EXPLORING THE POTENTIAL FOR USING ARTIFICIAL INTELLIGENCE TECHNIQUES IN POLICE REPORT ANALYSIS
A Design Research Approach

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Keywords: Artificial Intelligence, Data Mining, Neural Networks, Criminology, Design Research.

Abstract: Storing digital data is increasingly affordable and attractive for many organizations, thus allowing longitudinal *postum* analysis of events and for identifying trends that may hold interest for predicting future scenarios. Results of manual data analysis suffer from high time consumption and human error due to the complexity or volume of data. Responding to this, our study explores advances in artificial intelligence techniques by presenting experiences from the iterative development of a prototype that assists intelligence officers in identifying trends in serial crimes. This study contributes by illustrating the first steps that may be taken towards diffusing advances in artificial intelligence into a practice area serving the general public.

1 INTRODUCTION

Storing large sets of data is no longer a problem for organizations due to the increasing affordability of digital storage solutions, as well as technical advancements in computing power, bandwidth for data retrieval. The problem instead lies in how we may leverage advantages from the data we collect (Shaon & Woolf 2008). Analyzing the data to gain benefits requires more time to complete than before, as the data volume grows exponentially over time (Chen et al. 2004; Liang & Austin 2005; Rajagopalan & Isken 2001). Furthermore, another challenge in performing longitudinal analysis lies in interpreting the raw data (Nath 2006). Data mining is one field linked with artificial intelligence (AI) that strives to address these challenges (Williams 1983; Liang & Austin 2005) that holds the potential for saving time for the analyst (Charles 1998; Chen et al. 2004). However, mining complex data is difficult and often requires a skilled data miner and an analyst with good domain knowledge (Nath 2006) to ensure a low rate of human errors (Chen et al. 2004; Charles 1998).

This highlights an opportunity for software systems to reduce the data volume to only include data sets that are most likely relevant to the analysis. Completing the analysis manually therefore becomes less time consuming when the raw data has been pre-processed. Additionally, software may be used to replicate repetitive existing human analysis steps to provide human analysts with higher quality data to work with, e.g. showing data trends, narrowing the frame of analysis, and making decisions easier through suggesting likely beneficial answers. The potential for practical application of this in software systems to complement and assist analysis has been established (cf. Chen et al. 2004; Liang & Austin 2005; Charles 1998). It remains unclear, however, as to how an effective interplay between AI systems and human actors may be found for these organizations, as well as how such balance may be struck as adapted system designs based on AI techniques are introduced.

In response to this, the research question for this paper is: *how can AI techniques be used and adapted to assist in identifying data trends that are likely to be of relevance for further investigation by human agents?* To answer this, we use the increasingly recognized design research approach (cf. Hevner et al. 2004; Hevner & Chatterjee 2010). The main contribution of this paper subsequently lies in

Bengtsson F., Hein A. and Magnus Olsson C..
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DOI: 10.5220/0003710802130218
In *Proceedings of the 4th International Conference on Agents and Artificial Intelligence* (ICAART-2012), pages 213-218
ISBN: 978-989-8425-95-9

illustrating how advances in AI may be approached to diffuse and adapt these into practice.

2 THEORETICAL BACKGROUND

Two attributes for data analysis are of particular interest: volume and complexity. We refer to volume as the amount of data being analyzed, and complexity as the challenge in interpreting data. Using these, we develop a matrix model which illustrates how they relate and roles that different actors are likely to play in negotiating them.

2.1 Data Volume

Over the past decades, the world has fully entered into the information age, resulting in exponential increases in computing power and communication bandwidth (Shaon & Woolf 2008). In turn, this has resulted in a rise of the amount of data that can be accessed (Rajagopalan & Isken 2001), and therefore also increasing the time it takes to perform data analysis. Organizations involved in data analysis have to face the challenge of accurately and efficiently analyzing the growing data volume (Chen et al. 2004; Liang & Austin 2005). One reason for the challenges is that the relevant data is often hidden in a larger set of irrelevant data, making it difficult to find for human actors. Data mining is one field that strives to address these challenges by efficiently extracting information from large data sets (Liang & Austin 2005).

2.2 Data Complexity

Complex data may be differently expressed and structured in different data sets, changed periodically, be generally diffuse, and/or span long periods of time (Tanasescu et al. 2005; Chen et al. 2004). Furthermore, volume also brings complexity as the permutations of possible interpretations increases (Nath 2006). Humans are inherently good at recognizing complex patterns in data sets due to our brain being perceptive of patterns (Kingston 1992). However, the more complex data, the more time the analysis will take while the risk of human error increases (Chen et al. 2004; Charles 1998).

2.3 Illustrating the Relationship between Complexity and Volume

The relation between data volume and complexity can be shown in what we refer to as a Complexity-Volume matrix (CVmatrix). A CVmatrix consists of the four permutations of volume and complexity that a data set may exist in. The suitability for an agent (human or AI) to analyze a data set depends on the configuration of the attributes in the specific permutation. Human actors are good at analyzing complex data in smaller volumes, while an AI is more efficient with large volumes of less complex data (Charles 1998). In the case when the data set is both complex and contains a large volume of data the risk of errors are highest (Chen et al. 2004). Thus, finding a method for reducing either (or both) of the attributes is desirable to make the analysis of large data sets more efficient and correct.

The CVmatrix presents two plausible paths from the full set of raw data towards a more manageable subset: (1) having human actors focus only on a small subset of the complex data for in-depth analysis, or (2) using computer based algorithms for precise but more basic and repeated analysis of the full data set. For the purposes of this paper, and as shown in our CVmatrix (Figure 1), our interest lies in exploring the first option where the role that the software-based system assist human actors in the selection process of data subsets, and defer interpretation of this data set to human actors based on AI-informed suggested links.

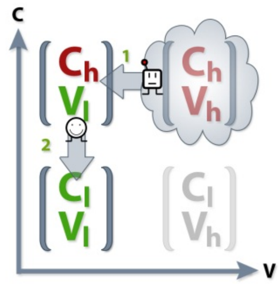

Figure 1: A CVmatrix showing the approach taken for reducing volume and complexity in this paper.

3 METHOD

3.1 Research Setting

This study is done in collaboration with the police intelligence unit in Gothenburg, Sweden. As the Swedish police are under government directive to work against ‘crimes of quantity’ such as burglary, physical abuse, and vandalism, the challenge in effectively analyzing the growing number of police reports is of particular interest to address. In addition, the Gothenburg police have lately noted increasing problems with 'roaming burglaries'. Roaming burglaries are crimes where the criminals travel quickly around the country while committing burglaries which makes it particularly difficult for the police districts to apprehend the criminals and notice patterns in these crime tours. Statistics show that only 4% of burglaries were resolved in 2009 (BRÅ 2009), meaning the risk for being apprehended is currently very low and is a growing problem from a societal perspective.

This paper reports from the first stage of the collaboration and focuses on exploring the impact of a software prototype (Sherlock) using advances in AI to assist in negotiating the large volume of crimes and identify patterns in police reports that are of particular interest for analysts to assess.

3.2 Research Approach

This research combines qualitative interpretation (Creswell 2003) with an iterative design research approach (Hevner et al. 2004). Design research is characterized by the focus on improving current practices through design of artifacts based on best practices identified in research (Hevner et al. 2004). Through the design artifact, practice needs and research findings are provided with a vessel for contributing to both practitioners and researchers.

The approach taken holds benefits given that our experience as researchers with criminology is low compared to our collaborating partner, and the iterative nature of design research (Kuechler & Vaishnavi 2007) affords opportunities for learning-by-doing (Jeffries et al. 1981) and reflection-in-action (Schön 1983). These practices are inherently qualitative acts of testing hypotheses that are guided by interpretation based on the active collaborative participation and prototype driven approach.

3.3 Data Collection

Data collection during the iterative development of Sherlock has been a combination of informal discussions on a daily basis and open-ended interviews (Creswell 2003; Wolcott 1994). The open-ended interviews were further semi-structured, holding some general questions prepared in advance to stimulate interviewees to freely share reflections, experiences, local knowledge and practices (Myers & Newman 2007). This allows the interviews to be guided by both research interest and practitioner experiences, in the same way as intended by design research. The interview results are presented in this paper as an integrated part of the three design iterations, and are discussed in section 4.

4 DISCUSSION OF RESEARCH PROCESS AND OUTCOMES

Our design process is based on three iterations (I1 through I3) and the following subsections discuss the research outcomes of each such iteration, followed by a summary of the outcomes as a whole.

4.1 I1: Data Preparation

Through interviews with our intelligence analysts, we identified that the *modus operandi* (crime scene behavior) has a major impact on the potential for recognizing crimes that are part of a larger series. We therefore opted for using neural networks in our prototype, as extant research outlined this AI technique as promising for crime analysis (cf. Charles 1998; Chau et al. 2002; Chen et al. 2004). Specifically, we decided to rely on a neural network architecture called Self-Organizing Map (SOM). It is based on unsupervised training and is commonly used for classifying patterns (Heaton 2008).

Before relying on this approach, the data from the police reports had to be pre-processed and filtered (as suggested by Goodwill & Alison 2006). As also noted by Helberg (2002), the preparation process plays an extensive role in the analysis procedure, and the initial development of our study was thus focused on preparing the data for neural network analysis.

To achieve this, we designed and implemented a way of normalizing all crime data to be better suited as input for the neural network. The normalizing process' primarily objective is to translate the relevant data from police reports to be used as input for the neural network. We started by assigning each attribute a predefined numerical value with a unique meaning. For example, the gender attribute was awarded three numerical values: '0', '1' and '2', which represents 'unknown', 'man' and 'woman'.

This was then repeated for all attributes, forming a complex matrix of numerical values with unique meaning associated with each crime. Normalizing the data thus provided a chance to discuss and define ways in which crime types could be characterized based on the existing practice of our analysts, and was the foundation for input to be used by the neural network.

The SOM network was evaluated together with the developed input structure. The input structure consisted of two normalized crimes that the network compared. However, when testing the network with two normalized crimes we experienced a redundant and unmanageable number of different patterns suggested. Furthermore, the network had too little information to base its analysis on, meaning extracting more data from the police reports and revising the input structure was necessary.

4.2 I2: Main Development Phase

To revise the input structure, additional interviews were held to understand which data needed to be retrieved from the police reports and why. Based on this, we turned to the suggestions by Chau et al. (2002), Nath (2006) and Bache et al. (2007) who emphasize that the free text open-entry field of police reports contain much valuable.

The open-entry information may be difficult to interpret, however, as the data is expressed and structured depending on who writes the report. Such differences are part of what defines data sets as complex (Tanasescu et al. 2005). Interpretation of the open-entry field was thus decided on as a focal point for the software prototype as advances in pattern recognition in such fields are likely to provide particular value to the analysis. The second iteration thus emphasized a broadened use of data mining through exploring an efficient way for retrieving relevant data from a complex data set.

To address the challenge of interpreting open-entry fields and reducing the volume of data to review for the human analysts, we implemented an open-entry interpreter based on a lexical-lookup (Chau et al. 2002) extraction approach which we adapted to establish a *modus operandi*. The lexical lookup details were defined in collaboration with the intelligence analysts, and we implemented the open-entry interpreter to softly match keywords using an algorithm called Q-gram (Younghoon et al. 2010) to recognize different tense of words and misspelled words as part of the match.

As a result of the evaluation performed in the first iteration, in which the SOM network was unable to produce the expected output, we realized that there was a need of modifying the input structure in order for the neural network to find crime patterns. The proposal was to create an algorithm that merged all attributes of two normalized crimes to generate an input pattern for the neural network that would indicate the similarities and differences between the crimes. The neural network then interprets high peaks of the pattern as differences and low peaks as similarities to decide whether crimes are related or not.

The advantage of using neural networks for recognizing and classifying complex patterns is that the network can be taught over time. This means that the neural network's ability to analyze effectively increases over time, similar to how human actor experience works and may positively influence results. Training a neural network involves gathering both training and evaluation data (Heaton 2008). Sherlock's neural network is trained and evaluated through data retrieved by the intelligence analysts for previous crime series where the manual work has already been done to be able to interpret the success of the Sherlock implementation in relation to the known manual analysis results. Throughout the development of Sherlock it was important that the intelligence analysts contributed with their perspective of how to analyze and classify crimes.

We evaluated the implementation of the SOM neural network with predefined input based on the new structure and discovered that the SOM network did not function as well as needed. This was similar to our initial evaluation, and the reason for why the structure of the neural network input was emphasized and why the merge algorithm and the open-entry interpreter were developed. At this stage it was evident that the network still had difficulty mapping crimes itself, due to the input structure required, resulting in output that was very hard to perceive any patterns of value in. After evaluating the open-entry interpreter by running it on 60 manually pre-analyzed police reports, the results showed that all *modus operandi* of these reports could be correctly structured by the open-entry interpreter.

4.3 I3: A New Neural Network Model

We were now at a point where we required more control over the learning step of the neural network and thus started the search for a new neural network model. This led us to the feedforward backpropagation network (FB). Feedforward is a method for recalling patterns and backpropagation is a supervised training method (Heaton 2008). By using a supervised training method, rather than automated as described in iteration two, we could now manipulate the neural network more actively during the training session to assist in rejecting or accepting suggested patterns.

To evaluate the implementation of an FB based Sherlock, the intelligence analysts provided us with a crime series they identified in 2009 containing a total of 58 linked crimes in the same crime series. We evaluated the FB network analysis capabilities by using a training set consisting of a subset of 10 crimes to train the FB network as our hypothesis was that it should then be able to recognize most of the remaining 48 crimes in the series when executed on the full set of crimes. To provide realism to this scenario, we included the entire 58 known and linked crimes in the police report database of burglaries in the Swedish region of Skaraborg 2009. This brought the number of crime reports to a total of 318 crimes, with the 58 linked crimes included. Executing Sherlock on this data set based only on the 10 linked crimes it had been trained on, the software identified 41 out of the 58 crimes that the human analysts had already established as linked.

Sherlock's failure to identify 17 crimes indicates that further training and potential tuning of the FB is still needed, but the results are nevertheless a substantial improvement over the SOM based approach. Given the manipulation based training of the FB based neural network, the human agents have an important role to play for increasing the reliability of Sherlock. As the intelligence analysts train the network with more crime series, the network should learn to better determine whether the crimes belong to a crime series, thus reducing the error rate in relation to manual analysis by human actors.

4.4 Reflection on Iteration Outcomes

From the evaluation stage of the FB network in the third iteration, this study demonstrates that it is possible to reduce the volume of a complex data set through combining a set of AI techniques in a practice situation. The AI techniques that Sherlock uses are open-entry interpretation, a crime merge algorithm, and aided by an FB neural network, our results indicate that it is possible to follow the path indicated in the CVmatrix earlier (Figure 1).

As a result of the growing body of research in neural networks, future work may both improve our current approach and offer new alternatives altogether. We strongly believe that assessing such advances for extracting more of the relevant data in practice situations is likely to play an important role in moving them from potential options to best practice examples in different and specific contexts. Our study marks one such example, but as with neural networks themselves, many more data points are needed to capture a more complete set of linked needs between different practices. We are, however, in this study taking an active stance that practice driven needs are of particular relevance for such continued work.

The open-entry interpreter which we developed and used in the Sherlock implementation is itself a technique that could be used separately from the neural network to reduce the volume of complex data sets. As the purpose of this paper has been towards exploring and demonstrating the potential of applying advances in AI in practice situations, rather than technical discussions of the design artifact, we hold further elaboration on the open-entry interpreter as part of future papers. When generalized for use towards all crime types, the interpreter would allow the human analysts to run more specific search queries, for example matching the *modus operandi* of a crime to get more precise data to analyze.

Discussing the long-term impact of the prototype, the police analysts reflect that exhaustively analyzing 'crimes of quantity' is a task not performed at present due to the human resource demands this holds. Subsequently, the potential of Sherlock is perceived as very strong: "We know that Sherlock is still in its early stage of development, but it is still able to provide great help to us since it is performing a task that we cannot do at present. By introducing a software system that takes care of the collecting and cleaning process, it is possible for us to focus on what we were trained for – analysis." They further recognized how the collaborative marriage between research and actual practices brings visible benefits to them when adopting the system into their daily work routines: "Another important factor with Sherlock is that it is based on the same coding schemes as we already use, meaning it does not bring additional overhead work to integrate into our current work processes."

5 CONCLUSIONS

This study set out to explore the assisting role AI techniques may have in identifying data trends that are likely to be of relevance for additional investigation by human agents. We found practitioners who struggle with large volumes of complex data and collaborated actively with them to adapt the developed prototype to their needs, based on best practices and advances in extant research. The focus on serial crime was due to such crime marking the majority of incidents and is of great societal impact due to the repeated nature of them and the difficulty in terms of resources and time faced by manual analysis of such crime.

The contributions of this paper are linked to the practice implications and potential of the Sherlock implementation experiences. Not only is our research approach one that argues for the mutual contributions to practice and research, but we also strongly feel that advancements in the field of artificial intelligence stands much to gain from studies that also expose practice needs and challenges for diffusing theoretical advances.

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