Canonical Behavior Patterns

Walter C. Mankowski (walt@cs.drexel.edu)
Department of Computer Science, Drexel University, 3141 Chestnut Street
Philadelphia, PA 19104 USA

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Introduction

In the development of cognitive models, data are often collected in the form of behavioral protocols — sequences of actions performed by the user during the execution of a task. Behavioral protocols have been employed to study a wide variety of actions, including mouse clicks and keystrokes (e.g., Card, Newell, & Moran, 1983), eye movements (e.g., Byrne et al., 1999), and driving (e.g., Salvucci, 2006). While protocols are a rich source of data, they have one significant limitation — often so much data are recorded that it is impractical to analyze by hand. Researchers have sometimes tried to get around this issue by performing some form of aggregation on their data. While this can help in seeing overall behavior, it masks potentially interesting patterns in individual users and subsets of users. Alternatively, researchers have sometimes laboriously studied individual protocols by hand to identify interesting behaviors. While some work has been done on automated protocol analysis, such techniques typically focus on matching observed behaviors to the predictions of some type of user process model.

The goal of my dissertation is to develop a new, automated method of protocol analysis to find canonical behaviors — a small subset of behavioral protocols that is most representative of the full data set, providing a reasonable high-level view of the data with as few elements as possible. The method I am proposing takes advantage of recent algorithmic developments in computational vision, and the method has already been successfully employed in diverse fields such as image analysis and software engineering. By adapting this algorithm to the analysis of behavioral protocols, I hope to provide a new tool for cognitive modelers working with large protocol data sets that are infeasible to study using current methods. My method can also be used as an important complement to existing protocol analysis techniques, allowing researchers to build their models based on a few highly representative samples.

Finding Canonical Behaviors

My technique for computing canonical behaviors derives from work in the area of computational vision, where techniques have been developed to identify canonical members of a class of visual patterns (Denton et al., 2008). The goal is to reduce a large set of patterns (in this context, behavioral protocols) to a smaller (often much smaller) subset of patterns that is most representative of the entire data set. Specifically, I define a canonical set of behaviors as a subset of protocols such that behaviors within the canonical set are minimally similar to each other, and behaviors in the canonical set are maximally similar to behaviors not in the set. The problem of finding such a set of patterns is known to be intractable (Garey & Johnson, 1979), and thus an approximation algorithm is utilized. Please refer to Denton et al. (2008) for a full description of the algorithm.

The key aspects of the method I propose are the specification of a similarity measure between behaviors and the determination of canonical behaviors given this similarity measure. The similarity measure is dependent upon the nature of the particular protocol. For web browsing, it might be the edit distance between two sequences of URLs (i.e., the number of insertions, deletions, or substitutions needed to transform one sequence to the other). For eye-tracking data, an appropriate measure might compare the x, y coordinates of the fixations, the number of fixated items, or the exact sequence of items fixated upon. Similarly, the determination of canonical behaviors is also dependent upon the context. For example, canonical behaviors for going to the next page in a word processor might include "press the page down key on the keyboard" and "click the scroll bar".

The principal benefits of my canonical set technique are (1) it is an unsupervised algorithm: no training data set is needed; and (2) no a priori knowledge of the number of sets is needed: both the sets themselves and the most representative elements of the sets arise naturally from the algorithm.

Preliminary Work

To test the application of the canonical set algorithm to human behavior protocols, I have done initial experiments in two problem domains. In the domain of web browsing, I have identified canonical web browsing patterns. I have also found canonical lane changes in a driving experiment. I briefly summarize each of these experiments below.

Web Browsing

As an initial experiment to validate this automated method of finding canonical sets, my colleagues and I collected data from users performing typical web browsing tasks. Each subject was asked to answer 32 questions that could be found on a college web site. The questions covered a range of realistic topics such as finding information about professors, athletic programs, and academic departments. (Please see Mankowski et al. (2009) for a full description of this experiment.)

Figure 1 shows the various behaviors for a single question ("What is the phone number of ⟨*department*⟩ professor ⟨*name*⟩") for (a) an expert human coder with significant experience in analyzing behaviors and cognitive modeling, and

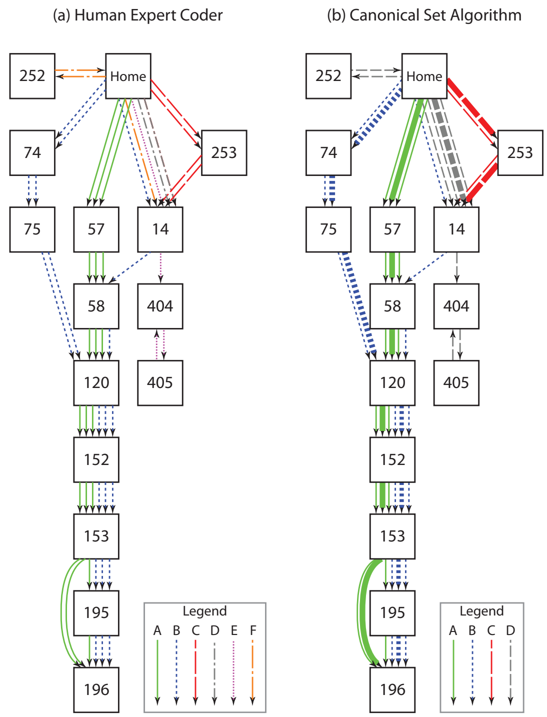

Figure 1: Sample analysis graphs.

(b) the canonical behavior algorithm. In both graphs, each node represents a web page (labeled with a unique integer) and each edge represents a clicked link from one page to another taken by one of our subjects. The expert coder found 6 sets of behaviors, labeled A-F: A and B are different ways of finding the professor's home page via their department's website; C and D are different ways of accessing a directory search page (node 14); and E and F are slight variations on C and D. The canonical set algorithm found 4 canonical behaviors in the same graph; these are shown as bold in graph b, and the other behaviors are labeled in terms of their most similar canonical behavior. The behaviors it found correspond exactly with sets A-D found by the expert coder. Instead of identifying E and F as separate behaviors, the algorithm decided to group these behaviors with their nearest canonical behavior (D).

Grouping behavior patterns is clearly a subjective process, since expert coders could each have their own notions about whether two behaviors are similar enough to be grouped together. For example, our second coder put behaviors A and B into the same group. To model this, the algorithm can be tuned to be more tolerant of differences in a grouping, or to allow more significant variations to become canonical elements themselves.

Driving

I have also applied the canonical set algorithm to the domain of driving, specifically the problem of identifying canonical lane changes (Mankowski, Shokoufandeh, & Salvucci, in press). Our data came from a previous experiment examining driving behavior (Salvucci, 2006), where subjects navigated a simulated straight, flat highway and were required to pass a number of automated vehicles. For each lane change we constructed a histogram of the car's position and lateral velocity, and computed the similarity between each histogram.

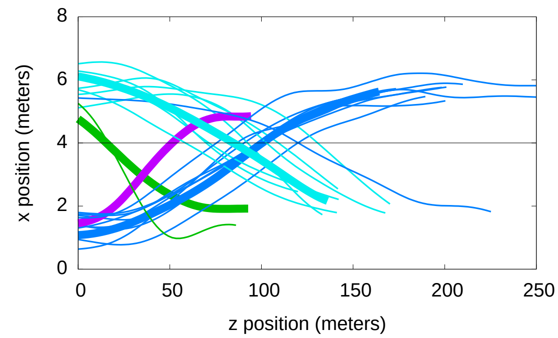

Figure 2: Lane changes for a representative subject.

Figure 2 shows the lane changes our algorithm found for a typical subject. Results were similar for the other subjects with these settings. The canonical lane changes are shown in bold, and the other lane changes are drawn in the same color as their most similar canonical lane change.

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