Proceedings of the 2015 Winter Simulation Conference
L. Yilmaz, W. K. V. Chan, I. Moon, T. M. K. Roeder, C. Macal, and M. D. Rossetti, eds.

BUILDING HIGH FIDELITY HUMAN BEHAVIOR MODELS IN THE SIGMA COGNITIVE ARCHITECTURE

Volkan Ustun

Institute for Creative Technologies
University of Southern California
Playa Vista, CA 90094, USA

Paul S. Rosenbloom

Department of Computer Science & Institute for Creative Technologies
University of Southern California
Los Angeles, CA 90089, USA

Julia Kim

U.S. Department of Veteran Affairs
1800 G St., NW, Suite 880
Washington, DC 20006, USA

Lingshan Li

2-1-3-2 Jinyu Linpanshenyun
168 Shuangshan Road, Dadukou District
Chongqing, 400080, China

ABSTRACT

Many agent simulations involve computational models of intelligent human behavior. In a variety of cases, these behavior models should be high-fidelity to provide the required realism and credibility. Cognitive architectures may assist the generation of such high-fidelity models as they specify the fixed structure underlying an intelligent cognitive system that does not change over time and across domains. Existing symbolic architectures, such as Soar and ACT-R, have been used in this way, but here the focus is on a new architecture, *Sigma (Σ)*, that leverages probabilistic graphical models towards a uniform *grand unification* of not only the traditional cognitive capabilities but also key non-cognitive aspects, and which thus yields unique opportunities for construction of new kinds of non-modular high-fidelity behavior models. Here, we briefly introduce Sigma along with two disparate proof-of-concept virtual humans – one conversational and the other a pair of ambulatory agents – that demonstrate its diverse capabilities.

1 INTRODUCTION

Sigma (Rosenbloom 2013) is being built as a computational model of general intelligence with the long-term goal to understand and replicate the *architecture of the mind*; i.e., the fixed structure underlying intelligent behavior in both natural and artificial systems. This ambitious goal strives for high-fidelity control of virtual humans (VHs) that behave as closely as possible to humans, primarily by developing and integrating not only crucial cognitive capabilities but also key non-cognitive capabilities, such as perception, motor control, and affect. In pursuing this goal, Sigma brings together ideas from over three decades of independent research in traditional symbolic cognitive architectures and probabilistic graphical models.

Most of the work to date on Sigma has individually explored particular capabilities for learning, memory and knowledge, decision making and problem solving, perception and imagery, speech, Theory of Mind, and emotions. These individual capabilities are important in building human-like intelligence but getting them to work together is particularly challenging. Sigma's non-modular, *hybrid* (discrete + continuous) *mixed* (symbolic + probabilistic) character supports attempting a deep integration across cognitive and non-cognitive capabilities, straddling the traditional boundary between symbolic cognitive processing and numeric sub-cognitive processing. This short paper very briefly introduces Sigma and then provides two examples of VHs that utilize and integrate quite different sets of capabilities.

2 THE SIGMA COGNITIVE ARCHITECTURE

The Sigma cognitive architecture is built on *factor graphs* – undirected graphical models with variable and factor nodes, plus functions that are stored in the factor nodes. Graphical models provide a general computational technique for efficient computation with complex multivariate functions – implemented via hybrid mixed *piecewise-linear functions* in Sigma – by leveraging forms of independence to: decompose them into products of simpler functions; map these products onto graphs; and solve the graphs via message passing or sampling methods. Graphical models are particularly attractive as a basis for broadly functional, yet simple and theoretically elegant, cognitive architectures because they provide a single general representation and inference algorithm for processing symbols, probabilities and signals.

The core processing in Sigma is driven by a *cognitive cycle* that comprises input, graph solution, decisions, learning, and output. Graph solution yields inference via the *summary product algorithm*. Perception and action occur predominantly within graph solution, rather than within external modules. Decisions select the next operator to execute based on distributions over them, and learning modifies long-term functions in the graph. A single cognitive cycle yields *reactive processing*; a sequence of them yields *deliberative processing*; and *reflective processing* occurs when decisions can't be made.

3 EXAMPLE SIGMA VIRTUAL HUMANS

Two disparate proof-of-concept Sigma VH models have been developed in Sigma, one focused on language and conversation and the other on robot-like perception and action in a virtual environment. The first one replicated the mind of a deployed but cognitively rather simple agent that provided training for junior Naval officers in interpersonal communication skills (Campbell et al. 2011). The control structure of this agent is a discourse model based on a directed acyclic network of states and utterances, where an utterance classifier determined what was said, and therefore which response to make at each point. In Sigma these two functionalities were mapped, respectively, onto: (1) deliberative movement in a discourse problem space composed of operators for speaking and listening, and (2) a reactive bag-of-words naïve Bayes utterance classifier.

The second proof-of-concept involved a pair of adaptive, interactive agents animated in a virtual environment for a typical retail store physical security plot (Ustun and Rosenbloom 2015). The intruder agent's goal is to locate a desired item in the store, grab it, and then leave the store. The security agent's goal is to detain the intruder before s/he leaves the store. The agents are adaptive not only in terms of dynamically deciding what to do, but also in terms of embodying two distinct forms of relevant learning: (1) the automated acquisition of maps of the environment from experience with it, in the context of Simultaneous Localization and Mapping (SLAM); and (2) reinforcement learning (RL), to improve decision making based on experience with the outcomes of earlier decisions The VHs are interactive with both their (virtual) physical environment – through high-level perception and action – and other participants, although the latter is still quite limited.

4 CONCLUSION

The elegant combination of the capabilities of the traditional symbolic cognitive architectures and probabilistic graphical models not only helps building high-fidelity computational behavior models but also potentially yields *plug compatibility* between humans and artificial systems. Such compatibility potentially contributes to creating very flexible agent simulations in virtual environments.

REFERENCES

Campbell J. et al. 2011. "Developing INOTS to Support Interpersonal Skills Practice". In *Proceedings of the Thirty-second Annual IEEE Aerospace Conference (IEEEAC),* 1-14. Washington, DC:IEEE

Rosenbloom P. S. 2013. "The Sigma Cognitive Architecture and System." *AISB Quarterly* 136:4-13

Ustun V. and P.S. Rosenbloom. 2015. "Towards Adaptive, Interactive Virtual Humans in Sigma." In *Proceedings of the Fifteenth International Conference on Intelligent Virtual Agents*, edited by W.P. Brinkman, J. Brookens, and D. Heylen, 98-109. Heidelberg:Springer.