A tool for generating, structuring, and analyzing multiple hypotheses in intelligence work

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***Abstract*—In this paper, we present an analysis tool that is developed to support the process of generating and evaluating a large set of hypotheses. The computer tool is to a large extent based on two established analytical methods, *Morphological Analysis* and *Analysis of Competing Hypotheses*, and aims to facilitate the analysis by offering support for organizing and visualizing information. In particular, the tool provides support for efficient management of links between evidence and hypotheses. By linking evidence directly to elements of a morphological chart, the analyst can work directly with sets of hypotheses and thereby significantly decrease the number of manual steps necessary to complete the analysis.**

I. Introduction

When evaluating the risk of a potential threat or conducting a forensic analysis, there is often a set of hypotheses that at an early stage in the investigation are identified as particularly interesting. Each such hypothesis can have a number of possible variations. In addition, there may exist a set of hypotheses that need to be considered even though they are seen as less likely, for instance because the consequences of having disregarded them if they should come true are so severe that the risk cannot be taken. As a consequence, the number of relations between evidence and hypotheses rapidly increases when new evidence related to the investigation become available. For a human analyst, keeping track of all the information associated with the investigation can become a challenge even with only a few general hypotheses. To reduce the risk of overlooking important information, a structured analysis process is recommended.

In this paper, we present a computer tool developed to support a structured process covering both the generation and evaluation of hypotheses. We refer to the tool as the *Multi-Hypothesis Management and Analysis tool*, or the *MHMA tool* for short. The support for hypothesis generation is based on *Morphological Analysis* [1], a method that from a number of user defined variables and values structured in a so called morphological chart, generates a large amount of hypotheses. In our tool, these hypotheses are then evaluated through a process inspired by the analytical method called *Analysis of Competing Hypotheses* (ACH) [2]. In ACH, all hypotheses are matched against all evidence in a hypothesis-evidence matrix. For each combination of hypothesis and evidence, an assessment is made of how strong that particular evidence supports or contradicts that particular hypothesis. The assessments are noted in the corresponding matrix elements and by analyzing the resulting matrix the most likely hypotheses can be found. However, as the number of hypotheses generated using morphological analysis becomes very large, it is not feasible to apply ACH directly on all hypotheses. Our approach for solving this is to match evidence indirectly against hypotheses via the elements in the morphological chart. This significantly decreases the number of manual steps necessary to complete the analysis and allows the management and evaluation of large amounts of hypotheses.

The paper is organized as follows. Sections II and III give some background to the presented work; in section II the use of structured analytical methods in intelligence analysis is motivated, and in section III the two analytical methods that constitute the basis for this work are described. Section IV contains a discussion on related work. The tool is described in section V, and the work flow is illustrated with an example in section VI. Section VII contains a passage on future work and finally, an overall summary is given in section VIII.

II. Background: Structured analytical methods in intelligence analysis

A. The intelligence process

Traditionally the intelligence process is described through a model called the intelligence cycle, which consists of a number of steps including planning, collection, processing and dissemination. In its original form the model describes a one-directed flow through the steps of the cycle, but this is far from always the case in reality. In [3], Pirolli and Stuart suggest a more elaborate model derived from a cognitive task analysis based on interviews of intelligence analysts (figure 1). The model shows a lot of back loops suggesting a very iterative process, mixing top-down and bottom-up perspectives. Two main parts of the model can be discerned, the *foraging loop* and the *sensemaking loop*. The foraging loop consists of activities involving searching, filtering, reading and extracting information, which eventually ends up in some sort of schematized evidence. The sensemaking loop uses the schema to build a case with multiple hypotheses which are evaluated based on the evidence. Most often the case resides inside the head of the analysts as an implicit mental model. The purpose of the MHMA tool described in this paper is to support the sensemaking loop by allowing the analysts to express their mental models explicitly and make auditable connections between the evidence and the hypotheses of the model.

Intelligence analysis can be data-driven, model-driven or a hybrid of the two. In model-driven methods, the analysis is centered around a model that is put together with the purpose of describing the situation in the real world with an apropriate

978-0-7695-5062-6/13 $26.00 © 2013 IEEE
DOI 10.1109/EISIC.2013.11

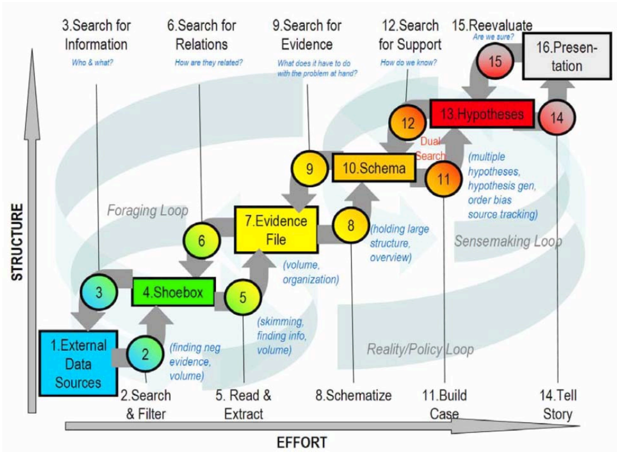

Fig. 1. The foraging and sensemaking loops acoording to [3].

level of abstraction. Preferably, an experienced analyst with expert knowledge should take part in the development of the model. In data-driven methods on the other hand, analysis is centered around data. When investigating rare events, such as terror attacks, the amount of data is usually not large enough to enable purely data-driven methods. Instead model-driven or partly model-driven methods must be applied. The reverse problem arises when the amount of data is too large for manual treatment, but there are no computer support tools available to assist in the analysis process. The analyst may then be forced to use a model-driven approach, although a data-driven or a hybrid approach would have been preferred. In such a case, introduction of computer support tools, such as the one described here, would allow for an increased influence of collected data on the analysis results.

In hybrid systems, a common approach is to first construct a model and then use it to generate hypotheses that can be validated or discarded based on collected data. A hypothesis in this case can for instance be a theory about future turns of events or an attempt to explain how past events could have been responsible for a set of observations. The process of generating and identifying the hypothesis that best explains a set of observations is known as abductive reasoning, and can be conducted qualitatively, with methods such as ACH, or quantitatively, using for instance Bayesian networks.

B. *Motivation for using structured analytical methods*

Perhaps the most powerful argument for using structured analytical techniques is that they can help reduce the risk of cognitive bias affecting the analysis [2], [4]. Human cognitive factors that might bias an investigation include:

- *The tendency of finding patterns where there are none;*
  It is often tempting to overinterpret data to match some pattern. Conclusions should never be drawn without substantial data to back them up.
- *The tendency of placing undue confidence in evidence that support one's own opinion;*
  Humans tend to search for evidence that support, rather than contradict, established hypotheses. In addition, there is a tendency of assessing evidence that support established hypotheses as more reliable than other evidence.
- *Prejudice due to previous experience;*
  If one has previous experience from similar situations is easy to unconsciously apply this experience in the analysis without reflecting over the fact that one thereby introduces new assumptions into the analysis.
- *Group behavior;*
  It is likely that the opinions of family members, friends and co-workers affect our own opinions.

Other reasons for using structured analytical methods in intelligence are:

- Analytical methods can be used to get the thought process started in a workgroup, so called facilitation, and serve as a basis for discussion.
- The risk of missing important aspects in the analysis is reduced.
- Analytical methods can provide some support in the assessment of reliability and credibility of the analysis results.
- Documentation is easier if a structured work process is used in the analysis. Notes and other working material, such as charts and diagrams, can be used as part of the documentation.

The use of structured analytical methods and techniques can help analysts to question established opinions more often and give better account for underlying assumptions. Structured analytical methods can be very useful when trying to verify that conclusions drawn are as objective as possible and based on reliable information rather than on subjective assumptions.

III. Background: Method descriptions

The tool presented in this paper is based on established analytical methods used in intelligence analysis, although the methods have been somewhat modified in order to fit better with each other and the selected representation of data. In this section we describe two methods that have influenced the proposed method and the design of the MHMA tool, namely *Morphological Analysis* and *Analysis of Competing Hypotheses (ACH)*. In the MHMA tool, morphological analysis is used more or less in its standard form to generate the hypotheses. Analysis of competing hypotheses on the other hand is not used explicitly, but the underlying ideas for how to connect hypotheses and evidence have been incorporated in the tool. Exactly how the methods are used with the MHMA tool is described in more detail in section V.

A. *Morphological analysis*

Morphological analysis is an analytical method that is used to systematically generate plausible hypotheses or possible future developments given a specific situation. The method is typically used in situations where the solution space is too large to overview, but where there is a need to make it more concrete in order to be able to analyze it.

The idea in morphological analysis is to identify a limited number of key parameters, or *dimensions*, which make up essential parts of a hypothesis and use them to discretize the solution space. Once the discretization has been made and possible values for all key parameters have been defined, all feasible hypotheses associated with the discretized problem can be listed. In this representation, a hypothesis is composed of one value from each of the selected dimensions. We illustrate with an example.

Example: *In a specific homicide investigation, relevant variables are* Culprit, Placement of culprit *and* Weapon. *After identification of possible values for the three variables, the morphological chart (table I) is constructed. An example of a hypothesis that can be generated from the morphological chart is* (Lee Harvey Oswald, Book depository, Carcano rifle).

TABLE I. EXAMPLE OF MORPHOLOGICAL CHART.

Culprit	**Placement of culprit**	**Weapon**
Lee Harvey Oswald	Hotel kitchen	22-caliber revolver
Sirhan Sirhan	Book depository	Remington 760 Gatemaster
James Earl Ray	Hotel bathroom	Carcano rifle

Hopefully, the set of hypotheses generated from the discretized problem will give a good idea of the span of the real solution space. The procedure can be summarized as follows:

1) Select key parameters/dimensions. In order to keep the number of hypotheses down, try to limit the number of dimensions to 5-8.
2) List possible values for all key parameters/dimensions.
3) Create the morphological chart. The chart is used to give a visual overview of the dimensions and their corresponding values, thereby improving the analysts understanding of the problem
4) Reduce the solution space using cross-consistency assessment. This step is optional. An analyst studies the morphological chart and mark pairs of values that cannot be part of the same hypothesis because they are logically inconsistent.
5) Extract hypotheses/scenarios. The complete set of feasible hypotheses is found by systematically generating all possible combinations of values from the different dimensions, discarding the hypotheses that contain pairs of values that were marked as infeasible in the cross-consistency assessment.

One purpose of using a structured method like morphological analysis can be to find feasible but in some sense unexpected solutions or hypotheses that are otherwise easily overlooked.

Morphological analysis does not require computer tools. The morphological chart can be drawn manually on e.g. white board and serve as a basis for discussion. However, computer tools are helpful especially in the cross-consistency step where they can assist in keeping track of pairs of values that are identified as infeasible. Also, if one wants to explicitly generate all feasible solutions, computer tools are recommended.

B. Analysis of competing hypotheses

Analysis of competing hypotheses is a well-established method for intelligence analysis. It was developed during the eighties by former CIA associate Richards J. Heuer and is used when there is a need to decide which one of a number of mutually exclusive hypotheses that is most (or least) likely to be true, based on available evidence. In ACH, a combined assessment of the reliability and credibility of each individual piece of evidence in relation to each hypothesis is made. The assessments are entered in a table which is then used to weight the hypotheses against each other. An example of an ACH table is shown in table II.

TABLE II. EXAMPLE OF ACH TABLE.

	Hyp. 1	Hyp. 2	Hyp. 3	Hyp. 4
Evidence 1	+	/	/	/
Evidence 2	/	+ +	/	/
Evidence 3	/	-	/	/
Evidence 4	/	/	/	+
Evidence 5	/	- -	+	/

ACH can be summarized in the following steps:

1) List all hypotheses and evidence (including assumptions and logical arguments).
2) Draw/set up a table with hypotheses vs. evidence.
3) For each combination Hypothesis Evidence, classify how strongly that specific evidence supports/contradicts that specific hypothesis. Use a pre-defined scale for the classification, for instance a symbolic scale like the following:
   - - - strongly contradicts the hypothesis
   - \- contradicts the hypothesis
   - / neither contradicts nor supports the hypothesis
   - \+ supports the hypothesis
   - \+ + strongly supports the hypothesis
   - NA not applicable

   Insert the classifications in the table.
4) Revise the table. If necessary, add, remove or merge hypotheses.
5) Analyze. Which hypotheses are most strongly supported? How reliable are the assessments made and how robust are the conclusions to misjudgements?
6) Summarize the process and the results. Discuss the robustness, identify weak links in the analysis, suggest actions that can be taken to increase reliability, etc.

The aim of ACH is not only to generate a decision by singling out one of the hypotheses as the most/least probable, but also to provide a strong motivation for the decision made. ACH, just like other methodological approaches to intelligence analysis, helps to bring transparency into a process that is otherwise difficult to get a grip of. In particular, ACH forces the analyst to explicitly declare all assumptions made, thereby reducing the risk of prejudices and weakly supported assumptions to decisively affect the end result of the analysis. If all steps in the ACH process are properly documented it should be easy to go back and see exactly what circumstances/evidence/assumptions motivated the overall conclusion.

ACH can be used by a single analyst, or by a group of analysts working together. As much of the ACH process revolves around the assessment of subjective information and assumptions, the method provides a good basis for discussion. A weakness is that although the method is well-known there is little research that shows when, or even if, the method actually improves results. On this area, more research is needed. Technical tools are not necessary when working with ACH, but computer tools that are designed to support ACH can facilitate the work in many ways. Some of the functionalities a computer program could provide are:

- Sorting options for the ACH table.
- Options to visualize different sorts of additional information, such as for instance where in the ACH table different analysts' assessments differ.
- Functions for handling of large amounts of evidence and related information/details.
- Automatic documentation of changes in the model.

IV. Related work

The existence of computer tools that support analytical methods is nothing new. Simple tools that support a single method, such as for example ACH, are readily available both commercially and as free versions on the Internet [5]. However, the authors of this paper have found few references to tools that are designed to support a more comprehensive analysis process through several different phases of the analysis.

At the Swedish Defence Research Agency (FOI), morphological analysis has long been used for hypothesis generation in operations research. To facilitate the generative process a support tool, *MA/Casper* (*Computer Aided Scenario and Problem Evaluation Routine*), was developed around year 2000. The tool and the computer aided process are described in [6]. The MHMA tool presented in this paper is not based on Casper directly, but the procedure for constructing the morphological table in the MHMA tool is very similar to the procedure in Casper, although simplified.

In addition to the simple ACH-tools mentioned above, more advanced tools for hypothesis evaluation are being developed in academia. Impactorium is a tool which allows an analyst to split hypotheses into many sub-hypotheses in order to structure evidence and make probability-based assessments [7]. A similar tool is the Disciple-LTA which is focused on assisting inexperienced analysts through the assessment process [8]. However, none of these tools give good support for managing large amounts of competing hypotheses.

In [9], the authors describe a prototype tool that is designed to assist analysts in managing multiple hypotheses. More specifically, the tool is designed to support *Multiple Hypothesis Situation Analysis* (MHSA), which is a framework for handling uncertainties in analysis of hypotheses. The MHSA approach clearly differs from our approach. The purpose of the MHMA tool is to introduce method into the analysis, by first helping the analyst find all possible hypotheses, and then assisting in going through evidence systematically to find the hypotheses that are most interesting to analyze further. The MHSA support tool, on the other hand, has focus on quantitative analysis and does not provide the same support for discussion and intuitive understanding. As the two tools support different phases of the analysis process they can in a sense, despite the differences in hypothesis representation, be seen as complementing each other.

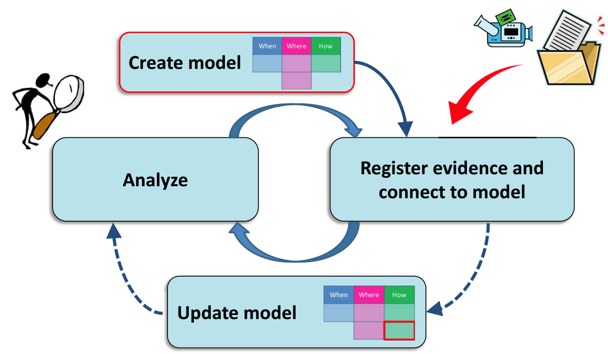

Fig. 2. The multi-hypothesis analysis process.

A tool which actually claims to be designed to support a more comprehensive analysis process is the Globalytica Tool Suite [10] which is under development by Globalytica LLC. The Globalytica tool suite contains support for both hypothesis generation (based on morphological analysis) and ACH, and the company (Globalytica LCC) claims that information can be seamlessly transferred between the different tools. However, in contrast to our approach, the Globalytica tool suite supports the various analytical methods in their standard forms, which means that the hypotheses generated during the morphological analysis have to be assessed individually in the ACH. As the number of generated hypotheses quickly can grow large, this in practice means that only a fraction of the generated hypotheses can be selected for evaluation, and the rest must be discarded.

V. Presentation of the Multi-Hypothesis Management and Analysis tool

The analysis process supported by the MHMA tool is illustrated in the form of a process diagram in Figure 2. The MHMA tool has three main functionalities: *Hypothesis generation*, *Evidence processing support* and *Basic support for analysis*. These functionalities correspond to the nodes *Create model*, *Register evidence and connect to model* and *Analyze* in the process diagram. In this section the steps in the analysis process and the corresponding functionality in the MHMA tool are explained. An overview of the user interface can be seen in Figure 3. The description of the analysis process and the MHMA tool is complemented by a step-by-step example in section VI.

As seen in Figure 2, the analysis process is iterative. In the first step of the analytic process the analyst creates a model of the investigated problem. The model is used by the MHMA tool to generate a set of hypotheses for the analyst to work

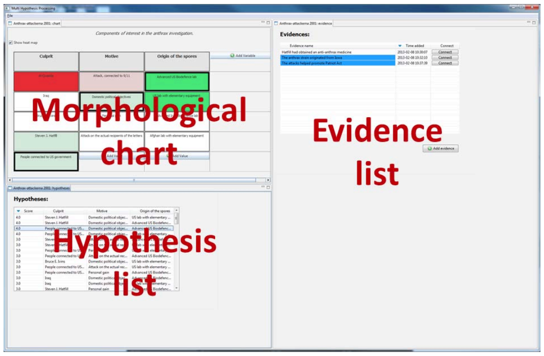

Fig. 3. A view of the user interface, showing the placement of the morphological chart, the hypoteses list and the evidence list.

with. Once the model is in place, the process enters a loop; when a new piece of evidence is reported, it is registered and connected to the model, the support for different hypotheses will automatically be updated by the MHMA tool and the analyst can proceed to focus on the analysis phase until new evidence that may affect the case becomes available. The iterative process proceeds until no more evidence is reported, or until the analyst in charge makes the judgement that the available evidence is enough to decide which hypotheses that should be selected for more in-depth analysis.

A. *Hypothesis generation*

In the structured analysis process we propose, the analyst must start by setting up a model that defines the hypothesis space (note that registration of evidence in the MHMA tool is possible even before the process has been started). The hypothesis generation supported by the MHMA tool is based on Morphological Analysis (section III). Thus, the model in this case is the morphological chart, which is made up by a set of variables corresponding to the morphological dimensions and their possible outcomes/values. The set of variables should represent key parameters of the investigated problem and are defined by an analyst or subject matter expert.

Defining a suitable set of variables is a non-trivial task and it requires domain knowledge. If suitable dimensions are not obvious in the modeling phase, one can try to use the classical *five Ws*; *who*, *what*, *when*, *where*, *why*, with the optional addition of *how*. These dimensions are used as default options in the Globalytica toolsuite, but in the MHMA tool the decision is left for the analyst. In section VI we show an example of how a specific problem can be modeled. A model may need to be modified or revised several times during the analysis process. Revision of the model is supported by the MHMA tool and can be done at any time.

B. *Evidence processing*

One of the main tasks of the MHMA tool is to assist the analyst in managing evidence. Each piece of evidence is registered in the system with name and description and is then displayed in a list that can be sorted in alphabetical (based on evidence name) or chronological order. The analyst can then choose to connect the evidence to the hypothesis model, *i*.e., the morphological chart. A connection is by definition allowed between a single piece of evidence and a single value in the model and is either *supportive* or *contradictive*.

As evidence is connected to individual elements in the morphological chart, connections between evidence and complete hypotheses are implicit. A value in the morphological chart is typically part of several different hypotheses. If a piece of evidence supports or contradicts one specific value, that evidence will also implicitly support or contradict all hypotheses associated with that value. This fact enables a ”semi-automatic” assessment of hypotheses. Instead of having to individually assess the possibility of a connection between every new piece of evidence and every single hypothesis, the analyst can get a satisfactory result from assessing only the possible connection to one or more of the values in the morphological chart. A value representing the overall support for a hypothesis can be automatically computed by weighting together the amount of supportive and contradictive evidence that is connected to the hypothesis in question. The potential gain that comes from a decreased need for manual assessments is illustrated by the following example.

Example: *A morphological chart with* n *variables, all having* m *possible values each, contains a total of* mn *values. The same table will generate* m^n *hypotheses. With* $n = 3$ *and* $m = 4$*, there will be* 12 *values in the chart and* $4^3 = 64$ *hypotheses. With* $q = 4$ *registered pieces of evidence, there will be* $mnq = 48$ *links for the analyst to consider in the first case and* $qm^n = 256$ *in the second case.*

In the current version of the MHMA tool the *ranking score* is crudely computed as

$$\text{\# supporting evidence} - \text{\# contradicting evidence}. \quad (1)$$

In future versions of the tool, a more versatile formula for weighting together evidence support should be considered. Also, the binary classification of evidence connections as either supportive or contradictive is in many cases inadequate and should be replaced with a scale that has higher resolution. Further discussion that relates to the weighting of evidence and ranking of hypotheses is found in section VII.

C. *Basic support for analysis*

The first version of the MHMA tool includes a set of basic analytical support features, including

- Ranking of hypotheses. As described above, a ranking score is computed for each hypothesis based on the amount of evidence that are connected to the hypothesis.
- Overview of connections between evidence and hypotheses / model values
- A heat map view of the morpholgical chart visualizing which values have strong support from evidence or is strongly contradicted by evidence.

These features are intended to help the analyst assess the current situation and to visualize the evidence and assumptions on which decisions are based. Future versions of the MHMA tool will include support of exploratory analysis, such as excluding or including sets of evidence to see how they influence the analysis result.

TABLE III. POSSIBLE CULPRITS

Possible culprit	Comment
Al-Qaida	Immediately indicated due to the fact that the anthrax letters were sent shortly after 9/11.
Iraq	Since the first Gulf war, the Hussein regime was a sworn enemy of the US, and was known to have an extensive bio weapons programme.
Steven Jay Hatfill	American bio-weapons expert. In 1999, Hatfill commissioned William C. Patrick, retired head of the old US bioweapons program to write a report on the possibilities of terrorist anthrax mailing attacks. The resulting report was seen by some as a "blueprint" for the 2001 anthrax attacks.
Bruce Edwards Ivins	American biodefense researcher. The investigation showed that Ivins had access to a flask of anthrax spores of the same strain as the one used in the attacks.
People connected to US government	

TABLE IV. POSSIBLE MOTIVES

Possible motive	Comment
Attack inspired by 9/11	Could be politically and/or religiously motivated.
Domestic political objectives	For instance, the attacks likely contributed to the momentum which ultimately led to the 2003 war against Iraq.
Personal gain	Biodefense researchers might be said to gain personally from the attacks, as they spurred significant increases in U.S. government funding for biological warfare research.
Attack on the actual recipients of the letters	The attack could have been aimed specifically at the recipients.

VI. EXAMPLE: MODELING THE 2001 ANTHRAX ATTACKS

In this section we illustrate how the MHMA tool can be used in a forensic investigation. As a demo case we have chosen to consider the investigation following the 2001 anthrax attacks in the United States. As the terror attacks in themselves are not the focus of this paper we use the facts of the case as described on Wikipedia [11] and take no responsibility for the reliability of the source. Naturally, the scenario has been somewhat simplified to fit in the paper. In the following subsections we show how to construct a model, connect evidence to the model, and analyze the result.

A. Background on the case

A mere few weeks after the 9/11 attacks, it was discovered that letters containing anthrax spores had been mailed to three major New York-based news broadcasting networks, two newspapers and two democratic senators. Within a month, 22 people were infected by anthrax. In the subsequent investigation conducted by the FBI, terrorist organizations such as Al-Quaeda, as well as American biodefense experts were included in the list of suspects. On August 6, 2008, the investigation was closed as federal prosecutors declared biodefense researcher Bruce E. Ivins to be the sole culprit of the crime. However, the investigation and its conclusions have been questioned by several parties.

B. Step-by-step walk-through example

Identify parameters: The first thing to do in the analysis process is to identify the key parameters in the problem and possible values for those parameters. In this example, we identified three fundamental components that were of particular interest for the investigation: culprit, motive, and source of the anthrax spores. To limit the complexity, a maximum of five different values for each variable were considered. The values are listed in tables III, IV and V.

TABLE V. POSSIBLE SPORE SOURCES

Possible source of anthrax spores	Comment
Advanced American Biodefense Laboratory	Only a few american laboratories had the technical equipment needed for advanced weaponization of anthrax spores.
US laboratory with elementary equipment	
Afghan laboratory with elementary equipment	
Advanced Iraqi bioweapons laboratory	Laboratories left from the Iraqi bio-weapons program were likely to have equipment needed for advanced weaponization of anthrax spores.

Create the Morphological chart: The dimensions and their corresponding values are added to the morphological chart via the graphical interface. Additional dimensions and values can be added to the morphological chart at any time during the analysis process. As new variables are added to the morphological chart, the list containing hypotheses is automatically updated.

Register evidence: Available information (and possibly also assumptions) that is related to the case is registered as *evidence*, with corresponding name and description. All evidence registered in the system is displayed in the evidence list.

Connect evidence: An entry in the evidence list can be connected to one or several values in the morphological chart by a simple clicking procedure. Each connection can be either positive/supporting (green color) or negative/contradicting (red color). Figure 4 shows a positive connection between the piece of evidence "Hatfill had obtained an anti-anthrax medicine" and value "Steven J. Hatfill" in the morphological chart.

Analyze: When new evidence is linked to the model, the ranking score will automatically be updated for each hypothesis in the system. Figure 5 shows the hypothesis list (bottom left) sorted on ranking score in descending order, *i.e.*, with the hypotheses that have most support from registered evidence on top of the list. If a hypothesis is selected in the hypothesis list, all evidence connected to that hypothesis is highlighted in the evidence list. Also, as seen in Figure 5, the individual components of the hypothesis will be marked in the morphological chart. Another analysis function provided by the MHMA tool is the heat map, which can be switched on and off in the morphological chart depending on preference. When activated, the heat map gives an overview of how the support from registered evidence is distributed over the values in the morphological chart. Figure 5 shows the heat map (top left) for the example scenario after registration of the first three pieces of evidence. Apparently, these three pieces of evidence contradicts the possibility that Al-Qaida was behind the anthrax attacks and vaguely support the hypothesis that either Hatfill or people with government connections were involved. They also suggest that the spores originated from a US laboratory.

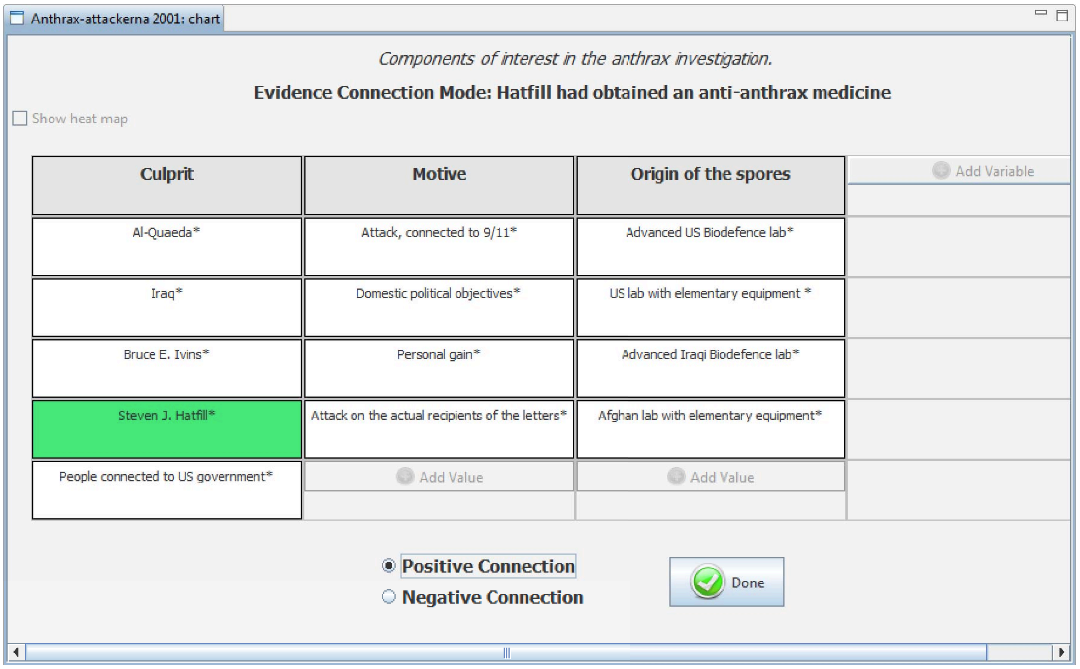

Fig. 4. The morphological chart in *evidence connection* mode, here showing the positive connection between evidence "Hatfill had obtained an anti-anthrax medicine" and value "Steven J. Hatfill" in the morphological chart.

VII. Future work

A. User studies

So far, the MHMA tool has been presented and demonstrated for analysts in the Swedish Armed Forces, but in order to properly evaluate the pros and cons of the proposed methodology and the computer tool, a more organized user study is planned. The focus of the user study is to evaluate the usefulness of the MHMA tool and to get feedback on existing and future functionality. A smaller study focusing on evaluating the user interface has also been discussed.

B. Further technical development

During the development of the MHMA tool, the aim has been to create a base platform for testing functionalities that successively can be extended and improved, for instance by the addition of new and more advanced analysis functions. Some of the functionalities that we plan to add are the following.

- The possibility to do cross consistency assessment on the morphological chart. In standard Morphological Analysis, cross consistency assessment is a procedure used to exclude hypotheses that are judged to be (logically) infeasible [12]. The procedure can potentially reduce the solution space, *i.e.*, the number of hypotheses to consider in further analysis, fairly drastically.
- The option to visualize connections between hypotheses and evidences in a standard ACH table.
- The possibility to activate/deactivate individual evidences in the evidence list. This functionality would make it possible to quickly and easily check how sensitive analysis results are to individual pieces of evidence. Although very basic, this sort of robustness analysis is intuitive and we believe it can be quite efficient.
- A more refined way of computing the ranking score for the hypotheses, as for instance in [13]. It should be possible for the user to choose whether to use a binary classification of evidence connections (classification as either *supportive* or *contradictive*) or an extended scale with higher resolution and more options. In addition, it should be possible to connect evidence to *combinations* of values instead of only to single values.
- The possibility to add weights to evidence based on an analyst's assessment of reliability and credibility for the given evidence.

VIII. Summary

In this paper we have presented a computer tool that is intended to support analysts in the sensemaking process. The tool is based on two well-known analytical methods, Morphological Analysis and Analysis of Competing Hypotheses. These are normally used independently of each other, both with and without computer aid, to support different parts of the sensemaking process. To our knowledge the methods have not previously been systematically used together. A contributing reason for this could be that the two methods require slightly different problem models, and that they therefore are not readily combined. To overcome this problem we have adapted the methods so that they can use a common model, and the computer tool is designed to support a greater part of the process so that unnecessary transferring of information between

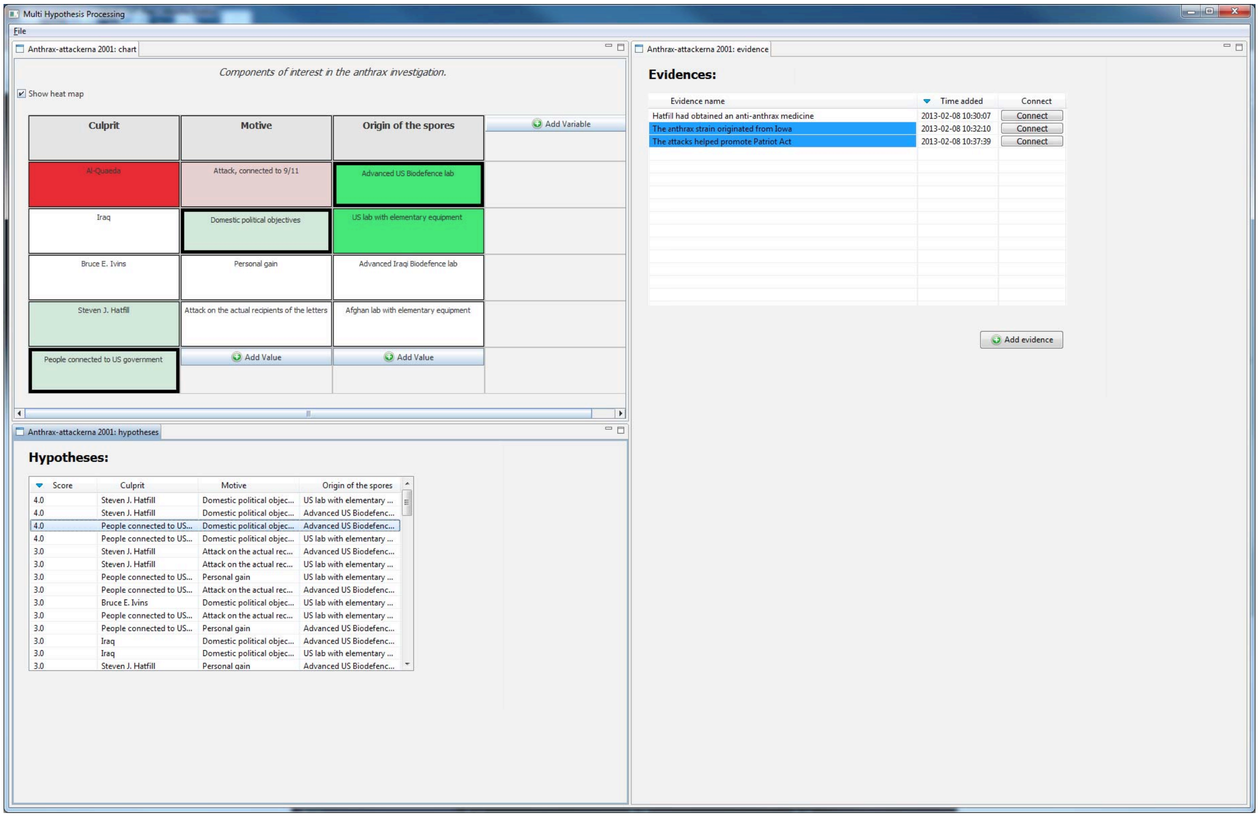

Fig. 5. A view of the full user interface in analysis mode, showing the morphological chart (upper left), the hypothesis list (lower left) and the evidence list (right).

systems is avoided. In addition, the tool provides support for handling of evidence. The tool has not yet been tested in a controlled user study, but feedback from demonstrations have been positive.

Acknowledgment

This research was supported by a VinnMer grant from Vinnova and the R&D programme of the Swedish Armed Forces.

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