



**COMPUTER SCIENCE  
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## **An Ontology-Based Dictionary of Understanding as a Basis for Software Agents with Understanding Capabilities**

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# Aim

- to introduce nearly 60 types of machine understanding,
- to promote understanding as a critical component in agents with situation awareness capability,
- to introduce a framework that represents a metamodel for software agents.

# Plan

- **Motivation: Exploring the significance of understanding in situation awareness**
- Background on understanding
- Understanding systems
- Types of understanding and ontology-based dictionaries
- Agent components and input units for agents.
- Agents with understanding capabilities
- Conclusions

# Motivation

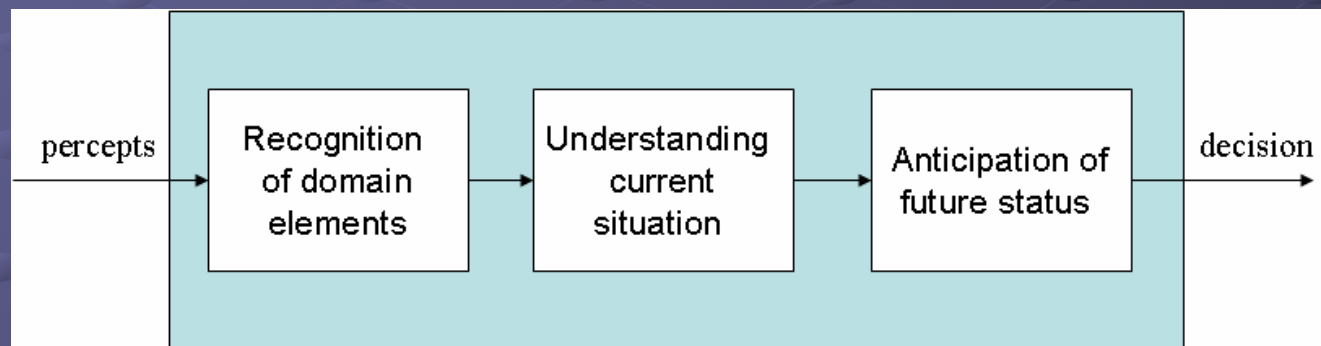
- In the study of natural phenomena, the role of simulation is often cited as “to gain insight” which is another way of expressing “to understand.”
- From a pragmatic point of view, it has a broad application potential in many computerized studies including
  - program understanding, machine vision, fault detection based on machine vision, situation assessment.

# Motivation

- 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).

# Situation Awareness

- Situation awareness is an important cognitive skill that is essential for expert performance in any field involving complexity, dynamism, uncertainty, and risk.



- The failure to perceive a situation correctly may lead to faulty understanding

# Perception

- The first step in achieving SA is to perceive the status, attributes, and dynamics of relevant elements in the environment.
  - For instance, a pilot needs to perceive important elements such as other aircraft, mountains, or warning lights along with their relevant characteristics.

# Understanding

- Understanding (comprehension) of the situation is based on the synthesis of disjointed elements identified during perception
  - For example, a military pilot or tactical commander needs to comprehend that the appearance of enemy aircraft arrayed in a certain pattern and in a particular location indicates certain things about their objectives.

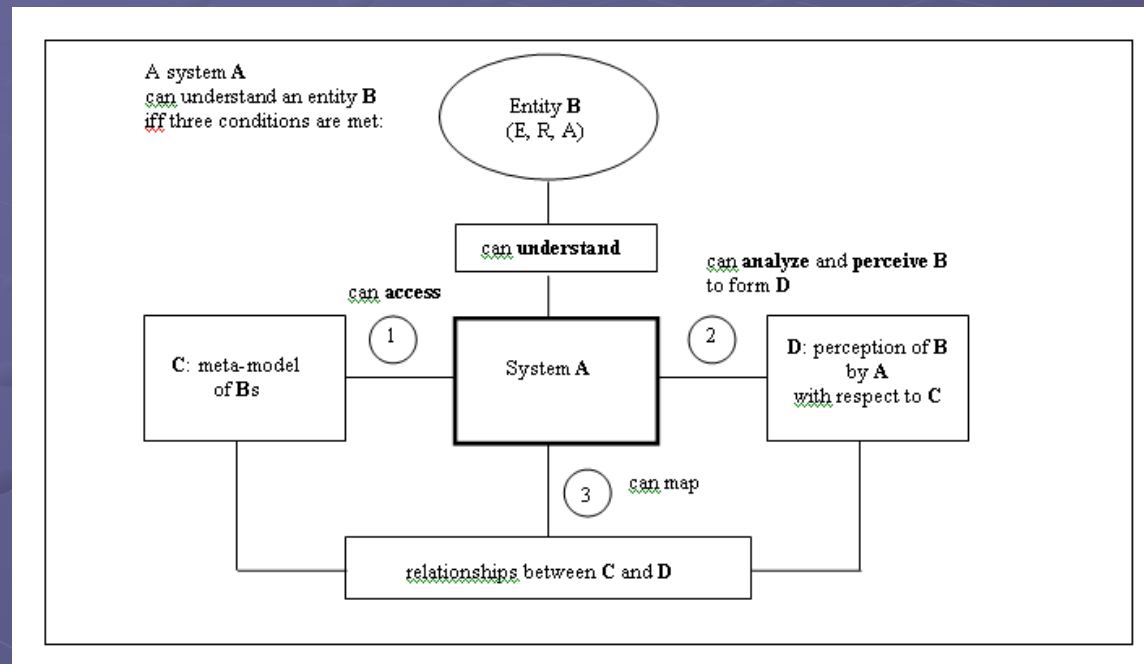
# Anticipation

- And finally, it is the ability to project the future actions of the elements in the environment that forms the third and highest form of SA.
  - Anticipatory systems theory provides a promising basis to develop means to realize that goal.

# Conditions for Understanding

- Understanding or comprehension of the situation is based on synthesizing the perceived disjoint elements to form a coherent representation of the entity, the elements of which are observed.
- Misunderstanding may degrade an individual's ability to predict future states and engage in effective decision making

# Conditions for Understanding



A system **A** can understand an entity **B** (Entity, Relation, Attribute) iff three conditions are satisfied:

1. **A** can access **C**, a meta-model of **Bs**.

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.

## Factors Affecting Performance of Understanding Systems

- A system's ability to understand an entity **B** depends on
- the restrictions on the three conditions; i.e.,
  - (1) on the existence of a meta-model and accessing it,
  - (2) on the perception and analysis of the entity and
  - (3) on the mapping abilities of its comparator.
- Therefore, the characteristics of these conditions can also be interpreted as factors affecting the performance of understanding systems.

## Factors Affecting Performance of Understanding Systems

### Perception/Analysis Capabilities

- Perception necessitates conception; therefore, a system cannot perceive an entity if it does not have a metamodel (or knowledge) about it.
- What cannot be perceived or discriminated in the analysis cannot be understood.

## Factors Affecting Performance of Understanding Systems

### Mapping Ability

- To understand an entity **B**, a system **A** needs to perform a mapping between a meta-model **C** of **Bs** and **D**, a perception of **B** or the result of analysis of **B**.
- The characteristics of the relations, (e.g., detectable, found, or non-existent relations) affect the limit of understanding.

# Ontology for Understanding

- To classify a set of entities, 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.
- 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.

# Types of Understanding

## Types of Understanding

analogical understanding  
apprehension  
associative understanding  
autonomous understanding  
blackboard understanding  
bottom up understanding  
brittle understanding  
broad understanding  
broadcast understanding  
coarse understanding  
comprehension  
cooperative understanding  
corrupt understanding  
cumulative understanding  
delegated understanding  
detailed understanding (syn: in-depth understanding)  
direct understanding (syn: apprehension)  
distributed understanding  
dogmatic understanding  
evolving understanding  
external understanding

focused understanding  
generalized understanding  
group understanding  
incorrupt understanding  
in-depth understanding  
indirect understanding (syn: comprehension)  
individual understanding  
instantiated understanding  
internal understanding  
invalid understanding  
learning understanding  
legacy understanding  
lexical understanding  
logical understanding  
mediated understanding (syn: comprehension)  
morphological understanding  
multiaspect understanding  
multimodal understanding  
multivision understanding  
objective understanding  
parallel understanding

partial repetitive understanding  
pragmatic understanding  
re-initialized understanding (syn: tabula rasa understanding)  
reliable understanding  
remote understanding  
repetitive understanding  
robust understanding  
semantic understanding  
sequential understanding  
single vision understanding  
subjective understanding  
switchable understanding (syn: multivision understanding)  
syntactic understanding  
tabula rasa understanding  
top-down understanding  
understanding for subscribers  
understanding per command  
unimodal understanding  
unreliable understanding  
unverified understanding  
valid understanding  
verified understanding

# Product of Understanding

- The following 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.

# Classification Based on Product of Understanding (Partial)

Criteria	Types of understanding	Definitions & (explanations)
domain	<i>internal understanding</i>	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.)
	<i>external understanding</i>	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	<i>lexical understanding</i>	Understanding the lexical characteristics of an entity. ( <i>Lexical understanding</i> is the lowest level of understanding and discriminates the elements of an entity.)
	<i>syntactic understanding</i>	Understanding the syntactic characteristics of an entity. ( <i>Syntactic understanding</i> discriminates how the elements of an entity are related.)
	<i>morphological understanding</i>	Understanding the structure (morphological characteristics) of an entity. ( <i>Morphological understanding</i> discriminates how relevant forms and structures are represented.)
	<i>semantic understanding</i>	Understanding the meaning (semantic characteristics) of an entity. ( <i>Semantic understanding</i> involves with the meanings attached to the elements of an entity as well as to their relationships.)
	<i>pragmatic understanding</i>	Understanding the intention (pragmatic characteristics) related with an entity. ( <i>Pragmatic understanding</i> 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	<i>focused understanding</i>	Understanding one or a few characteristics of an entity.
	<i>broad understanding</i>	Understanding several or all characteristics of an entity.
	<i>multiaspect understanding</i>	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	<i>coarse understanding</i>	Understanding the highlights of an entity. (Understanding without details.)
	<i>in-depth understanding (detailed understanding)</i>	Understanding the details of the characteristics of an entity.

product of the understanding process

# 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.
- Next table includes 13 terms related with the understanding process.

# Classification Based on Process of Understanding

Criteria		Types of understanding	Definitions & (explanations)
understanding process	directness	<i>apprehension (direct understanding)</i>	<i>Apprehension</i> is direct understanding or self-evidence.
		<i>comprehension (indirect understanding) (mediated understanding) - logical understanding</i>	<i>Comprehension</i> is indirect or mediated understanding.
	direction	<i>top-down understanding</i>	<i>Top-down understanding</i> starts with background knowledge (meta-model) about an entity to gather knowledge about it.
		<i>bottom up understanding</i>	<i>Bottom up understanding</i> starts with an analysis or perception of an entity and maps relevant knowledge to a meta-model of it.
	Precedence	<i>sequential understanding</i>	Understanding done in sequence.
		<i>parallel understanding</i>	Understanding done in parallel.
	modality	<i>unimodal understanding</i>	Understanding one modality at a time. (e.g., text, picture, or gesture.)
		<i>multimodal understanding</i>	Understanding more than one modality simultaneously.
	dependability	<i>robust understanding</i>	Understanding by a system that has the ability to recover gracefully from the whole range of exceptional inputs and situations in a given environment.
		<i>brittle understanding</i>	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	<i>tabula rasa understanding (re-initialized understanding)</i>	<i>Tabula rasa understanding</i> 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.)	
	<i>cumulative understanding</i>	<i>Cumulative understanding</i> builds up an understanding on top of previous understanding(s).	

# 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.
- Next table includes terms related with metamodels that can be used in understanding process

# Classification Based on Metamodel Used in Understanding

<b>metamodel</b>	<b>fixed</b>	single vision understanding	<i>Understanding</i> that is based on a single meta-model.
		- <i>dogmatic understanding</i>	Single vision understanding is <i>dogmatic understanding</i> if the meta-model is not fully questioned and rationally justified,
	<b>evolvable</b>	<i>evolving understanding</i>	<i>Understanding</i> where the meta-model used may be changing (evolving) through time.
		- <i>learning understanding</i>	<i>Evolving understanding</i> 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)
	<b>replaceable</b>	<i>multivision understanding (switchable understanding)</i>	Understanding systems that can switch to an appropriate meta-model to understand characteristics of different sets or aspects of entities.
	<b>equivalent</b>	<i>analogical understanding</i>	Understanding with respect to a functionally equivalent (similar but not identical) meta-model. (e.g., considering solar system model to understanding atomic structure.)

## Understanding based on the Characteristics of the Understanding System

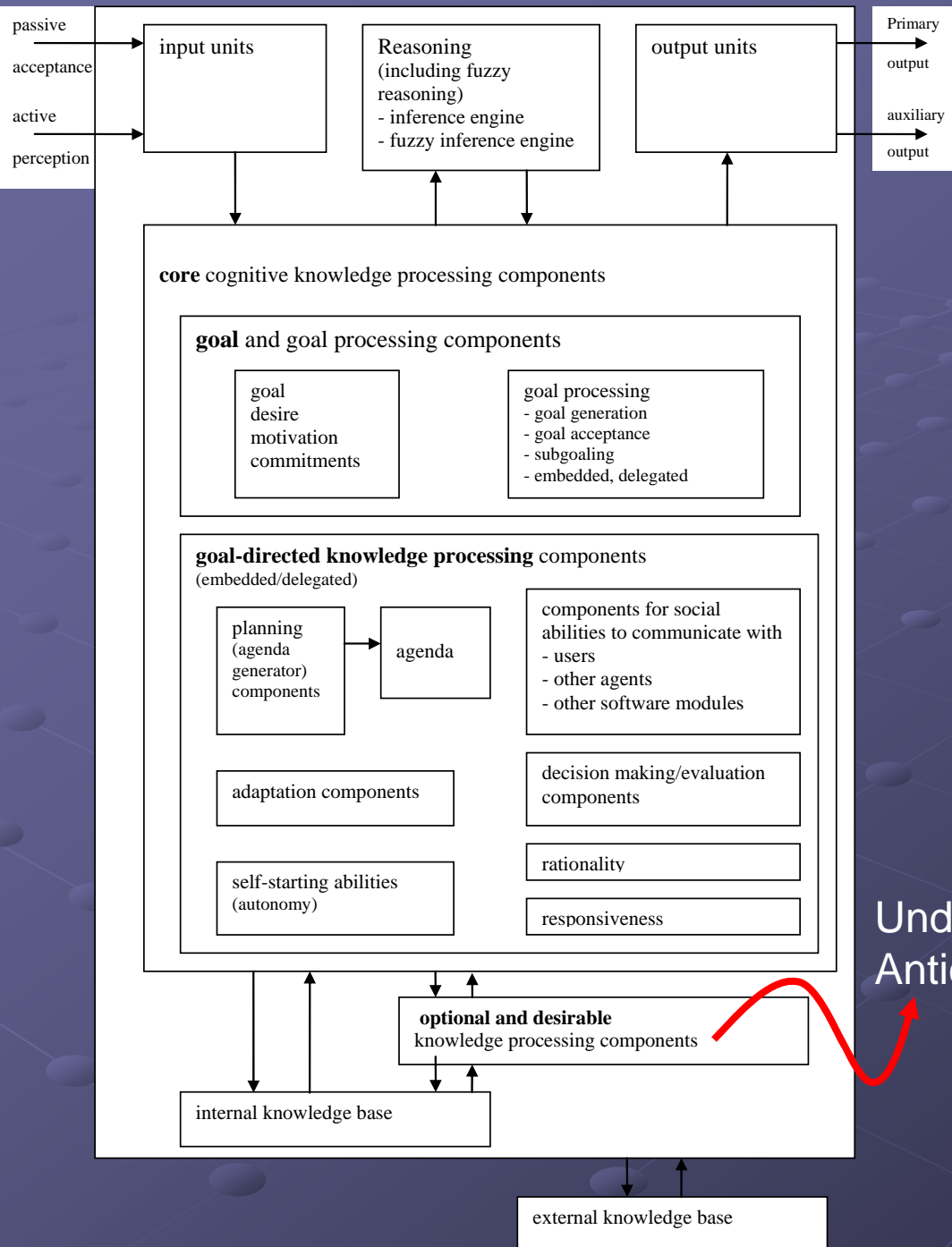
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Criteria		Types of understanding	Definitions & (explanations)
Understanding <b>system</b>	initiative of the understanding system	<i>autonomous understanding</i>	<i>Autonomous understanding</i> involves a system which initiates and performs the understanding process. (Understanding system may or may not use the product of the understanding process.)
		<i>delegated understanding</i>	<i>Delegated understanding</i> 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).)
		- <i>remote understanding</i>	<i>Remote understanding</i> 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	<i>individual understanding</i>	<i>Individual understanding</i> involves one single understanding system. (In individual understanding the initiator, the understander, and the user are all the same system.)
		<i>group understanding</i>	<i>Group understanding</i> involves several understanding systems. (In <i>group understanding</i> , 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.)
		- <i>distributed understanding</i>	<i>Distributed understanding</i> involves two or more understanding units located on different computers.
	emotion or prejudice	<i>objective understanding</i>	<i>Understanding u influenced by emotions or prejudice</i>
		<i>subjective understanding</i>	<i>Understanding u influenced by emotions or prejudice</i>
	knowledge sharing features	<i>repetitive understanding</i>	<i>Repetitive understanding</i> involves several understanding systems where each of which performs similar understanding processes without sharing the results of their understanding.
		<i>partial repetitive understanding</i>	<i>Repetitive understanding</i> involves several understanding systems where each of which performs similar understanding processes with limited sharing the results of their understanding.
<i>cooperative understanding</i>		<i>Cooperative understanding</i> 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.)	

## 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 involves:
    - (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.”

# Agents with Understanding Capabilities

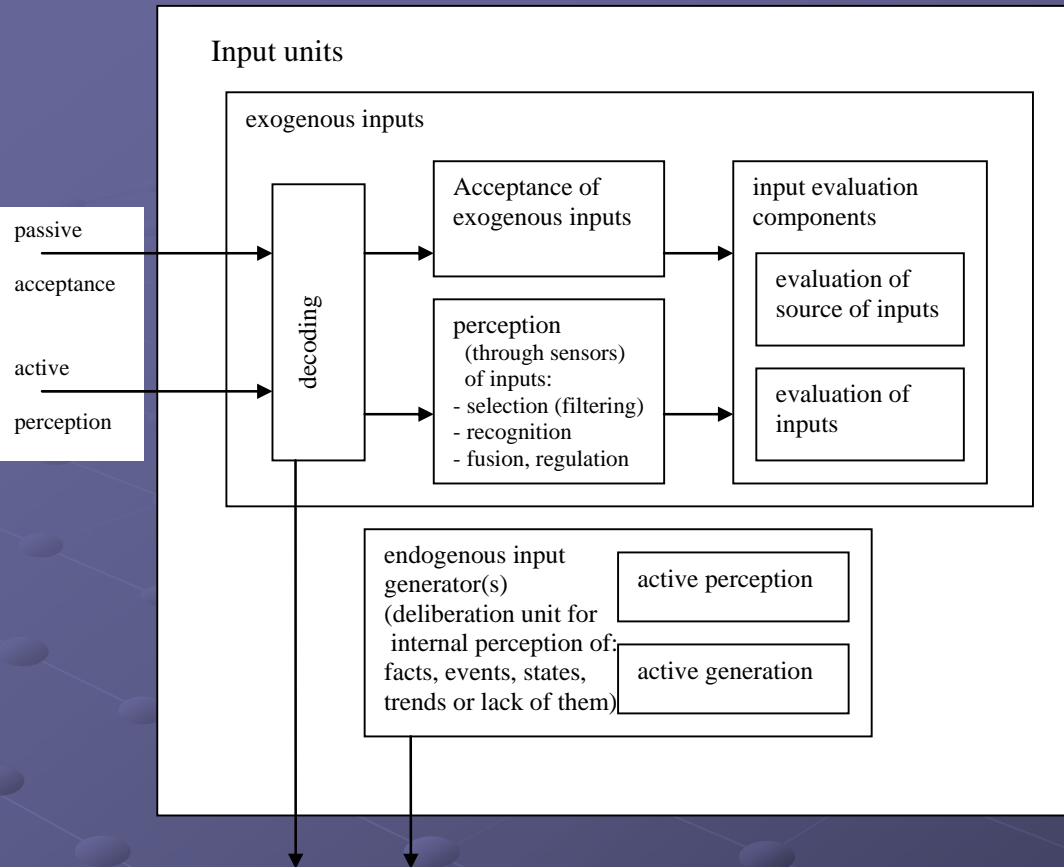


Understanding Anticipation

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 with Perception Capabilities



- (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.

## Future Work

- Design and prototype software agents with perception, understanding, and anticipation capabilities.
- Integrate such agents into situational awareness modules in a decision support system (multisimulation).
- Extend Naturalistic Decision Making Framework with Agent Augmented Cognitive Engineering and Decision Making Capabilities.



Questions?