A Knowledge Representation for Cardiovascular Problems Applied to Mobile Monitoring of Elderly People

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Abstract— **Although the decline of physical conditions is a continuous process related to the ageing, elderly people generally desire to maintain their privacy and autonomy for as long as possible. The technology of mobile health monitoring is an important approach to be applied into this scenario, once such technology enables a prompt identification of health problems. One of the trends in this area is to implement levels of intelligence into monitoring systems, so that they can take decisions and act in a more optimized way. For that end, one of the approaches is to provide deduction resources to mobile devices, so that they can manipulate knowledge in form of rules. This work shows how we can implement a light deduction system using a free-context grammar, which is mainly used to codify experts' knowledge. Our focus is on a grammar for cardiovascular problems, once this is the main kind of problem that affects elderly people.**

Keywords- health monitoring; knowledge representation; mobile applications; cardiovascular.

I. INTRODUCTION

As medical science advances, people can live with better health and alone up to a very advanced age. Thus, we have a new kind of social behavior, where elderly people are becoming more independent. In this scenario, where we must allow elderly people to live in their own homes leading their normal life, while, at the same time taking care of them, requires new type of assistant systems [1].

In this context, we have seen an increase in the number of researches towards the implementation of systems that carry out a remote monitoring of patients [2,3]. In fact, such systems bring several advantages, such as reduction of the public health care costs and more convenience to their users. The literature [4] lists interesting scenarios where the use of a health monitoring platform could be useful. One of such scenarios is the support to elderly people who are living in their own households.

Current researches in health monitoring are mainly focused on infrastructure aspects, such as network support [5] and information security/privacy [6]. Independently of the nature of the research, we see the use of mobile devices just as a router of health information. In other words, mobile devices are used as a component that receives vital signals from wearing sensors and sends such signals to central databases. However, we argue that mobile devices can act as an active element, rather than a passive and temporary repository of information. This means that mobile devices should present an autonomous behavior and be able to take decisions in accordance with its current knowledge.

The technique of rule-based systems [7] is one of the classical ways to implement autonomy in a system. Rule-based systems are used as an alternative to store and manipulate knowledge, interpreting information in a useful manner. Typical examples of rule-based systems are domain-specific expert systems that use rules to make deductions or choices. For example, an expert system might help a doctor in choosing the correct diagnosis based on a cluster of symptoms, or selecting tactical moves to play a game.

One of the main advantages of rule-based systems is its difference from standard procedural or object-oriented programs. In order, in such systems there is no clear order in which code executes. Instead, the knowledge of the expert is captured in a set of rules, each of which encoding a small piece of the expert's knowledge.

Frameworks for the development of rule-based systems are complex, mainly because they are domain independent. Thus, we do not have support for implementations of rule-based systems in mobile architectures. Considering this aspect, we restricted our domain to cardiovascular problems and defined a free-context grammar to represent the knowledge associated with this domain. This grammar enables the description of rules and the implementation of a decision making process, as detailed later on in this paper.

The remainder of this paper is structured as follows: Section II describes an overview of the health monitoring area, relating their approaches to aspects such as use of specific or general mobile devices, or presence of intelligent resources. Section III presents the architecture of our monitoring approach, detailing its three modules. Section IV discusses our representation module, which defines a grammar to codification of rules. Section V describes our experiments and results so far. Finally, Section VI concludes this paper with the main remarks and future research directions.

II. RELATED WORKS

A complete elderly monitoring system should consider several typical problems of aging. For example, while this paper is focused on the cardiovascular domain, several other works consider problems such as recognition of unusual behaviors, dementia, detection of falls and diabetes.

The work presented in [8] uses a structural pattern recognition approach to propose a monitoring model using body sensors networks. This proposal is divided into two stages. First, a processing unit acquires health signals of uses, carrying out a pre-processing and local classification of such signals. In the next stage, a mobile device does a second data classification, storing the important information and triggering critical events, such as alert messages. The final aim of this work is to evaluate patient moving behavior and classify its physical activities. This approach is very useful for elderly monitoring, once activities patterns, such as low levels of activities, are strong indicators of health problems.

The work of Andreao et al. [9] considers the monitoring of cardiovascular problems. In this case they use a specific device, called Remote Unit, which receives cardiovascular signals and transmits such signals to a monitoring central where they are analyzed. The work presented in [10] also uses a similar approach. However, it integrates several kinds of sensors, differently of the previous work that only considers the ECG signal. Unfortunately, this work also uses a specific device to transmit data. In both cases, any kind of intelligent analysis is carried out. More recent works [11,12] tried to use traditional mobile devices, such as PDAs or mobile phones, rather than specific hardware. However, the devices are still only acting as a router of information.

Differently, some works started to use intelligent resources during the monitoring process. The system of Copetti [13], for example, uses several sensors, in a home care environment, which send health signals to a personal computer. The patient diagnostic process is carried out using Fuzzy Logic and a set of production rules in the own patient personal computer. In case of problems detection, this computer contacts health professional. Similarly, the work discussed in [14] is also classified as a home care system and it uses pattern recognition techniques to identify the behavior of patients in terms of locomotion and diary activities.

We see that when more advanced processing techniques are used, the monitoring systems tend to be a home care service, rather than a mobile application. The reason is the limited support that the Java Micro Edition provides for the mobile platform. The use of Android and other more powerful operating systems will eliminate the majority of these current limitations. For example, the LaCasa project [15] proposes a novel decision-theoretic model that estimates the risk faced by persons with dementia and decides on the appropriate action to take, such as prompting the person with dementia or calling the caregiver. The model can be tailored to the user needs (e.g. known locations, level of cognitive decline) and takes into account uncertainty, and contextual information gathered from sensors, such as current location, noise, and proximity to the caregiver. A preliminary version of the system has been instantiated in a wandering assistance application for mobile devices running on an Android platform.

From this discussion we see that current embedded systems that run in mobile devices do not support any kind of declarative codification in the form of production rules. Note that such rules are a natural way to codify knowledge. Indeed, ever production systems are not able to run in mobile

devices, once we do not have first-order logic engines available to this platform. Rule-based systems are a natural way to codify knowledge if we have the knowledge providers. One of its main advantages is the ability to provide explanations about its decisions, once the reasoning flow can be tracked. Differently, case-based reasoning needs a high number of past cases to be configured, while conexionist (e.g., neural networks) forms of reasoning also need a training set and they generally do not provide ways to identify the reasons for their conclusions.

III. THE RULE -BASED MONITORING ARCHITECTURE

The monitoring architecture that we are specifying is composed of health sensors and an assistant agent running at a mobile device. Health sensors account for capturing important vital signals of patients and transmit such signal to the assistant agent. The sensors can use the Bluetooth technology, which is a standard communication protocol primarily designed for low power consumption, with a short range (power-class-dependent: 100 m, 10 m and 1 m, but ranges vary in practice) based on low-cost transceiver microchips in each device. Because the devices use a radio (broadcast) communication system, they do not have to be in line of sight of each other.

The assistant agent has three main modules (Figure 1): the Bluetooth drivers, the reasoning process and the SMS handler. Bluetooth drivers account for receiving signals from health sensors and transform such signals in facts. In order, getting rid of cables is a trend in the medical field, as it gives patients and healthcare workers more freedom and possibilities. Thus, Bluetooth is used in a variety of medical applications as a secure and reliable connection method.
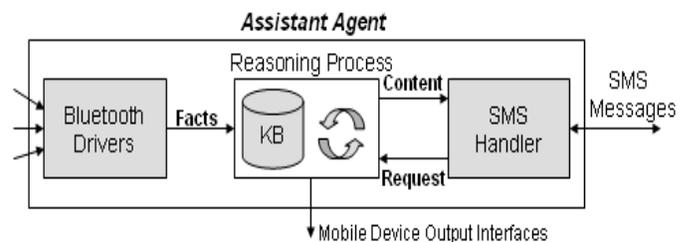

Figure 1.   Architecture for a rule-based assistant agent.

Typical implementations have been based on Bluetooth *Serial Port Profile* (SPP) and manufacturers specific proprietary implementations and protocols. Therefore, different implementations have had a poor level of interoperability with each other. For this reason some initial efforts, such as the *Bluetooth SIG Medical Device Working Group*, intend to develop a profile that would introduce interoperability between different medical sensors and collecting devices from different manufacturers. Initial works resulted in the *Multi-channel Adaptation Protocol* (MCAP) and the *Bluetooth Health Device Profile* (HDP) [16].

The facts extracted from the Bluetooth communication are then saved in the *Knowledge Base* (KB) of the reasoning

process module. These facts must respect a general pattern-value format, which is specified as

$$((data\ time\ vital\text{-}signal\text{-}identifier), vital\text{-}signal\text{-}value)$$

This could be instantiated to mean, for example, "on 19/10/2009 (*data*) at 17:30 (*time*) the temperature (*vital-signal-identifier)* was 38.5 (*vital-signal-value*)". Apart facts, a knowledge base is also composed of *rules* that represent the expertise of a health specialist. A rule has a left hand side (a sensory precondition or "IF" statement) and a right hand side (action or "THEN" statement). The left hand side contains information about certain facts and objects which must be true in order for the rule to potentially fire (that is, execute). Any rules whose left hand sides match in this manner at a given time are placed on an agenda. One of the rules on the agenda is picked (there is no way of predicting which one), its right hand side is executed and then it is removed from the agenda. The agenda is then updated (generally using a special algorithm called the Rete algorithm), and a new rules is picked to execute. This continues until there are no more rules on the agenda.

A production system [17] controls the reasoning process and it also contains a database, sometimes called working memory, which maintains data about current state or knowledge, and a rule interpreter. The rule interpreter must provide a mechanism for prioritizing productions when more than one is triggered.

The reasoning process can generate content to be delivered to its user, via display or sound interfaces; or to the central root via short messages. The *SMS handler* accounts for encoding the content, which was generated by the reasoning module, into SMS messages. The principal reason to use this kind of communication service is its low cost. This aspect is important if we want to monitor the health conditions of different social classes, once we need to reduce the operational cost of this environment. Furthermore, the kind of discrete information that we intend to transmit (*e.g.* blood pressure, pulse and temperature) does not require a high band to be transmitted on.

IV. KNOWLEDGE REPRESENTATION AND USE

The best option to create an instance of a production system is to use a framework, which abstracts several of the production systems concepts. Several options are available to the personal computer platform, such as Jess and JEOPS [18], which are extensions of the Java language.

At a first moment, we tried to use a framework called KEOPS [19], a restricted adaptation of JEOPS to mobile platform. However, this framework requires a previous compilation of the rule base each time that the base is modified. Thus, this requirement prevents the process of updating the knowledge base by the own device. Considering this fact, we decided to create a light and domain-dependent inference mechanism to running in mobiles, as detailed in the next subsections.

A. Grammar Symbols

The grammar language is composed by reserved words, identifiers, punctuation signals and relational operators. The reserved words are only used in specific cases, as in any other formal language. An example is the "conditions" word, which is used to identify the beginning of the preconditions section of a rule. The punctuation signals are used to mark the end of a file (.), the end of a precondition or action (;) and the beginning of a block (:). The relational operators are used to define premises that must be (on not) validated by the system. When we define premises in the same precondition section, we are indirectly applying the "and" logical operator on such premises.

Table I shows all the elements that were considered in this version.

TABLE I.   GRAMMAR SYMBOLS

Type	Token	Function
Reserved word	ruleBase	Name of the knowledge base
	Rule	Name of the production rule
	Conditions	Beginning of conditions
	Actions	Beginning of actions
	Normal	Type of detected health situation
	Alert	
	Emergency	
Identifiers	Name	Name identifier
	Age	Age identifier
	Gender	Sex identifier
	Weight	Weight value
	VitalSigns	Health signal identifier
	SBP	Systolic blood pressure value
	DBP	Diastolic blood pressure value
	heartRate	Heart frequency value
	respiratoryRate	Respiratory frequency value
	temperature	Body temperature value
	oximetry	Blood oxygen rate
	SBPVarianceSleeping	Variance of SBP during the sleeping
	SBPVarianceHomeActivity	Variance of SBP during home activities
	SBPVarianceStand	Variance of SBP during rest
	VERY_LOW	Possible constants used to classify the variation of health signals
	LOW	
	NORMAL	
	HIGH	
	VERY_HIGH	
Punctuation symbols	:	Indicates the beginning of a condition in a rule
	;	Indicates the end of a line in a condition or action
	.	Indicates the final of a rule base
Relational operators	< <= > <= = #	Symbols used to carry out relational operations

B. Creating Instances of Rule Bases

To represent production rules using such symbols, we have specified a simple context free grammar to facilitate the

work of formalizing the expertise used in this work. Figure 2 shows a simple example of rule base specified in accordance with that grammar.

```
ruleBase test
    rule first:
        conditions:
            SBPVarianceSleeping = LOW;
        actions:
            alert;
    rule second:
        conditions:
            SBPVarianceSleeping = NORMAL;
        actions:
            normal;
    rule third:
        conditions:
            heartRate = HIGH;
        actions:
            alert;

.
```

Figure 2.   Example of simple rule base specified in accordance with the defined language

This example shows that every base is composed for a set of rules and each rule has obligatorily two parts: the conditions and the actions. Given this initial example, next sections discuss both the elements of the grammar and its syntactical aspects.

C.   Intrepretation of Instances of the Grammar

The description of a knowledge base instance is carried out according to the previous figure (Figure 2). This instance is stored in a text file called "RuleBase.rule", which is loaded to be interpreted by the algorithm described in Figure 3. Such algorithm also uses input signals (health information acquired via sensors) during the evaluation of logic sentences.

The idea of such algorithm is to interpret the conditional part of the rules and, based on the results of such interpretation, to activate the right side of the rules, which are related to actions of emergence, alert or normality. In order, the algorithm can be interrupted to execute an action and, after that, resume such execution.
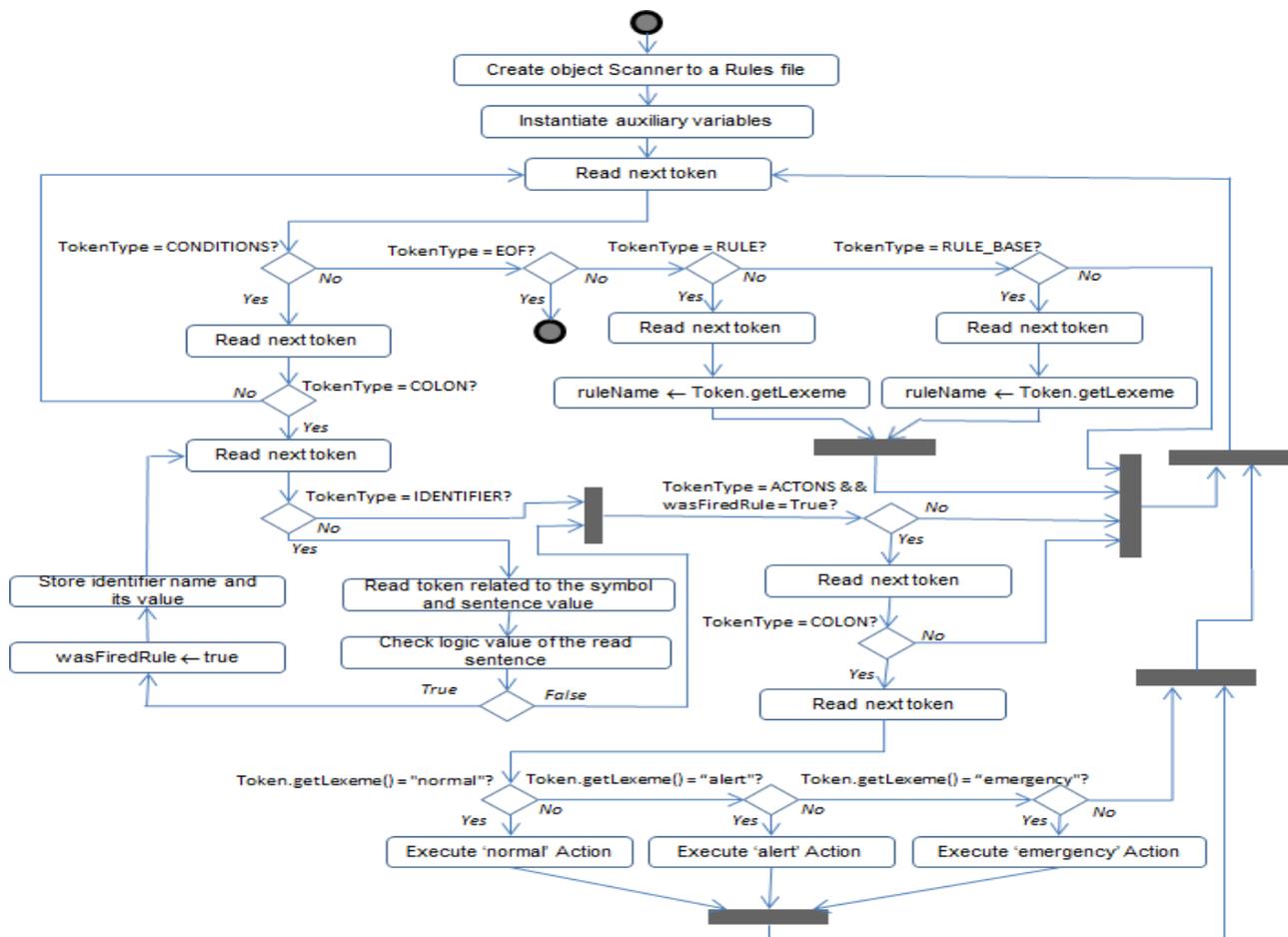

Figure 3. Activity diagram of the rule base analysis algorithm

When an action is chosen, a second algorithm (Figure 4) is triggered to execute such action. This algorithm receives the action identifier and additional data related to the rule that was activated. Then, the algorithm controls the calling of several methods, such as:

- *sendSMS*: this method uses one or more pre-defined telephone numbers to send warning messages. Before transmission, messages are divided into packages of 160 characters;
- *reportHistoric*: this method accounts for reporting all the information of patients that is stored in the devices database, which are stored in the device, to a central database (e.g., web server);
- *activeTimer*: this method accounts for scheduling the automatic execution of the algorithms based on the time that is defined by the production rules.
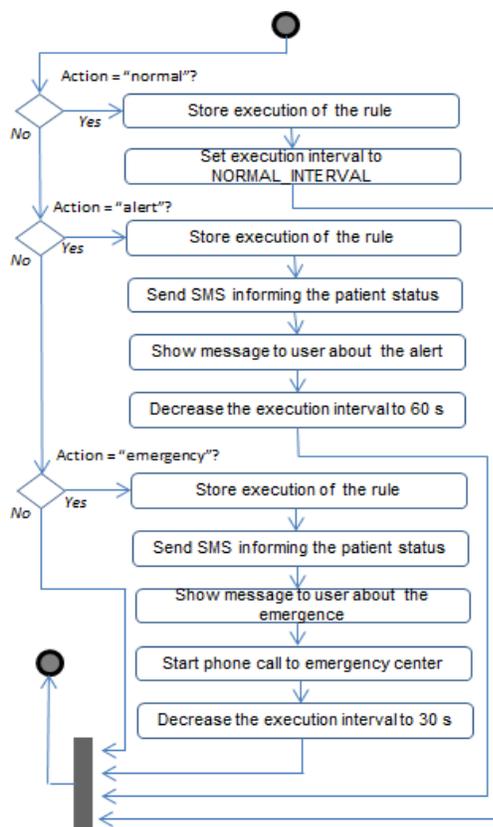

Figure 4. Activity diagram of the action control algorithm

In a situation of "alert", the system sends a message via SMS to pre-defined receivers and displays such message in the device's graphic interface, informing its user about the alert status. This message shows the health signals that are not normal. After that, the algorithm reduces the time regarding the next execution of the rule base. When an emergency situation is detected, the system acts similarly to the alert scenario. The differences are associated with the time for execution, which is adjusted to 30 seconds, and the warning messages. In this case, the system suggests a phone call and prepares a shortcut button for such call.

During the interpretation of rules, the system can stand by its execution to ask its user about her/his current physical activity. Alternatives to answer this question are: Stand, Home Activity, Sleeping, Other. Users can also pre-define the answer for this question. For example, when they go sleep, the "Sleeping" status can be pre-defined.

V. EXPERIMENTS AND RESULTS

To create the knowledge base, we have used the reference patterns for cardiovascular anomalies and different combinations of the set of production rules defined in [13]. The precedence is defined by the order of the rules in the "RuleBase.rule" file. Then, different test cases were defined to evaluate the correctness of the system. For such cases, synthetic facts were used to generate different scenarios. An example of scenario is specified in next table (Table II).

TABLE II. ONE OF THE SCENARIOS FOR EVALUATION, WHERE SIX HEALTH SIGNALS ARE REGISTERED: S1 (CARDIAC FREQUENCY), S2 (RESPIRATORY FRQUENCY), S3 (SBP), S4 (DBP), S5 (BLOOD OXIDATION) AND S6 (BODY TEMPERATURE).

	S1	S2	S	S4	S5	S6
Measure 1	100	16	120	80	100	37
Measure 2	90	15	141	90	95	38
Measure 3	160	30	120	75	98	37
Measure 4	100	17	120	80	95	38
Measure 5	90	16	110	60	90	36
Measure 6	100	20	160	90	97	38
Measure 7	110	19	120	85	99	37
Measure 8	112	18	120	80	95	36

The print screens presented in Figures 5 show messages that are displayed to users during the execution of one of the test scenarios.
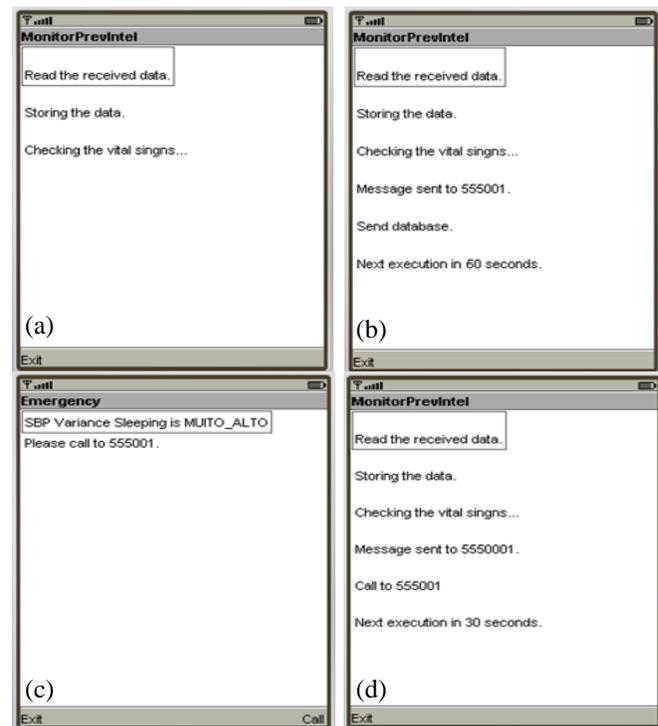

Figure 5. Print screens of the execution scenarios

This emulation was carried out via the Wireless Toolkit 2.5.2. Figure 5a displays messages about the initialization of the system Figure 5b shows an execution where, at the end of the execution, the system performs a backup of the device database to a datacenter represented by the number 555001. In Figure 5c, the system detects an emergency situation and shows a warning message to its user suggesting a phone call to a pre-defined number. Figure 3d presents a moment after the detection of an emergency situation, where we can notice the new period of 30 seconds to check vital signs.

We have used a knowledge base with 21 rules and 20 different scenarios to validate this approach. The scenarios were first analyzed by one health specialist, which described the procedure that should be done for each case. After that, the scenarios were sequentially uploaded by the system, and the results of its behavior were compared to the specialist analysis. This experiment validated the correctness of the rules and also demonstrated the easy way to codify knowledge.

VI. CONCLUSIONS AND RESEARCH DIRECTIONS

One of the advantages of real time and pervasive monitoring systems is their ability of detecting possible problems in an early stage of evolution. Thus, they are very useful as support to preventive medicine. Our main contribution in this context is to present an alternative to codify the knowledge of expertise, so that this representation can be easily manipulated inside a limited computer platform. Unfortunately, this form of manipulate the knowledge is domain dependent, so that it must be changed to deal with other domains.

As monitoring systems provide diagnostic about particular situations, they must be reliable. This means, such systems must provide correct and accurate interpretations of income information. However, a complete reliable system is hard to be implemented once we need to consider possible software and hardware failures. We are aware of this problem, so that we consider that the system outcomes are currently only indications of users` health status rather than final diagnostics. Then, health specialists must evaluate the results before taking some action. To support such evaluation, the system can be configured to generate explanations that justify its interpretations. Future directions of this research can investigate the design of fault-tolerant modules to ensure reliability, using, for example, cross information analysis of diverse sources.

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