tree-hole agent and suicidal risk detection

An intelligent agentic system based on a semantic data processing platform has been implemented. It can capture data from the tree hole every day, and intelligently analyze the data with Tree-hole Knowledge Graph as support [7]. It generates the monitoring notification every day to report those who have high suicide risk (> Level 5). The rescue team will take prevention strategies and rescue actions after receiving the notification. The processing workflow of the tree hole intelligent agent is shown in Fig. 2.

It consists of the following processing modules:

- *Data capture*. Intelligent agent grab the data of the day from the tree hole website and generate the corresponding HTML format data. The data capture module needs to determine which data needs to be collected and which data has been collected to avoid repetitive work.
- *Data summary*. Data properties are extracted from the every piece of information that contained in the HTML data and generate a new document. The eight data attributes we care about include date, time, message ID, Microblog name, message content, emotional sign, name of response object, ID of response object.
- *Data analysis*. This module mainly analyses the collected data of tree holes. Here we use natural language processing tool for word segmentation and syntactic analysis. Through reasoning analysis of the knowledge graph to extract information which was considered to be suicide risk above level 6. Tree-hole knowledge graph and it's rule algorithm for risk discrimination are used in the analysis process. We have constructed discriminant rules for descriptive knowledge corresponding to suicidal risk from level 6 to 10. These rules adopt Definite Clause Grammars (DCG) transformation rules which based on the logic programming language Prolog [8, 9]. We add the

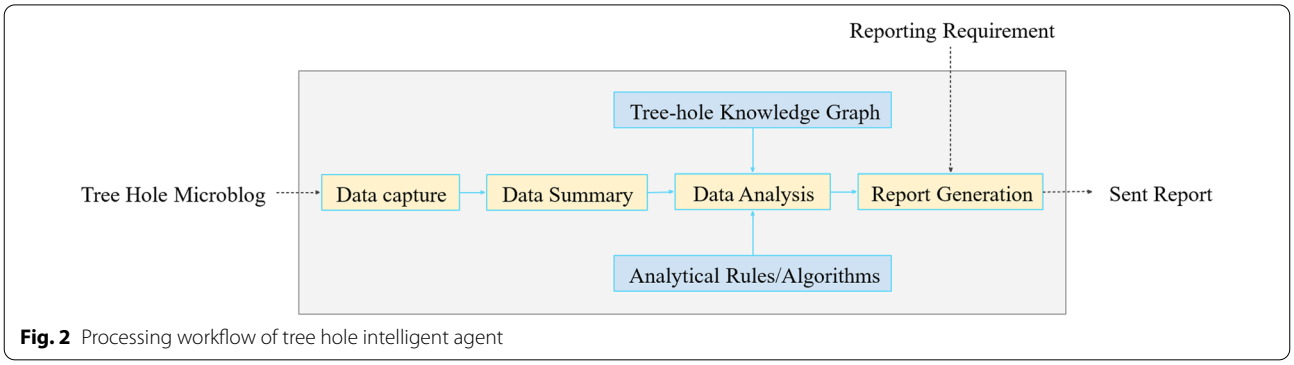

Fig. 2 Processing workflow of tree hole intelligent agent

expansibility description of knowledge graph reasoning ability on DCG rules. Interpreting each information of domain knowledge obtained from knowledge graph to determine its risk level. For example, we define the risk of suicide level 8 as: suicide plan has been made and suicide may occur in a few days. It can be formally described as the following logic rules:

```
statement(suicideRisk(8, [Plan,Time])) ->
uninterestedText(_L1),
rdfsSubclassOf(Time, future, timeOntology),
uninterestedText(_L2),
rdfsSubclassOf(Plan, suicidePlan, suicideOntology),
uninterestedText(_L3).

statement(suicideRisk(8, [Plan,Time]))->
uninterestedText(_L1),
rdfsSubclassOf(Plan, suicidePlan, suicideOntology),
uninterestedText(_L2),
rdfsSubclassOf(Time, future, timeOntology),
uninterestedText(_L3).
```

A message will classified as an 8-level risk if it does not contain any negative desire, but with suicide plans and time. In such a rule description, we use rdfsSubClassOf to determine if a suicide plan described in the suicide ontology and a time description in the time ontology are included. Code uniterestedText used to further judge if there any negative desire that we concerned about contained in the message.

- *Report generation*. Based on the data analysis results, Tree-hole Agent will generate tree hole monitoring notification in the following form.

```
Tree Hole Monitoring Notificaiton
Date: 27. 07. 2019

Publisher:  Tree-Hole  Agent 002
Suicide Risk Level 9: 2019. 07. 27 11: 29;
 Microblog name: xxx; Message: I want to
 cut my wrist tomorrow. I will never see
 the world again.
Microblog address: https://weibo.com/...

Suicide Risk Level 7: 2019. 07. 27 13: 50;
 Microblog name: xxx;
 Message: I'm scared of the world. I know
 I'm a big coward and not even the courage
 to end my life. Does anyone wants to join
 me? My mind is clear.
 Microblog address: https://weibo.com...
 ......
```

Evaluation and analysis

The Tree-hole Agent releases daily tree hole monitoring notification since July 27, 2018. In order to evaluate the reliability of suicide monitoring and early warning of Tree-hole Agent, we randomly extract 16-day monitoring data for analysis. The 16-day monitoring data contains 21,356 tree holes messages with an average 1335 messages per day. Among the 16-day monitoring data, 34 messages are at level 6 suicide risk, 119 messages are at level 7 suicide risk, 1 messages is at level 8 suicide risk, 9 messages are at level 9 suicide risk. That is, there are 163 messages with suicide risk above level 6 and then we analyze the precision of these messages. The precision rate is up to 100% (8 levels) and the lowest is 78% (9 levels). The analysis shows that the recall rate of 9, 8, 7, 6-level risk is 31%, 20%, 81% and 36%, respectively. The average recall rate is 59%. The reliability assessment of tree hole information discrimination is shown in Table 2.

The precision rate of early warning information sent by the Tree-hole Agent is 82% on average. But this does not

Table 2 Evaluation of suicidal risk detection

Risk Levels	Number of messages	Correct number of messages	Precision rate	Number of omissions	Recall rate	F value
9	9	7	0.78	20	0.31	0.0
8	1	1	1.00	4	0.20	0.33
7	119	93	0.78	28	0.81	0.80
6	34	33	0.97	60	0.36	0.53
Total	163	134	0.82	112	0.59	0.69

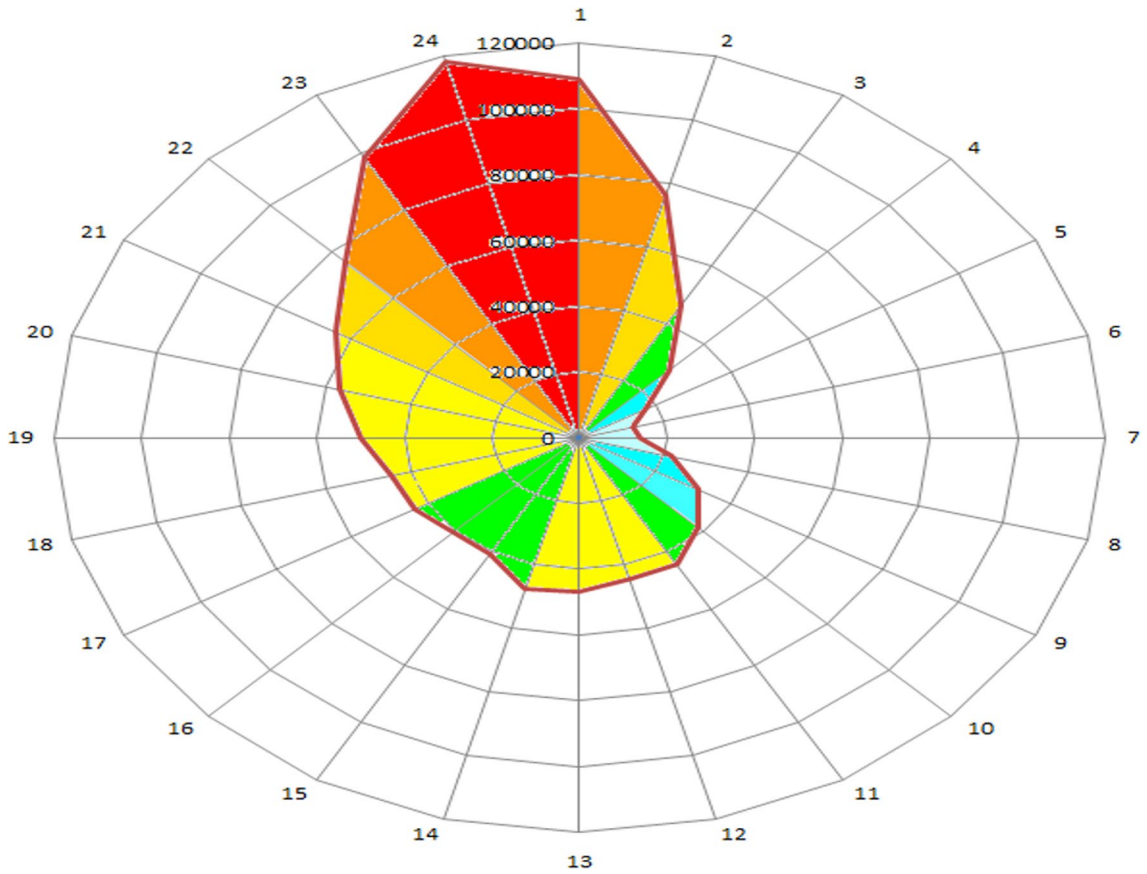

Fig. 3 Active cycle of tree hole

lead to erroneous judgment in the actual rescue process. Because the decision whether to rescue or not is decided via the volunteer's judging in the "Tree Hole Rescue Team". The Tree-hole Agent can locate 163 messages that need attention from 21,356 pieces, which eliminates 99% of irrelevant information. This greatly reduces the workload of manual intervention and significantly improves the efficiency of the interpretation of tree hole messages. From this evaluation analysis, we have seen the technical advantages of artificial intelligence technology, especially the knowledge graph. However, we have noticed that the current system still misses some information about the high risk of suicide. We need to improve the existing discriminant rules from the analysis of these missing information to improve the system recall rate. This will be an important follow-up to us.

Rescue procedure

In this section we present the basic rescue procedure for those volunteers in Tree Hole Rescue Team after they have received the tree hole monitoring notification. The main idea here is life-saving has the top priority for the rescue work. Namely those persons who have the direct danger to die (namely, high suicide risk is higher than Level 7), we have to try to find their parents/relatives/friends to make the alarm about suicide possibility. Since web-blog users are anonymous, we have to read the information of web-blog and make reasoning about relevant information to detect real information about those persons. In some urgent cases in which we cannot find any information/hint where we can find someone who can prevent the suicide at the site, we have to contact the police for help.

For those persons who have no direct danger in their life (namely they would not die in coming a few days, i.e., the suicide risk is lower than Level 8), we send private message at Web-blog to try to contact them personally. Namely the rescue operations are only undertaken for those at high risk of suicide who are already on the taking of suicidal actions.

The first principle of tree hole rescue is: *saving lives is the highest ethics*.

For those patients whose lives are not in immediate danger, we must fully protect their privacy so that their lives are not disturbed.

note that the data on Weibo is anonymous and public. Information publishers all know that the information they publish on Weibo may be seen by people on the Internet. In this sense, our capture of tree hole data does not directly touch personal privacy issues. Of course, in order to prevent some imminent suicides, we must interpret the relevant information to locate the person who may commit suicide. However, we will still adopt strict confidentiality methods so that the personal information of the rescued persons will not be leaked.

From the data analysis of over 2 millions pieces of tree hole message, we have the following discovery:

Most suicidal messages in tree holes appear between 10pm in the evening and 2am in the midnight (Fig. 3). We know that most people are sleeping at that period. Thus it justifies the necessity of using artificial intelligence agents for online suicide monitoring [10, 11].

From the July 2018 to the end of 2023, within 5 years, more than 6600 suicides were prevented by the volunteers of Tree Hole Rescue Team. Namely a few thousands of lives are saved within almost 5 years. About 150 media (including BBC News [12], the Washington Post [13], etc.) have reported the stories of tree hole rescue. More than 15 TV stations [including 4 CCTV (China Central TV) program] have made TV of tree hole rescue. A movie company has decided to turn Tree Hole Rescue into a feature film and TV series.

Conclusion

We have presented the technical framework of Web-based "Tree Hole" intelligent agents that use knowledge graphs as domain knowledge. Those intelligent agents have been implemented and used for suicide monitoring and early warning practices for social media. The quality of its suicide monitoring and early warning have been confirmed through the quality assessment. Compared with the technique of using the deep learning method to conduct suicide risk detection [14], the accuracy of suicidal risk detection based on knowledge graph technology is higher. Certainly, we will use a combination of deep learning and knowledge graphs if we want to extend the suicide risk discrimination to all eleven levels. Through the application practice of real scenes in the past years, we have seen the huge development prospects of artificial intelligence technology for suicide early warning analysis. This technology not only has good social value but also has great technical value. We will further improve and enrich the interpretation of suicide analysis rules and algorithms to obtain higher precision and recall rates on suicide risk detection.

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Declarations

Conflict of interest
All authors declare that they have no conflict of interest.

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