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A Bond Graph Approach for Wellness Management based on the Client-Therapist Model

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Abstract

There is an urgent need to represent and reason about human behavior to enable a large number of emerging applications. Our interest is to understand how to encourage behaviors that result in promoting wellness management for individuals. In this short paper, we present a bond graph model for modeling human behavior. We demonstrate that these versatile models are useful to represent energy transfer across multiple domains. The approach offers us a systematic method to analyze the models and derive dynamic equations to represent the behaviors.

Keywords: Bond Graph, Human Behavior.

Introduction

Exploring human behavior is a critical problem in several domains. Several theories have been developed by psychologists and social scientists over the last few decades to explain human behavior at the scale of a population. Notable among these theories are *The Theory of Planned Behavior* (Ajzen, 1991), *Social Cognitive Theory* (Bandura, 1986), *Self-Determination Theory* (Ryan & Deci, 2000) and the *Transtheoretical Model for Stages of Change* (Prochaska, 2008). There are several other theories that are specialized to different domains such as the *Health Behavior Model* (Cohen, Scribner, & Farley, 2000). While such models can explain aggregate behaviors at the scale of a population, these models are not actionable at the level of individuals.

Another efforts have resulted in fluid analogy models for human behavior that aim to operationalize the above theories in a control systems framework (Navarro-Barrientos, Rivera, & Collins, 2010; C. A. Martin et al., 2014; C. Martin, Deshpande, Hekler, & Rivera, 2015; Navarro-Barrientos, Rivera, & Collins, 2011; Dong et al., 2012). These models provide an intuitive and easy approach to separate the state variables and system parameters that drive the models. Such models have been effectively used in socially relevant programs for smoking cessation and health management (Lai, Cahill, Qin, & Tang, 2010). Despite their simplicity and effectiveness, there can be ambiguities in these models that limit their full exploitation in automated tools. For this reason, we are examining the utility of domain independent models that can be used to represent and reason about human behaviors.

Bond Graphs

Bond graphs were introduced in (Paynter, 1961) as a domain independent graphical representation to reason about systems involving mechanical, chemical and electrical components in a unified framework. In this approach, a system is viewed as comprising several components; each component has ports through which energy can be exchanged with other components. Every component is identified as being one that generates energy in the system or one that consumes energy. Components are connected through bonds between corresponding ports. Every bond has a half arrow that denotes which element in the bidirectional relationship generates energy and which element consumes energy. Energy transfer between components is viewed as a bidirectional exchange of *effort* and *flow* (Gawthrop, 1991; Broenink, 1999; Breedveld, 2008).

Client-Therapist Interaction Model

We view human behavior as one that involves complex energy transfers across multiple domains. In the context of our ongoing investigation into modeling human behavior for wellness management (Chippa, Whalen, Douglas, & Sastry, 2014; Mahamadi & Sastry, 2016b, 2016a), our interest is to develop actionable models for human behavior that can guide the decision-support. In this section, we present a model for the interaction between a Client and a Therapist that is inspired by the work in (Liebovitch, Peluso, Norman, Su, & J.M., 2011).

Figure 1 illustrates a fluid analogy model that represents the interaction between a client and a therapist. In this model, there are two tanks — one representing the client (right) and the other representing the therapist (left). Following (Liebovitch et al., 2011), the level of fluid in each of the tanks represent the *valence*, or *affect*, of the client (I_2) and the therapist (I_1), respectively. The valence of the therapist is a function of his or her training and is represented by the valve N_1. We assume that a better trained therapist, i.e., more flow in N_1, would have higher valence. The valence of the client is affected by the environmental conditions as represented by N_2. Through the interaction, the valence of the client and the therapist is changed because of the flows through the valves that are labeled Therapy (R_1) and Feedback (R_2).

We follow the procedure in our earlier work (Mahamadi & Sastry, 2016b) to construct the bond graph model, that is shown in Figure 2.

We derive the dynamic equations of the system :

$$\frac{d}{dt}(I_1) = N_1 \times S_1 - R_1 \times I_1 + R_2 \times I_2, \tag{1}$$

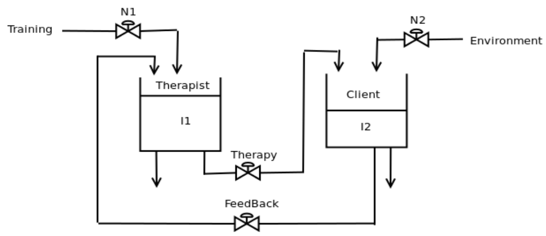

Figure 1: Fluid Analogy Model for the interaction between a Therapist and a Client.

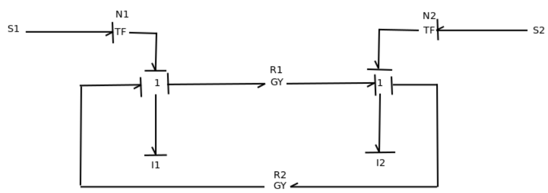

Figure 2: Bond Graph representation for the Therapist-Client model

and

$$\frac{d}{dt}(I_2) = N_2 \times S_2 - R_2 \times I_2 + R_1 \times I_1. \qquad (2)$$

Maintaining Client Valence

The model in this paper is developed form the model in our previous work (Mahamadi & Sastry, 2016a) by adding a feedback from the client to the therapist. Now to maintain the Client valence, a well trained therapist should be able to control the flow of therapy to the client and the flow of feedback from the client. To model this interaction, we designed a controller to regulate the valves R_1 and R_2.

There are many options of controllers to be chosen for this control problem. However, we chose the proportional controller for the simplicity and the advantage of faster tuning.

After integrating the controller to the system, the transfer function of the system is demonstrated in Equation 3.

$$H(s) = \begin{bmatrix} \frac{20.02s}{25s^2+10s+20} \\ \frac{0.1s+20.02}{25s^2+10s+20} \end{bmatrix} \qquad (3)$$

In order to test the design of the client valence regulator described above, we chose reasonable values for the training and the environment variables, then the response of the system to a unit set point is depicted in Figure 3.

We can conclude form Figure 3 a well trained therapist, has the ability to regulate the valence of the client by manipulating the rates of both the therapy and the feedback.

Examining the Client-Therapist Relationship

The model shown in Equation 1 and Equation 2 was also used to analyze the stability of the system. For example, we identified the critical points and plotted the system trajectories

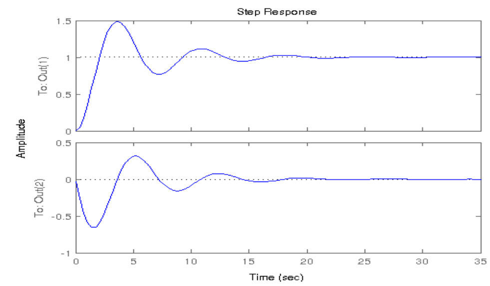

Figure 3: The step response of the client valence under the proportional controller

starting from different initial conditions, i.e., different initial states of both the client and the therapist. For example, if the therapist has initially positive valence, how is that going to affect the initially negative, neutral or positive client. Using the parameters from (Liebovitch et al., 2011) we obtained the phase portraits shown in Figure 4.

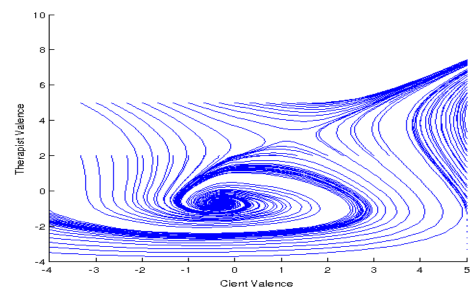

Figure 4: The phase portraits for the psychotherapy relation

Notice from Figure 4 that there are two critical points — the first is the stable point, *Attractor*, which is the point reached as a conclusion of a successful therapy program. The other point is the saddle point that represents a failed therapy. The figure shows that, when the therapist has a positive valence, the therapy sessions can lead a client with a negative or positive valence to the attractor. On the other hand a when the therapist has a negative valence, the session will conclude in the saddle point. These two stable points are similar to the ones reported in (Liebovitch et al., 2011).

Conclusions

The bond graph approach presented here to model human behavior is encouraging. Starting from a fluid analogy model for the interaction between a client and a therapist, we demonstrated that the bond graph approach yields a dynamic systems model that is similar to the one reported in the literature. As with any other model, one can analyze the behavior of the system and design controllers to achieve specific objectives.

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