Declarative AI and Digital Forensics: Activities and Results within the DigForASP project

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Abstract
This paper reports the activities done and the results obtained by the University of Bari within the COST Action DigForASP. The objectives of this project are to create a cooperation network for exploring the potential of logic-based Artificial Intelligence (AI) applications in the Digital Forensics field. Specifically, the challenges of our work were to develop a declarative AI approach, based on Answer Set Programming, to call pattern analysis, for extracting useful information or suspects "lifestyles" from anonymized phone recordings of real crimes, made available within the DigForASP project.

Keywords
Evidence Analysis, Declarative Pattern Mining, Answer Set Programming

1. Introduction

Digital Forensics (DF) is the discipline that deals with identification, conservation, protection, extraction, documentation and any other form of processing of digital data [1]. Data can be evaluated as evidence in a criminal or civil context after they have been transformed into informative content by applying appropriate activities.

DF is therefore a branch of Forensic Sciences whose activities are aimed at highlighting the existence of digital evidence relevant to the fulfillment of a trial, or even before the investigative phases. It is the process that uses science and technology to analyze digital objects, developing and testing theories that can also be used legally to answer questions about events that happened [2]. The DF has quickly carved out a large space also within corporate environments, with the aim of highlighting the violations within the industrial secret and/or violation of security policies and to deal with IT incidents. Also, DF is characterized by constantly evolving and changing techniques, according to the fast innovation process in the ICT sector, involving analysis methods, tools, protocols and structural components relating to the digital systems being analyzed as well as rights to safeguard the privacy of the individual.

The continuous evolution of digital devices, the large amount of data available, require efficient and effective tools to analyze this amount of data. More, verifiability, reliability and justifiability are keys features for software tools to be applied in DF, where the evidence produced is aimed at the reconstruction of crimes and assist/facilitate the court in the decision process to establish if an accused is innocent or guilty. For these reasons, the COST Action CA17124 "Digital forensics: evidence analysis via intelligent systems and practices" (DigForASP)[1] aims to create a research infrastructure for the application of *Artificial Intelligence* (AI), in the field of Digital Forensics, in particular to *Evidence Analysis* phase (EA) [3].

Several AI techniques have been applied to DF for different purposes. They have mainly been exploited for data retrieval and categorization, e.g., for the analysis of image and video multimedia or the detection of anomalies. These tasks benefit especially from Machine Learning (ML) techniques. The Action takes a step beyond, since it considers to apply methods from *Knowledge Representation* (KR) and *Automated Reasoning* (AR), in particular those based on Answer Set Programming (ASP) [4], to retrieve data in order to elicit evidence that can be used in a trial. For instance, from data items retrieved from different sources (like, e.g., mobile devices, social network activities, cloud computing tracks, phone records, log files etc.), we may obtain the set of all possible patterns of activity of a suspect during the execution of a crime. Notably, Costantini *et. al* [5] explored the applicability of ASP to partially automate the activities in the EA phase. They showed how meaningful complex investigations, hardly solvable for human experts, can be expressed as optimization problems belonging in many cases to P or NP complexity classes.

With this paper we summarize the activities done and the results obtained by the research group of Prof. Francesca Alessandra Lisi at the Department of Computer Science of the University of Bari "Aldo Moro", Italy,

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[1]https://digforasp.uca.es/

within the DigForASP project. Our contribution to the project started with the MSc thesis in Cybersecurity (University of Bari) of Gioacchino Sterlicchio under the supervision of Prof. Lisi. We developed special ASP tools that automatically extract useful information from telephone records instead of being found manually, reducing the working time. In fact, evidence on possible crimes and perpetrators of crimes collected from various electronic devices (through specialized software, and according to specific regulations) must be examined and aggregated in order to reconstruct possible events, sequences of events and scenarios related to a crime.

The paper is structured as follows. In Section 2 we briefly introduce the DigForASP project. In Section we describe the case study considered in our contribution to DigForASP, which is then detailed in Section 4. Section 5 reports the collaborations with DigForASP members which helped us to carry out our research. Section 6 concludes with final remarks.

2. The DigForASP project

The project started on September 10, 2018 and ended on March 9, 2023. DigForASP constituted a timely challenge for both areas: DF and AI. From the point of view of AI, the research fostered the development of new theoretical results, methods and techniques that will contribute in the long term to the development of new software tools that will be based on a complex combination of concepts and results from different areas of KR&AR such as diagnosis, causal explanation, temporal reasoning on actions, epistemic reasoning, treatment of incomplete knowledge, ethical and legal reasoning, inductive learning and analysis of formal concepts. At the same time, the application of (intelligent) automated tools to DF, capable of being reliable and able to comprehensively explore evidence and with a level of analysis that is beyond the reach of human observation and over time, it will be a breakthrough that will have a direct impact on the practical investigation of criminal scenarios.

To take up the challenge, the *Action* has built a "Network" made up of researchers and engineers in the field of AI together with DF experts belonging to government institutions and NGOs alongside scholars from the world of information and technologies. communication (ICT) law, as well as social scientists, criminologists and philosophers (the latter for ethical issues). The "Network" carried out a series of activities and building resources to promote interaction, exchange and cooperation between these different areas. It sought to understand the main issues and open problems of DF, in particular the analysis of evidence, and is helping to promote the exploitation of AI to address the key problems of this domain in an innovative, adaptive way. The partners of the "Network" were thus able to identify the KR and AR techniques that can be applied to EA and to suggest guidelines for the creation and development of new techniques and methods suitable for progress state of the art in both DF and AI, strengthening European research and innovation capacity in these sectors. The long-term objective of the "Network" is to increase the know-how and skills, so as to concretely design and implement projects and tools that must be applied by the Scientific Investigative Departments of the Police in the resolution of real cases in the countries COST members, COST Near Neighbor Countries (NNCs) and COST International Partner Countries (IPCs). This is also to promote coherent and effective cooperation with third countries.

3. The case study

Everyone uses their smartphones and the mobile networks that surround us run in parallel with the real world, turning people into traceable mobile identities. Information is automatically stored in phone records and in a device's memory, an invaluable source of evidence for criminal court cases. Through telephone records it is not possible to trace the content of audio calls, messages and e-mails sent or received, the list of the web history of the sites visited. It is a set of data relating to the external communications of the devices, that can be requested by the Judicial Authority if it deems it useful to get hold of them in order to carry out investigations on the individual owner of the user. Telephone records contain all the digital traces of communications relating to a specific user over a certain period of time like telephone calls, text messages/SMSs, and data traffic of the mobile phone. For example, such data are (a) caller telephone number, (b) recipient telephone number, (c) communication category (e.g. call, SMS, missed call, etc.), and (d) how long the call lasted. As invaluable source of evidence, law enforcement can analyze these data for compare the geographical positions with respect to the declarations and reconstruct the network of contacts for a single user to trace which conversations he/she had and at what time.

Analyzing phone data can be time consuming. So, the (partial) automation of this activity limits the amount of data to be processed during the EA phase. With our research, we encouraged formal and verifiable AI methods and techniques to *call pattern analysis*, an intelligence technique used to identify patterns in telephone call traffic such as timing of events and actions, possible causal correlations and contexts in which suspicious actions have occurred. As said before, we have considered the analysis of the real-world phone records, carefully anonymized in order to preserve privacy and confidentiality, provided by Prof. David Billard (University of Applied Sciences of Geneva) under non-disclosure agreement to DigForASP members for academic experimentation. The dataset consists of four Excel files, one for each suspect: “Eudokia Makrembolitissa”, “Karen Cook McNally”, “Laila Lalami”, “Lucy Delaney”. Each file has the following features:

- *Type*: incoming/outgoing call or SMS;
- *Caller*: who makes the call/SMS;
- *Callee*: who receives the call/SMS;
- *Street*: the place of the operation;
- *Time*: when the operation took place;
- *Duration*: how long the operation lasted;
- *Date*: day, month, year.

Our goal was to address questions posed by Prof. Billard and other DF experts within the DigForASP project such as:

1. From the Eudokia Makrembolitissa dataset, would it be possible to find her accomplices Karen Cook McNally or/and Laila Lalami?
2. From the Eudokia Makrembolitissa, Karen Cook McNally and Laila Lalami dataset, would it be possible to find Lucy Delaney?
3. Do same people gather physically often?
4. When X calls Y, do always Y calls Z shortly afterwards?
5. At the time of the crime, who was at the same location, or called by Eudokia Makrembolitissa?
6. The day before, who spoke with Eudokia Makrembolitissa? Or any other suspect?

To this aim, we have proposed to analyze the dataset by looking for *sequential* [6] and *contrast* [7] patterns that could highlight habits of the suspects. The novelty of our work is the declarative approach followed, based on ASP, as detailed in the next Section.

4. Analysing Phone Calls with Declarative Pattern Mining

Data mining means the identification of information of various kinds (not known a priori) through targeted extrapolation from large, single or multiple databases applicable to the most varied fields: economic, scientific, operational, etc. The techniques and strategies applied to data mining operations are largely automated, consisting of specific software and algorithms suited to the single purpose. To date, in particular, neural networks, decision trees, clustering and association analysis are used. *Pattern Mining* is a data mining subtask in which rules that describe specific patterns are identified within graphs, sequences or itemset. A pattern p is interesting if given a threshold k and set of data $\mathcal{D}$, p occurs at least in k examples in $\mathcal{D}$ and p is called frequent pattern. ASP is used

Table 1
An example of sequence database $\mathcal{D}$.

ID	SEQUENCE
1	$\langle d\ a\ b\ c \rangle$
2	$\langle a\ c\ b\ c \rangle$
3	$\langle a\ b\ c \rangle$
4	$\langle a\ b\ c \rangle$
5	$\langle a\ c \rangle$
6	$\langle b \rangle$
7	$\langle c \rangle$

for the stream of research known as *Declarative Pattern Mining* (DPM). DPM covers many pattern mining tasks such as sequence mining [8, 9] and frequent itemset mining [10, 11]. Very recently, the case of contrast pattern mining has been covered as well [12]. Besides ASP-based approaches like [9, 13], other declarative frameworks have been considered such as Boolean Satisfiability (SAT) [10], and Constraint Programming (CSP) [14, 11].

Sequential Pattern Mining finds statistically relevant patterns within sequences of data examples [6]. It is usually presumed that the values are discrete within a time series. Given a sequences dataset $\mathcal{D}$ (Table 1) the *cover* of a sequence s is the set of sequences of $\mathcal{D}$ which includes s: $cover(s,\ \mathcal{D}) = \{t \in \mathcal{D} \mid s \subseteq \mathcal{D}\}$. The number of sequences that includes s in $\mathcal{D}$ is called *support*: $support(s,\ \mathcal{D}) = |cover(s,\ \mathcal{D})|$. For an integer k, frequent sequential pattern mining means discovering all sequences s such that $support(s,\ \mathcal{D}) \geq k$, where s is called *frequent sequential pattern* and k *minimum support threshold*. As said before, sequential pattern mining can reason about sequences of events in a given time frame and we encoded this in ASP by exploiting temporal information to create the suspects' relationship network, to identify associations between individuals and to highlight the patterns or “lifestyles” of the suspects [15, 16]. To better understand the following example, we provide some clarifications regarding the syntax and the semantics. Each answer set returned is a sequential pattern represented by means of the $path/2$ predicate. Listing 1 shows one of the 15 generated run over 100 instances from the DigForASP dataset, with maximum pattern length equal to 3 and minimum support threshold equal to 25%. It represents the sequential pattern which consists of two communication events. The first is between Karen Cook McNally and Margaret Hasse (Line 1), while the second is between Joan Aiken and Karen Cook McNally (Line 2), finally between Lucie Julia and Karen Cook McNally (Line 3). For example, considering the day Sept. 8th, 2040, we know that Karen, the subject of the phone records, sent a text message to Margaret at 1:1:34 (Line 5). Later, Karen received a incoming call from Joan at 8:19:53 (Line 6) and once again Karen re-

Listing 1 Example of sequential patterns found

```
1: pat(1,(karen_cook_mcnally,margaret_hasse))
2: pat(2,(joan_aiken,karen_cook_mcnally))
3: pat(3,(lucie_julia,karen_cook_mcnally))
4: support((8,9,2040)) support((11,9,2040))
5: pat_information((8,9,2040),
   (1,(karen_cook_mcnally,margaret_hasse)),
   out_sms(simple),(1,1,34))
6: pat_information((8,9,2040),
   (2,(joan_aiken,karen_cook_mcnally)),
   in_call(simple),(8,19,53))
7: pat_information((8,9,2040),
   (3,(lucie_julia,karen_cook_mcnally)),
   in_call(simple),(8,53,18))
8: pat_information((11,9,2040),
   (1,(karen_cook_mcnally,margaret_hasse)),
   out_call(simple),(13,21,47))
9: pat_information((11,9,2040),
   (2,(joan_aiken,karen_cook_mcnally)),
   in_call(simple),(15,21,36))
10: pat_information((11,9,2040),
   (3,(lucie_julia,karen_cook_mcnally)),
   in_call(simple),(15,44,14))
11: pat_information((11,9,2040),
   (1,(karen_cook_mcnally,margaret_hasse)),
   out_sms(simple),(16,20,32))
12: len_support(2)
```

ceived an incoming call from Lucie at 8:53:18 (Line 7). The same type of information is obtained by analyzing the other day (September 11th, 2040). Patterns can be graphically presented by Clingraph[2] [17] to better clarify the semantics of each answer set as in Figure 1.

Contrast Pattern Mining [7] involves the concept of contrast. It can therefore describe the significant differences between datasets under different contrast conditions. A *transaction dataset* $\mathcal{D}$ (Table 2) is a multi-set of transactions, a *transaction* t is a non-empty set of items with associated a *transaction identifier TID* and the TIDs are unique and can occur multiple times in $\mathcal{D}$. A dataset $\mathcal{D}$ may be associated with classes. In this case, some number $k \geq 2$ of class labels $C_1, \ldots, C_k$ are given, and $\mathcal{D}$ is partitioned into k disjoint subsets $\mathcal{D}_1, \ldots, \mathcal{D}_k$ such that $\mathcal{D}_i$ is the dataset C_i class. Contrast pattern mining could exploit background knowledge to extract less but meaningful patterns. It is an interesting class of pattern mining problems halfway between discrimination and characterization of a data set, thanks to the use of classes to guide the search for regularities. We have encoded a basic contrast pattern mining problem with ASP and applied the encodings to find the outgoing/incoming calls/SMS characteristics and habits (from now on, referred to as *classes*) of each suspect in the DigForASP dataset [12]. A single pattern is associated with each answer set and, in our approach, represented by means of the *in_pattern/1* and *absolute_diff/1* predicates. The latter expresses the difference in support of the pattern between the class under consideration and the complementary class. Each pattern conveys information that allows to characterize the considered class. In Listing 2, as an illustrative example of the potential usefulness of contrast pattern mining in the DF field, we report the results obtained on Karen's phone records for the class "in call". Here, we have set the minimum support threshold to 10% and the maximum pattern length to 3. Overall, the patterns found provide rich information about Karen's incoming calls in contrast to other types of communication. Notably, they tell us that incoming calls of Karen are mainly received in the afternoon (Answer 3) and less in the morning (Answer 4).

Details of the ASP encodings and the experimental

[2] https://clingraph.readthedocs.io/en/latest/.

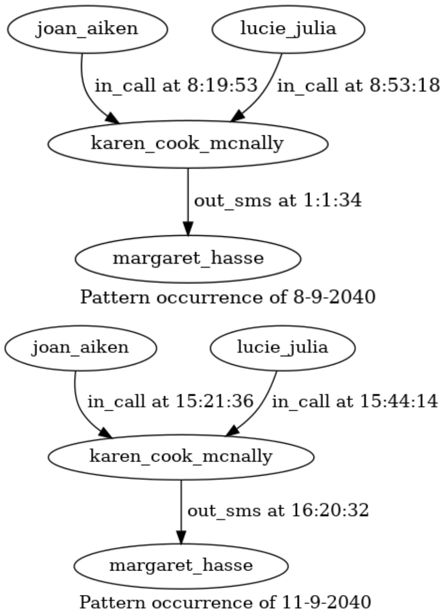

Figure 1: The two occurrences of the sequential pattern corresponding to Listing 1.

Table 2
An example of transaction dataset $\mathcal{D}$.

TID	ITEMS
T1	bread, cat food, cereal, egg, milk
T2	bread, juice, yogurt
T3	butter, cereal, diaper, juice, milk
T4	bread, juice, yogurt

Listing 2 Some contrast patterns for incoming calls

```
1: Answer: 1
   in_pattern(callee(karen_cook_mcnally))
   absolute_diff(216)
2: Answer: 2
   in_pattern(callee(karen_cook_mcnally))
   in_pattern(time(afternoon)) absolute_diff(106)
3: Answer: 3
   in_pattern(time(afternoon)) absolute_diff(130)
4: Answer: 4
   in_pattern(time(morning)) absolute_diff(43)
5: Answer: 5
   in_pattern(callee(karen_cook_mcnally))
   in_pattern(time(morning)) absolute_diff(72)
```

results for the sequential pattern mining and the constrast pattern mining problems considered in our application to the DigForASP dataset can be found respectively in [15, 16] and [12].

5. Collaborations

Thanks to the Short-Term Scientific Mission (STSM) funded by the DigForASP project, Gioacchino Sterlicchio (currently Ph.D. student in Aerospace Sciences and Engineering at the Polytechnic University of Bari under the supervision of Prof. Lisi) could visit Prof. Billard at the University of Applied Sciences of Geneva. During the mission it was possible to share the results obtained and establish future collaborations. This STSM was intended to exchange knowledge and obtain feedback for our work from DF experts. However, it turned out to be also a great opportunity to disseminate our work also in other application domains. Prof. Billard organized different interesting meetings for him, with experts from the DF field and from other fields interested in applying our approach to solve their problems to broaden the application horizon. We showed our work to Patrick Ghion, head of the forensic department of the Geneva Police. We talked about our work that attracted interest in the type of insights that can be extracted and we discussed how to apply a new privacy-preserving technique of anonymization to spatial data so that they can be used safely in the DigForASP dataset. After a meeting with Prof. Giovanna Di Marzo, head of the Computer Science Department at the University of Geneva, we have been invited to show our work at Digital Innovators[3], a series of monthly seminars describing a digital innovation and its application in a use case. We also showed our work to Prof. David-Zacharie Issom, head of Algorithms and Programming Division Department of Information Systems at University of Applied Sciences of Geneva. He is fascinated on how pattern mining can be applied to his problem in medical science, and extremely interested in using IA to translate knowledge into action, specifically to enable data analysis using IA methods and to visualize and reduce risks.

[3]https://cui.unige.ch/fr/pin/digital-innovators/

6. Conclusions

The challenge in DigForASP and in our work was to create a link between declarative AI and DF. In particular, we have contributed to the creation of innovative tools that automatically extract useful information about "lifestyles" of suspects from their telephone records. The application of our declarative AI techniques in investigative contexts is certainly an advantage, thus reducing the time to collect evidence and consequentially to capture the perpetrator(s) of a crime. The use of automated tools, such as these ones, capable of exhaustive research to explore evidence and go beyond human observation will surely become a breakthrough with an immediate impact on the practical investigation of crime scenes. Therefore, law enforcement, investigators, intelligence services, criminologists, prosecutors, lawyers and judges will have decision support systems in place, and can help make judicial proceedings clearer and faster essential properties in DF.

For the future we are interested in expanding the analysis by considering spatial data. Also, we intend to discover anomalous behavior by applying *Rare Pattern Mining* [18], and to enrich the sequential patterns with new knowledge about the sequences of actions done or not done by a suspect (*Negative Sequential Pattern Mining* [19]). Furthermore, we would like to improve the efficiency and scalability for the contrast pattern mining task. This implies different choices for: (a) the hardware, (b) the encoding, (c) the solver, and (d) the computing platform. For instance, experiments could be replicated with other ASP solvers, such as DLV2 [20]. Beyond the efficiency improvement, we would like to consider other variants of the contrast pattern mining problem. Last but not least, we would like to continue the collaboration with DF experts (from inside and/or outside the DigForASP network) in order to get their feedback as regards the validity and the usefulness of our work, and their suggestions for new interesting directions of applied research in this field.

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