An Ontology-Based Dictionary of Understanding as a Basis for Software Agents with Understanding Abilities

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Abstract

Nearly 60 types of machine understanding is presented in an ontology-based dictionary as a basis for the development of software agents with understanding abilities. Then of software agents are presented..

Keywords: software agents with understanding abilities, ontology-based dictionary

1. Introduction

With the widespread use of software agents comes the requirement for more advanced features. One such requirement is the ability to understand. However, as it is the case with many concepts used in everyday language, the term "understand" has several meanings. In this article, we delimit the meanings that we are not considering for machine understanding; and we offer a top-down decomposition of over 50 types of "understanding" as a framework to clearly delineate the types of understanding an agent may have. The types of understanding are presented by using an ontology-based dictionary that can easily be coupled with an alphabetically sequenced regular dictionary. However, an ontology-based dictionary (OBD) has a definite advantage over a regular dictionary to display the logical relationships of the terms and their associated concepts in an intuitively obvious way. In Section 2, some meanings of "understanding are reviewed and a detailed ontology-based dictionary of 58 understanding terms and additional six synonyms are presented. In Section 3, after a brief introduction to software agents, a framework is presented to represent a metamodel for software agents. Section 4 concludes our current work and introduces our planned future work.

2. Understanding

The taxonomy is based on Ören (2000). However, it is revised and updated and the ontology-based presentation of the understanding concepts as an ontology-based dictionary is developed specifically for this article.

2.1 Background

In the study of natural phenomena, the role of simulation is often cited as "to gain insight" which is another way of expressing "to understand." Understanding is one of the important philosophical topics. From a pragmatic point of view, it has a broad application potential in many computerized studies including program understanding, machine vision, fault detection based on machine vision as well as situation assessment. Therefore, systematic studies of the elements, structures, architectures, and scope of applications of computerized understanding systems as well as the characteristics of the results (or products) of understanding processes are warranted.

Dictionary definitions of "to understand" include the following:
- to seize the meaning of,
- to accept as a fact, believe,
- to be thoroughly acquainted with,
- to form a reasoned judgment concerning something,
- to have the power of seizing meanings, forming reasoned judgments,
- to appreciate and sympathize with, to tolerate,
- to possess a passive knowledge of a language

The following is a good starting point for the specification of the scope of machine understanding: "… if a system knows about X, a class of objects or relations on objects, it is able to use an (internal) representation of the class in at least the following ways: receive information about the class, generate elements in the class, recognize members of the class and discriminate them from other class members, answer questions about the class, and take into account information about changes in the class members" (Zeigler 1986).

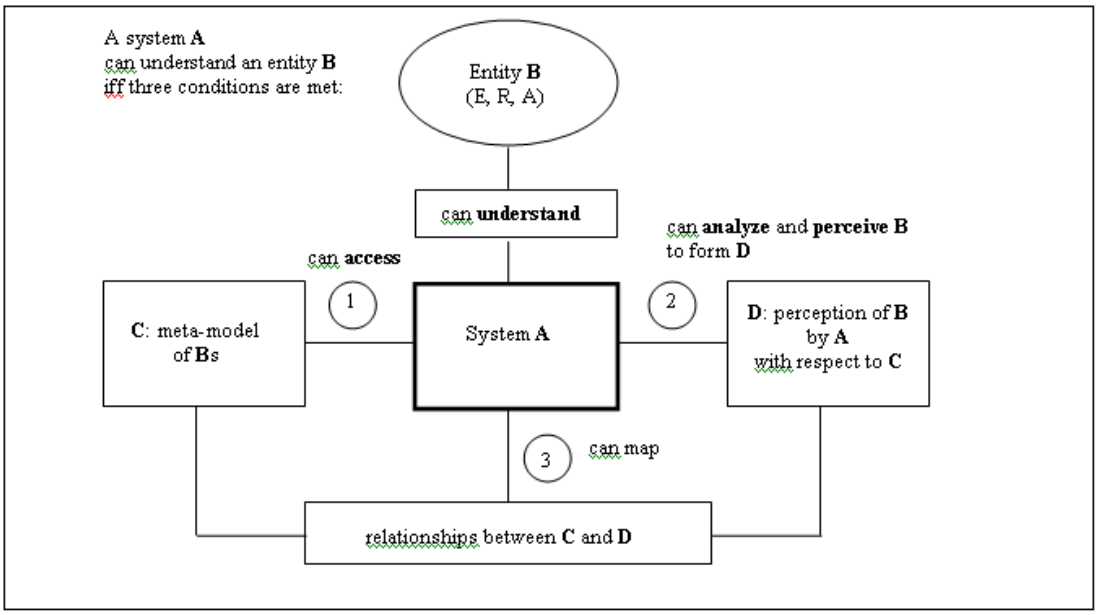

Figure 1. Elements of an Understanding System

From this point of view, knowing and computerized understanding can be taken as synonyms. However, one should remark here that knowing (something, somebody, some event, etc.) refers to the result (or product) of the process of acquiring knowledge and not the knowledge processing activity required to know.

2.2 Understanding Systems

A system **A** can understand an entity **B** (**E**ntity, **R**elation, **A**ttribute) ff three conditions are satisfied:

1. **A** can access **C**, a meta-model of Bs.
   (C is the knowledge of A about Bs.) The meta-model can be unique or multiple, fixed, evolvable, replaceable, or functionally equivalent (similar but not identical) to another one.
2. **A** can analyze and perceive **B** to generate **D**.
   (D is a perception of B by A with respect to C.)
3. **A** can map relationships between **C** and **D** for existing and non-existing features in **C** and/or **D** to generate result (or product) of understanding process.

As seen in Figure 1, an understanding system needs to have the following three basic elements: (1) a meta-model of the entities to be understood, (2) a perception element with respect to the meta-model and (3) an analyzer and a comparator to map a perception of an entity to be understood with the meta-model for existing and/or non-existing features in either one of them.

2.3 Types of Understanding and Ontology-Based Dictionaries

Table 1 lists 58 types of understanding and additional six terms to denote some synonyms. By adding the definitions of the terms, Table 1 can be converted to a dictionary of understanding terms. However, a more systematic approach, an ontology-based dictionary can be desirable (1) to ease learning/teaching several types of understanding (2) to be able to see logical relationships of the nuances and the relationships of terms, and (3) to possibly systematically enhancing the dictionary. Ontology-based dictionaries are relatively new; see for example Paskin (2006). One of the first examples in modelling and simulation (without using the term “ontology-based” was given by Ören and Elzas (1987).

To classify a set of entities, such as the types of understanding given in Table 1, one needs a set of criteria preferably orthogonal (and some sets of sub criteria for each of the criteria). Then one can partition the entities with respect to the criteria and the sub criteria. Hence, understanding can be classified with respect to: the product (result) of the understanding process, understanding process, the metamodel used, and the characteristics of the understanding system.

2.3.1 Product of Understanding

Table 2 is an ontology-based dictionary of 23 understanding terms related with the product (result) of the understanding process. The additional sub criteria used are: domain, nature, scope, granularity, reliability, and post processing of the product of understanding.

2.3.2 Process of Understanding

Sub criteria used to partition understanding terms related with the understanding process are: directness, direction, precedence, modality, dependability, and accumulation of knowledge. Table 3 includes 13 terms related with understanding process.

2.3.3 Metamodel Used in Understanding

Knowledge about the system to be understood, or the metamodel can be unique or multiple and can be fixed, evolvable, replaceable, or functionally equivalent to another one. The meta-model constitutes the world view as well as the bias of the understanding system. Table 3 includes 6 terms related with metamodels that can be used in understanding process

Table 1. Types of Understanding

analogical understanding	focused understanding	partial repetitive understanding
apprehension	generalized understanding	pragmatic understanding
associative understanding	group understanding	re-initialized understanding (syn: tabula rasa understanding)
autonomous understanding	incorrupt understanding	reliable understanding
blackboard understanding	in-depth understanding	remote understanding
bottom up understanding	indirect understanding (syn: comprehension)	repetitive understanding
brittle understanding	individual understanding	robust understanding
broad understanding	instantiated understanding	semantic understanding
broadcasted understanding	internal understanding	sequential understanding
coarse understanding	invalid understanding	single vision understanding
comprehension	learning understanding	subjective understanding
cooperative understanding	legacy understanding	switchable understanding (syn: multivision understanding)
corrupt understanding	lexical understanding	syntactic understanding
cumulative understanding	logical understanding	tabula rasa understanding
delegated understanding	mediated understanding (syn: comprehension)	top-down understanding
detailed understanding (syn: in-depth understanding)	morphological understanding	understanding for subscribers
direct understanding (syn: apprehension)	multiaspect understanding	understanding per command
distributed understanding	multimodal understanding	unimodal understanding
dogmatic understanding	multivision understanding	unreliable understanding
evolving understanding	objective understanding	unverified understanding
external understanding	parallel understanding	valid understanding
		verified understanding

2.3.4 Understanding System

Sub criteria used to classify terms related with understanding systems are: initiative of the understanding system, number of the understanding system, involvement of emotions or prejudice, knowledge sharing features, and dissemination of the results. Table 4 includes 14 terms related with understanding systems.

2.4 Relationship of Understanding with Cognitive Processing

From a pragmatic point of view, it is important to see the role of understanding within higher-order thinking. Tennyson and Breuer (2006) posit the following: "Higher order thinking strategies involve three cognitive strategies: differentiation, integration, and construction of knowledge. … Differentiation is defined as a twofold cognitive process as follows: (a) the ability to understand a given situation; and (b) the ability to apply appropriate criteria by which to select necessary knowledge from storage. Integration is the process of forming new schema(s) from selected knowledge. Construction is the process to form new knowledge by employing the total cognitive system." Hence, machine understanding process has to be associated with additional cognitive processing and most often with appropriate action.

Table 2. An Ontology-Based Dictionary of Understanding

Based on the **Product** of Understanding

Criteria		*Types of understanding*	Definitions & (explanations)
product of the understanding process	**domain**	*internal understanding*	Understanding the characteristics of the elements of a system and their relationships as well as their attributes. (The elements, relationships, and attributes can be time-invariant or time-varying. In internal understanding, a system is treated as a white box.)
		external understanding	Understanding the relationships of a system and its environment. (The relationships can be time-invariant or time-varying. In external understanding, a system is treated as a black box.)
	nature	*lexical understanding*	Understanding the lexical characteristics of an entity. (*Lexical understanding* is the lowest level of understanding and discriminates the elements of an entity.)
		syntactic understanding	Understanding the syntactic characteristics of an entity. (*Syntactic understanding* discriminates how the elements of an entity are related.)
		morphological understanding	Understanding the structure (morphological characteristics) of an entity. (*Morphological understanding* discriminates how relevant forms and structures are represented.)
		semantic understanding	Understanding the meaning (semantic characteristics) of an entity. (*Semantic understanding* involves with the meanings attached to the elements of an entity as well as to their relationships.)
		pragmatic understanding	Understanding the intention (pragmatic characteristics) related with an entity. (*Pragmatic understanding* involves with the interpretations of the intentions, which might be attributed to the existence or absence of the elements of an entity as well as to their relationships.)
	scope	*focused understanding*	Understanding one or a few characteristics of an entity.
		broad understanding	Understanding several or all characteristics of an entity.
		multiaspect understanding	Understanding of multiaspect systems. (In multiaspect, understanding, several metamodels can be used to understand several aspects of an entity. These aspects may even be contradictory. Multiaspect understanding is different from broad understanding.)
	granularity	*coarse understanding*	Understanding the highlights of an entity. (Understanding without details.)
		in-depth understanding (detailed understanding)	Understanding the details of the characteristics of an entity.
	reliability	*reliable understanding*	Understanding worthy of reliance or trust. (Reliable understanding needs to be valid and verified.)
		- valid understanding	Understanding that assures appropriate (i.e., relevant and complete) knowledge with respect to the goal.
		- verified understanding	Understanding with additional proof that it is correct.
		- incorrupt understanding	Understanding that is not changed in wrong ways.
		unreliable understanding	Understanding not worthy of reliance or trust. (Unreliable understanding may be invalid and/or unverified. Understanding obtained by a system where there may be flaws in the computerization of its elements.)
		- invalid understanding	Understanding that can not assure appropriate (i.e., relevant and complete) knowledge with respect to the goal.
		- unverified understanding	Understanding without additional proof that it is correct.
		- corrupt understanding	Understanding that is changed in wrong ways.
	process-ing	*associative understanding*	Transformation of understanding with respect to another meta-model.
		generalized understanding	Understanding based on the generalization of the original understanding.
		instantiated understanding	Understanding based on the instantiation of the original understanding.

Table 3. An Ontology-Based Dictionary of Understanding

Based on the Understanding **Process** and the **Metamodel** Used

Criteria		*Types of understanding*	Definitions & (explanations)
understanding **process**	**directness**	*apprehension (direct understanding)*	*Apprehension* is direct understanding or self-evidence.
		comprehension (indirect understanding) (mediated understanding)	*Comprehension* is indirect or mediated understanding.
		- logical understanding	*Logical understanding* is indirect understanding where logical inference is used as a means for the attainment of an understanding.
	direction	*top-down understanding*	*Top-down understanding* starts with background knowledge (meta-model) about an entity to gather knowledge about it.
		bottom up understanding	*Bottom up understanding* starts with an analysis or perception of an entity and maps relevant knowledge to a meta-model of it.
	Prece-dence	*sequential understanding*	Understanding done in sequence.
		parallel understanding	Understanding done in parallel.
	modality	*unimodal understanding*	Understanding one modality at a time. (e.g., text, picture, or gesture.)
		multimodal understanding	Understanding more than one modality simultaneously.
	dependability	*robust understanding*	Understanding by a system that has the ability to recover gracefully from the whole range of exceptional inputs and situations in a given environment.
		brittle understanding	Understanding by a system which is functional but easily broken by changes in operating environment or configuration, or by any minor tweak to the software itself. (Also, any system that responds inappropriately and disastrously to abnormal but expected external stimuli.)
	accumulation of knowledge	*tabula rasa understanding (re-initialized understanding)*	*Tabula rasa understanding* does not depend on the results (products) of previous understanding process(es). (At the beginning of an understanding process, any remnant understanding from previous understanding process(es) is ignored.)
		cumulative understanding	*Cumulative understanding* builds up an understanding on top of previous understanding(s).
metamodel	**ffixed**	single vision understanding	*Understanding* that is based on a single meta-model.
		- dogmatic understanding	Single vision understanding is *dogmatic understanding* if the meta-model is not fully questioned and rationally justified,
	evolvable	*evolving understanding*	*Understanding* where the meta-model used may be changing (evolving) through time.
		- learning understanding	*Evolving understanding* where the meta-model used may be changing (evolving) through time based on learning. (In learning understanding, several types of learning approaches may be applicable. However, the system's learning ability should be monitored to assure that the learning performance is not deteriorating)
	replace-able	*multivision understanding (switchable understanding)*	Understanding systems that can switch to an appropriate meta-model to understand characteristics of different sets or aspects of entities.
	equiv-alent	*analogical understanding*	Understanding with respect to a functionally equivalent (similar but not identical) meta-model. (e.g., considering solar system model to understanding atomic structure.)

Table 4. An Ontology-Based Dictionary of Understanding

Based on the Characteristics of the Understanding **System**

Criteria		*Types of understanding*	Definitions & (explanations)
Understanding **system**	**initiative** of the understanding system	*autonomous understanding*	*Autonomous understanding* involves a system which initiates and performs the understanding process. (Understanding system may or may not use the product of the understanding process.)
		delegated understanding	*Delegated understanding* involves at least two systems, or modules: the initiator and the understander. The initiator activates directly or indirectly the understanding system, i.e., the understander. The delegated system, i.e., the understander performs the understanding. (The user of the result of the understanding can be the initiator, the understander, or some other system(s).)
		- remote understanding	*Remote understanding* is a delegated understanding where software modules or metamodels used in understanding exist at remote locations. (Intranets, internets and the Internet are natural media for the realization of remote understanding.)
	number of understanding system	*individual understanding*	*Individual understanding* involves one single understanding system. (In individual understanding the initiator, the understander, and the user are all the same system.)
		group understanding	*Group understanding* involves several understanding systems. (In *group understanding*, each understanding system may have same or distinct understanding abilities. In the latter case, they can be specialized in understanding different entities or different aspects of some entities. A special type of group understanding is distributed understanding.)
		- distributed understanding	*Distributed understanding* involves two or more understanding units located on different computers.
	emotion or prejudice	*objective understanding*	*Understanding u influenced by emotions or prejudice*
		subjective understanding	*Understanding u influenced by emotions or prejudice*
	knowledge sharing features	*repetitive understanding*	*Repetitive understanding* involves several understanding systems where each of which performs similar understanding processes without sharing the results of their understanding.
		partial repetitive understanding	*Repetitive understanding* involves several understanding systems where each of which performs similar understanding processes with limited sharing the results of their understanding.
		cooperative understanding	*Cooperative understanding* occurs in group understanding systems (with possible partial repetitive understanding). (Some of the understanding subsystems are specialized understanding systems; therefore, functionally they can complement each others abilities.)
	Dissemination of the results	*understanding per command*	*Understanding per command* is the understanding performed upon activation of an understanding system.
		understanding for subscribers	*Understanding for subscribers* is understanding performed automatically for units that already indicated their preferences.
		broadcasted understanding	*Broadcasted understanding* makes available the understood knowledge to all units by delivering the knowledge to them.
		blackboard understanding	*Blackboard understanding* posts the understood knowledge on a common area; the units can fetch the relevant knowledge, if they have access permission. (*Blackboard understanding* can also be used in group understanding where knowledge understood by different understanding subsystem is made available to any subsystem of the understanding system or to any other system which can access the blackboard.)
		legacy understanding	*Legacy understanding* bypasses the understanding process and relies on understanding stored in a database.

3. Software Agents

A software agent is an autonomous software module with perception and social ability to perform goal directed knowledge processing over time. It can work on behalf of humans or other software agents in software or physical environments. Infohabitants open new application possibilities. “The infohabitants of the connected information systems include individuals, organizations, smart appliances, smart buildings, and other smart systems, as well as virtual entities acting on their behalf. Hence their behaviour is important for the sustainability of the overall system. … The virtual entities acting on behalf of individuals and organizations and smart systems are (or can be) implemented as software agents” (Ören, 2002).

3.1 Software Agents: A Framework

Several references exist for software agents in general (CAA, Odell et al., Scheutz and Andronache) and in agent-directed simulation (Yilmaz, 2005). Studies on software agents with understanding abilities are rather scarce (Yang et al. 2000) even though very promising and desirable. Figure 2 represents the major components of an agent.

Major components of an agent are:
- input/output units
- reasoning (including fuzzy reasoning) components
- core cognitive knowledge processing components
  -- for goal and goal processing,
  -- embedded or delegated goal-directed knowledge processing elements for: planning (agenda generation), adaptation, self-starting abilities, social abilities to communicate with users and other agents, decision making and evaluation, rationality, and responsiveness.

Agents can access internal and external knowledge bases and may have additional desirable knowledge processing components.

As depicted in Figure 3 there are basically three groups of inputs for an agent: (1) Agents can passively accept inputs generated in their environments (exogenous inputs), or (2) they can have an active role in the perception of exogenous inputs. (3) As intelligent entities, deliberation units can be used for internal perception of facts, events, states, trends or lack of them as endogenous (internally generated) inputs.

Optional and desirable knowledge processing components include, anticipation, understanding, learning, responsibility, accountability, representation of personality, emotions, as well as emotional intelligence components. This article clarifies nuances of several types of understanding that can be implemented by agents.

4. Conclusion and Future Work

Understanding or comprehension of an entity or situation is based on synthesizing the perceived disjoint elements to form a coherent representation of the entity, the elements of which are observed. For instance, the tactical commander of a military unit needs to comprehend that the appearance of enemy aligned in a specific pattern and in a particular location depicts certain specific objectives. Augmenting decision makers by providing capabilities that integrate perceived domain elements to facilitate comprehension of the situation requires computational facilities that enable situational awareness with understanding capabilities
In decision making recognition and diagnosis capabilities are critical. Recognition Primed Decision (RPD) is an example of Naturalistic Decision Making model, and it attempts to emulate what people actually do under conditions of time pressure, ambiguous information, and changing conditions.

If the observed situation and perceived inputs are not categorized to be prototypical, then a diagnosis (i.e., understanding) procedure that synthesizes the features of the percepts to causal factors is enacted to facilitate comprehending the situation until a prototypical or analog case is identified. More specifically, a well-defined mental model provides (1) knowledge about the concepts, attributes, associations, and constraints that pertain to the application domain, (2) a mechanism that facilitates integration of domain elements to form an understanding of the situation, and (3) a mechanism to project to a future state of the environment given the current state, selected action, and the knowledge about the dynamics of the environment. In realistic settings, establishing an ongoing awareness and understanding of important situation components pose the major task of the decision maker.

As our future work, our group is interested in implementing switchable understanding to have multiple perceptions of complex situations by using several (switchable) meta-models and studying their implications in advanced simulation environments allowing multisimulations.

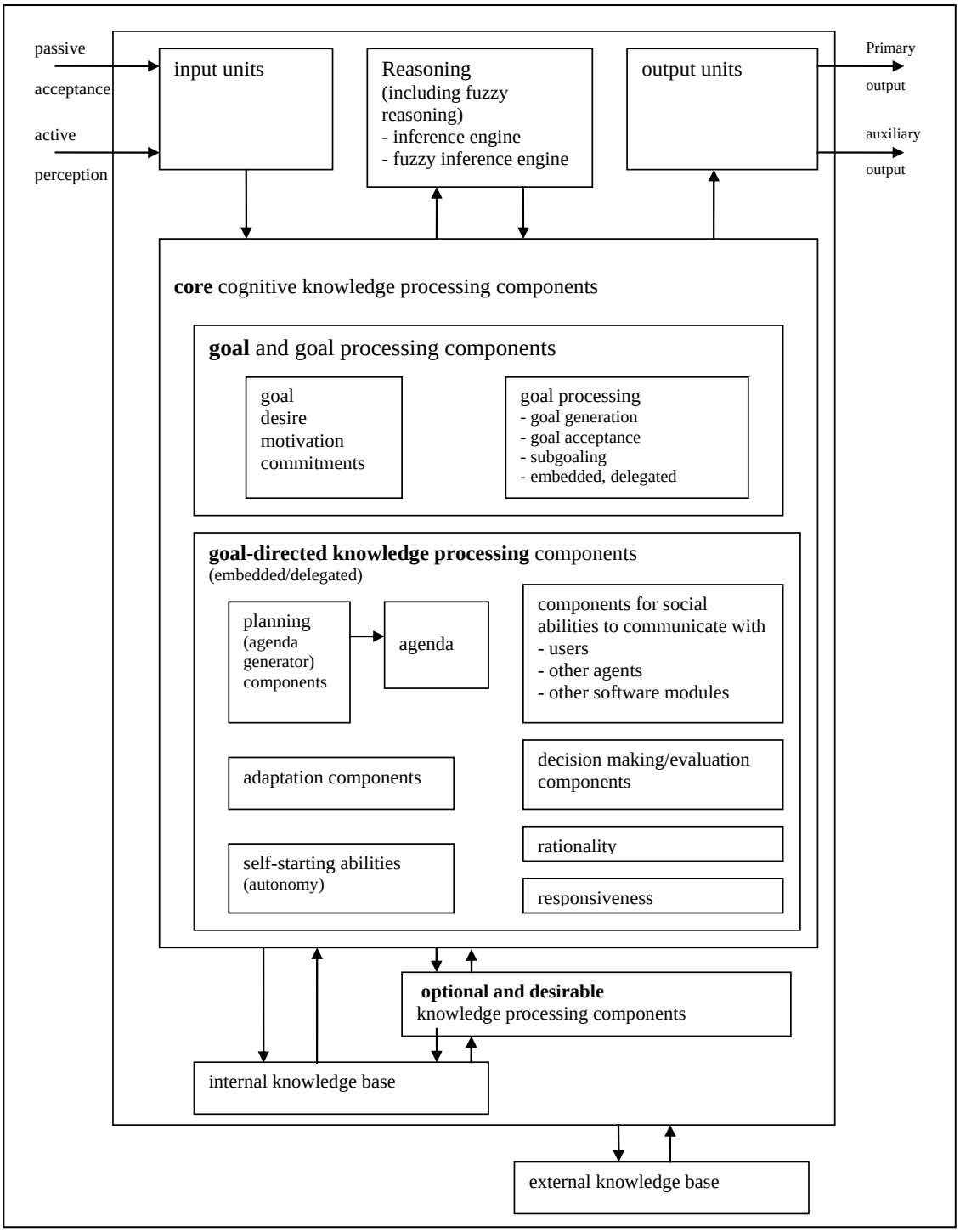

Figure 2. Components of Agents

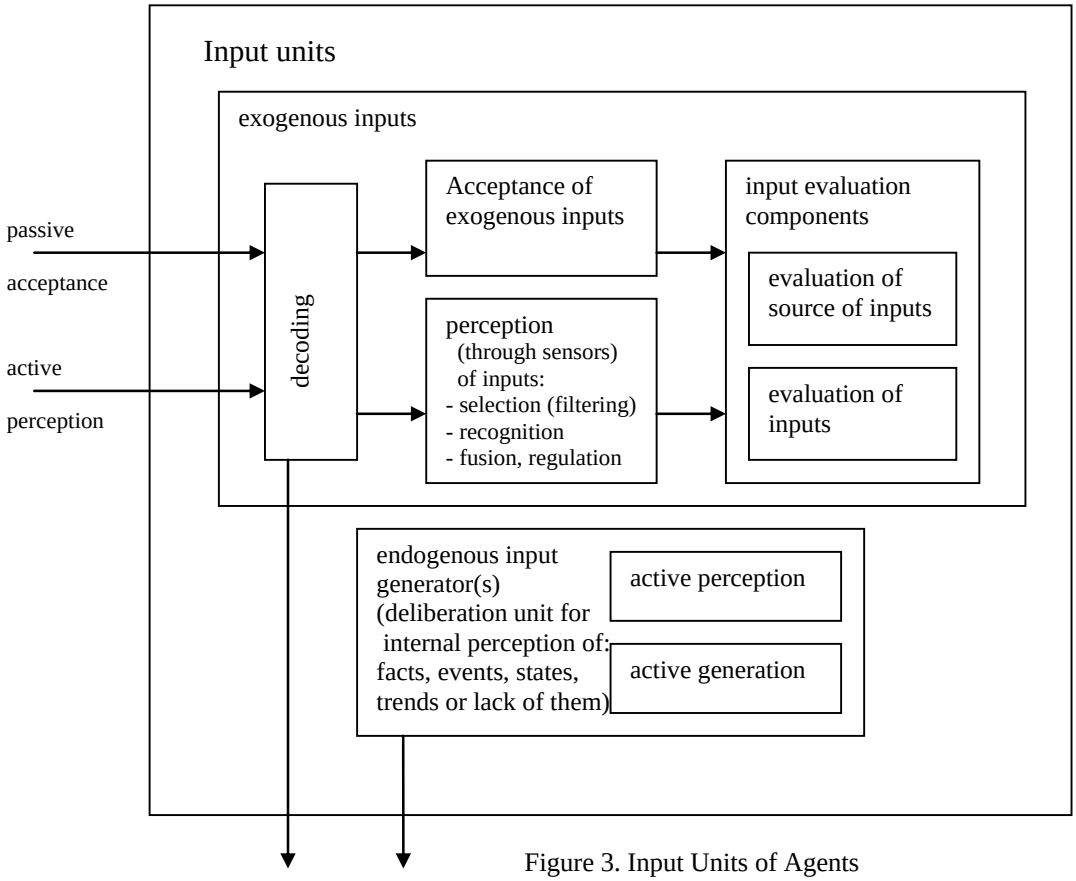

Figure 3. Input Units of Agents

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