A Cognitive-based Agent Architecture for Autonomous Situation Analysis

Augustine Kwon (ICF International)
Gary Berg-Cross (EM&I)
Wai-Tat Fu (University of Illinois)

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Outline

- The challenge of multiple aspects in agent based Intelligence
  - A hybrid approach based on dual reasoning
  - ACT-R in a large distributed agent architecture
- Mechanics of Situation assessment
- SAW & SAWU Ontologies
- Issues & Future Research Directions

Multiple Aspects of Intelligent agents

- No single technique or tool available to built or develop intelligent agents has proven adequate to address all the functionality needed for even relatively simple information agents such as envisioned in the original DAML effort.

- Current agent based systems have a difficulty to accommodate things like diverse spatiotemporal information, including quantitative and qualitative assessments within a single analytic context in a suitable period of time.

- Yet as a part of analytic process for understanding situation, humans can easily integrate both quantitative and qualitative information assessments to arrive at analytic conclusions.

Why agent based architecture?

- Often human knowledge is systematically formed, validated, verified, applied, improved, and transferred by a social network through competition and collaboration – ideal attribute for a large distributed intelligent agent based system, supposedly highly efficient to handle a large network of different data sources for real time situation assessment.

Dual Reasoning in Cognitive Agent

- Dual processing in human reasoning:
  - Two systems integrated by an overall reasoner
  - Distinguishes between processes that are
    - unconscious, rapid, automatic and high capacity, and
    - those that are conscious, slow and deliberative.
  - Characterizes human reasoning as an interplay between an automatic belief-based system and a cognitively demanding logic-based reasoning system.

- A need for research on multi-level hybrid architectures growing from a cognitively realistic base.

Terms for dual-cognitive processes

	System 1	System 2
Fodor (1983, 1989, 2001)	Input modules	Higher cognition
Schneider and Schiffrin (1977)	Automatic	Controlled
Epstein (1994, 1999)	Experiential	Rational
Chaiken (Chaiken 1980, Chen & Chaiken 1999)	Heuristic	Systematic
Reber (1993); Evans & Over (1996)	Implicit / tacit	Explicit
Evans (1989, 2006)	Heuristic	Analytic
Sloman (1996); Smith and DeCoster (2000)	Associative	Rule based
Hammond (1996)	Intuitive	Analytic
Stanovich (1999, 2004)	System 1 (TASS)	System 2 (Analytic)
Nisbett et al. (2001)	Holistic	Analytic
Wilson (2002)	Adaptive unconscious	Conscious
Lieberman (2003)	Reflexive	Reflective
Toates (2006)	Stimulus-bound	Higher-order

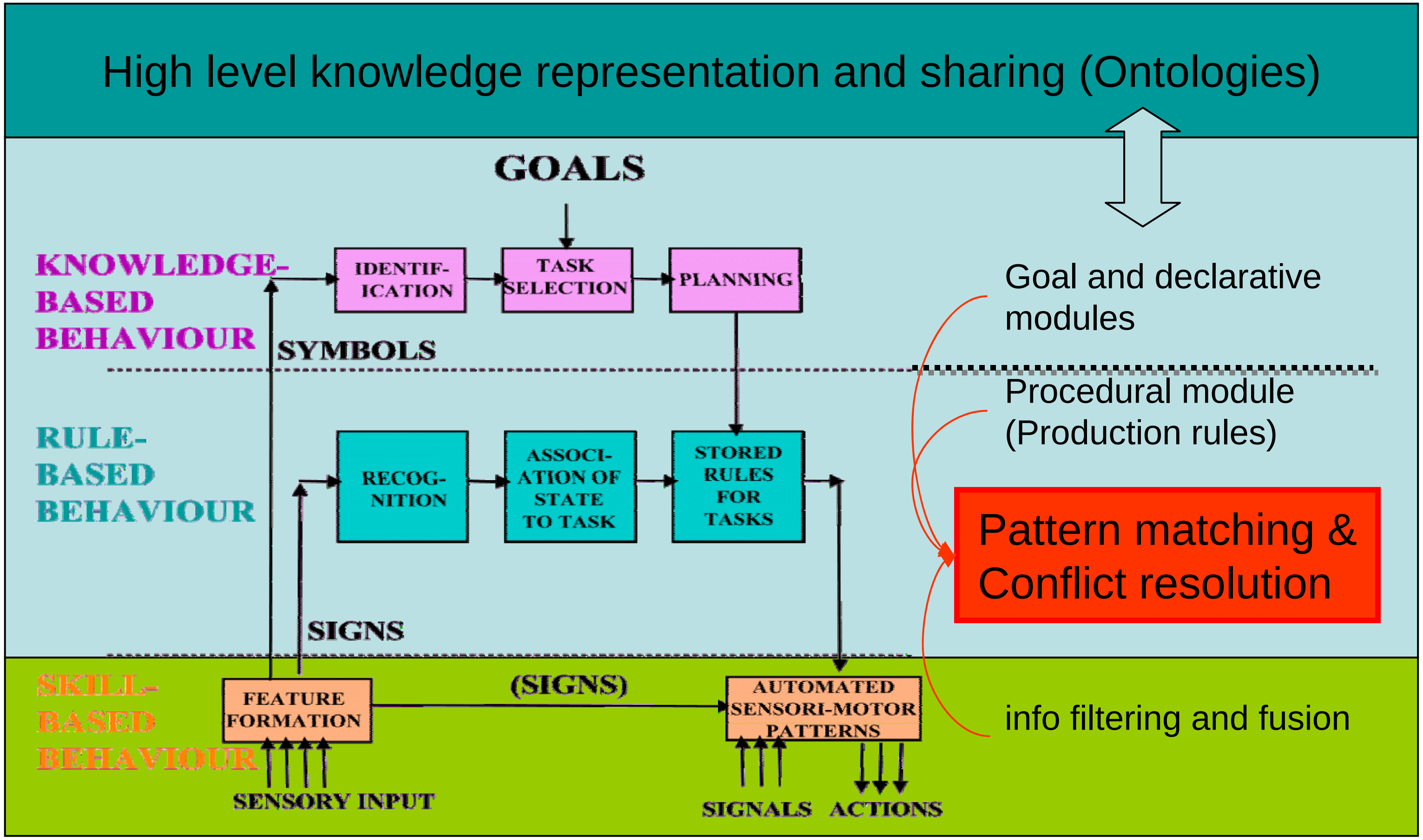
DUAL-PROCESSING ACCOUNTS OF REASONING, JUDGMENT AND SOCIAL COGNITION in Annual Review of Psychology (2008, in press) *By Jonathan Evans*

A Hybrid Multi-level Approach

- Proposes to leverage our understanding of cognitive agent architecture in integrating three levels of processing:
  - Low level machine learning (information fusion).
  - Rational level knowledge representation with human-like learning capabilities (ACT-R).
  - High level distributed agent technology providing semantic representation and ontologies to be shared among cognitive agents (DOLCE and Cougaar).

- Capitalizes on the success of ACT-R in simulating the rational/adaptive nature of human information processing to coordinate activities in low level information fusion/selection and high level semantic ontological reasoning to support distributed decision making.

Adapting ACT-R to the multi-level Hybrid Approach



High level
Ontologies & Agent architecture

Rational level
ACT-R

Low level
Machine learning

Why ACT-R?

- Rationale for ACT-R:
  - Strongly based on years of Psychological research
  - Rational action selection based on Bayesian estimates of information needs -- ideal for integrating low and high level info
    - Rich representation of high level declarative (memory chunks) and procedural (situation-action rules) knowledge
    - Low level "perceptual" modules for goal-directed info processing
  - Strong learning components for adaptation/training in different situations

  Current extensions to ACT-R:
  - Allow multiple agents/models to "talk" to each other
  - Each ACT-R model can play a role in a wide range of ISR tasks
- Suitable performance measure in intelligent capability because it has been widely shown to be capable of predicting human learning and performance in a wide range of complex tasks.

Task Analysis of Situation Assessment

- Situation/context-aware systems have been proposed as an important class of applications and an important step towards ubiquitous computing.
- But what is understood about situation understanding?
  - Models are based on a high-order knowledge type of concept that is formed using existing concepts
  - Role of concepts and their relationships
    - Representation of common constructs in DOLCE
    - Description and Situation Models
    - SAW Ontology
    - Similarity and familiarity
- Concept learning and mastery by a network of intelligent agents in a coordinated system.

Modeling Approach of Situation Understanding

- A natural direction to achieve realistic behavior is to model situated understanding and analysis as a rational empirical process involving:
  - Object & target recognition, Expectation/model-based perception
  - *Incremental, flexible perceptual learning*
  - Retrieval of relevant memories, Situation-based and analogical retrieval
  - *Incremental, flexible conceptual learning*
- Situation knowledge can be formed by an agent's interaction history with the environment.
- Situation "concepts" can be formed by agents, observing that certain patterns of sequence of inputs from the environment.
  - Perceived objects and their interactions from these inputs lead to a situation understanding that allows an agent to predict some aspect of the future.

Situation Understanding: Learning and Communication

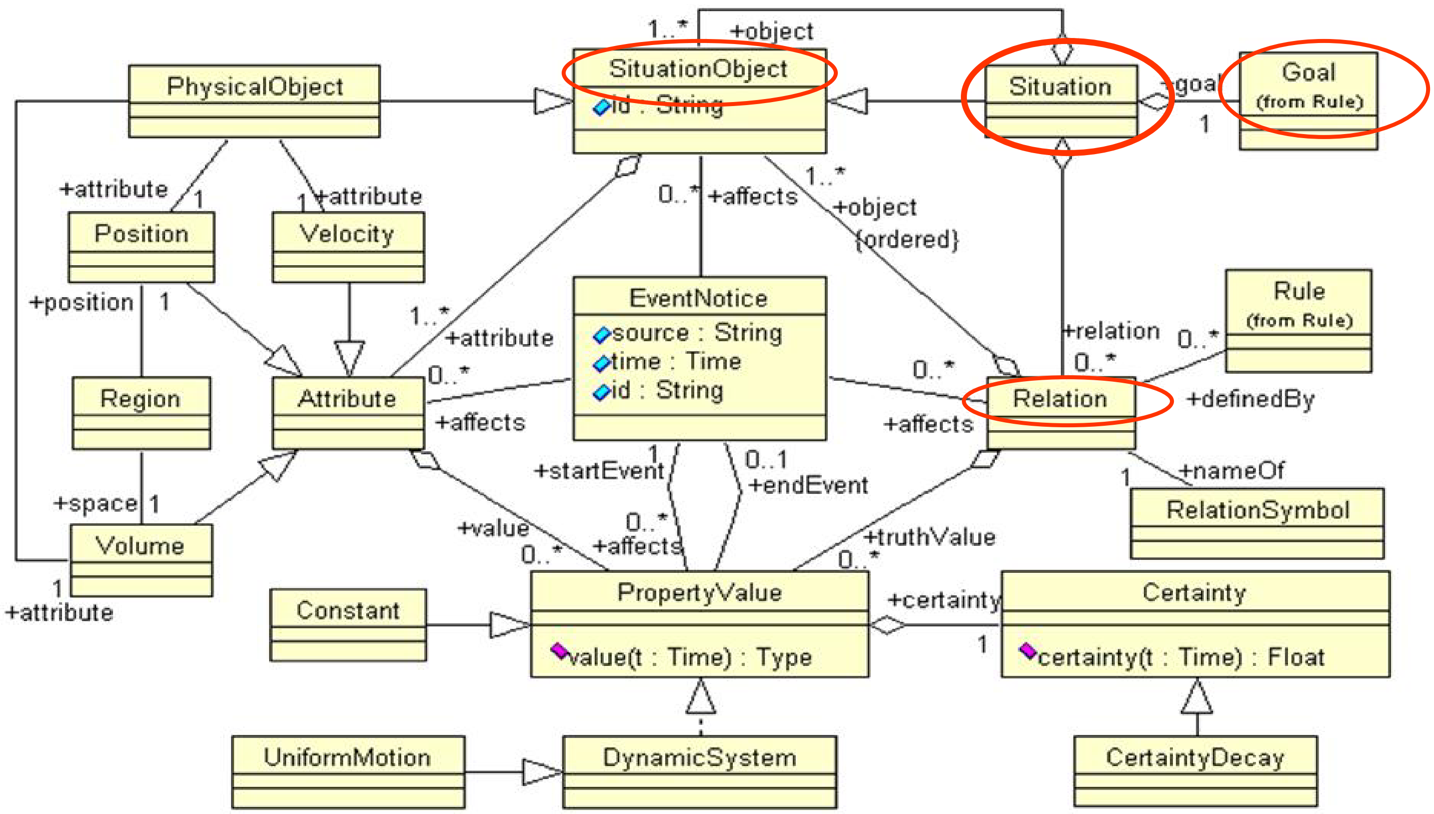
- Knowledge acquisition via incremental learning through experiences.
- Situation concepts should be developed by intelligent autonomous agents since only evaluative feedback is assumed to be available from the environment.
  - Use of simulations with feedback might be an easy way to develop such a situation understanding agent
  - Given a standard vocabulary for the concepts involved and some language skills such an agent would be able to describe a situation in common terms, language disambiguation
- Characterizing the information present in situations and the resulting agent knowledge is a key aspect in knowledge about circumstances that form settings for an external event, the actors in it, causes and implications about future states.
- Since modeling the process of situational understanding is recognized as challenging, incremental improvements in the model is expected as the research continues.

Situational Awareness (SAW) & Understanding (SAWU)

- SAWU - the ability to maintain a cognitive state 'big picture' associated with a dynamic situation and thinking ahead from this state. A rational empirical approach to SAWU is in general defined by three sequential components:
  1. perception/awareness of elements/objects in the environment within a volume of time and space, along with
  2. a comprehension of their functional nature and organizational relationships (their “meaning”) as well as
  3. an ability to go beyond the current situation to project the status & relations of situated objects in the near term as an empirical test of “expectations”.
- A top-down, rational model of SAWU incorporates an agent’s goals & objectives into its reasoning about events, relations and situations.
- This helps upper-level agents reduce the number of possible relations definable within an agent’s knowledge to constrain situational possibilities.
- By knowing something about what is expected, attention on relevant events and relations can improve agent operation (Matheus et al. 2005).

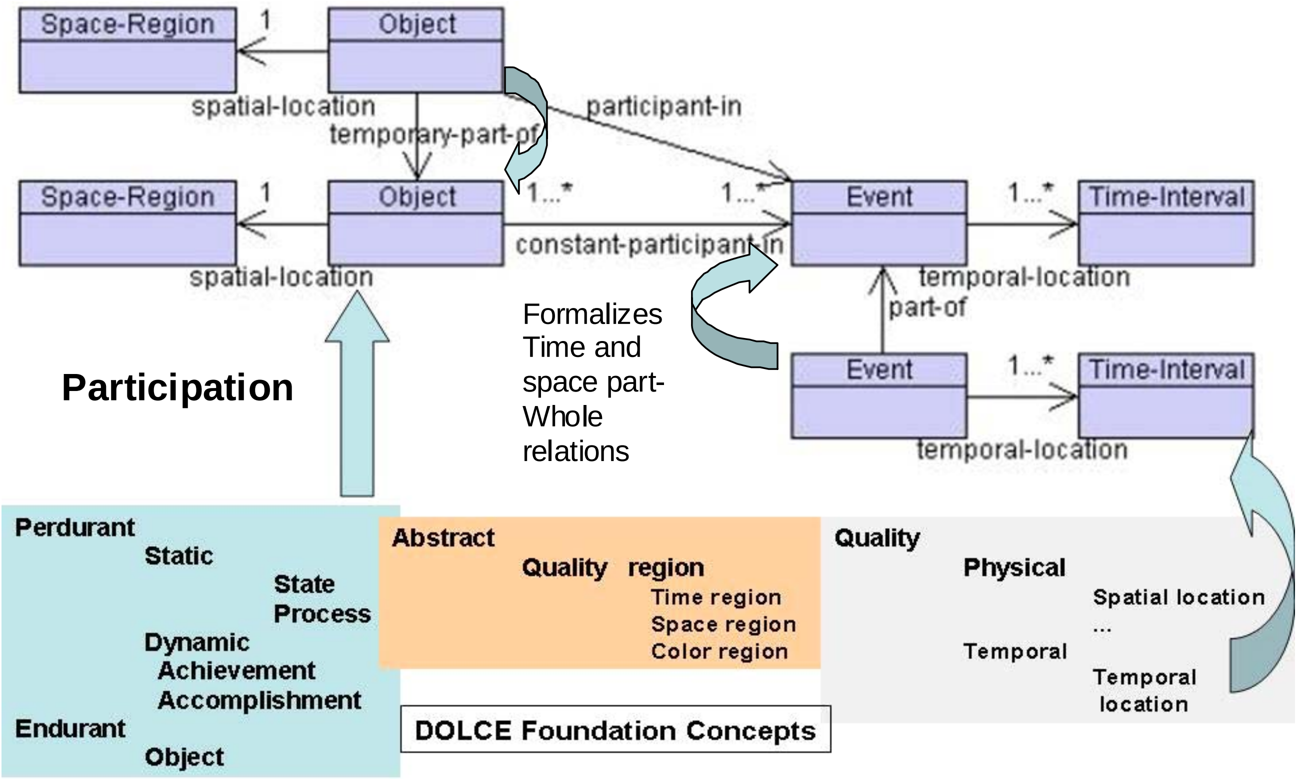
Using Ontologies to Represent Situations

SAW is light Situational Ontology (Matheus et al 2003)– Situations (object, events) are defined as a relationship to three things: Goals, SituationObjects and Relations



Foundational Ontology Extensions for Situations

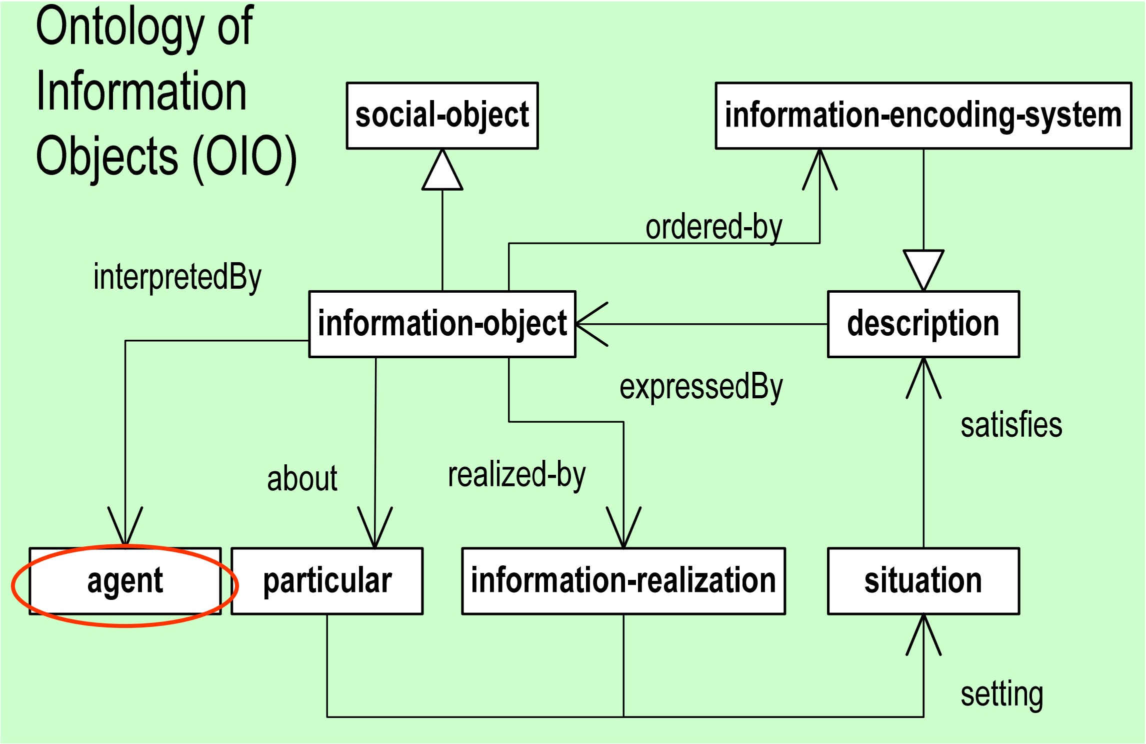
The DOLCE Ontology ((Masolo et al., 2003) - more expressive and includes a Participation Pattern of objects taking part in the *Events* in the SAW model (Gangemi et al, 2004)



Ontology Design Pattern for Object "Participation" in Situations
Built on DOLCE Foundation (After Gangemi et al 2004)

Ontology of Information Objects and Distinguishing Description of Situations from Situations

- Nice way to represent the knowledge that agents use to fuse into situations was proposed by Gangemi et al's (2006).
- Useful for agent communication.



A. Gangemi, S. Borgo, C. Catenacci, and J. Lehmann. Task Taxonomies for Knowledge Content. Technical Report, Metokis Deliverable 7, 2004.

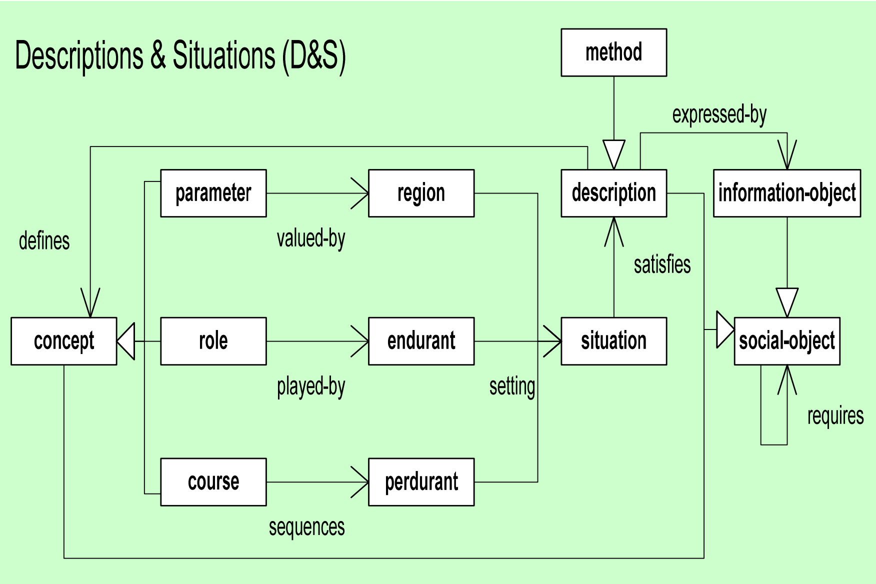
Ontology of Information Objects and Distinguishing Description of Situations from Situations -continued

- OIO builds on the idea that situations (S) are unique, while descriptions (D) expressed by information, and used socially by agents, are not.

- Information objects used in the model are based on interpretations of situations and they represent social reifications of abstract information which are assumed to have an existence over time, and are realized by some "entity."

The D&S Ontology

- The D&S ontology (Gangemi & Mika, 2003) is based on a conceptualization that supports a first-order manipulation of *descriptive objects* (such as clinical plans, evacuation routes, emergency plans, institutions, etc.).
- Descriptions
  - formalize context
  - define descriptive concepts
- Situations
  - explained by descriptions
  - settings for ground entities



- It supports organizing domain theories for areas like Disasters & Healthcare into different ontologies as well as into different *descriptions* or *situations*.

Issues and Future Research Directions

- Appropriate agent social behavior in both competition vs. collaboration mode based on circumstances
- Knowledge storages and retrieval – distributed vs. replicated
- Knowledge sharing and transfer through proper ontologies
- If replicated, synchronization issues under limited bandwidth
- Suitable consensus building mechanism
- Hierarchical vs. Peer-to-peer infrastructure or mix
- Autonomous task delegation and volunteer capability
- Dynamic goal switching
- Appropriate performance metrics to evaluate the collective intelligence including social behavior displayed by a group of intelligent agents