

# Ontology for Complex Mission Scenarios in Forensic Computing

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**Abstract**—Complex mission scenarios are those in which information changes continuously and quickly or scenarios where have large quantities of expensive resources, large number of norms and rules, large number of personnel including, for instance, crimes in the cyber space, computer forensics, computer and digital investigation. Organisations performing in such scenarios may have components in different geographic locations: some are in the battlefield, while others are at their offices. Enabling coordination between these components (i.e., special skills, intelligence, planning, expensive devices, and sophisticated software) in highly unstable environments is a challenging task. The aim of this research is investigate the use of ontology with computational agents to support complex mission scenarios in Forensic Computing. This paper presents a logic- and set-based model to represent scenarios of a formal organisation. In addition to this, it was implemented an outstanding ontology that describes typical mission activities, their relationships, required resources, and constraints. This ontology is used to map a mission to an organisation. Also, we present a realistic ontology schema in Forensic Computing for the Brazilian Federal Police and a concrete case study where agents from a formal organisation are deployed in complex mission scenarios. This ontology can be easily extended for other police or military force. Hence, it is an efficient tool to manage people and resources.

**Index Terms**—artificial intelligence, complex mission scenarios, forensic computing, international scientific exchange, ontology.

## I. INTRODUCTION

The aim of this research is investigate the use of ontology with computational agents to support complex mission scenarios in Forensic Computing. An ontology is a model of a real domain that is represented in some declarative formalism. In this way, an ontology associates the names of entities in the universe of discourse (e.g., classes, relations, functions, agents, or other objects) with human-readable text describing what the names mean, and formal axioms that constrain the interpretation and well-formed use of these terms. Formally, an

ontology is the statement of a logical theory. We intend to present a logic- and set-based model representing the knowledge aspects that a formal organisation performing. In addition to this, an outstanding ontology will describe typical activities for missions, their relationships, required resources, and constraints. This ontology can be used to map a mission to organisations like police or military forces.

In this context a formal organisation can be understood as planned, coordinated and purposeful action of agents (human beings or computer programme) to construct or to achieve tangible or intangible objectives. The general approach is to study existing organisations and fully describe the organisational structure before implementation. Thus, we analyses an organisation as an entity centred in a structural perspective. In this sense, organization is a permanent arrangement of physical (static structure) and virtual (dynamic structure) elements. These elements and their actions are determined by agents, abilities, roles, goals, resources, legal and administrative norms, competencies, missions and complex events so that a certain task can be fulfilled through a system of coordinated division of labour by the multi-agents units. Afterwards, we intend to present fragments of realistic ontology schema in Forensic Computing for the Brazilian Federal Police. Furthermore, it will be presented a concrete case study where agents from a formal organisation are deployed in complex mission scenarios.

To clarify, we define that complex mission scenarios are those in which information changes continuously and quickly or scenarios where have large quantities of expensive resources, large number of norms and rules, large number of personnel including, for instance, crimes in the cyber space (e.g., sexual exploitation of children, frauds against financial institutions, cyber terrorism, divulging of criminal information), computer forensics (e.g., live analysis, botnets - prevention, detection and monitoring, prevention and detection of intrusion), computer and digital investigation (e.g., events

requiring different abilities and devices to manage). Organisations performing in such scenarios may have components in different geographic locations: some are in the battlefield, while others are at their offices. Enabling coordination between these components (i.e., special skills, intelligence, planning, expensive devices, and sophisticated software) in highly unstable environments is a challenging task.

Therefore, this work seeks to explain, to the research community and society in general, the problem of complex mission scenarios in Forensic Computing and how to manage them using ontology based in artificial intelligent technology.

## II. WORK IN THE AREA

The problems missions are very complex:

- ❖ Large number of personnel;
- ❖ Large quantities of expensive resources;
- ❖ Large number of norms and rules;
- ❖ Information needs and its speed of change.

Several studies of artificial intelligence techniques were carried out in mission scenarios [9, 24, 25, 29, 30, 32, 50]. A good example of this important research field is the International Technology Alliance (ITA) project [20, 21]. The main goal of ITA project is to retrieve and disseminate information relevant to specific missions within a required resource-frame to maximize the utility of the resource. Maximizing utility encompasses giving priority to more important missions, balancing the quality of information with the energy costs of gathering the data, and storing and disseminating information in a manner so that it can be used most effectively:

- ✓ Developing representations of missions that can be used to determine the data required for a mission;
- ✓ Developing of available mission scenarios, including those used in police training;
- ✓ Modelling, through ontology, the sensors and sources required by a mission.

On the other hand, it is necessary to reasoning about missions as part of organisations. In this way, organisations can be seen as societies of agents [1, 6, 8]. Actions and decisions are not the simple outcome of any single, orderly activity: they emerge from ecology of information process. Hence, the relationship between organisations, missions and environments became a subject of practical studies of the real life. In order to this some applicable researches and works about formal organisations were done:

Choo [5] develops an understanding of how an organisation may manage its information processes more effectively in order to learn and adapt. His vista of information manage is broad, encompassing information processes, information resources, and information technologies.

Tarapanoff et al [45] deal with competitive intelligence and scenarios in formal organisations. They show a methodological proposal for a case study.

Vasconcelos et al [48] present the MOdel of Organisational Change using Agents (MOCHA) as a means to formally specify, check and simulate organisations and their changes using agents. They define the structure of the organisation without making any assumptions about the internal characteristics of the agents who will populate it. They adopt a normative view of organisations, and capture a notion of social influence through relationships between roles.

Dignum et al [10] discuss how and why organisations change. They identify and classify situations for change and explore how these changes can be made dynamically. In systems where the organisational structure is defined in terms of roles that agents enact, the system is required to adapt as agents move in and out of those roles.

Ferber et al [11] adopt a purely organisational approach in the model AGR (Agent, Group, Role). Agents are active, communicating entities that enact roles with groups. Groups are sets of agents sharing some common characteristic; they are contexts for patterns of activities and are used to partition organizations and define organisational structure. Roles are abstract representations of functional positions that agents may hold in a group and have associated interaction protocols.

Sichman and Demazeau [44] present the core notions of a social reasoning mechanism, based on dependence theory. This model enables an agent to reason about the others, in particular to calculate his dependence relations and dependence situations in formal organisations.

## III. FORMAL DEFINITIONS

An important component to this research is to prove that the formal model proposed is scientifically valid and practicable with the reality. Therefore, we intend to present a logic- and set-based model representing the knowledge aspects of a formal organisation performing as defined below.

### Def. 1. Organisation

An organisation  $O$  is a pair of static and dynamic structures, explained below.

$O = \langle S, D \rangle$ , where:

- $S$  represents the static structure;
- $D$  represents the dynamic structure.

Examples:

$O = \text{Interpol};$

$O = \text{Brazilian Federal Police};$

$O = \text{US Army}.$

## Def 2. Static Structure

A static structure is a set  $S = \{U_1, U_2, \dots, U_n\}$ , where each  $U_i$ ,  $1 \leq i \leq n$ , is a unit (def. 3).

## Def. 3 Unit

A unit is a physical structure that is complete by it.

$U = \langle id, C, N, Rls, Rs \rangle$ , where:

- $id$  is the name of the unit;
- $C$  is a non-empty set of deontic formulae (permissions) representing the competencies of the unit;
- $N$  is a non-empty set of deontic logic formulae (permissions, obligations and prohibitions) representing norms the unit must conform to;
- $Rls$  is a non-empty set of roles;
- $Rs$  is a possibly empty set of resources.

Examples:



Fig. 1. Graphic diagram of the Brazilian Federal Police units  
[http://www.dpf.gov.br/web/organog\\_grand.htm](http://www.dpf.gov.br/web/organog_grand.htm)

A structure,  $S_1$ , represents one more complete and extended vision of units for Brazilian Federal Police based on figure 1:

$S_1 = \{U_{\text{Directorate}}(\text{General}), U_{\text{Directorate}}(\text{Technical-Scientific}), U_{\text{Directorate}}(\text{Intelligence Police}), U_{\text{Directorate}}(\text{Organized Crime Combat}), U_{\text{Directorate}}(\text{Executive}), U_{\text{Directorate}}(\text{Administration and Logistics}), U_{\text{Council}}(\text{Ethical and Discipline}), U_{\text{Council}}(\text{High Police}), U_{\text{Assistance}}(\text{Legal}), U_{\text{Assistance}}(\text{Technical}), U_{\text{Assistance}}(\text{Internal Control}), U_{\text{Assistance}}(\text{International Relationship}), U_{\text{Institute}}(\text{Criminalistics}), U_{\text{Institute}}(\text{Identification}), U_{\text{Academy}}(\text{Police}), U_{\text{Division}}(\text{Forensic Science}), U_{\text{Sector}}(\text{Drug Abuse Combat}), \dots, U_{\text{Service}}(\text{Expertise in Computer Crime})\}.$

This new paradigm of knowledge representation of a formal hierarchy can be easily modified to represent another formal organisation. For instance, a structure fragment,  $S_2$ , of the operational units for US Army is represented in a hierarchy according to figure 2.

$S_2 = \{U_{\text{Operational}}(\text{Field Army}), U_{\text{Operational}}(\text{Corps}), U_{\text{Operational}}(\text{Divisions}), U_{\text{Operational}}(\text{Brigades}), U_{\text{Operational}}(\text{Battalions}), U_{\text{Operational}}(\text{Companies}), U_{\text{Operational}}(\text{Platoons}), U_{\text{Operational}}(\text{Squads \& Sections})\}.$

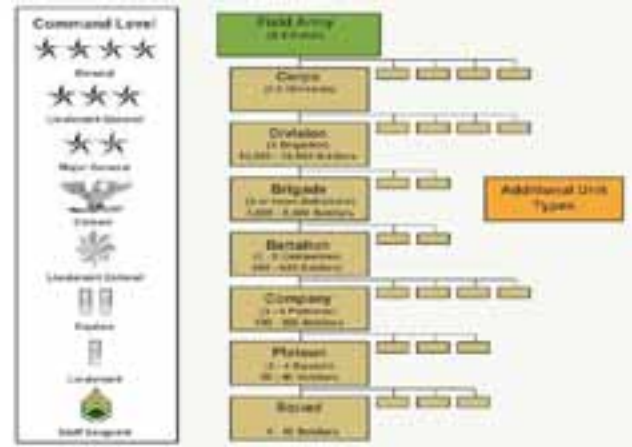


Fig. 2. Diagram of the operational unit for US Army

<http://www.army.mil/institution/organization/unitsandcommands/oud/>

NOTE: All units have a tuple  $\langle id, C, N, Rls, Rs \rangle$  associated with them.

## Def 4. Agent

An agent is a pair  $ag = \langle a, ABa \rangle$ , where:

- $a$  is the agent's unique identifier;
- $ABa$  is the set of abilities of agent  $a$ .

The set of agents is  $Ags$ .

Example:

$Ag = \left\{ \begin{array}{l} 007, \\ \text{cyber\_crime\_investigation}_{007}(\text{Case}), \\ \text{hardware\_knowledge}_{007}(\text{microcomputer, mainframe}), \\ \text{software\_knowledge}_{007}(\text{windows\_based, unix\_based}), \\ \text{use\_idiom}_{007}(\text{english, french, portuguese, spanish}), \end{array} \right\}$

## Def. 5. Dynamic Structure

All functional aspects of the missions are components of the organisational dynamic structure.

$D = \langle Ms \rangle$  where:

- $Ms$  is the set of missions (def. 8).

## Def. 6. Action

An action  $Act$  is a first-order logic predicate  $p(t_1, \dots, t_n)$ .

The set of all possible actions is  $Acs = \{Act_1, \dots, Act_m\}$ ,  $1 \leq i \leq m$ .

The actions in Forensic Computing could be related via the following predicate.

Example:

$$Acs = \left\{ \begin{array}{l} \text{preparation(Evidence),} \\ \text{physical\_extraction(Evidence, Result1),} \\ \text{logical\_extraction(Result1, Result2),} \\ \text{timeframe\_analysis(Result2, Report1),} \\ \text{data\_hiding\_analysis (Result2, Report2),} \\ \text{application\_and\_file\_analysis (Result2, Result3),} \\ \text{documentation(Report1, Report2, Report3, Outcome)} \end{array} \right\}$$

#### Def.7. Resource

A resource,  $t_i$ , is a material or immaterial support. Each resource is an asset of a unit and to be used in missions by agents. The set of resources is  $Rs$ .

- $Rs = \{t_1, \dots, t_n\}$ ,

where  $t_i$ ,  $1 \leq i \leq n$ , is the resource from the unit.

The resources supplied for an expert agent in computer crime in a mission could be, for instance:

$$Rs = \left\{ \begin{array}{l} \text{functional\_identity,} \\ \text{mission\_order,} \\ \text{search\_authority\_copy,} \\ \text{forms,} \\ \text{radio\_communicator,} \\ \text{workstation\_computer,} \\ \text{duplication\_media,} \\ \text{connector\_cable,} \\ \text{expert\_software,} \\ \text{target\_documentation,} \\ \text{contact\_data} \end{array} \right\}$$

#### Def. 8. Mission

A mission is a tuple,  $M = \langle mid, D, Acs, Rs \rangle$ , where:

- $mid$  is the identification of the mission;
- $D$  is the duration of the mission;
- $Acs$  is a set of actions associated with the mission;
- $Rs$  is a set of resources that will be used in a mission.

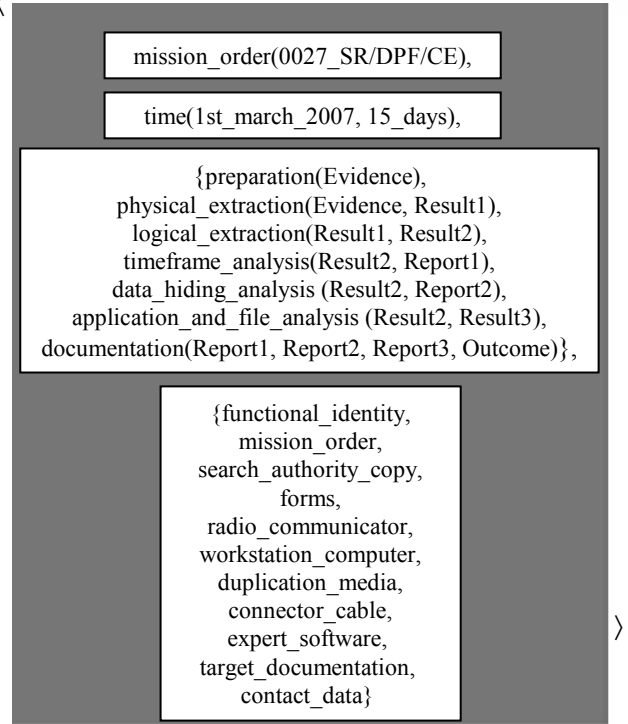
Missions are the set formed by all missions belongs to a specific organisation. Therefore, the set of all missions is  $Ms$ .

$$Ms = \{M_1, M_2, \dots, M_n\}.$$

Example:

A complete case study of a typical mission,  $M_1$ , in Forensic Computing:

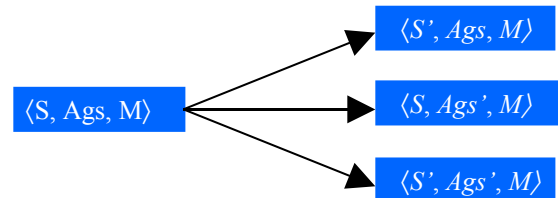
$M_1 = \langle$



#### Def. 9. Complex Mission Scenarios

This new concept was created in this work for the success of a mission in a formal organisation like the police force. In a practical approach, Complex Mission Scenarios, *CMS*, are those in which information changes continuously and quickly or scenarios where have large quantities of expensive resources, large number of norms and rules, large number of personnel.

In a general way, resources and roles of the static structure may change or, more likely, the set of agents (and their abilities) associated to a mission changes. So, CMS are those scenarios in which some critical component changes in a static structure ( $S \rightarrow S'$ ) or in the set of agents ( $AGS \rightarrow AGS'$ ) or both situations.



where,

$S$  is all components of static structure (def. 2);

$Ags$  is the set of agents (def. 4);

$M$  is a mission (def. 8).

#### IV. ONTOLOGY CASE STUDY

An ontology is an explicit specification of a conceptualization of the real world. The term is borrowed from philosophy, where an ontology is a systematic account of existence. For Artificial Intelligence (AI) systems, what “exists” is that which can be represented [18]. When the knowledge of a domain is represented in a declarative formalism (we create a logic- and set-based model to represent scenarios of a formal organisation), the set of objects that can be represented is called the universe of discourse. This set of objects, and the describable relationships among them, are reflected in the representational vocabulary with which a knowledge-based program represents knowledge. Thus, in the context of AI, we can describe the ontology of a program by defining a set of representational terms. In such an ontology, definitions associate the names of entities in the universe of discourse (e.g., classes, relations, functions, or other objects) with human-readable text describing what the names mean, and formal axioms that constrain the interpretation and well-formed use of these terms. Formally, an ontology is the statement of a logical theory. Hence, an ontology defines a common vocabulary for researchers who need to share information in a domain. It includes machine-interpretable definitions of basic concepts in the domain and relations among them.

Why would someone want to develop an ontology?

Some of the reasons are:

- To share common understanding of the structure of information among people or software agents;
- To enable reuse of domain knowledge;
- To make domain assumptions explicit;
- To separate domain knowledge from the operational knowledge;
- To analyze domain knowledge.

We create an ontology that can represent mission scenarios of a real organisation. We intend to go in the same direction of [3, 7, 18]. After that, it is important to develop an ontology solution using some software tool. To achieve this purpose we investigate ontology computational languages: Chimaera [4], Ontolingua [38], and Protégé [39, 40]. In this way, after test of the tools above we created an ontology implementation (figures 3 to 6) for Brazilian Federal Police using Protégé.

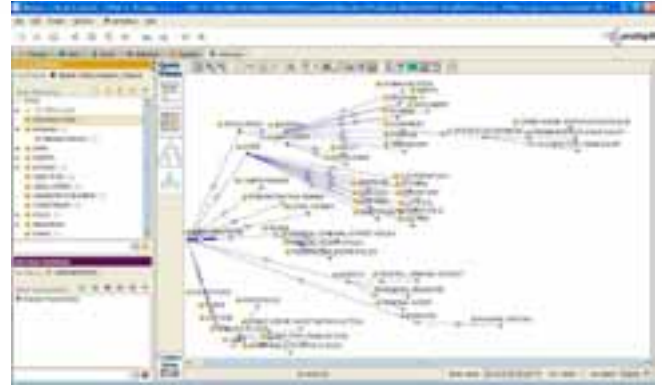


Fig. 3. Ontology implementation and its components with a mission schema

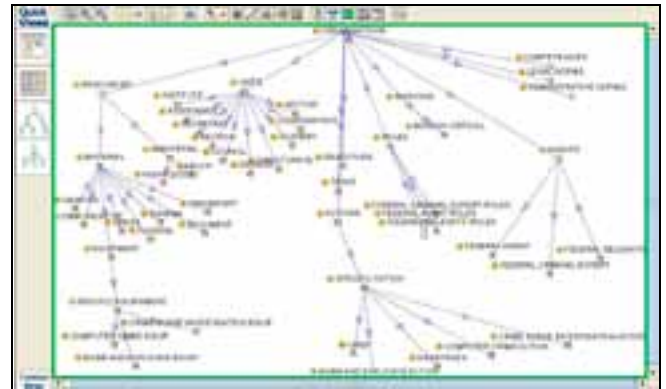


Fig. 4. Taxonomy diagram for Brazilian Federal Police using our ontology

Pragmatically, a common ontology defines the vocabulary with which queries and assertions are exchanged among agents [50]. Ontological commitments are agreements to use the shared vocabulary in a coherent and consistent manner (figure 5). At this moment it is possible to know that an ontology schema is more powerful than any database. It has propositions, rules, predicates, knowledge, relationship and constraints over the base. With an ontology it is possible to manage resources, to prove axioms, to make decisions between missions, agents, units, and several components in an organisational structure.

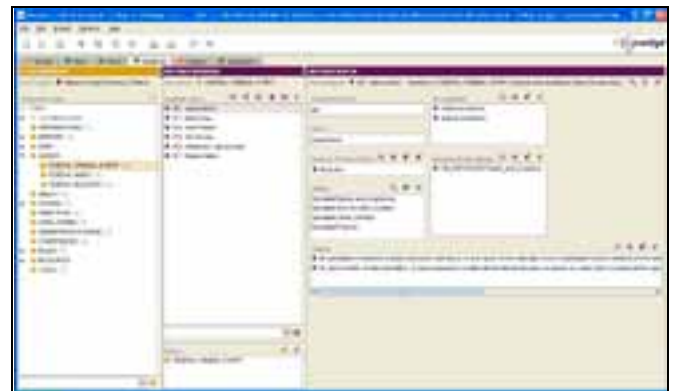


Fig. 5. Ontology with agents in a complex mission scenario



For complex mission scenarios in a police force it is important to answer questions like:

- Which missions are in process?
- Which missions are complex?
- Which agents do possess the ability x?
- Where do I find agents with the abilities x and y?
- Which resources can dispose in this mission?
- In which unit organization I can request the material resource for mission z?
- Which laws, norms and instructions should be satisfied in the mission k?
- Is the service of expertise in computer science competent to execute the mission k?
- Which the tasks the agent x needs to accomplish to conclude the mission k?

We elaborated a complete case study for Brazilian Federal Police where our ontology implementation answered all these questions above. An example of this implementation can be seen in figure 6.



Fig.6. Query and answer about missions in our ontology

## V. INTERNATIONAL SCIENTIFIC EXCHANGE

Due to complexity of the knowledge between formalisms and practical aspects from mission scenarios we already begin investigate researches about new formalisms and some tools to represent ontologies. Since January/2007 we have been read over 50 references in a variety of topics primarily focused on first-order logic, deontic logic, relational algebra, set theory, norms, constraints, and architecture for organizations. Following, we have also acquired a vast content in knowledge representation, mainly in specific literature [19, 28, 33, 34, 37]. We have investigated some languages and tools to represent our ontology, for instance, Protégé [39, 40], Ontolingua [38], and Chimaera [4].

Actually, we work with real mission scenarios in Technical-Scientific Directorate at Brazilian Federal Police. So, we have been experience with missions for several years in the field of high-tech crime combat. Investigating the cases by units and sectors we have verified that more than a hundred missions; about 40 per cent of the total per year, involve complex or mission-critical scenarios. With this experience we have brought for the scientific research new practical view points

that have aided to comprehend real problems and aspects of missions in formal organisations.

This year we sent a Federal Criminal Expert (Brazilian police office specialist in computer crime combat) to take part in an international exchange and visit the Department of Computing Science at University of Aberdeen, Scotland, UK, to carry out joint work in the topic "Software Agents to Support Information & Workflow in Police Forces" with Dr. Wamberto Vasconcelos, member of the ITA project [21]. At this period it was examined some aspects about agents, norms, deontic logic, architecture for formal organisations, and other important subjects related with this research. Also, it was investigated new concepts and visions of knowledge representations, taxonomy hierarchies, ontologies, mission-critical scenarios. A number of meetings with local police members, researchers and professors was done to change knowledge and to discuss about this theme. At the end of this exchange and visiting it was presented a work in a seminar "Using Agents to Support Mission-Critical Scenarios" [25]. This seminar just was an initial point for this work, but there is a huge research to do.

## VI. CONCLUSIONS AND FUTURE TENDENCIES

The main objective of this work was use ontology to support complex mission scenarios in formal organization like police and military forces. This research covered a number of practical and realistic themes. One direction was managing missions in an ontology. After that, for the first time, it was treated formally complex mission scenarios. It is a kind of special mission where there are great or complex scenarios for an organisation to perform. In this sense, complex events are those in which information changes continuously and quickly [25]. Also, we examined if complex mission scenarios are only those in which resources and roles may change or if it is the set of agents (and their abilities) associated to a mission changes. This is the same approach of mission scenario that can be found in [30, 41, 43].

All the formalisms created were done in a mathematical way to prove actions by agents, to verify the norms and competencies, to check roles, and to carry out the relationships between organisation and its components. We created a logic- and set-based model to represent aspects of a formal organization and its components [2, 13, 16, 27], but we intend to study the possibility to use relational algebra to model the relationship between units and agents from an organization.

In addition, we modelled an ontology that can represent complex mission scenarios in real organisations. It was elaborated a complete case study for Forensic Computing based in real cases at Brazilian Federal Police where our ontology implementation answered important questions in management of agents and resources. However, it is necessary to improve the international cooperation and to enlarge our ontology for new applications (case studies) in other forces.

Therefore, this is a new research area where applications are done to manage mission in an efficient way. Major

governments (funded jointly by the UK MoD and US DoD), universities (CMU, Columbia, UCLA in US; University of Aberdeen, University of Cambridge, Imperial College in UK), research centres (UK MoD Science Innovation Technology, US Army Research Laboratory) and a considerable number of commercial companies, led by IBM, are facilitating safe research with ontologies and artificial intelligent techniques for missions scenarios. The Brazilian Federal Police cannot be excluded from this new technology. So, this work is just an iceberg point as instrument to fight criminality.

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