Agent-directed Simulation Symposium
March 26, 2007

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

Tuncer I. Ören

M&SNet, Ottawa Center of the MISS, SITE, University of Ottawa, Ottawa, ON, Canada and Beykent University, Istanbul, Turkey

Nasser Ghassem-Aghaee

Department of Computer Engineering, University of Isfahan, Isfahan, Iran

Levent Yilmaz

M&SNet: Auburn M&S Laboratory Computer Science & Software Engineering Auburn University, Auburn, AL 36849

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.
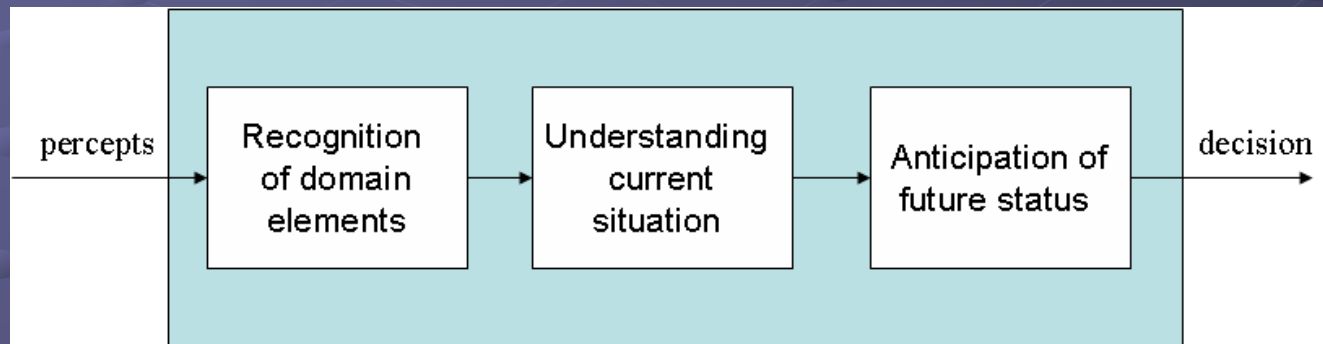- Agents with understanding capabilities
- Conclusions

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.

percepts → Recognition of domain elements → Understanding current situation → Anticipation of future status → decision

● 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.
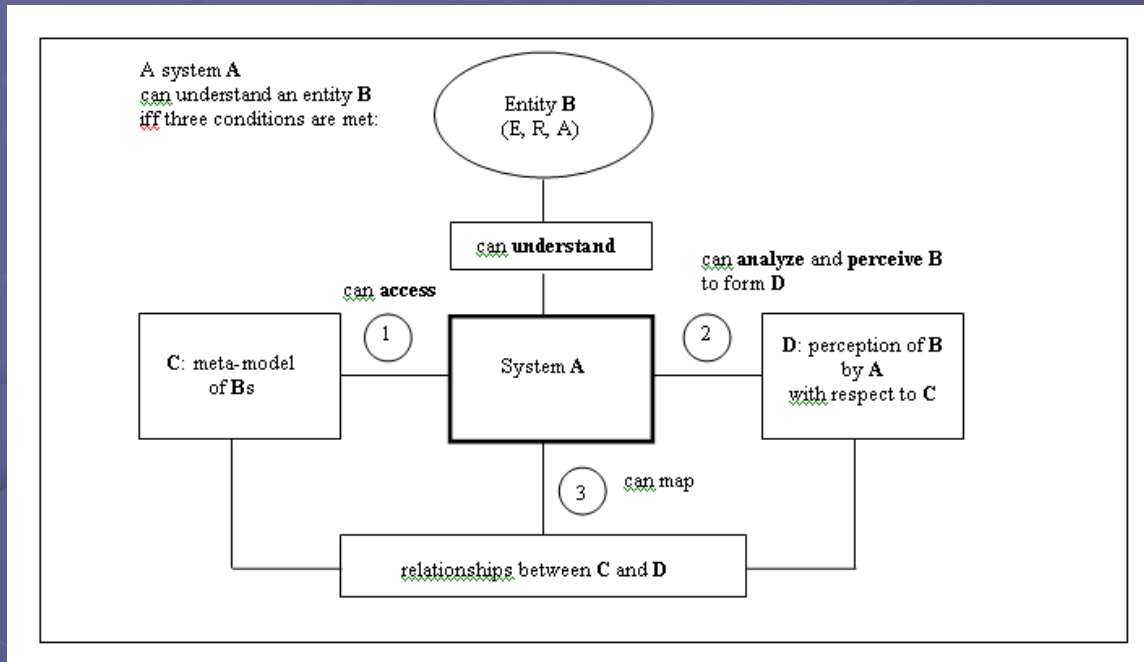
Anticipation

- 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** iff three conditions are met:

Entity **B** (E, R, A)

can **understand**

can **access**

can **analyze** and **perceive B** to form **D**

1

2

C: meta-model of Bs

System **A**

D: perception of **B** by A with respect to C

3   can map

relationships between **C** and **D**

- An agent **A** can understand an entity **B** (**E**ntity, **R**elation, **A**ttribute) 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 Agents

- An agent'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**, an agent **A** needs to perform a mapping between a meta-model **C** of **B**s 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	focused understanding	partial repetitive understanding
apprehension	generalized understanding	pragmatic understanding
associative understanding	group understanding	re-initialized understanding (syn:
autonomous understanding	incorrupt understanding	tabula rasa understanding)
blackboard understanding	in-depth understanding	reliable understanding
bottom up understanding	indirect understanding (syn:	remote understanding
brittle understanding	comprehension)	repetitive understanding
broad understanding	individual understanding	robust understanding
broadcasted understanding	instantiated understanding	semantic understanding
coarse understanding	internal understanding	sequential understanding
comprehension	invalid understanding	single vision understanding
cooperative understanding	learning understanding	subjective understanding
corrupt understanding	legacy understanding	switchable understanding (syn:
cumulative understanding	lexical understanding	multivision understanding)
delegated understanding	logical understanding	syntactic understanding
detailed understanding (syn: in-depth	mediated understanding (syn:	tabula rasa understanding
understanding)	comprehension)	top-down understanding
direct understanding (syn:	morphological understanding	understanding for subscribers
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

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)
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.

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	apprehension (direct understanding)	Apprehension is direct understanding or self-evidence.
		comprehension (indirect understanding) (mediated understanding) - logical understanding	Comprehension is indirect or mediated 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 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

metamodel			
	fixed	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.)

Understanding based on the Characteristics of the Understanding System

● Characteristics of understanding systems such as

- initiative,

- number,

- knowledge sharing features, as well as

- mechanisms to disseminate the results of understanding process

can be used to further discriminate understanding.

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.)

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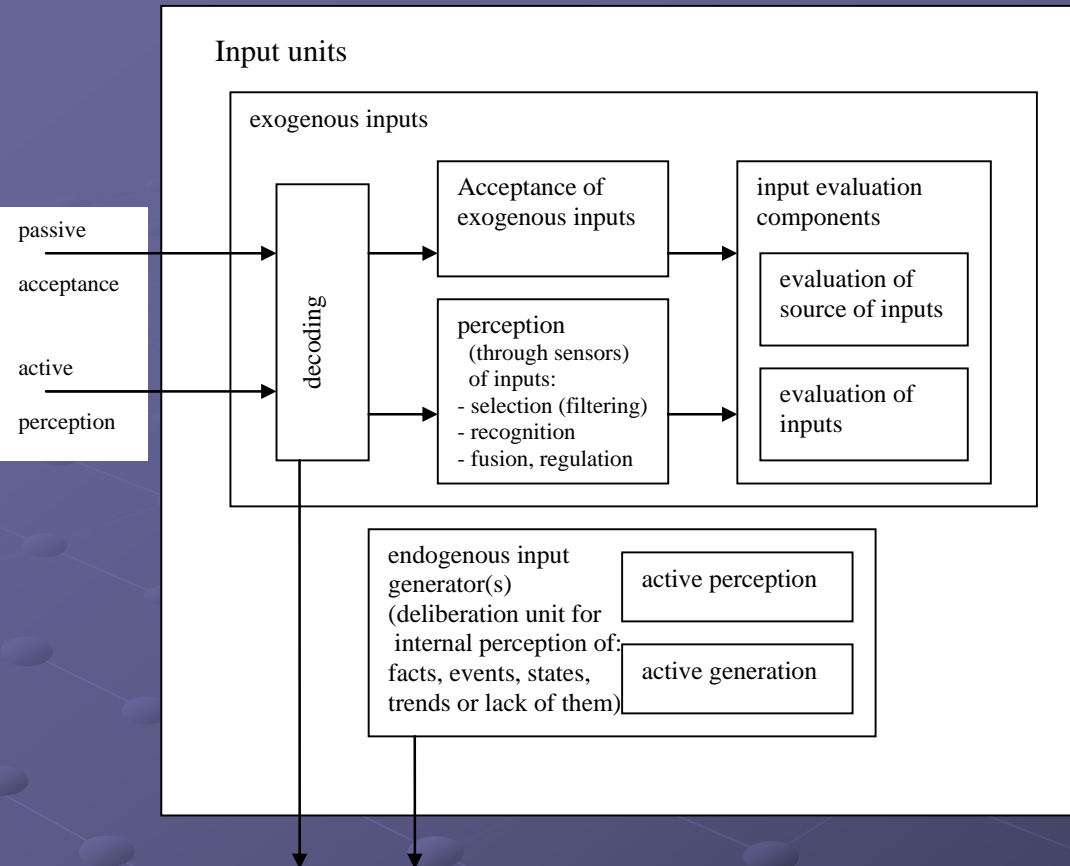
Agents with Understanding Capabilities
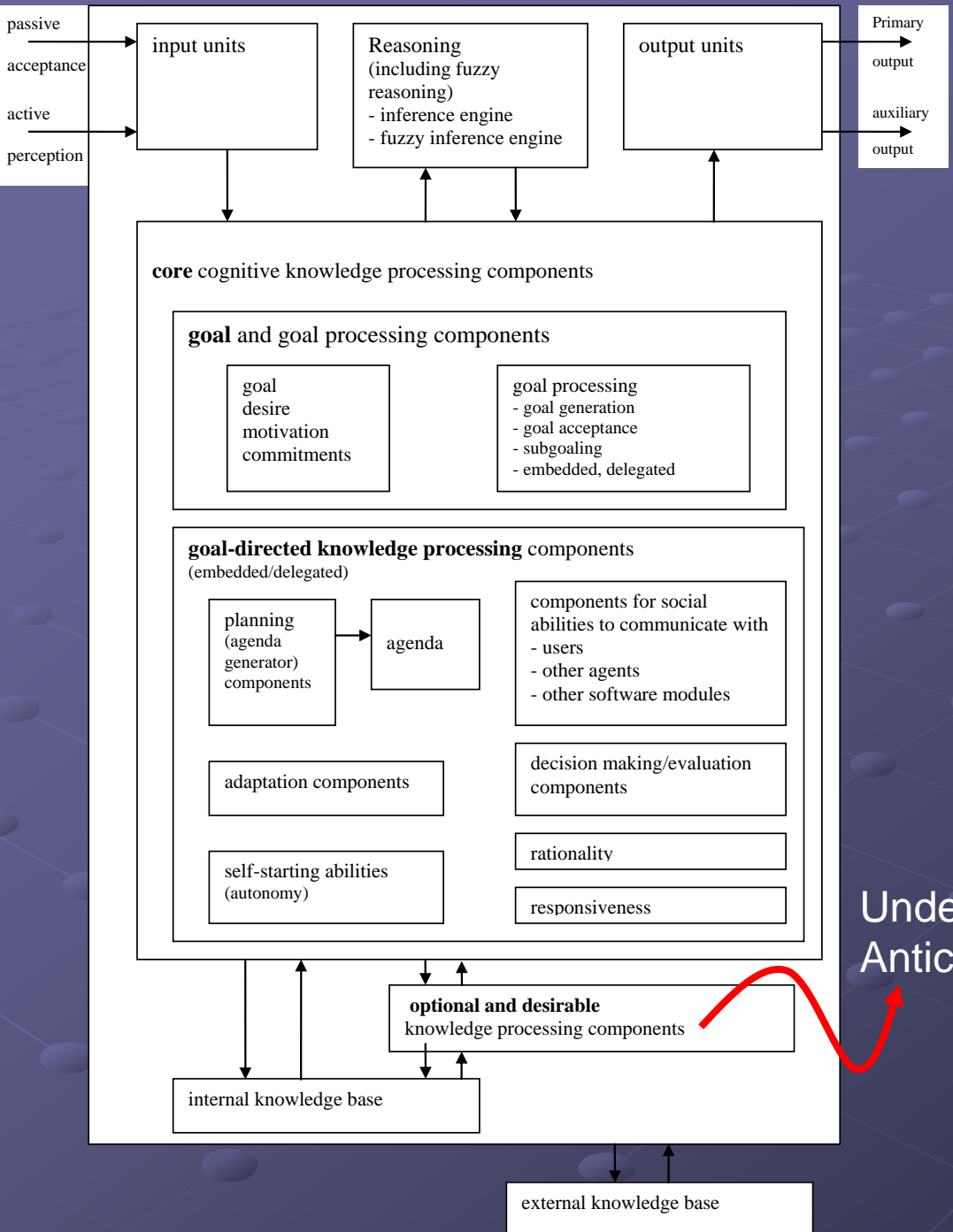
- Major components of an agent are:
  - input/output units
  - reasoning (including fuzzy reasoning) components
  - core cognitive knowledge processing components
  - for goal and goal processing,
  - embedded or delegated goal-directed knowledge processing elements for: planning (agenda genera-tion),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

Agents with Perception Capabilities

Input units

exogenous inputs

passive acceptance

active perception

decoding

Acceptance of exogenous inputs

perception
 (through sensors)
 of inputs:
- selection (filtering)
- recognition
- fusion, regulation

input evaluation components

evaluation of source of inputs

evaluation of inputs

endogenous input generator(s)
(deliberation unit for
 internal perception of:
facts, events, states,
trends or lack of them)

active perception

active generation

- (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?