Data Collection and Analysis of Interaction Trails

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Abstract

This literature review is intended for use in papers related to the use of MAPSAT for analyzing data collected during interactions with digital games and simulations. It briefly describes the history of the development of MAPSAT, defines Analysis of Patterns in Time (APT), and describes several studies that used MAPSAT methodologies. This is followed by a review of the literature related to the collection and analysis of data generated by users' interactions with and in hypermediated environments. It concludes by proposing the term "interaction trail" to stand for the sequence of actions performed by a subject in a hypermediated environment.

DATA COLLECTION AND ANALYSIS OF INTERACTION TRAILS

Map & Analyze Patterns & Structure Across Time (MAPSAT) is a set of relation mapping and analysis methods developed by Dr. Theodore Frick and Kenneth Thompson. Frick's MAPSAT research group at Indiana University is developing software to conduct MAPSAT analyses of systems, including a database designed to facilitate the analysis of temporal and structural patterns of systems. The MAPSAT method for analyzing temporal patterns—known as Analysis of Patterns in Time (APT)—is the focus of this study. Therefore we will begin with a brief overview of MAPSAT, focusing on APT. We will then discuss the relevant literature on data tracking and analysis as a way of understanding how APT is similar to and different from other methods of analyzing and representing temporal patterns of data.

MAPSAT

Frick (1983) proposed a method for analyzing temporal patterns in his doctoral dissertation. Originally conceived "in the mid-1970s as a methodology of classroom observational research to investigate patterns of transactions among students, teachers, curricula, and educational settings," (Frick, 1990, p. 181) nonmetric temporal path analysis (NTPA) was based on concepts from set, probability, information, and general systems theories, in particular as synthesized by Maccia and Maccia as the SIGGS (set, information, graph, and general systems) theory model (Frick & Thompson, 2008). Frick concluded that this approach was superior to the linear models approach (LMA) when studying stochastic educational relations. In 1990 Frick changed the name of the methodology to Analysis of Patterns in Time (APT) to avoid confusion with statistical path analysis. In the late-1990s, Frick began collaborating with Thompson, who had been working to extend SIGGS as Axiomatic Theories of Intentional Systems (ATIS; Thompson, 2005; 2008a; 2008b), a "logico-mathematical theory model for analyzing and predicting behavior of systems that are goal-directed or intentional" (Frick & Thompson, 2008, p. 71). This led to a method of measuring system structure which, when combined with Frick's method of measuring system dynamics (temporal patterns), became Analysis of Patterns in Time and Configuration (APT&C) (Frick, Myers, Thompson, & York, 2008a; 2008b). Because both methods may be conceived as the mapping of patterns, the combined methods became known as MAPSAT: Map and Analyze Patterns and Structures Across Time. Therefore MAPSAT consists of two methods: Analysis of Patterns in Time (APT) and Analysis of Patterns in Configuration (APC). It is also possible to combine these methods to examine changes in the structural properties of a system over time.

APT is an empirical approach to observing and coding phenomena as mutually exclusive and exhaustive categories within classifications. In effect, researchers create measures of temporal patterns by counting the occurrences of these categories (Frick, 1990). Once these data have been collected, researchers specify APT queries to calculate the probability of joint and/or sequential patterns of interest. This is different than the linear models approach of measuring variables separately and using statistics to analyze their relations (Frick et al., 2008a). For example, an early study (Frick & Rieth, 1981, as cited in Frick, 1990) applied APT in the classroom observation of academic learning time of handicapped students. Of the numerous classifications used in the study, the analysis of two time measures—the amount of available instruction and the amount of student engagement—revealed a high proportion of student engagement when direct instruction occurred (0.967) as opposed to a much lower proportion when nondirect instruction occurred (0.573). Frick (1990) noted that "students were 13 times more likely to be off task during nondirect instruction than during direct instruction," whereas "the linear correlation between direct instruction and student engagement was about 0.57 …

[which] does not reveal the clear pattern indicated by the APT time measure functions for joint events” (p. 184).

In recent years, several studies with diverse research questions have utilized APT maps as a way of understanding temporal patterns of data. An (2003) applied APT in usability tests of software to analyze the frequency of various types of mode errors and their relationship to categories of design incongruity. Frick, Chadha, Watson, Wang, and Green (in press) analyzed student evaluations of courses using APT. Among their findings was that “students were three to five times more likely to agree or strongly agree that they learned a lot and were satisfied with courses when they also agreed that [Merrill’s] First Principle of Instruction were used *and* students were frequently engaged successfully.” Koh (2008) used APT to study the relationship between scaffolded instruction and computer self-efficacy among pre-service teachers. Howard and Barrett (2009) used APT to determine the frequency of desirable discourse patterns in the asynchronous computer-mediated communications of pre-service teachers who were critiquing each other’s work. Barrett and Howard (2009) used APT to investigate the relationship between the quality of a student’s product (a website created by the student) and the types of comments that the product receives as well as the types of comments that the student makes about other students’ products.

Data Collection and Analysis

In the past twenty years, interest has grown regarding the need to collect data on users’ interactions with hypermediated environments. A user’s particular sequence of choices from among a prescribed set of alternatives is referred to metaphorically as an audit trail, an information trail, a solution path, a navigation path, and in an educational context, an instructional path. Schwier and Misanchuk (1990) attributed to M. W. Petruk the term “audit trail" as a description of "the instructional path taken by each learner" (p. 1). Williams and Dodge (1993) propagated the use of the term in their description of methods for collecting and analyzing data from computer-based instruction, as did Judd and Kennedy (2004). More recently, Loh proposed "information trail" as "a series of agent-detectable *markings* left by another *moving agent* within an information ecology" (2007, p. 329, emphasis in the original). The term "navigation path" is generally used in the context of Web analytics to describe the sequence of links followed by a user, which is sometimes called a "clickstream."

In a series of papers, Schwier and Misanchuk (1990; Misanchuk & Schwier, 1991; 1992) discussed the reasons for collecting audit trail data, methods for analyzing those data, and problems encountered during collection and analysis. They noted the increasing interest in naturalistic observation (cf. Lincoln & Guba, 1985) and the concomitant feature of the audit trail as an unobtrusive method for obtaining data. They proposed that descriptive data captured at decision points could be used for a variety of purposes. During formative evaluation of specific instructional products, such data may indicate where and how learners make errors. Audit trail data may also be use to derive generalizable rules about the construction of paths through interactive or hypermediated instruction, especially when combined with other data "to explain the influences of social variables, individual differences, and cognitive style on the paths taken through the instruction" (Schwier & Misanchuk, 1990, p. 3). McEneaney (2001) extended this idea by suggesting that the association of paths and outcomes may be used to design better paths for different user needs and objectives. Finally, audit trail data may be used for conducting basic research on the design of computer-mediated environments.

Schwier and Misanchuk (1990) described both descriptive and inferential approaches to analyzing audit trail data. For the former, the simplest method proposed was a raw (unsummarized) data matrix, which would be relatively easy to construct yet difficult to interpret. A summarized version of this matrix would show nodal frequencies and proportions, but it would be difficult to interpret relationships across nodes. Judd and Kennedy (2004) also recognized the limitation of simple counts for discovering and interpreting meaningful patterns in the navigation of complex environments. Williams and Dodge (1993) recommended selecting a small sample of raw data due to limited resources and utilizing qualitative methods to seek phenomena of interest. Given subsequent advances in computing power and software capabilities, this advice may no longer be relevant.

Methods proposed by Schwier and Misanchuk (1990) for visually representing audit trail data include a “petit-point pattern” inspired by Tukey’s stem-and-leaf representation of data, and an audit trail tree that uses line thickness to represent path frequency. They discussed using inferential approaches for comparisons between groups and, like Frick, realized the potential for confusion with path analysis in multiple regression. They noted that a normal distribution cannot be assumed and proposed collecting data for a large group of users and regarding that as the “usual distribution” (p. 7) for comparison with data for an individual. This approach might lend itself to the use of a chi-square one-sample goodness of fit test to determine “statistical significance of observed deviations from ‘usuality’” (p. 7). Williams and Dodge (1993) proposed time series and non-linear regression as viable statistical techniques for analyzing trend patterns in data gathered over time. McEneaney (2001) proposed formalizing the node-and-link model of hypertext as both an adjacency matrix for computational analysis and a di-graph for visual analysis.

There are many potential problems related to the collection and analysis of audit trail data. In particular, many interactive or hypermediated environments are multilinear, which can make it difficult to define the differences between individual audit trails and to combine and compare groups of audit trails (Schwier & Misanchuk, 1990; Misanchuk & Schwier, 1991). Furthermore, audit trails may be of different lengths and may loop back to previously visited nodes. Depending on how navigation decisions are coded, data may lack context, which Schwier and Misanchuk call “the dependency problem” (1990, p. 3). In brief, given a sequence of numbers representing choices made at each decision point, the meaning of a number depends on the previous numbers (decisions). That is, if two learners each have “1” in the second position, that “1” means something different if one learner chose “2” in the first position and the other chose “3” (because they followed different paths and presumably where given different choices at the second position).

Williams and Dodge (1993) addressed the dependency problem by capturing contextual data along with user actions. They described the programming constructs used to capture categorical data of user actions that included the action taken by the user (e.g. mouse click, menu selection, keyboard response), the location of a mouse event (X/Y coordinates for both click and release when relevant), and the time at which the interaction occurred. At the time, they were working with HyperCard, a programming application for the Macintosh computer. Objects created in HyperCard could contain scripts (handlers) that responded to events. They created four major handlers to track learner actions (trails). These handlers initiated the trail variable in memory, added events to the trail, saved the trail in a text file on disk, and output the trail. They identified several possible types of measurement errors that may be caused by general disruptions, accidents and carelessness, offline behaviors, confusion leading to unintended mistakes, disinterest, perceived intrusiveness, and individual differences in learners.

More recently, Judd and Kennedy (2004) adapted exploratory sequential data analysis (ESDA) techniques for use with audit trail data from multimedia or hypermedia environments. They described four techniques for sequence analysis, one of which is related to APT in that it deals with state transitions. This technique is “based on Guzdial’s (1993) adaptation of Markov chain analysis” (p. 479) and results in diagrams with probabilities of sequences. Judd and Kennedy concluded that EDSA techniques are useful in understanding users’ interactions with multimedia applications and may prove fruitful in the analysis of computer-mediated discussions (cf. the use of APT in Barrett & Howard, 2009 and Howard & Barrett, 2009).

While “audit trail” may be sufficiently descriptive of the researcher’s intent in collecting these data, it carries financial connotations that may confuse or mislead the reader. While “information trail” is in some ways preferable to “audit trail,” the use of the word “information” is too imprecise for our purposes. Instead, at the risk of muddying the waters with yet another term, we propose “interaction trail” to stand for the sequence of actions performed by a subject. These actions may be programmatically coded or manually coded by an observer.

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