Operational Analysis of Cognitive Theories for a Ubiquitous Cognitive System

Alberto Greco
University of Genoa
greco@unige.it

1. Introduction

User-adaptive systems typically work in environments where data are "noisy". One of the biggest problems in AI and Robotics is that most existing systems do not address the problem that a collection of data about user or environment is not sufficient for having a *user model*. The same dataset may give rise to different information according to different current user plans or goals. Thus there may be different views or "senses" that depend on theoretical *implicit* presuppositions. Most current systems just make use of commonsense presuppositions (embedded in programmers' heads) and often it is not clear how such presuppositions were translated into the computational models. On the other hand, the value of using technological intelligent systems in psychological research is now commonly understood, but models are generally still too "static" because they do not fully exploit the possibilities of dynamic interaction with users.

The present paper presents "I Am For You" (IM4U), a psychologically oriented project, aimed at tackling these issues. As a general objective, this project is aimed at developing a distributed cognitive system, possibly based on a Smart Space with ubiquitous sensors /actuators as well as multimodal interfaces, which, by a continuous interaction with its user, is able to monitor user behaviour and other relevant events, in order to build a dynamic user model.

In this model, psychological theories and results of cognitive experiments in the literature, as well as new hypotheses and experiments, inform and drive the design of the knowledge base and of perceptual and inferential processes. This allows to give an interpretation of data (what we call "making sense") and take decisions which better fit the profile of the user. Differently from most traditional systems, theories that are used for making sense must be explicitly stated, and also protocols for translating them into computational directives are essential part of the interpreting system.

2. Making sense

Any intelligent system, prior to interaction with the human, is assumed to be in a situation where it has no way to make use of stimuli in the environment, whatever sensory modality is involved (vision, hearing, touch). Even if it is placed in a sensorially very rich environment, if it is not well-equipped with some psychological capabilities, it can be considered like humans placed in an environment where all sensory stimulation is suppressed, a situation that has been experimentally studied as “sensory deprivation” (e.g. see Barabasz & Barabasz, 1993).

Traditional intelligent and robotic systems strive for translating sensory information into perceptual stimuli for pattern recognition, but this is not enough. Sensory information, in fact, can be really used if it can be placed inside a meaningful context. Any artificial system is also placed, at the start, in a situation that can be defined of “semantic deprivation” (Greco, 1997), because it has no way to make a sensible use of sensorial input, like people who are placed in a situation where stimuli are meaningless and there is no obvious connection with actions performed. Semantic deprivation is a situation where a clear meaning of objects, events, actions is not presupposed, a situation where a human or an agent is not able to “make sense”, to know what is happening and/or how to manage it (i.e. what to do). In this situation, perceived features cannot be connected with each other, do not match a single framework or schema, because no previous experience can help in doing that. We call “making sense” here the capability of developing strategies for coping with this sort of semantic deprivation.

We claim then that a ubiquitous system that is designed to interact and possibly cooperate with humans must have some “making sense” capabilities. Such capabilities will come to the system by analysing and fully exploiting knowledge coming from cognitive and psychological theories. This is the Operational Analysis of Cognitive Theories (OACT), which will be described here.

3. Operational Analysis of Cognitive Theories (OACT)

The purpose of OACT is to provide the IM4U system with some embedded psychological knowledge.

The IM4U system is designed to be modular, so as to allow it the greatest possible flexibility. It is composed of a *core engine* and a collection of special-purpose *plugins*. The core engine is scenario-independent and performs basic operations, like raw sensory data processing, event detection by subsymbolic or hybrid techniques, symbol grounding, and user model outputting. It interacts and cooperates with plugins using an analysis-by-synthesis method (see below) in order to fit as much as possible the characteristic plugin behavioral ontologies, which are pre-defined, as we see next. Technical details about the core engine are beyond the scope of the present paper.

Each available plugin is designed to deal with one aspect drawn from a theory, which is considered relevant *in one related scenario*. A special type of plugins are the experimental plugins (see below), which are designed to perform dynamic experiments. Given the modular and open nature of the system, the collection of plugins may in the future be enriched by using our method also by other researchers.

Each plugin will concern situation descriptions, coded as ontologies, concerning theory-driven expectations and related decisions. Such ontologies may include standard information about objects, locations, etc. but also possible behaviour and user psychological aspects, according to the related theoretical meaning. Standard decisions will affect user model updating, and performing common actions like giving messages, asking questions, operating physical devices, joining persons in a telepresence system, etc.

4. How to build an OACT plugin

Stage (A), formal: (1) *Scenario analysis* and selection of relevant theories; (2) Selection of relevant *sub-theories* (e.g. if "distraction" is the currently considered plugin, the cognitive theory of situation awareness, the theory of executive functions, etc. are relevant). (3) *Formal analysis* of theories: each theory is formally analysed and its theoretical statements are put into more simple schematic expressions, in natural language, including, as explicit variables, observations of behavior, expectations about outcomes, and related conclusions to be taken.

Stage (B), empirical: (1) *Experiments* with human volunteers performed when needed, in order to get more accurate information about knowledge people actually have in the considered situation, and observations of how they actually behave, by ordinary observation and experimental techniques. Situations may be simulated environments at this stage. Experiments may also include, for accurate definition of concepts, semantic association or implicit techniques like the IAT (Greenwald et al., 2003). (2) *Experts consulting*: especially in cases when plugins are concerned with the prevention of psychological diseases, also interviews with clinicians may be performed.

Stage (C), final, formal again: expressions coming from previous analysis are translated, in cooperation with ontology experts, into *formal ontologies*. These will be used by the system as the high-level representation system, and matched - interacting with the core engine - with the symbolic representations attained bottom-up from sensory data by the symbol grounding process. If the intended plugin is an "experimental plugin", then an experimental paradigm will be set up, where the kind of stimuli to be given, the kind of response to be monitored, and the decisions to be taken will be included.

5. OACT operation

In this section we describe how the IM4U system can use and improve its making sense capabilities. The standard use of plugins is that the system attempts to match observed patterns with expected ones, and decides accordingly to what the implemented theory suggests. The most appropriate method for performing this task appears to be the analysis-by-synthesis method, inspired by Neisser (1967) model on human attention. It consists in setting a continuous cycle between top-down expectations and bottom-up data. Coarse expectations at the start direct subsequent observation, acting as hypoteses to be tested, and expectations become more and more refined as data are analysed. This mechanism can be employed to make plugins more dynamical and updatable by the system.

A second, novel paradigm, devised for giving IM4U a unique feature in ambient intelligence systems, is the possibility of gradually developing a meaningful framework of particular users, greatly augmenting its flexibility. This consists in proactively stimulating the user according to defined experimental plans. It can be done by the use of "experimental plugins", which are special plugins whose decision part includes the definition of possible stimuli to be given to the user in certain conditions, making the system work as an "experimenter". This way, simple tests about user states can be programmed and the system acquires the possibility of dynamically updating the user model, in real time on the basis of proactive stimulation.

Proactive stimulation can also include questioning the user. Almost all user interfaces, from PC to smartphone ones, ask questions. But extracting knowledge by questioning is not always so simple affair. Also from this side, IM4U systems can benefit from cognitive theories. Strategies for chosing a correct communication style can be learned from patterns extracted by psychological experiments using a sense-making method (Dervin, 1983).

6. Examples

In this section we shall give some examples of kinds of theories, and related scenarios, where the OACT method can be used and how it could work.

1. Situation awareness theory (Endsley, 1995), being strongly focused on the analysis of the situation, is particularly appropriate as a starting theory to be analysed (very few attempts to establish ontologies on this topic have already been done, e.g. Matheus, Kokar, Backlawski, 2005; Kokar, Matheus, Backlawski, 2009; Rodriguez et al., 2014). Setting ontologies is not the whole story, however, since in OACT, as we have explained, expectations are conceived as hypotheses to be tested by the system during the interaction with the user, and consequently modified and refined.

2. A theory (Johnson & Shiffrar, 2011) describes how from the analysis of body motion and posture (walk, etc.) personality aspects, including vulnerability, can be inferred. Analysis of usual posture habits could be then automatically interpreted as an increased vulnerability risk. Subsequent observations can be planned in the system to test this hypothesis.

3. Some increasing hidden disability in motor coordination, like bradykinesia, can be revealed by accurate analysis of user postures, which can be a symptom of an incoming Parkinson's (or other) disease (Cooper & Shallice, 2000). Subsequent observations can be planned in the system to test this hypothesis.

4. If a person stops the habit of listening to music, or exhibits an unusually violent behaviour (drops objects to the floor, slams the doors, etc.), then this may be detected and interpreted as a symptom of some emotional distress. The tendency to multitasking (doing several things at a time) for people, which has been considered harmful for cognitive health (Bergman, 2010), can be monitored with a relative ease. Other states which can be revealed by real-time behavioural analysis are fatigue, lack of sleep, etc.

In previous examples we have shown how the analysis of a theory leads to set new expectations for the system, related to some hypothesis-testing.

5. An unusual increasing of drinking behaviour could be one symptom of incoming depression (Mezuk, Bohnert, Ratliff, Zivin, 2011). Detecting a strong change of habit in drinking behaviour can reveal an incoming risk of alcoholism. This conclusion may be strengthened if such observation is associated (and related) also to spatial memory blackouts (Bowden & Mccarter, 1993; White, 2004) and abnormal response perseveration (Oscar-Berman, Hutner, Bonner, 1992). Examples of spatial memory blackouts are: not being able to remember things that one did, or places that one went in. Response perseveration consists in the inappropriate repetition of preceding behaviour when a new adapted response is expected.

In this example we have shown how the analysis of theories leads the system to use and compare different sets of observations that otherwise would have not be related. The described kind of responses may be detected by the system, if it is well equipped with the appropriate sets of ontologies, connected with the appropriate low-level behaviour and event definitions.

6. During some kinds of psychotherapy (cognitive-behavioural therapy), a common practice is to prescribe to the patient certain behaviour to be performed, in order to help him/her to relax and/or overcome certain fears or anxieties. Patients are encouraged to control their behaviour (e.g. by reporting it in some diary) but there are no effective means to help them in doing so. They might agree to seek such help from a IM4U intelligent assistant which is able to observe their behaviour and match with expected patterns.

In this example we have shown how the analysis of theories can lead to targeted expectations, related to behaviour checking.

All the examples above show the kind of theories that can be processed for eveloping a OACT method. This will consist in "operationalising" expectations expressed in linguistic form inside theories, by expressing behaviour and other environmental constraints in formal terms compatible with the ontology system used by IM4U. This will tell the system exactly what has to be observed, what can be expected, and how it has to be compared with previous observations.

7. The system, by means of experimental plugins, may be used as a tool for performing cognitive research or as a novel kind of interactive testing device. As an example of proactive stimulation, the system (using its human interface) can try to capture user's attention N times, in condition X and Y, and compute how many times s/he responded , and/or the kind of response, reaction times, etc. If the number of some kind of responses was below a treshold, then the system proceeds with some planned further test, or notifies the user a message, etc. This way, psychological knowledge is effectively embedded into the system, improving the quality of user understanding and allowing to flexibly adapt to its individual user.

Note

This work is dedicated to the memory of Nicla Rossini. She would have significantly contributed if her lifetime had been enough.

References

Barabasz, A., & Barabasz, M. (1993). *Clinical and experimental restricted environmental stimulation.* New York: Springer-Verlag.

Bergman P. (2010) How (and why) to stop multitasking. *Harward Business Review*, 5.

Bowden SC. & Mccarter RJ. (1993) Spatial Memory in Alcohol-Dependent Subjects. *Brain and Cognition*, 22, 51–62.

Cooper R, Shallice T. (2000) Contention scheduling and the control of routine activities. *Cognitive Neuropsychology*, 17, 4, 297–338.

Dervin, B. (1983). An overview of Sense-Making research: Concepts, methods, and results to date. *Paper presented at the ann. meet. Intern. Communication Association*, Dallas, TX.

Endsley, M.R. (1995) Toward a theory of situation awareness in dynamic systems. *Human Factors*, 37, 1, 32–64.

Greco A. (1997). La deprivazione semantica. Una indagine empirica sulla nascita del senso [Semantic deprivation. An empirical inquiry on making sense - in Italian]. *Ricerche di Psicologia*, 21, 4, 81-115.

Greenwald, A., Nosek, B. and Banaji, M. (2003). Understanding and using the Implicit association Test : An improved scoring algorithm. *Journal of Personality and Social Psychology* , 85, pp. 197-216.

Johnson K., Shiffrar M. (2011) *Perception of the Human Body in Motion: Findings, Theory and Practice*, Oxford University Press.

Kokar, Matheus, Backlawski (2009) Ontology-based situation awareness, *Information Fusion*, 10, 83-98.

Matheus, C.J., Kokar, M.M., Baclawski, K. (2005). A core ontology for situation awareness. *Information Fusion*, 2003. Proceedings of the Sixth International Conference of Information Fusion.Volume 1, pp. 545 - 552.

Mezuk B, Bohnert AS, Ratliff S, Zivin K. (2011) Job strain, depressive symptoms, and drinking behaviour among older adults: results from the health and retirement study. *J Gerontol B Psychol Sci Soc Sci.* , 66(4), 426-434.

Neisser U. (1967) *Cognitive Psychology*. Prentice-Hall, Englewood Cliffs.

Oscar-Berman M, Hutner N, Bonner RT. (1992) Visual and Auditory Spatial and Nonspatial Delayed-Response Performance by Korsakoff and Non-Korsakoff Alcoholic and Aging Individuals. *Behavioural Neuroscience*, 106, 613–622.

Rodríguez, N. D., Cuéllar, M. P., Lilius, J., & Calvo-Flores, M. D. (2014). A fuzzy ontology for semantic modelling and recognition of human behaviour. *Knowledge-Based Systems, 66,* 46-60.

White A. (2004) What Happened? Alcohol, Memory Blackouts, and the Brain. *Publications of NIAA, National Institute of Alcohol Abuse and Alcoholism.*