Providing a foundation for interpretable autonomous agents through elicitation and modeling of criminal investigation pathways

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Criminal investigations are guided by repetitive and time-consuming information retrieval tasks, often with high risk and high consequence. If Artificial intelligence (AI) systems can automate lines of inquiry, it could reduce the burden on analysts and allow them to focus their efforts on analysis. However, there is a critical need for algorithmic transparency to address ethical concerns. In this paper, we use data gathered from Cognitive Task Analysis (CTA) interviews of criminal intelligence analysts and perform a novel analysis method to elicit question networks. We show how these networks form an event tree, where events are consolidated by capturing analyst intentions. The event tree is simplified with a Dynamic Chain Event Graph (DCEG) that provides a foundation for transparent autonomous investigations.

Key Words

Autonomous agents; cognitive task analysis; XAI

INTRODUCTION

Criminal investigations involve high risk and high consequence situations in which it is vital that accurate and timely information is available to decision makers. Criminal intelligence analysts use this information for reasoning so that they, and their superiors, can make well informed decisions on important questions such as where to allocate resources, who to consider as potential suspects, or what risks a victim faces. Past research has considered the processes applied in criminal intelligence analysis, finding that they involve an "iterative combination of abductive, inductive and deductive inferences, information searching, associations, and further sense-making" (Wong and Kodagoda, 2016). Manual information searching comprises a significant proportion of this, where "each piece of insight leads to intense periods of manual information gathering" (Hepenstal et. al. 2019b) and the initial investigation scope frames subsequent lines of inquiry. The potential benefits of speeding up this process are significant, where, if in a threat to life situation, reducing the time to find crucial information "could save someone's life" (Hepenstal et. al. 2019b). Artificial intelligence (AI) systems that can automate questioning to explore various investigation paths, therefore, present a significant opportunity for investigators to both speed up investigations and to challenge their initial scope. However, in such a high risk and high consequence domain there are important ethical concerns around bias and algorithmic opacity (Duquenoy, 2018) and these are potential barriers to the adoption of complex systems. A lack of understanding and oversight of algorithmic processes is identified as a serious issue by both system users, for example police officers (Babuta, 2019), and by human rights campaigners (Couchman, 2019). There are, therefore, critical design requirements for autonomous systems to be used in the context of criminal investigations, and a notable issue is the need for algorithmic transparency (Hepenstal et. al. 2019a).

In this paper, we show the potential to model an event tree and a Dynamic Chain Event Graph (DCEG) (Barclay et. al. 2013) that represents the lines of inquiry in an investigation. A DCEG is a discrete graphical model constructed from infinite event trees. We analyse data from Cognitive Task Analysis (CTA) (Klein et. al. 1993) interviews with expert analysts, each interview covering a specific investigation scenario, to identify question networks and underlying intentions. We use these networks to form event trees that define a DCEG. We provide an example case to demonstrate how the DCEG identifies helpful investigation paths in a new investigation scenario. A DCEG simplifies infinite and complex option stages in an event tree, to form an accessible visual representation of the statistical model. A DCEG therefore provides a foundation to explore investigation paths, whilst clearly articulating them to analysts. In previous work, we have developed a conversational agent (CA) for information retrieval that provides algorithmic transparency of its reasoning (Hepenstal et. al. 2020a). We used the Recognition-Primed Decision (RPD) model to deliver an explanation structure for intention concepts, in order to enhance user recognition and understanding of system behaviours. We propose to build upon this research to represent investigation pathways within a DCEG, where intention concepts inform the relationships between stages. We believe that this approach provides a platform for autonomous multi-stage reasoning, which tackles critical transparency issues for using AI systems in the field of criminal intelligence analysis.

CRIMINAL INVESTIGATIONS ARE HAMPERED BY INFORMATION OVERLOAD

In criminal investigations it is typical that analysts make repeated requests for information (Kodagoda and Wong 2016), with each new piece of insight requiring validation and triggering additional lines of inquiry. Much of this data processing is manual and time consuming, suffering from strict resource constraints. As explained by Mark Stokes, Head of Digital, Cyber and Communications Forensics Unit for the Metropolitan Police, "in digital forensics within England and Wales, the capacity to undertake what is required on criminal investigations is not there. We currently have a seven-month backlog." (Stokes, 2018) Cressida Dick, Commissioner of the Metropolitan Police, reiterates the scale of information where she states, "there is so much data that has to be looked at…"

and “if police were able to harness data more effectively, a ‘very, very large proportion’ of crimes could be solved.” (Shaw, 2019) Criminal investigations involve high risk and high consequence scenarios and therefore the impacts of time saving can be significant. Additionally, past research has found that the scope of an investigation, while important to help direct inquiries when resources are stretched, can also be restrictive and introduce bias (Hepenstal et. al. 2019b). Traditional analysis methods used to broaden analyst thinking and address bias in investigations, such as analysis of competing hypotheses (ACH) are also flawed (Dhami et. al. 2019). AI systems that can perform their own investigations autonomously, whilst recommending information that may be of interest to an analyst, have the potential to speed analysis and challenge investigation scope without further burdening analysts. This could include the identification of known and unknown ‘unknowns’ (Logan, 2019). Even if a system can explore only simple paths and make recommendations, triggered by an initial question from an analyst, it could provide helpful assistance.

SYSTEMS MUST EXPLAIN THEIR INFLUENCE

Systems are used across a wide range of domains to make recommendations, for example to suggest items to buy following an initial purchase or additional films to watch. However, there are serious ethical considerations when it comes to criminal intelligence analysis, where algorithmic bias can have severe consequences. For example, if a system directs investigation resources towards an innocent person, through discriminatory processes.

Algorithmic bias can occur in various ways. “Human error, prejudice, and misjudgement can enter into the innovation lifecycle and create biases at any point in the project delivery process from the preliminary stages of data extraction, collection, and pre-processing to the critical phases of problem formulation, model building, and implementation.” (Leslie, 2019) Human rights campaigners have raised concerns over the use of AI systems in the criminal justice system, where “the nature of decision making by machines means there is no option to challenge the process, or hold the system to account.” (Couchman, 2019) Police analysts have also raised concerns that an inability to understand and challenge machine reasoning, and any bias that may have been introduced, is a critical barrier to the use of complex systems (Hepenstal et. al., 2019b). Central to the ability to challenge and critique machine reasoning is the provision of algorithmic transparency. In past work, we developed an algorithmic transparency framework that identifies the need, in high risk and high consequence domains, to provide both an explanation of a system response together with the ability to inspect and verify the goals and constraints of the system behaviour (Hepenstal et. al., 2019a). Hoffman et. al. (2018) identify some key concepts in literature on explaining systems, for example, that explanation is a continuous process, collaborative, triggered in specific situations, improves learning and understanding, should clearly articulate caveats and limitations, and should ensure the user understands what is not being done as much as what is being done. Previously, we have developed a transparent approach to interpret user intentions when interacting with a conversational agent (CA) (Hepenstal et. al., 2020). This approach can deliver explanations that meet the key concepts. Crucially, we provide an intention architecture that uses the way in which humans recognise situations, the Recognition-Primed Decision (RPD) model (Klein 1993, Hepenstal et. al. 2019b), to structure explanations of the functional modules triggered by the intention. This architecture allows a user to pick apart system behaviours, in terms of the intention triggered by their input, to clearly articulate caveats and limitations and to identify contrasting intentions. The explanation structure has been designed for a single stage interaction. The analyst asks a question and triggers the CA to do some processing based upon the matched intention. The analyst can step into the answer, to see explanations of the various functional processes, where intention attributes mirror the explanation structure of the RPD model. For an AI system to be able to conduct autonomous investigations it requires multiple stages of processing. We propose that our intention architecture and explanation structure aids us in providing transparency for multi-stage processes, by combining multiple intentions in a series.

ACCESSIBLE MODELLING OF EVENT SEQUENCES

Past approaches have looked to provide explainable recommendations for event sequences. EventAction (Du et. al 2019), for example, can be used to recommend an action plan to a student based upon their similarity to past students and their desired outcome, such as to become a Professor. EventAction models sequences of events as a probabilistic suffix tree, based upon historic events, and applies a Markov Decision Process (MDP) and Thompson Sampling to compute and select a recommended action plan. A probabilistic event tree could be a helpful way to explain possible inquiries at each stage of an investigation, where with each response to a question the analyst will have a set of options for how to proceed. “Shafer demonstrated that an elicited tree was often a much more powerful expression of an observer’s beliefs about a process”, compared to other approaches to elicit a model such as a Bayesian network (BN) (Shafer 1996, Smith and Anderson 2008). Additionally, for capturing decision events in an investigation, an event tree “provides a natural framework through which time sequences can be incorporated” (Barclay et. al., 2013). An event tree, however, can become complex to represent visually as it grows. A Chain Event Graph (CEG) can rectify this. “The CEG is derived from a probability tree which is simplified into a CEG by introducing the concepts of ‘stages’ and ‘positions’. These group the vertices in the tree together according to the associated conditional probabilities on their edges.” (Barclay et. al., 2013) The graphical nature of a CEG presents a useful opportunity for interpretability where a user can see what variables have influence over others, and can validate whether this is acceptable. Thwaites et. al. (2010) find that, “as with Causal BNs, the identifiability of the effects of causal manipulations when observations of the system are incomplete can be verified simply by reference to the topology of the CEG.” Chiappa and Isaac (2019), have demonstrated that BNs are a “simple and intuitive visual tool for describing different possible unfairness scenarios underlying a dataset”, and this also applies to the CEG. CEGs therefore have useful qualities for providing transparency in criminal investigations, where it is important to trace back through reasoning steps and to understand what and how states, or questions, have influenced each subsequent piece of information gathered. The decisions made at each step seek to achieve some goal and communication of these and the underlying reasoning is crucial when developing observable autonomous systems. McDermott et. al. suggest that a system should understand the goals of the human users and communicate their intent in terms of what goals it is trying to accomplish for a task (McDermott et. al. 2018). A CEG that chains together cues, methods and goals for questions, is an effective foundation for observable autonomous reasoning.

Investigations involve repetitive questioning strategies. If, for example, a vehicle is presented in an output, an analyst may look for the owner and for any events in the database which have involved the vehicle. They may wish to do this every time a vehicle is found throughout their investigations. In these cases, the options available are repeated at different stages in the investigation and the event tree is infinite. We capture the topology of an infinite staged tree in a similar way to the CEG by using a Dynamic CEG (DCEG), as described by Barclay et. al. (2013). A DCEG provides a succinct explanation of the stages available and their influences on one another, which could help to achieve algorithmic transparency. In our system event selections trigger complex processes that themselves require explaining, and we utilise our intention architecture (Hepenstal et. al., 2019b, Hepenstal et. al., 2020a), underpinned with an explanation structure reflecting the RPD model. In this paper, we model an event tree to form a DCEG (Barclay et. al., 2013). The DCEG is a useful aid to explore possible investigation paths, where each state reflects the explanation structure of the relevant intention.

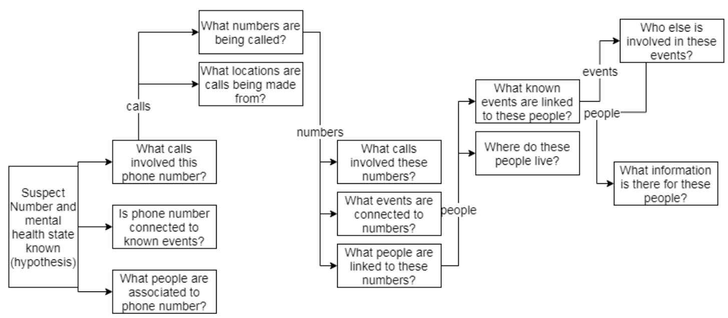
Table 1: Question Elicitation Example

Statement [CTA; Analyst 4; 2.00 -> 10.00] (Input=Suspect Phone Number)	Specific Need	Specific Question
"*3 things you do instantly with the number. Stick it through your (databases), see if any other existing links. ... Check with all call data we have collected from operation... run subscriber checks on numbers he has called to get info on contract subscriber...We then go and find other phone calls (involving suspect phone number)... Can get call data for others in the network… also check all numbers additional people have phoned against all other numbers (in databases).*" [A4; 2.00 -> 10.00]	*See if any other existing links for phone number*	Is the phone number connected to known events?
	Check with all call data and subscriber checks	What people are associated to phone number?
	Find other phone calls	What calls involved this phone number?
	Get call data for others in network	What numbers are being called?
		What calls involved these numbers
	Check all numbers additional people have phoned against all other numbers	What people are linked to these numbers
		What known events are connected to numbers?

INTERVIEW DATA

We conducted Cognitive Task Analysis (CTA) interviews, applying the Critical Decision Method (CDM), with four criminal intelligence analysts. In each interview we delved into a particularly memorable investigation that they were involved in from start to end. For this study, we were most interested in how analysts questioned data as they sought to retrieve information to advance their investigations, in particular how questions led to insights that triggered subsequent inquiries. Each analyst had more than 3 years’ experience. We have previously analysed the interview data to identify distinct questions and to structure them against the Recognition-Primed Decision (RPD) model (Hepenstal et. al., 2019b, IUI ExSS 2020). In this study we revisit these questions and identify links between them, where a link can be drawn if the result of one question is subsequently used to form cues in another. The questions could be asked of a conversational agent (CA) to retrieve the information required and we propose that question networks can be captured dynamically in the future through such interactions.

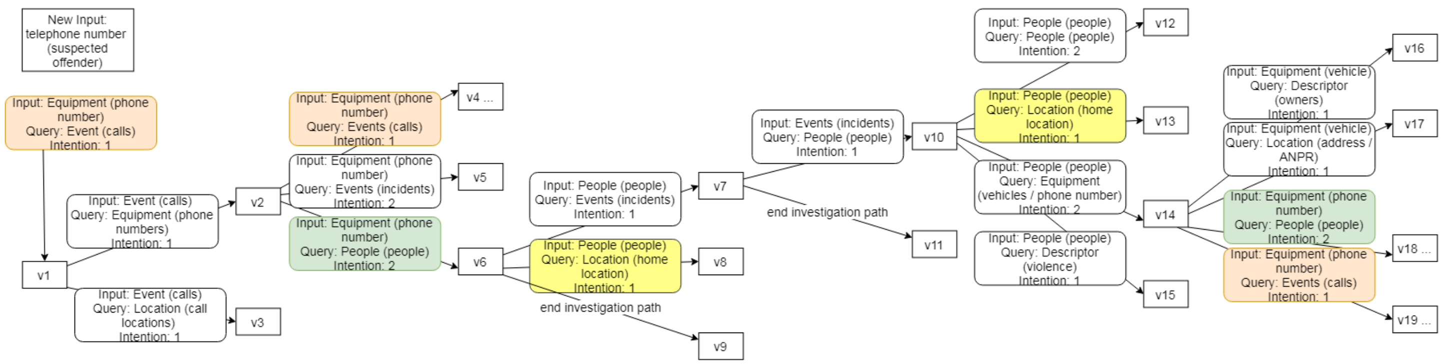
Figure 1: Question Network for Firearm Scenario



ANALYSIS: ELICITING QUESTION NETWORKS FROM INTERVIEW DATA

Drawing upon timeline analysis of the investigations (Hepenstal et. al., 2019b), we extracted questions asked by analysts in the order in which they were considered. Analyst questions were related to specific input cues, for example an entity found in the results of a previous inquiry. Interview statements tend to describe general processes performed in the investigation; Table 1 presents some examples to demonstrate how questions were elicited. We have attempted to capture the underlying information needs from each statement, and have extracted from this specific questions that could address requirements. Analyst questions are not asked in isolation, where there are directed relationships if the outputs of one feed another. The relationships between questions can be more clearly presented as a network and we applied a novel analysis technique to form networks from the interview data. Figure 1 shows a network of questions for one of the interview scenarios.

Figure 2: Resulting event tree from the starting point 'Suspects telephone number'.



Each node in the network represents a question event, where an analyst passes some cues in their question and performs some tasks according to their intention. In each event an analyst has options on how to process the results, represented by edges.

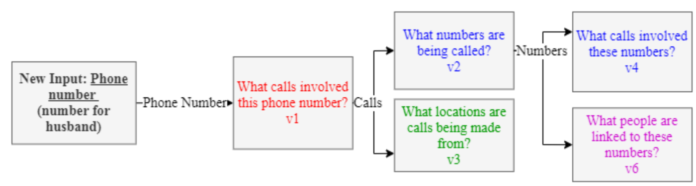
FORMING AN EVENT TREE FOR QUESTIONNING: EXAMPLE CASE RESULTS

We have used our previous work on developing intention concepts (Hepenstal et. al., 2019b, Hepenstal et. al., 2020) to consolidate question events for two interview scenarios, a kidnapping and a firearm dealing, allowing us to build an abstract question network. In our abstract network a node (question event) requires three components: an input i.e. the question subject (e.g. a phone number), a query class (e.g. people), and an intention. The intention defines the way in which the question will be processed. We can make our event stages more or less domain specific by manipulating class granularity.

A third interview scenario involved an attempted murder, where the female victim was found alone in her house and the incident was reported by her husband, who claimed to be on the phone with her at the time of the assault. The analyst explained that initially the husband was a suspect, due to on-going divorce proceedings between himself and the victim. At the outset of the investigation, the analyst was responsible for verifying the husband's statement, "*to identify conflicts*" [A4; 25:00], where the key piece of information available was the husband's phone number. In Figure 2, we show an event tree for this scenario where vertex stages have the prefix 'v'. We have identified possible options for stages in the tree from our abstract question network, where probabilities can be assigned based upon the proportion of times a particular edge is found. Coloured stages are revisited and the tree is infinite.

Despite situational differences in the scenario, by identifying a starting stage and input we can build a tree that describes all the questions the analyst asked. The network of investigation questions shown in Figure 3 are represented within event tree stages (Figure 2) and roughly reflects analyst questioning, where they explain that "(*the*) *husband alerted officers, he said she had been on the phone to him when the burglary and attack occurred. I looked at telephone records to confirm that his statement is correct, backed up by* ***phone records*** *and corroborating information. The analyst is trying to back up or refute information in the statement. I'm asking for* ***phone numbers within (call) data which are matched*** *and* ***person details****, such as* ***those involved in scene****. I look at the network of* ***which phones have called each other.***" [CTA; A2: 24.00] This example demonstrates the potential to predict plausible question networks, even for new scenarios.

Figure 3: Investigation Path for Attempted Murder Scenario



OUTCOME: A MODEL FOR INVESTIGATION QUESTIONING

Even in our simple example, there are 19 distinct stages and the tree is infinite. To represent the entirety of the tree is therefore not possible, yet the current tree does not clearly reflect the influences between states. A DCEG representation can be used to represent the tree "in a much more compact and easily interpretable form." (Barclay et. al 2013) To build the DCEG, we identified probabilistic symmetries in the tree, i.e. stages with identical probabilities across options available. In our example, these are the revisited stages. Representing the infinite event tree as a DCEG reduces the complexity significantly to 7 positions. The topology of the DCEG allows us to assess influences across positions, where we can inspect and verify information held at each and the cues and intentions that define relationships between them. The relationships in our DCEG introduce their own complexities and related methods for information retrieval. In our DCEG a possible path, for example, is to find equipment involved in event data, then find additional events that are linked to the equipment, before exploring these events further. However, a relationship does not exist to find events connected to the equipment and explore these further. Instead, connected events lead to the end position, as these are identified as a goal based upon past investigations. The possible paths are constrained and an analyst must be aware of this when interpreting results. We can use our intention architecture and explanation structure that reflects the RPD model to enhance analyst recognition of the goals and constraints of selected paths.

FUTURE WORK: A FOUNDATION FOR AUTONOMOUS QUESTIONING

Under certain assumptions, a DCEG "corresponds directly to a semi-Markov process." (Barclay et. al., 2013) Therefore, in a similar fashion to EventAction, it is possible to generate and select interesting lines of inquiry for an investigation from our DCEG. The automation of information retrieval could be valuable to analysts, who spend "*quite a lot (of time) doing detective work, where a piece of intelligence is nothing on its own, but we needed to trawl data and find links.*" [CTA; A4: 2.30] In the kidnapping scenario it took 16 question stages to gather the information required to identify where the person had been taken. Likewise, it took 12 question stages in the firearms dealing scenario to address their "*need to find this person (firearm dealer).*" [CTA; A4; 09:00] An autonomous approach would save much human effort. However, an analyst needs to sufficiently inspect and verify the reasoning, goals and constraints of the methods applied. We provide a foundation for observable automation.

CONCLUSION

We have demonstrated a novel approach to elicit question networks from interview data. In future work, we will look to capture these dynamically from interactions with a CA. The question networks form an event tree and a DCEG, from which we can generate and select lines of inquiry with an explanation structure at their foundation. Further consideration is needed for how to define goals in investigation paths. We propose that we can capture a better understanding of analyst processes and we should consider how to utlise this. Our approach could also develop transparent autonomous aids for other high risk and high consequence domains, such as medical diagnoses.

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