Argument Mapper: Countering Cognitive Biases in Analysis with Critical (Visual) Thinking

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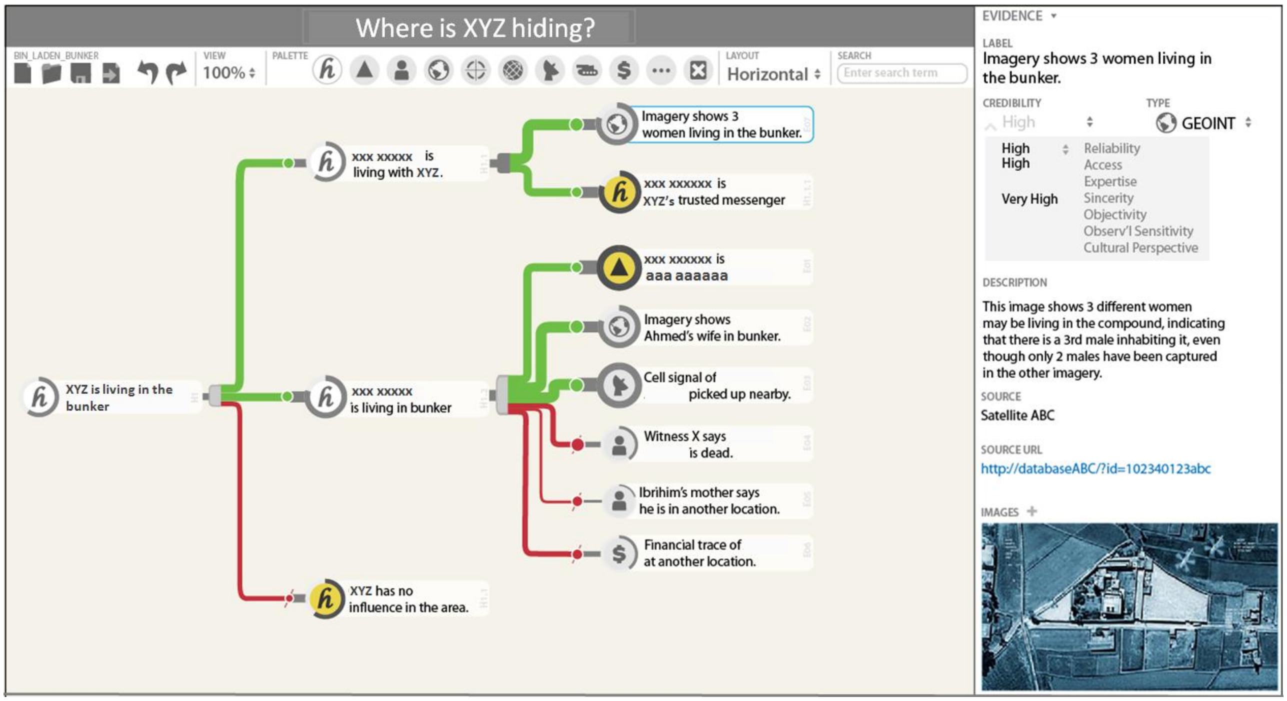

Figure 1. Argument Mapper layout. The central argument mapping canvas displays a node-link diagram. Nodes are hypotheses, evidence, assumptions or gaps. Links show the propagation of assessments from right to left. Analysts make assessments of evidence credibility and relevance. Assessments are shown with circular indicators. Gates combine evidence. The right hand sidebar shows details for a selected item of evidence (highlighted in blue in the canvas). The sidebar can also show aggregates of evidence, assumptions and evidence sources. The top toolbar provides palette of objects, layout options and search.

Abstract

Humans are vulnerable to cognitive biases such as neglect of probability, framing effect, confirmation bias, conservatism (belief revision) and anchoring. Argument Mapper addresses these biases in intelligence analysis by providing an easy-to-use, theoretically sound, web-based interactive software tool that enables the application of evidence-based reasoning to analytic questions. Designed in collaboration with analytic methodologists, this tool combines structured argument mapping methodology with visualization techniques to help analysts make sense of complex problems and overcome cognitive biases. The tool uses Baconian probability and conjunctive logic to automatically calculate the inferential force support for the upper level hypothesis. Evaluations with 16 analysts showed the tool was easy to use and easy to understand.

Keywords: Visual Analytics, Structured Thinking, Arguments

I. Introduction

Critical thinking in intelligence analysis and its education can be enhanced by creating interactive visualization support for structured thinking techniques. Visualization increases an analyst's perceptual and cognitive span thereby increasing the speed, comprehension, completeness, correctness and cognition applied to complex analytical tasks [23]. Structured analytic techniques help assess and make sense of complex problems, and overcome cognitive biases [8]. Combining visualization and structured analytic techniques will enable new "visual" critical and creative thinking. People will be able to more easily see and collaboratively share their structured thinking. Improved transparency into analysis and structured thinking enables strengths and weaknesses to be more easily visible and so improve the quality of arguments.

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The Argument Mapper tool is an example of visualization support for structured thinking techniques. It is an easy-to-use, theoretically sound, web-based interactive software tool that enables the application of evidence-based reasoning to analytic questions. This tool applies structured argument mapping methodology and visualization techniques to help analysts work with complex problems and mitigate against cognitive biases. Analysts use the tool to construct argument trees consisting of hypotheses, sub-hypotheses, assumptions and evidence. The analyst assesses the credibility and relevance of each evidence item. Once those assessments are done, then the inferential force or support for the upper level hypotheses is automatically calculated. Figure 1 shows an overview of the tool.

II. Overcoming Biases with Structured Thinking

Humans are vulnerable to cognitive biases such as neglect of probability, framing effect, confirmation bias, conservatism (belief revision), anchoring, recency bias, negativity bias and many others [7] [8]. For example, thirty-seven cognitive biases have been identified of relevance to decision support systems. They are grouped into categories related to memory, statistical, confidence, presentation and situation biases [1]. Cognitive biases can be viewed as predictable deviations from rationality.

To help compensate for these biases, structured thinking provides organizing frameworks to systematically evaluate a complex situation and its factors and relationships [24]. Heuer/Pherson list a "core" of 50 structured thinking techniques [9]. Structured thinking techniques externalize and make visible rationale thinking methods and so help an individual analyst to focus on details without losing sight of the whole. The externalization also allows people to collaborate by making it easier to review, ask questions and make suggestions. Use of structured thinking techniques makes critical thinking assessments easier to perform and helps mitigate cognitive biases.

III. Design Process

From the beginning, a user-centric approach to design has been followed with the Argument Mapper tool. The design process included structured interviews with representative analysts and methodology experts, design workshops that walked through initial sketches and exercises as well as early evaluations. It was also important to be theoretically sound in the assessment methodology. A review of current structured thinking analytical best practices [1][9] [14][24] and evidentiary theory [16][17] was completed.

Seventeen structured interviews in five organizations were conducted of which nine were with analytic methodologists. Structured interviews focused on the strengths and weaknesses of current methods of working with hypotheses and evidence. Example key observations included:

Terminology varied, and while few analysts used the term "hypothesis", in practice all organizations worked with analogies to evidence, hypotheses, assessment and confidence.

Analysis is often done in the absence of evidence e.g. anticipatory, predictive analysis.

Except for one group, no one used an existing argument mapping tool. However, methodology experts do facilitate sessions to manually apply argument mapping to an issue.

The scale of arguments was typically two to five "data points" or evidence items per "premise". Occasionally, for important assessments, about 50 to 100 "data points" were considered. When using the analysis of competing hypothesis structured thinking method [8][9], typically about three hypotheses are considered.

The capability for same time, different place as well as different time, different place collaboration was considered important.

The solution needs to be simple, easy-to-use, integrated with current data tools, and a step towards writing an assessment.

IV. Argument Mapper Workflow

Using the Argument Mapper tool, analysts can work both top down from hypotheses to evidence (i.e. deductive reasoning), and bottom up from evidence to hypotheses (i.e. abductive reasoning), and a mixture of both at the same time. Analysts can jot down alternative hypotheses, deconstruct them into simpler problems, and link evidence and assumptions to them in argumentation structures that establish the relevance, credibility and inferential force of evidence. Analysts can also start by compiling evidence, working with lists of evidence, and then arranging and linking evidence to support hypotheses. In place of evidence, analysts can use assumptions and note gaps. Evidence, assumptions, gaps and hypotheses are easily created, edited and moved in an argument map using drag and drop interactions or via efficient keyboard interactions. As the analyst evaluates evidence by assessing the evidence credibility and relevance, hypothesis and sub-hypotheses strength of *support* is continuously and automatically computed. Multiple alternative hypotheses can also be considered and compared at the same time. A competing or refuting hypothesis can be used to incorporate analysis of alternatives into an assessment. An example is shown in Figure 5. Eventually a report must be written. The argument map serves as an outline of the final report. While not currently implemented, report outlines could be generated based on a serialization of the argument map with automatic end notes for each evidence item. This would provide a "head start" for the analyst on writing their report.

V. ARGUMENT MAPPER COMPONENTS

The key concepts for the Argument Mapper tool include 1) deconstructing a hypothesis, 2) describing and associating evidence and assumptions, 3) setting evidence relevance in supporting the hypothesis, 4) setting evidence credibility, and 5) applying combining functions to evidence to determine if any or all evidence is needed to support the hypothesis.

In the visualization, nodes represent hypotheses, evidence, assumptions or gaps. Nodes give a quick visual summary of content, type, and credibility assessment. A layered icon technique is used to represent the properties of a hypothesis, assumption, evidence or gap. Figure 2 shows the icons used for evidence type, hypotheses and assumptions. Figure 3 shows the node fill encodings. A six point scale is used for evidence evaluation: No support, very low, low, medium, high and very high. Evidence may also be unassessed. Figure 4 shows the evidence credibility and relevance visual expressions for the six point scale.

Figure 2. Icons for evidence type, assumptions and hypotheses: (a) icons for special evidence sources, and (b) icons for public discourse.

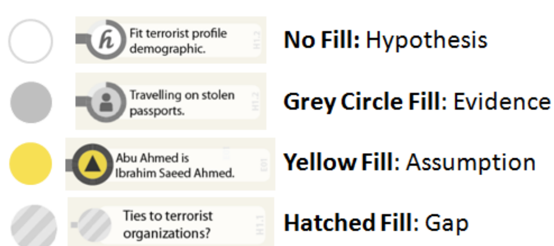

Figure 3. Node fill encodings. Gaps and assumptions are highlighted.

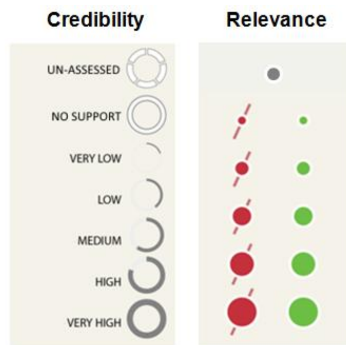

Figure 4. Evidence credibility and relevance circular indicators. Refuting evidence in red is double encoded for color blindness.

As shown in Figure 1 and Figure 5, the impact of evidence credibility and strength judgments is visually represented in the flow visualization shown as link thickness from right to left.

Much attention was paid to the careful expression of visual representations for information objects and their associated interactions. Small details make a big difference.

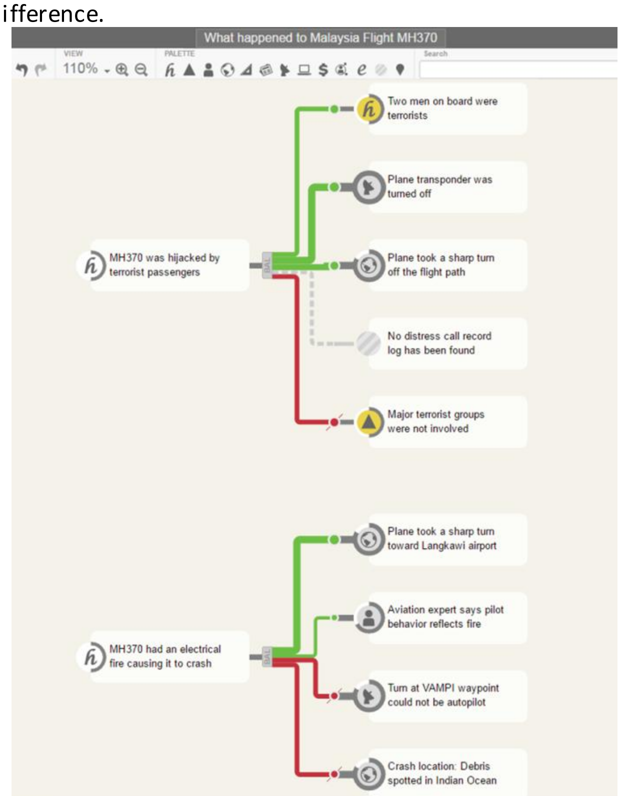

Figure 5. An example of another argument map. Two arguments are shown. Alternative hypotheses can be considered in the same argument context. One has a gap noted. The *link thickness* is proportional to the "probative force" of evidence and is a function of evidence credibility and relevance.

For example, the credibility ring increases in arc as well as thickness to grow in visual salience, and yellow is used to highlight assumptions as well as hypothesis support that have been manually set by the analyst to override the automatically computed support. In addition, as human short-term memory is limited, "paging" of information is avoided. Displaying larger amounts of an argument and its' characteristics in a single screen, while carefully avoiding clutter and conflict in the display elements, let people efficiently work with more complexity. Principles that link perception science to visualization graphics design guidance are used [23]. In addition, from a pragmatic perspective, Edward Tufte [21] articulates several best practices well which inspire the Argument Mapper design. Excellence in

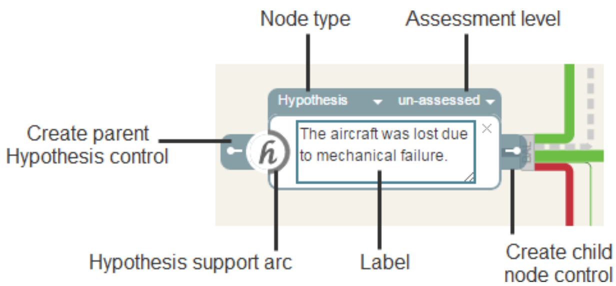

Figure 6. Node editing controls. Clicking on a node, or hitting the enter key while a node is highlighted, allows a user to edit a node and its' properties.

graphics consists of complex ideas communicated with clarity, precision and efficiency. Graphical displays should present many things in a small space, reveal data at several levels of detail, make large data sets coherent and induce the viewer to think about the substance.

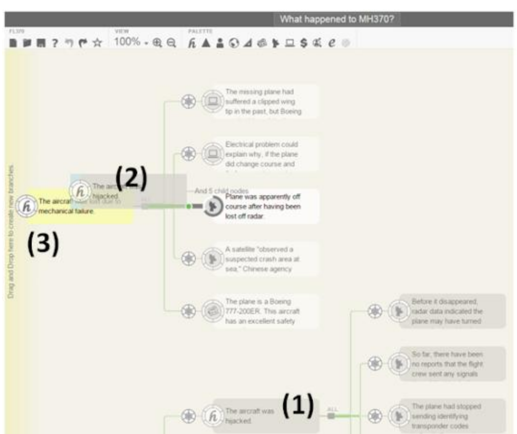

Figure 7. Interactive drag and drop editing of an argument map. (1) Select a part of the argument, (2) Move it to another part of the argument, (3) Drop zones are indicated in yellow.

Interaction methods were used to provide both a point and click, and drag and drop direct manipulation paradigm as well as a keyboard-centric tab and enter paradigm. Figure 6 and 7 show examples. Consistent and visible controls with an undo function promote exploration and learning of capability by novice users. Animated transitions maintain the user's contextual mental model. Zoom levels let people work with larger argument maps.

Ease of use with minimal training is an important objective to ensure acceptance by the end user community. Interactions are discoverable and understandable. Mouse-overs provide in-context explanations. In addition, there is an extensive help function available including short focused video tutorials.

VI. Evidence Evaluation

For evidence credibility, the analyst judges the strength of belief in the piece of evidence. There is a detailed system of criteria for credibility that can be used for key evidence (e.g. competence, authenticity, reliability, accuracy) [16][17]. The analyst expresses their assessment using a six point scale from "no credibility" to "very high".

For evidence relevance, the analyst considers how connected the evidence is to the hypothesis, and assuming the evidence has been evaluated by the analyst as having or not having some level of support. In other words, how relevant is the hypothesis based only on that piece of evidence? Does the evidence have a more or less direct bearing on the hypothesis? The analyst expresses their assessment of relevance using a similar six point scale from "no relevance" to "very high". Then, using conjunctive logic, the inferential force of that evidence is determined as the minimum of the relevance and credibility assessments. For example, low relevance and high credibility imparts only low support for the hypothesis. In other words, for an evidence item to be strong, it must be both credible and relevant to the hypothesis.

VII. Flow of Inferential Force

Argument Mapper allows analysts to estimate the strength of support for each hypothesis based on the inferential force of its evidence (where "force", also known as probative force [16], is a combination of evidence credibility and relevance). Forces are combined using conjunctive/disjunctive logic and Baconian probability combining functions and automatically propagated up the reasoning chain to show impact on the upper hypothesis. The automatic assessment of hypotheses is performed as the analyst assesses the evidence and is interactively updated as soon as the analyst changes any assessment of an evidence item. The analyst may choose to override the computed hypothesis support assessment (e.g. all the evidence, while strong, is coming from a single source and so the analyst decides to down grade the computed hypothesis support). When a hypothesis support strength is set by the analyst, it is colored yellow like an assumption node. An example is shown in Figure 1.

In the Argument Mapper, the strength of the evidence items are combined [18]. When considering a hypothesis H, there may be several items of evidence, both supporting and refuting the hypothesis H. "Gates" combine evidence assessments. Combining functions include "Any", "All" and "On Balance". "Any" is used when just one of several pieces of evidence are needed to support the hypothesis. In this case the maximum strength flows up. "All" is used when all the evidence items are needed. The minimum strength flows up for the "All" case. "On balance" is used when there is both supporting and refuting evidence types. The force of both types are combined using the lookup table in Figure 8 [19]. The "On balance" function uses Baconian ordinal probability [16]. For example, a very-high supporting evidence, when combined with a very-low supporting refuting evidence, becomes high supporting.

	U/A	NS	Very Low	Low	Med	High	Very High
U/A	U/A	U/A	U/A	U/A	U/A	U/A	U/A
NS	U/A	NS	NS	NS	NS	NS	NS
Very Low	U/A	Very Low	NS	NS	NS	NS	NS
Low	U/A	Low	Very Low	NS	NS	NS	NS
Med	U/A	Med	Low	Very Low	NS	NS	NS
High	U/A	High	Med	Low	Very Low	NS	NS
Very High	U/A	Very High	High	Med	Low	Very Low	NS

Figure 8. "On balance" combining function for supporting (along the left) and refuting evidence (along the top). "U/A" is unassessed. "NS" is no support (in the Baconian system of evidentiary reasoning).

This flow of inferential force to determine hypothesis support uses the "probative force or weight of evidence" and is based on simple Baconian ordinal probability methods for working with uncertainty rather than approaches based on Bayes' rule. Baconian methods allow working with situations where it is not possible to enumerate all possibilities. Many analytical arguments revolve around events that are not repeatable or amenable to enumerative statistical distributions and probability analysis. The Baconian ordinal probability approach originates from the judicial theory and traditions of working with evidence [16] [17] [18] which is in turn based on modern Baconian enhancements [5][6]. In the Argument Mapper tool, Baconian probability likeliness is used to compute the strength of hypothesis support [18][20].

VIII. Collaboration Functions

Analysts can share and collaborate on their structured reasoning using web-based user authentication and a storage component with a permissions structure. Meta-analysis notes are represented by markers over any argument map object as shown in Figure 9. The meta-notes can be used for explanations, questions, requests, etc. to complement the structured argument and communicate with other analysts working on the same issue, or act as notes-to-self when an analyst returns to an issue at a later date. Managers and reviewers can place their comments directly on the subject of their comments.

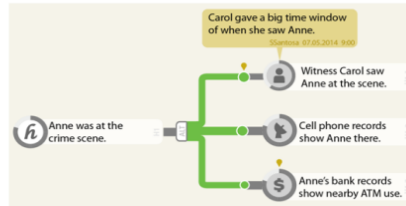

Figure 9. Meta analysis notes can be created to ease collaboration. They can be minimized and maximized.

IX. Implementation

The interactive Argument Mapper software tool has been developed by Uncharted Software Inc. (formerly Oculus Info Inc.) in collaboration with intelligence analysts and is supported by the evidentiary reasoning conceptual foundations of the Disciple-CD and Cogent expert systems developed by George Mason University's Learning Agents Center (LAC) [3][18][19]. The Argument Mapper is implemented in JavaScript and uses SVG to support graphic rendering and animated transitions. The requirement for cross-browser support for a wide selection of browsers had some influence on technology choices. The tool supports IE10+, Firefox 14+, and Chrome browsers and runs as either a widget within the open source Ozone Widget Framework [13] or embedded in the nSpace Sandbox [25] or as a stand-alone web-app. The server component persists argument maps, provides collaboration services and may communicate to other analytical services (e.g. LAC's Evidence-based Reasoning (EBR) expert system) through an API. Database management and user authentication and authorization protocols are determined deployment requirements.

X. Other Argument Mapping Tools

By providing web-based visual tools for evidence credibility and relevance assessment, as well as the automatic calculation, flow and visualization of evidentiary inferential forces in an argument, with the resulting evaluation of the strength of support for the upper hypotheses, the Argument Mapper tool provides a significant improvement in critical thinking support over Rationale [22] or other argumentation systems [15]. As discussed in the Evaluation section, the user evaluation workshops showed strong ease-of-use and comprehension of evidence-based argument mapping methodology for Argument Mapper. This is a significant improvement over previous evidence-based critical thinking tools like TIACRITIS or Cogent [18]. Working with gaps and assumptions is also an improvement as is the collaboration capabilities. With respect to concept maps [11] which can also be used to diagram an argument, concept maps are a flexible ideation tool to elaborate on ideas and their relationships but without an inherent rigorous evidence-based evaluation mechanism. Argument Mapper provides the latter but is not as flexible on the former.

XI. EVALUATION

Hands-on evaluations in a workshop setting with an initial version of the tool have been conducted with 16 experienced analysts from eight organizations. Participants were asked to make an argument for "What happened to Amelia Earhart?" and then complete a short post-exercise questionnaire. The questions are shown in Table 1. A broader discussion followed the exercise.

Was this tool easy to use?
Was this tool easy to understand?
Would this tool be useful for you?
Can you see this tool being widely adopted?
Was the tool consistent with argument mapping in current practice?
What is the most useful feature?
What needs the most improvement?
Other comments?

Table 1. Post Exercise Questionnaire.

100% of the participants thought the Argument Mapper tool was easy to use and easy to understand, and 94% thought the tool would be useful to them. 75% of the participants could see the tool being widely adopted with some noting the importance of connecting to the final product produced. With respect to, "Was this tool consistent with argument mapping in current practice?" 75% said yes consistent or an improvement. Open ended response questions allowed feedback to be received at any question, and in particular on the most useful features of the tool (e.g. ease of use, automatic computation) and suggestions for improvement (e.g. ability to combine/merge argument maps, control for level of detail for very large argument maps, more integrated help functions, and fine tuning the terminology). Most participants have asked for the tool once it is ready for deployment.

XII. CONCLUSION

The Argument Mapper tool supports many of the analytic tradecraft standards required by the intelligence community as found in ICD 203, Analytic Standards [12], including use logical argumentation, express uncertainties, describe quality of sources, identify assumptions and information gaps, and include analysis of alternatives. Using Argument Mapper will encourage including correct tradecraft practices in regular analytic activities and reports. The tool helps analysts apply structured thinking to minimize the effects of cognitive biases. Evidence assessment is explicit. The calculation of inferential force is automatically done using easy to understand Baconian probability and conjunctive logic. The argument is made visible to allow review and collaboration with other analysts. The use of structured argument mapping methodology, visibility and collaboration mitigates cognitive biases.

The next phases of the project include plans for deploying the tool to classrooms used to teach analytic methods. Additional capabilities are being designed to provide prompts to encourage adherence to analytic methodology (e.g. describing quality and reliability of sources, identifying key assumptions), and automatic logic checks (e.g. the "rabbit rule" where hypothesis terms are included in supporting evidence so avoiding "pulling a rabbit of the hat"). Another next step is to enable integration into analysts' multi-tool environments to create more fluid workflows from evidence collection to argumentation to collaboration to reporting. In addition, it is possible to consider automatic recommendations for improving arguments based on argument patterns. Learned argument patterns, and vetted by expert analysts, could be automatically made available to analysts as they structure their hypotheses and arguments, provided these patterns do not propagate bias from a previous analysis. Another useful next step would be to perform an experiment that quantifies the effect of the Argument Mapper on specific cognitive biases such as confirmation bias, conservatism (belief revision), anchoring, and recency bias. One challenge is to develop cognitive bias metrics as few exist for measuring cognitive biases [4]. Finally, automatic sensitivity analysis can be investigated in order to identify key evidence in an argument and recommend additional more detailed evaluation of credibility using a standard system of criteria (e.g. authenticity, accuracy, reliability for tangible evidence, plus truthfulness, competence and access for testimonial evidence) [10].

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