Predictive Analysis for Urban Planning based on Cloud Computing Adoption

Miki Shun[1], Ladson Newiduom[2] Mike Embouma[2], Ibrina Browndi[2]

[1] Department of Computer Science, Rivers State University, Port Harcourt, Nigeria
[2] Department of Urban and Regional Planning, Rivers State University, Port Harcourt, Nigeria

ABSTRACT

This paper presents a new approach to predictive analysis for social processes. Part I identifies a class of social processes, called positive externality processes, which are both important and difficult to predict, and introduces a multi-scale, stochastic hybrid system modeling framework for these systems. In Part II of the paper we develop a systems theory based, computationally tractable approach to predictive analysis for these systems. Among other capabilities, this analytic methodology enables assessment of process predictability, identification of measurable which have predictive power, discovery of reliable early indicators for events of interest, and robust, scalable prediction. The potential of the proposed approach is illustrated through case studies involving online markets, social movements, and protest behaviour.

KEYWORDS: Predictive Analysis, Urban Planning, Innovation Adoption

1.0 INTRODUCTION

AS discussed in Part I of this two-part paper, predicting the outcome of social processes is both important and very challenging. Many social phenomena of interest in applications are positive externality processes (PEP), in which individuals are motivated to behave as others do. Re- search in the social and behavioural sciences provides compelling evidence that for such processes it is often not possible to obtain useful predictions using standard methods, which focus almost exclusively on the intrinsic characteristics of the process and its possible outcomes [1-10]. We propose that accurate prediction requires careful consideration of the interplay between the intrinsic of a process and the social dynamics which are its realization. We there- fore adopt an inherently dynamical approach to predictive analysis: given a social process, a set of measurable, and the behaviour of interest, we invent prediction problems as questions about the reachability properties of the system. As an illustrative example, consider the task of assessing the predictability of market share in a popular culture market, say for music, in which "buzz" about products spreads through various social networks. If, in a market containing two products with indistinguishable appeal, it is possible for one product to achieve a dominant market share, the market may be regarded to be unpredictable [11-24]. Conversely, in a predictable market the market shares of indistinguishable products evolve similarly and market shares of superior products are typically larger than those of inferior ones. In our formulation, market share dominance by product A is associated with a region of market share state space, and deciding whether A can achieve such dominance while possessing an appeal that is indistinguishable from product B is posed as a question about state space reachability [1-18]. More generally, in order to formulate prediction questions in terms of reachability, the behaviour about which predictions are to be made is used to define system state space subsets of interest (SSI). Candidate measurable allow identification of indistinguishable starting sets (ISS), that is, sets of initial states and system parameters which cannot be re- solved with the available data. This setup permits the four predictive analysis tasks of interest to us – predictability assessment, identification of useful measurable, warning analysis, and prediction – to be performed in a systematic manner. Predictability assessment involves determining which SSI can be reached from ISS and deciding if these reachability properties are compatible with the prediction goals. For example, if moving between state-parameter pairs within an ISS leads to unacceptably large variations in the probability of reaching the SSI, then the process is deemed unpredictable. This analysis leads naturally to a way of identifying those measurable with the most predictive power: these are the ISS coordinates for which predictability is most sensitive. If a system's reachability properties are incompatible with the prediction goals – if, say, "hit" and "flop" in a cultural market are both reachable from a single ISS – then the given prediction question should be refined in some way. Possible refinements include relaxing the level of detail to be predicted or introducing additional

measurable [2-11]. If and when a predictable situation is obtained, the problems of discovering reliable early indicators for events of interest and forming robust predictions can be addressed. These problems are also readily studied within a reachability framework. Warning analysis involves identifying indicator (state) sets with the property that observing a trajectory entering an indicator set implies that the event of interest is likely to occur. Prediction entails estimating the probability that the process will evolve to an SSI and quantifying the uncertainty associated with this estimate [6-18]. The remainder of this paper transforms these intuitive notions into a rigorous, tractable methodology for predictive analysis, with a focus on predictability and early warning, and illustrates the utility of the approach through several real world case studies [12-22]. This section describes the proposed approach to predictive analysis for social processes. The presentation is structured to realize three objectives: 1.) provide reachability- based definitions for basic predictive analysis tasks; 2.) develop a rigorous, tractable methodology for reachability analysis; and 3.) derive efficient (reachability-based) algorithms for performing predictive analysis [17-27].

2.0 LITERATURE REVIEW

We conducted This section describes the proposed approach to predictive analysis for social processes. The presentation is structured to realize three objectives: 1.) provide reachability- based definitions for basic predictive analysis tasks; 2.) develop a rigorous, tractable methodology for reachability analysis; and 3.) derive efficient (reachability-based) algorithms for performing predictive analysis [13-24]. We now provide quantitative definitions for predictability assessment, identification of useful measurable, early warning, and robust prediction. Assume the behavior about which predictions are to be made and the measurable upon which these predictions can be based have been used to specify the system SSI and ISS, respectively. Denote by the social process of interest, and suppose it is modeled using the stochastic hybrid system (S-HDS) framework developed in [24-39]. For instance, we often specify the warning accuracy and indicator in such a way that if the indicator is observed then the probability of event occurrence exceeds the given threshold. Note that this definition for warning analysis and warning indicators captures the essence of the informal usage of these terms and is also convenient for formal analysis. The previous section formulates predictive analysis problems as reachability questions. In this section we show that these reachability questions can be addressed by adopting an analysis methodology which is related to familiar Lyapunov function stability analysis [1-9]. More specifically, we seek a scalar function of the system state that permits conclusions to be made regarding reachability without computing system trajectories. We refer to these as "altitude functions" to provide an intuitive sense of their role in reachability analysis: if some measure of "altitude" is low on the ISS and high on an SSI, and if the expected rate of change of altitude along system trajectories is no increasing, then it is unlikely for trajectories to reach this SSI from the ISS [13-23]. We begin with an investigation of (probabilistic) reachability on infinite time horizons. The following result is proved in [1-9] and is instrumental in our development Thus the search for altitude functions can be formulated as a convex programming problem [1-9]. Moreover, if the system of interest admits a polynomial description (i.e., the system vector fields are polynomials and system sets are semi algebraic) and if we restrict our search to polynomial altitude functions, then the search can be carried out using sum of squares (SOS) optimization [11-22]. Importantly, this approach is tractable: for fixed polynomial degrees, the computational complexity of the associated SOS program grows polynomial in the dimension of the continuous state space, the cardinality of the discrete state set, and the dimension of the parameter space Having formulated predictive analysis for social processes in terms of system reachability and presented a methodology for assessing reachability, we are now in a position to derive algorithms for predictive analysis. In what follows we focus on the tasks of predictability assessment and early warning analysis; algorithms for identifying measurable with predictive power and forming predictions are developed in [9-22].

3.0 MOTIVATION OF RESEARCH

We conduct reach warning analysis by employing the procedure outlined in Algorithm. Briefly, the theoretical study produced two main results. First, the degree to which movement related activity shows early diffusion across multiple social contexts is a powerful distinguisher of successful and

unsuccessful social movements. Indeed, this measurable has considerably more predictive power than the magnitude of such activity and also more power than various system intrinsic. Second, large social movements occur with finite probability only happen.) the intra-context "infectivity" of the movement exceeds a certain threshold.) the inter context interactions associated with the movement take place with a frequency that is larger than another threshold Social movements are large, informal groupings of individuals and/or organizations focused on a particular issue, for instance of political, social, economic, or religious significance. There is considerable interest to develop methods for distinguishing successful social movements, that is, movements which attract significant followings, from un- successful ones early in their lifecycle. This task is naturally cast as a warning problem within the proposed approach to predictive analysis. We study the problem in two phases: 1.) a theoretical investigation, in which a collection of general models for social movement dynamics are analyzed, and 2.) an empirical study, involving the emergence and diffusion of Sweden's Social Democratic Party (SDP) [7-19]. The latter result is particularly interesting, as it is reminiscent of, and significantly extends, well-known results for epidemic thresholds in disease propagation models. For instance, the characterization of intra context infectivity generalizes the notion of epidemic reproduction number to social movements. More intriguing is the completely new condition on inter-context interactions: in order for a social movement to propagate "globally", that is, to extend into social contexts beyond its original local setting, the probability of context interaction must exceed a threshold value. This threshold behavior is depicted in Figure 2, which shows the way the probability of realizing global propagation depends on the rate at which individuals interact across social con-texts; it can be seen that this dependency exhibits a classic threshold behavior. Note that the probabilities shown in provably-correct upper bounds for the global cascade probabilities and were obtained using Theorem 1 and SOS programming [12-26]. The empirical investigation of early warning analysis for social movements focuses on the emergence and growth of the Swedish SDP. The case of the SDP is particularly relevant for our purposes, as the early activities of political "agitators" associated with the SDP led to the establishment of a well defined and well documented network linking previously disparate geographically and demographically based social contexts in Sweden. We explore the role played by this inter context network by analyzing archived data and published accounts describing the dynamics of the SDP. Our investigation uses standard time series analysis techniques similar to those employed in, and reveals that an important predictor of SDP spatio-temporal dynamics is early diffusion of SDP related activity across geographically based social contexts. Thus both the theoretical and empirical investigations suggest that early social network dynamics are critical to social movement success. Recall that the first Danish cartoons event ultimately led to substantial Muslim mobilization, including massive pro- tests and considerable violence, and that the Egypt DVD event also resulted in significant Muslim protest and violence. In contrast, Muslim outrage triggered by Abu Ghraib, the pope lecture, the Rushdie knighting, and the second Danish cartoons event all subsided quickly with essentially no violence. Therefore, taken together, these six events provide a useful setting for testing whether the extent of early diffusion across social contexts can be used to distinguish nascent mobilization events which become large and self- sustaining (and potentially violent) from those that quickly dissipate [24-39]. A central element in the proposed approach to early warning analysis is the measurement, and appropriate processing, of social dynamics associated with the process of interest. In the present case study, we use online social activity as a proxy for real world diffusion of mobilization relevant information. More specifically, we use blog communications and discussions as our primary data set. The "blogosphere" is modeled as a graph composed of two types of vertices, the blogs themselves and the concepts which appear in them. Two blogs are linked if a post in one hyperlinks to a post in the other, and a blog is linked to a concept if the blog contains (significant) occurrences of that concept. Among other things, this blog graph model enables the identification of blog communities that is, groups of blogs with intra group edge densities that are significantly higher than expected. In what follows, these blog communities serve as one proxy for social contexts [4-24].

4.0 CONCLUSION

Sample results for Islamic mobilization case study. The time series plots at the top correspond to the pope event (left) and first Danish cartoons event (right). In each plot, the red curve is blog volume and the blue curve is blog entropy; the Danish cartoon plot also shows two measures of violence (cyan and magenta curves). Note that while the data are scaled to allow multiple data sets to be graphed on each plot, the scale for entropy is consistent across plots to enable cross- event comparison. The table at the bottom summarizes the results of the motif analysis study. Sample

results of applying the proposed approach to early warning analysis to the Islamic mobilization case study are shown. It can be seen that early diffusion of dis- cussions across blog communities is, indeed, an indicator that the associated Islamic mobilization event will be large. Such diffusion is observed in the mobilization associated with the first Danish cartoons and Egypt DVD events and not with the other four events, and this early diffusion is excessive relative to the synthetic ensemble. More specifically, in the case of the first Danish cartoons event, the PCE of relevant discussions (blue curve) experiences a dramatic increase a few weeks before the corresponding increase in volume of blog discussions (red curve); this latter increase, in turn, takes place before any violence. In contrast, in the case of the pope event, PCE of blog discussions is small relative to the cartoons event, and any increase in this measure lags discussion volume. Similar curves are obtained for the other four events. More importantly, the proposed motif detection process also yields the expected result: motifs are found only for the Danish cartoons and Egypt DVD events, and these motifs precede significant blog volume and real world violence. Note that qualitatively similar results are obtained for the graph community based and language based definitions of social context. This case study suggests that early diffusion of mobilization related activity (here blog discussions) across disparate social contexts may be a useful early indicator of successful mobilization events.

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