Action and Semantics of Time in Agro-ecology

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Abstract

In the systemic approach, the system is perceived as an action or a collection of overlapping actions expressed in reference to Time, Space, and Morphology (or Energy). When the system is studied by different disciplines, the referentials differ, as well as the semantics of terms used to describe the action. In order to establish the vocabulary of a collection of actions involving several disciplines, we propose a formal method for describing each action. The linguistic-based method enables (i) transcription of the literal description of an action in a semantic network, and (ii) building of a vocabulary in a formal setting. The method is illustrated through a complex biological system, i.e. the mutualistic relationship between two vine pests, while focusing particularly on temporality. The method provides a support for implementing multidisciplinary around a complex system.

1. Introduction

Most systems investigated by the life sciences (genetics, agronomy, ecology etc.) are complex. They are studied on the basis of observations that are analysed to give rise to knowledge. In the 1960s, with the advent of computers, observed systems could be represented as numeric simulation programs. The knowledge representation method usually adopted for designing such programs is based on systems theory, as presented by [1].

In the systemic approach, “a knowledge is an action taken by the one who knows” [2]. Accordingly, the system is perceived as an action, or a collection of overlapping actions that are implemented as processes, i.e. the transformation function of the system. This function is expressed in the Time – Space – Morphology reference system [3]. If the process is a formal construction expressed using mathematical language (numerical equation), the action is the result of a cognitive operation and is expressed literally using natural language. The systemic approach is based on the action concept, but the theory does not propose a formal framework for describing it [4].

According to [5], natural language evolves as a result of the need to describe an observation. In this sense, linguistics provides a framework for analyzing reference systems. For temporality, since the question arises as to whether it is time that moves or if we move relative to time [6], the Time reference system issue is complex. [7] distinguishes two forms of temporality, with one being timeless and the other a period, bounded by a beginning and an end. [8] identifies three types of time: universal time, which elapses irrespective of humans, conventional time shared by a community of individuals, and individual time which corresponds to a personal perception of elapsing time. [9] also differentiates physical time from historical time, "where the content of each moment depends on the contents of each of the moments that preceded it." This concept of time refers to the difference between the calendar date and the event.

In biology, when the referent system is not man, time is perceived in various ways depending on the organism studied. In homoeothermic organisms for instance, time is expressed in calendar time, i.e. an Earth rotation angle expressed as a number of hours, days, etc. For poikilothermic organisms, time is also a function of temperature. The mere mention of the plurality of time reference systems highlights the multiplicity of possible Time – Space – Morphology (TSM) reference systems.

If a complex system is described by one observer as overlapping actions, a single reference time is usually imposed: calendar, temperature, etc. [10]. On the other hand, when a system is studied by different observers from different disciplines, the reference systems may differ, as well as the semantics of the terms used to describe the action. When overlapping actions are described by multidisciplinary teams, it is necessary to match up the adopted reference systems and the vocabulary formulated to deal with issues of polysemy and polyphony. In this document, vocabulary is defined as an organization of terms that reveal the multiplicity of meanings that are given in relation to the uses to which they are made. We thus propose a formal method of describing actions. This method, based on linguistics literature, enables (i) representation of an action as a semantic network [11], and (ii) formulation of a vocabulary. The paper presents the method and an illustration, while focusing particularly on temporality.
This illustration concerns a vine-pest biological system in which a mutualistic relationship between the insect *Lobesia botrana* and the fungus *Botrytis cinerea* is observed [12, 13]. This system includes biological entities studied by three life science disciplines: agronomy, entomology and plant pathology. Moreover, as part of the mutualistic relationship, the insect's consumption of a sterol of fungal origin (a molecule involved in moulting) shortens its larval life [12]. In return, active transport of spores by the insect favours scattering of the fungus. The mutualistic relationship therefore leads to a modification of the initial temporal reference system of the insect and fungus.

2. Description of the method

Natural language enables three fundamental operations: describe the world, ask about the world and change the world [14]. This issue occupies a prominent place in human relationships [15]. The question always presupposes ignorance by the speaker and a drive towards a state of knowledge [16]. It is therefore the fundamental operation that enables access to the description of an action.

2.1 The functional group as a description support

Three types of query are allowed by the French language: global for overall truth conditions (answer true/false), alternative to propose choice of answers (which, etc.), and partial to get information about the unknown. A partial query concerns a specific member of the utterance, and the response requires a set of words that form a single unit, i.e. a functional group. In direct mode, a partial query is constructed by replacing a functional group by an unknown word (i) whose semantics is shared by all stakeholders, and (ii) which requires a specific response [17]. For example, the functional group provided by the answer to the question "Where are you?" may be "at home".

Seven words — pronouns or adverbs — are used in French, which are sufficient to question the world [18]. The pronoun "Who" questions the identity, the determination of a person [19]. This person is animated, fundamentally human or treated as a human [20]. The pronoun "What" is the bearer of an inanimate type [19] and "asked about the nature, the determination of something" [21]. The pronoun "Que" (other French form of what) questions something located in the direct object or as an attribute [21]. Responses to the adverbs "Where," "When", "How", and "Why" must be adverbial of Location, Temporality, Manner or Reason, respectively [18]. With regard to a sentence (or action), the pronouns Who, "Que", and What question the agent, verb, and the object complement, respectively. [22] distinguishes the direct object that complements the verb (called the essential complement) from the adverbial. The verb and the essential complement constitute the Act [23].

The addition of a preposition (to, from, by, etc.) to the query word varies the scope of the question. For example, the expected response to a query initiated with the word "when" is a precise moment. The addition of the preposition "from" transforms the response status: although this is a moment that is requested, it reveals a time extension of the action [24].

2.2 Structure of the functional group

According to [5], language is based on the principle of classification and hierarchy. The possible response types to a question therefore enable us to identify an organized description structure of a functional group. A comparative study of each functional group of typologies available in the literature enabled [25] to identify common features. The author distinguishes informative items, the relative position of these items next to an informational referential, and the meaning conveyed by the informative items. Three classes are proposed, which are respectively called Information (CI), Referential (CR) and Semantics (CS). In the example "larvae (the insect) transports conidia (fungus) in the grapes, upon which they feed," the answer to the question on the location of the transfer act produced by the insect, is “in the grapes, upon which they feed”. The informative item is "the grapes", the reference is "the vine", and the semantics is "which they feed”, corresponding to a food.

For CI, [25] identifies a common structure for all functional groups. The structure differentiates permanent items from the chain of items, perceived as a sequence: initial, median (whose length varies from 0 to n, and n> 0), and final (Figure 1). For instance, the concepts of displacement [26] and temporality [7] provide the location chain (initial/middle/end) and the period chain (start/current/end), respectively.

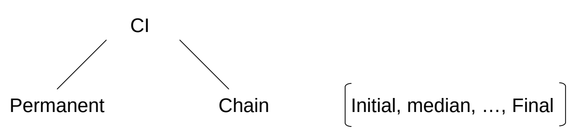

Figure 1. Organization of the Information class (CI): typology (left) and chain structure (right).

For CS, [25] observes a recurrence of the discriminatory character of intrinsic/extrinsic in inventoried typologies. For location, for instance, [26] distinguishes the place where the semantics is unique to itself (intrinsic), such as the toponym, from the place where the semantics is derived from other sites (extrinsic), such as a topological item. For temporality (Figure 2), [9] differentiates the historical time (extrinsic), from the physical time corresponding to a measurement system of self-significant universal time (intrinsic).

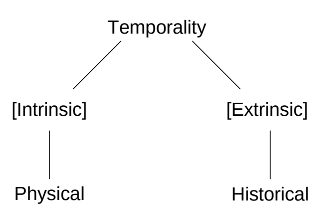

Figure 2. Organization of the Semantic class (CS) for the temporality functional group.

For CR, all typologies are not available in the literature. Using available typologies, [25] failed to reveal a common organization. To continue with the examples of location and temporality, [26] looks at the referential in the case of multiple locations and questions the link between these places. The referred is the place we are talking about, the referential is the place that locates the referred. For the location, two relationships are described, i.e. the inclusion and the neighbourhood. Inclusion is the relationship between container and content, and is made explicit in stating the container. For the neighbourhood, the following has to be specified: (i) adjacent items constitutive of the referential, and (ii) the relationship between the referred and the items of the referential (e.g. “the house at the seaside”). For temporality, since the question arises as whether it is time that moves or if we move relative to time [6], the Time system reference issue is complex. According to [8], there are different perceptions of time: Universal, Conventional or Individual. This leads us to consider a referential related to the nature of the considered time. Moreover, and as in the case of localization, the coexistence of several times can be found in the statement ('last summer, every afternoon, etc.’). In the case of time, we then have an inclusive referential homologous to that presented in the localization ('last summer' in the example), while also taking the referential nature of time into consideration (Conventional time in the example). In terms of relationship, we hypothesize that that which is relative to the nature of time is subsumption, and that between the referential and the referred when several times coexist is the inclusion. Finally, regardless of the referential in question, the relative position of the referred from the referential is provided according to [24] by combining the notions of point, duration and iteration.

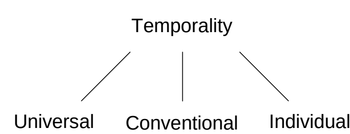

Figure 3. Organization of the Referential class (CR) for the temporality functional group.

In Figure 4, the multi-level structure of the functional group appears to be divided into classes, with each one consisting of items connected by a relationship (order, subsumption, neighbourhood, etc.). For each class, the first nodes of the graph correspond to the classifications and hierarchies obtained in the linguistics literature. The lower level nodes (or leaves) correspond to informative items. To introduce a relationship between classes, [25] proposes to establish a projection relationship of items located in the Information class on items located in the Referential and Semantic classes (Figure 4). For example, in the sentence "As a host, the vine provides larvae with the nutrients required for their development, which includes sterols”, the consumed item is 'Sterol', the referential of the consumed item is the vine, to which it is connected by the inclusion relationship. In terms of semantics, the item 'Sterol is extrinsic to the larva (the insect).

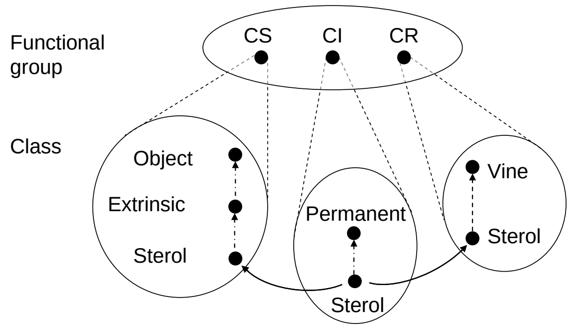

Figure 4. Description of the multi-level structure of a functional group. Example of projection of the item 'sterols' of the Information class (CI) in the Referential (CR) and Semantic (CS) classes.

2.3 The organisation of functional groups to describe an action

Different grammar concepts are used to assemble functional groups. As part of the structural syntax, [27] captures the verb as the descriptor of a state or an action. The state verb expresses a manner to be, characterized by a quality or a position, and the action verb expresses an activity (to run, to contaminate, etc.). The verb is described as the number of arguments, called valence. An avalent verb does not require the presence of an argument, and its valence is zero. In this case, the verb is only used in the third person singular ('it rains'). For other verbs, the valence is set at 1 ('I run'), 2 ('I eat an apple'), or 3 ('I give you an apple').

Moreover, [28] analyzes syntactic constructs containing zero, one, two or three arguments (without agent, uni-agential, bi-agential and tri-agential). In the analysis, the author distinguishes between the agent, i.e. the one who acts (agent, person addressed, etc.), and the object, "corresponding to the patient in the action sentences and to those who are treated the same in other types of sentences." In the tri-agential construction, as for instance “He gives her the apple”, 'her' is considered as a device agent (complement of direction). This formalism enables perception of a tri-agential construction as a bi-agential. In the construction without agent ('it rains'), the agent (it) cannot be explained by any substantive, and is therefore devoid of semantic content. The agent is then called "empty" and the construction is described as uni-agential. This work distinguishes between the three functional groups of Agent, Object, and Act plus the adverbials of Temporality, Localization, Manner, and Reason.

In grammar, the incidence is defined as the relationship of what is said to what is spoken [29]. This principle, outlined by [30], brings together in the sentence the support, which is what we speak about, and the contribution, which is what is said. This principle formalizes, in a predicative way, the mechanism of establishing links between words in the sentence. Applied to functional groups, this principle apprehends (i) the Agent as the action support element, supplemented by other items (contribution), (ii) the Act as incident to the Agent, and (iii) the adverbials as incidents to the Act. In the case of a bi-agential construction, the Object is incident to the Act. Expressed as a semantic network (Figure 5), the use of the incidence principle leads us to formulate an Action as follows: the Agent commits an Act endured by the Object, this Act is occurring at one Location and at a specific Temporality for a particular Reason and a certain Manner.

Finally, [31] distinguishes between two syntactic constructions depending on whether the manner adverbial is incident to the verb or to the agent of the sentence. Regarding the functional groups, these two syntactic constructions enable us differentiate between the serial Act committed by an Agent on an Object, such as “drive a nail with a hammer”, and the parallel Act committed by an Agent on two Objects simultaneously, such as “it works while singing”.

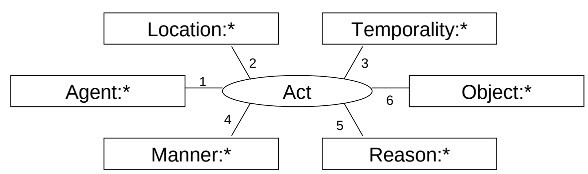

Figure 5. Representation, in the form of a semantic network, of an action conducted by an Agent on an Object. Concepts of Agent, Location, Temporality, Manner, Reason and Object are implemented as functional groups, as well as the Act relationship.

2.4 Construction of the vocabulary

The set of the graph leaves of the Semantic class is a lexicon. Beyond the scope of application, each term has a meaning given in relation to the functional group to which it depends. The dictionary of terms corresponds to the pooled terms complemented by their semantics, which is specified by the graph in the Semantic class in which they are leaves. The dictionary is related to the action. In the case of overlapping actions, the question is asked on the relative meaning of the terms in the combined dictionaries. The vocabulary, built from dictionaries, aims to bring out the multiple meanings of the terms with respect to the uses to which they are made. The vocabulary is gradually constructed by successive generalizations of the Semantic class concepts. The generalization operation requires experts in the discipline (life sciences) to explain the implicit meaning of the concepts. The identity of words is verified by the identity of meaning provided by the Semantic classes and by the equivalence of the Referential classes.

3. Illustration of the approach on a biological system

3.1 Description of the biological system

The biological system is composed of three subsystems, i.e. an autotrophic organism and two heterotrophic organisms, corresponding respectively to vine, insect and fungus. From [12, 13], the biological system has been described in nine actions. These actions, denoted by a letter (A to I), are classified by level of dependency of a sub-system with the others.

At level 0, the sub-system is considered individually:
- B: The vine produces sterols
- C: Conidia becomes mycelium
- G: Mycelium produces sterols
- I: The larvae become chrysalis (pupate)

At level 1, there is a dependency of one system over another (parasitism = nutritive substrate and habitat)
- A: The larva consumes grapes
- D: The fungus actively enters (pathogen) the grape using an enzyme (cutinase)
- F: The larva carries conidia (scattering)

At level 2, there is an interdependency of subsystems (mutualism relationship)
- E: The fungus passively enters (saprophytic) the grape using the lesions produced by the larva
- H: The larvae consume contaminated grape (vine + fungi)

A summary of these actions is given in Figure 6. Note that action H is a parallel action combining two simultaneous consumption actions.

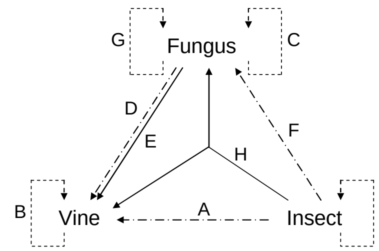

Figure 6. Summary of actions (dashed line for level 0, mixed line for order 1, and continuous line for level 2) conducted within the biological system.

3.2 Transcript of the action in the form of a semantic network

For action B, the answer to the question "Who does What?" is "the vine produces sterols". In this response, the Agent is 'vine', the Act is 'production', and the Object is 'sterol'. Agent and Object are permanent items of this action. To the question "When is that who does what?", the expert’s answer is "the development cycle of the vine", which corresponds to the functional group of Temporality. This temporal information is represented by an item in the Information class. For this action, the 'vine cycle' concept is timeless [7] (Figure 1).

For the Semantic class of functional groups, the Agent is necessarily intrinsic to itself for the considered action. For action B, the Agent 'vine' is thus described as intrinsic. As the sterol is produced by the vine, the Object 'sterol' is intrinsic to the Agent 'vine'. Similarly, the item of the functional group of Temporality 'vine cycle' is intrinsic to the Agent 'vine', and inherits the ‘physical’ classification proposed by [9] (Figure 2).

For the Referential class of the Temporality functional groups, the item 'vine cycle' is liable to two kinds of referential, Conventional and Individual [8]. The conventional perception of time applies to concepts accessible by measuring instruments, like the temperature. The individual perception of time applies to biological concepts such as vine phenology. In the graphs of Figure 7, the top graph corresponds to the perception type of the referential and the last nodes to the informative items. The intermediate nodes correspond to the path to access the 'absolute' referential of the informative item in relation to the action. For example, the informative item 'vine cycle' is included in 'phenology', which itself corresponds to a composition of the variety and environment of the vine cultivated plot. The environment is itself a composition of two conventional concepts, i.e. the air temperature and soil moisture.

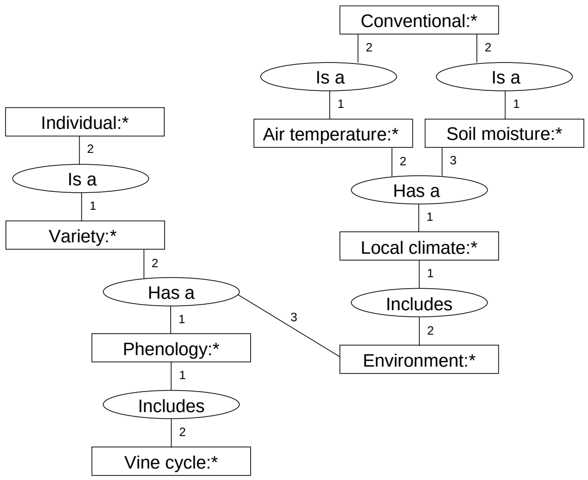

Figure 7. Graph of the Referential class of the Temporality functional group of action B.

3.3 The semantics of the terms for overlapping actions

Once all the actions are transcribed by the procedure described above, we have a set of semantic networks containing the Semantic and Referential classes. Figure 8 presents the semantic networks of the Temporality functional group of actions D and E, respectively corresponding to relations of level 1 (mushroom-vine) and level 2 (vine-fungus-insect). Six concepts are used as temporal items, relating to the development stage of the fungus, conidia and germination (conidia), the developmental stage of the grape, the presence of lesions and the local climate of the grape cluster. Of those six concepts, the concept (grape) 'cluster climate' is common to both graphs and the question arises as to the identity of those two concepts.

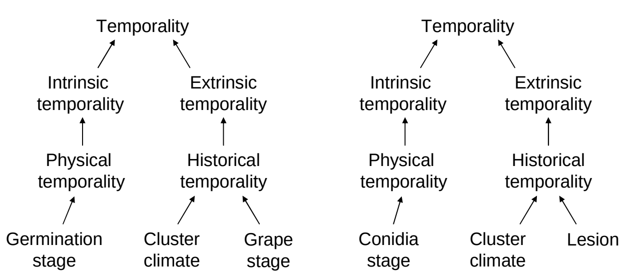

Figure 8. Semantic network of the Semantic class of the Temporality functional group of Action D (on the left) and action E (on the right). The relationship indicated by an arrow is subsumption.

Figure 9 shows the semantic networks of the concept 'cluster climate' of the Referential class of the Temporality functional group of actions D and E. The semantic network comparison shows that level 2 escapes the referential concept ‘air humidity'. As a result, there is no semantic identity of this item according to its use. In the vocabulary, it is therefore necessary to distinguish between the pathogenic grape cluster climate and the saprophyte grape cluster climate. In the vocabulary, these two concepts are linked by generalization to the 'cluster climate' concept. The temporality vocabulary of the biological system described by nine actions is gradually constructed by such generalization operations.

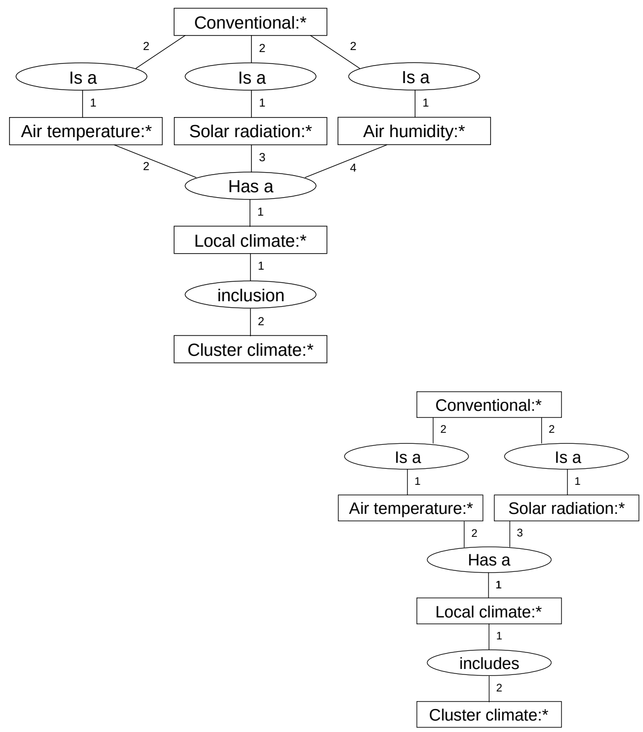

Figure 9. Semantic network of the 'cluster climate' concept of the Referential class of the Temporality functional group of action D (top) and E (bottom).

The resulting vocabulary graph (Figure 10) shows, for example, that the 'cluster climate' concept has a different meaning depending on the actions, and a specialization is required to distinguish between the state of the cuticle in action D and the chemical composition of grapes in actions A, C, and F. We also note that, in the expert’s opinion, although the larvae shares the grape cluster as a substrate and habitat, there is no 'cluster climate' concept specific to the larva, with the latter being identical to the 'pathogenic cluster climate'.

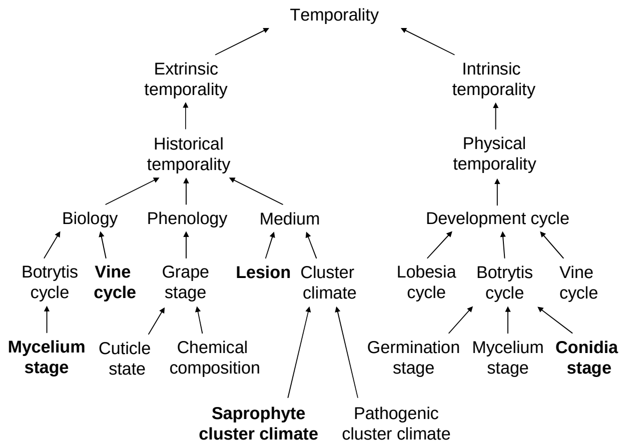

Figure 10. Vocabulary of the Temporality functional group for the overlapping actions A to I. The concepts in bold correspond to actions E and H (level 2).

4. Conclusion

The proposed method enables transcription of the literal description of an action in the form of a semantic network. In this exercise applied to a biological system, classifications borrowed from linguistics lead us to consider individual times in addition to conventional times. In the illustration, the 'vine cycle' concept, for example, has the 'variety' concept for referential, which in turn is an individual temporality concept. For disciplines such as plant physiology and genetics, the 'variety' concept is liable to the morphology referential in the Time-Space-Morphology reference system. This way of considering the referential leads us to consider temporality as a system. In addition to temporality, the proposed method applies to questions of Location (space in the Time-Space-Morphology reference system), but also of Manner and Reason (treatment of causality).

The questioning-based method clarifies the meaning of terms used to describe systems observed by experts from different disciplinary backgrounds, according to a formal setting. By allowing a relative comparison of terms with respect to (i) the semantics given by a particular discipline for an action, and (ii) the referential to this action, the method provides a tool for establishing a multidisciplinary setting to represent a complex system. The adopted generalization method, based on expertise of the disciplines involved, is empirical. This approach is consistent for supporting interdisciplinary discussions on the meaning of terms while overcoming the implicit character of disciplinary constructions.
From a theoretical standpoint, however, the adopted representation support is the graph and automation of the generalization process can be considered. Expressed as a math problem, the formal support of this work is category theory (not shown here) and it is solved at the lambda-calculus level.

5. Related works

This work deals with the action, the referential of time and vocabulary. It spans several disciplines. In the agro-forestry field, [32, 33] use semantic networks to represent expert knowledge expressed using natural language. The temporal logics (LTL or CTL) enable reproduction of the evolution of a system under a succession of states of constitutive items [34]. In the treatment of temporality expressed in natural language, linguists (TimeML) are particularly interested in the event. For all of those works, the knowledge concerns the state of the system and not the action. To process information, the authors use an inference mechanism to connect the states between them. The inference mechanism is chosen a priori.
Regarding the vocabulary construction, the method usually adopted is based on establishment of ontology. In the case of multidisciplinary approaches, the ontology matching process is used [35]. The method applies a posteriori to existing knowledge established elsewhere.

Our work differs from those works because the approach focuses on action rather than on the system state. In addition, it applies to the construction of multidisciplinary approaches for the representation of complex systems.

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