Cognitive Simulation in Virtual Patients

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Abstract

We present an overview of the Virtual Patient project at the University of Maryland, which is developing a cognitive model of humans experiencing various states of health and disease to be used in interactive simulations for physician training.

Overview

This Virtual Patient[1] project is devoted to creating a cognitive, knowledge-based model of a virtual patient (VP) that undergoes both normal and pathological physiological processes. VPs are ontological objects, specifically, subclasses of VIRTUAL-HUMAN that have various diseases and disorders. Like all VIRTUAL-HUMANs, their large inventory of property-value pairs changes in response to ontological events, including internal and external stimuli. All VPs inherit the lion's share of physiology from VIRTUAL-HUMAN, meaning that GERD-PATIENT and HEART-DISEASE-PATIENT (as ontological concepts, not instances) differ only with respect to the disease-specific changes that affect certain of their property values over time.

A cornerstone of a realistic learning environment is creating a wide variety of instances of VPs with a given disease. The basic model of a disease typically involves many tracks (i.e., paths of disease progression), and property values of VPs may fluctuate within specified ranges, adding to the variety of possible VP instances. Authoring an instance of a VP (typically done by a physician-teacher or disease specialist) involves establishing specific values of the VP's basic physiological properties, relevant lifestyle factors, the rate and direction of progression of the disease, the specific symptom profile at given times, and so on. The VP authoring process is, thus, similar to a multiple-choice questionnaire that takes little time to complete. In fact, large inventories of instances of VPs with a particular disease can be generated automatically on the basis of a relatively small inventory of basic ontological "models."

Importantly, once a VP instance is under the care of a medical student, whatever treatment the student administers causes a change in the state of the VP instance. VP instances are, thus, not canned scenarios, they are flexible software agents; and if a student causes a deterioration in a VP instance's state in some unexpected way, he or she needs to recover from that error by treating the patient in this new condition. What makes modeling VPs feasible – since comprehensively modeling human physiology in the abstract would be a boundless and amorphous endeavor – is our goal-oriented approach: we are not trying to recreate the human organism in all its details, we are trying to recreate it only to the extent necessary to support its autonomous functioning in useful training situations.

[1] Patent pending.

The OntoSem Environment

The main knowledge substrate for the VP project is the OntoSem (Ontological Semantics) ontology (Nirenburg and Raskin 2004). This ontology was initially developed to support knowledge-based language processing, but the rich inventory of features (properties) it uses – including descriptions of complex events (scripts) – has facilitated a smooth transition to broader modeling and simulation applications. In augmenting our general-purpose ontology with knowledge from the the medical domain, we are including knowledge from existing resources, notably, the Foundational Model of Anatomy (FMA), whose structure and terminology is becoming the standard in the field.

Using the same environment for medical modeling as for natural language processing has two significant advantages. First, many of the architectural and expressive means apply equally well to both domains: the language-independent, property-rich ontology; the use of scripts; the division of labor between ontology, fact repository (a repository of concept instances) and lexicon; and the management of instances within the fact repository. Second, to be really useful, interactive systems must include natural language communication, and high-quality level natural language processing (NLP) is what OntoSem developers have been pursuing for over a decade. Using the same representation language and "world view" to create a simulation and to interact with it promises accuracy and efficiency throughout the system.

Comparisons with Other Systems

A common type of medical simulation is realized in technical task trainers, which concentrate on a technical task and include only the minimal amount of cognitive simulation necessary for the user to understand a specific technical step, like how to insert a needle. A second type is non-biomechanistic manikin trainers (e.g., "SimBaby", Laerdal, Inc., and "The Human Patient Simulator", Medical Education Technologies, Inc.), which focus on a narrow scope of acute physiological processes. A third type is scenarios based on clinical decision-making algorithms at the case-level (e.g., MedCases, Inc.); in these, user options are restricted and responses are highly pre-scripted to provide predetermined patient outcomes. A more sophisticated type of medical simulation is the Sim-Patient developed by RTI, where acute traumatic patient scenarios are available to a user; however, few details about this system are available as the data structures and content are proprietary.

A well-known project is the Virtual Soldier (http://www.virtualsoldier.net/), which seeks to produce a simulation of the human thorax that is functional for penetrating trauma. The Virtual Soldier project differs from the VP project in its focus on anatomical trauma and emergency interventions, as opposed to the diagnosis and long-term care of patients experiencing disease.

Another notable simulation environment is CIRCSIM (Illinois Institute of Technology), which teaches about the baroreceptor reflex, the body's rapid response system for dealing with changes in blood pressure. The history of this project shows a movement away from research on the mathematical model toward research on pedagogical aspects of online tutoring: "The most effective teaching was being generated from the stored correct predictions for each procedure, not from the quantitative outputs generated by the model" (Michael and Rovick 1996). We plan to incorporate some pedagogically-oriented results from CIRCSIM into the further development of the VP environment, but will take a different approach to the language processing aspect (which that team has deemed integral to teaching systems; Evens et al. 2001), since we already have a rich language processing system in place.

In the past 4 years, the International Meeting on Medical Simulation has produced over 200 papers, none of which describe the type of cognitive simulation being pursued in the VP project. A similar absence of cognitive simulation efforts is reflected in the past four years of the journal *Artificial Intelligence in Medicine.*

In the AI tradition, arguably the most well-known script remains Schank and Abelson's (1977) restaurant script. Most previous efforts to implement scripts were in a narrow domain, and typically suffered when some unforeseen script move was encountered.[2] In fact, the difficulties in implementing scripts has led to their relatively marginal status in AI. We believe we can largely circumvent the problem of unexpected input by using an ontological substrate that includes default effects of all events that can affect a virtual patient – be they medical interventions or events of daily life, like smoking. The default effects will be used in all cases when specific, non-default effects of events have not been encoded by the author of the given VP instance. Our team of physicians and knowledge engineers is working to arm the system with sufficient domain knowledge to permit any VP to respond in a reasonable way to any available intervention at any time.

[2] Cullingford et al.'s SAM system (Cullingford 1981) is among the most well-known. It read stories that corresponded to scripts and output multi-lingual summaries and answered questions about the texts.

The Present and Future of the VP Project

At present, the ontological substrate of the VP concentrates on the esophagus. It covers the anatomy of the esophagus, the physiology of swallowing (including esophageal peristalsis), and a selection of pathologies (such diseases of the esophagus as achalasia, GERD and esophageal tumors). Whenever medical knowledge allows, diseases and diagnostic and treatment procedures are described through their mechanisms and in terms of accessing or modifying the ontological properties of various anatomical elements. In other cases, bridging is used, which can be described as using temporal chains as the substrate for scripts instead of causal chains, pending the discovery of the latter.

In addition to the ontological work, the project is also developing a simulation environment for the VP, an interaction environment between the VP and the operator, and a library of VP instances with specific diseases to support simulation and training. Results of that development and experimentation will be reported separately. We plan to extend the coverage of the VP to the entire gastrointestinal tract and then beyond it to other systems in the organism. We are also working on a mentoring component for the system and on natural language interaction capabilities for the VP.

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