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A multi-disciplinary review of knowledge acquisition methods: From human to autonomous eliciting agents

George Leu*, Hussein Abbass

School of Engineering and Information Technology, University of New South Wales Canberra, ACT 2600, Australia

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ABSTRACT

This paper offers a multi-disciplinary review of knowledge acquisition methods in human activity systems. The review captures the degree of involvement of various types of agencies in the knowledge acquisition process, and proposes a classification with three categories of methods: the human agent, the human-inspired agent, and the autonomous machine agent methods. In the first two categories, the acquisition of knowledge is seen as a cognitive task analysis exercise, while in the third category knowledge acquisition is treated as an autonomous knowledge-discovery endeavour. The motivation for this classification stems from the continuous change over time of the structure, meaning and purpose of human activity systems, which are seen as the factor that fuelled researchers' and practitioners' efforts in knowledge acquisition for more than a century.

We show through this review that the KA field is increasingly active due to the higher and higher pace of change in human activity, and conclude by discussing the emergence of a fourth category of knowledge acquisition methods, which are based on red-teaming and co-evolution.

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1. Introduction

Knowledge acquisition (KA) refers in a very broad view to gaining understanding about the processes underlying the observable behaviour of an entity. The immediate output of KA, the knowledge, is a representation of the real phenomenon at the level of detail and abstraction required by the purpose of the KA exercise. The representation takes the form of an ontological construct, i.e. a set of concepts considered necessary and sufficient to capture the understanding about the real phenomenon, which offers the possibility to re-instantiate it (replicate it in a different context), to improve it, or to further communicate the understanding about it to peers. The range of purposes for knowledge acquisition exercises is very broad, from the basis of learning in itself, to the creation of computational models and applications that improve the behaviours of the entities under investigation or solve problems on behalf of them (e.g. knowledge-based systems, expert systems).

The entities the KA can be performed on fall into three major categories—natural, man-made and humans—further referred to throughout the paper as natural systems, technical systems, and human activity systems. An example of KA applied to natural systems can be the weather cycle in a certain region of the Earth, which one needs to understand in order to ensure safe aircraft operation over that region in different periods of the year. The tools available for gaining understanding about the weather are observations and measurements. The weather cycle is observed, measurements are taken on some relevant aspects such as air speed, temperature, pressure or humidity, and records of these observations and measurements are analysed and structured in order to understand how and why the weather behaves the way it does. This further allows the representation of the weather cycle in a manner that can be communicated to and used by aircraft operators. The same tools, i.e. observations and measurements, are available when applying KA to man-made technical systems, like in the case of an aircraft life-cycle. During its life-cycle, from design to manufacturing, operation and decommissioning, an aircraft is under permanent observation, and large amounts of measurements are performed in order to gain understanding on all possible aspects that allow normal operation. For example, before commissioning into operation, the design is tested in simulations, then in controlled realistic environments (e.g. wind tunnels) and finally in real flight tests in order to gain understanding about how all system components interact internally within the aircraft and externally with other systems such as the weather or the operators. The resultant

List of abbreviations: KA, Knowledge acquisition; HAS, Human activity system; CTA, Cognitive task analysis; SME, Subject matter expert; KD, Knowledge discovery; EC, Evolutionary computation; CRT, Computational red teaming.

* Corresponding author: Tel.: +61262688424.
E-mail address: g.leu@adfa.edu.au (G. Leu).

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knowledge can be used to improve the design if the initial design assumptions are not met, or to release the aircraft into operation and communicate this knowledge to its operators.

Unlike natural and technical systems, in the case of human activity the processes underlying the observable behaviour can be unveiled not only through observations and measurements, but also by asking. Weather can be observed and measured, but cannot be asked about why it is the way it is. Similarly, the operation of an aircraft can be observed and measured, but the aircraft cannot be asked why it manifested a certain behaviour in some particular weather conditions. Humans instead, can be asked and thus knowledge can be elicited through various techniques that are unavailable in the case of natural and technical systems. For example, we assume an activity such as piloting an aircraft. This is a human activity system through that it involves the existence and the interaction of all types of entities: natural—the weather, technical—the aircraft and human—pilot's actions and decision making, with the human being the pertinent entity that steers the whole resultant system and is accountable for its behaviour. The pilot in this case makes use of its knowledge about the natural system, its knowledge about the technical system, and its innate or acquired cognitive-motor and decision-making skills in order to perform the task of flying the aircraft in good conditions. If one intends to improve the skills of this pilot (for purposes such as safety, flight duration, passenger comfort) or to transfer the existing skills to other pilots (through creation of training programs), then it is paramount to gain understanding about how and why the pilot takes decisions and performs various actions, and how are these yielding from the subsequent interactions with the natural and technical counterparts (the weather and the aircraft). Further, it is paramount to create and commit to an ontological construct that represents this understanding effectively, in order to be able to use it for fulfilling the established purposes.

In the light of the above examples, in this paper we concentrate on knowledge acquisition in relation to the generalised concept of human activity (described in the third example—the pilot), a research direction in which knowledge acquisition is employed as a facilitator for finding ways to improve human performance in various tasks in real-world contexts [142,182]. Historically, this research direction emerged in response to the need for improving the "workplace", where the word workplace has a broad meaning, referring to the physical work-place itself, but also encompassing the tasks performed by humans as part of their lucrative activity, their proficiency in accomplishing those tasks, their interaction with the technology they use in support of that lucrative activity, and the artefacts resulting from their activity. Roth et al. [182] see knowledge acquisition through a cognitive task analysis (CTA) lens, and note that KA is nowadays an indispensable tool used to understand the "cognitive and collaborative demands" that contribute to performance and facilitate the formation of expertise. They also note that KA is used as a support for designing ways to improve individual performance through various forms of training, user interfaces, human–machine interaction or decision-making support systems.

Today KA in relation to human activity systems is addressed in multiple fields of activity. In *Cognitive Systems Engineering* the KA methods are used to analyse the work environment in order to inform the design of various systems, focusing on the integration of humans, technologies and physical work space [142]. In *Cognitive Work Analysis* [101,181] the KA exercise is used for making real-world constraints more visible to human operators in order for them to make better-informed decisions in unanticipated circumstances. In *Naturalistic Decision Making* [157], some researchers proposed KA methods for investigating how human decision-making emerges in real world tasks, as a result of time pressure and risk [142,191]. *Human-Centered Computing* is another major field of research where KA techniques were used as a support for designing technology that amplifies or extend human capabilities [195]. KA was also considered essential for general *Knowledge Engineering* [49,51], where KA can be used in any or all of the knowledge elicitation, analysis and representation stages. In addition, in *Knowledge Discovery and Data Mining* [105] computational intelligence instantiations of KA exercises are used for autonomous knowledge discovery in problem domains that only offer access to inexact and imprecise artefactual data resulting from human activity systems. While this list is not exhaustive, it shows the magnitude of the KA paradigm and its importance in the investigation of what we can broadly consider, virtually any human activity system.

Fig. 1 summarises the above discussion in a visual manner, presenting broadly the position and scope of this study within the larger field of knowledge acquisition. More specifically, the review sees the human activity KA literature from an agent perspective and classifies it into three major categories of methods: human agents, human-inspired agents, and machine agents. In the most

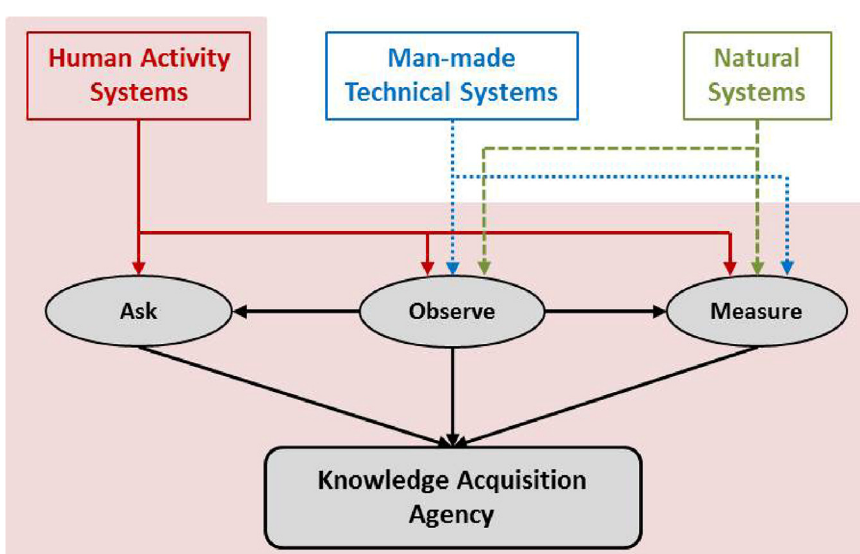

Fig. 1. The shaded area shows the position and scope of the review within the larger KA field.

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