An Argumentation Model of Forensic Evidence in Fine Art Attribution

Douglas Walton CRRAR

[Abstract] In this paper a case study is conducted to test the capability of the Carneades Argumentation System to model the argumentation in a case where forensic evidence was collected in an investigation triggered by a conflict among art experts on the attribution of a painting to Leonardo da Vinci. A claim that a portrait of a young woman in a Renaissance dress could be attributed to da Vinci was initially dismissed by art experts. Forensic investigations were carried out, and evidence was collected by art history experts and scientific experts. The expert opinions were initially in conflict, but new evidence shifted the burden of proof onto the side of the skeptics. This paper presents an analysis of the structure of the interlocking argumentation in the case using argument mapping tools to track the accumulation of evidence pro and con.

Key Words: the Carneades Argumentation System, argument from expert opinion; fraudulent art; evidential reasoning; inquiry dialogue; burden of proof; Leonardo da Vinci.

1. Introduction

The Carneades Argumentation System[1] (Gordon, 2005, Gordon and Walton, 2006; Gordon, 2010) is primarily designed to analyze, evaluate and construct legal argumentation. But it is also meant to be open domain software (meaning it can be applied to any domain of argumentation), and so the question arises whether (or how well) it can also be applied to examples of argumentation that are not specifically legal in nature. In this paper a case study is conducted to test the capability of Carneades to model the argumentation in a case where forensic evidence based on expert opinion evidence was deployed in an investigation triggered by a conflict among art experts on the attribution of the painting to Leonardo da Vinci. In this case an unsigned portrait of a young woman in a Renaissance dress sold for only $22,000 in 2007, but later investigations by experts turned up evidence it may have painted by da Vinci. Forensic investigations were subsequently carried out, and evidence was collected by art history and forensic experts. The portrait was sold to an art collector for $20,000 in 1998, and valued at $160 million in 2012, but if proved to the art world to be painted by da Vinci, it could be worth more than $600 million. The expert opinions were initially in conflict, but as the forensic evidence came in, new scientific evidence shifted the burden of proof onto the side of the skeptics. This paper presents an analysis of the structure of the interlocking argumentation in the case using argument maps to track the accumulation of evidence pro and con.

Section 2 presents a brief outline of the case that enables the reader to get a grasp of the overall sequence of argumentation in it by presenting the case as a story. It is important for the reader to grasp the temporal sequence of how the dispute about the attribution of the painting arose, and how the various pieces of evidence were introduced in a sequential manner. It can be seen that the story about the attribution of the painting takes the form of a series of conflicts of opinions among experts on art history and forensic evidence. Section 3 offers a summary account of what each of the experts claimed. The material presented in section 3 is designated as the case to be studied. The way the actual dispute took place, and how they collection and marshaling of forensic evidence proceeded, is a very long and complicated story chronicled in several books and many articles about the subject of the disputed da Vinci painting. It is important to realize

[1] http://carneades.github.com/

that the analysis presented in this paper is not an attempt to model all this data using argumentation tools. That would be a huge project, well beyond the scope of a single paper. The purpose of this paper is merely to take the data presented in parts one and two as the so-called "case", in which some key propositions in the investigation have been selected out as arguments to be modeled by the system. The secondary purpose is to put these propositions into an order so that they can be represented as a connected sequence of argumentation that bears on the unsettled issue of whether the painting can justifiably be attributed to da Vinci or not.

It is very important that attention be paid to the actual wording of what each expert said, for in the paper each of these arguments will be modeled using the Carneades argument mapping tool along with the argumentation schemes for argument from expert opinion. Argumentation schemes are recognizable forms of argument that are generally defeasible but that can be used to create evidential support in favor of, or against a conclusion (Hastings, 1963; Kienpointner, 1992; Grennan, 1997; Walton, Reed and Macagno, 2008). Section 4 describes two theoretical instruments that will be applied to the case. The first one is a pair of argumentation schemes that will be shown to be necessary to use the argument mapping tool of Carneades in the case study, namely argument from expert opinion and inference to the best explanation, also called abductive reasoning. The second one shows how the burden of proof can be applied in the inquiry in which these two schemes are used. Section 5 introduces the reader to the essentials of the Carneades Argumentation System. Section 6 builds six separate argument maps drawn to represent each of the arguments in part two. Section 7 examines each of the six argument maps in order to see how each one is linked to the next one in the sequence. The culmination in section 8 is the construction of a large argument map connecting the mass of evidence in the case.

The remainder of the paper discusses the problem of how to evaluate the argumentation in the case, based on the notion of burden of proof. Section 8 begins this process by showing how the argument went through three main stages, and how the middle stage used inference to the best explanation to connect three sequences of argumentation to three hypotheses that could be used to explain the basic facts of the case. This analysis is used to build a model of the sequence beginning with the formulation of the ultimate issue and proceeding through the collection of evidence from which the best hypothesis was selected, to application of the burden of proof allowing the closure of the investigation. Section 9 shows how Carneades models the whole sequence of argumentation as a tree with the ultimate conclusion at the top, and how as each piece of evidence is introduced, it propagates support for the final conclusion up the branches of the tree. Section 10 discusses how the model of evaluation presented in section 9 relates to what actually happened in the case as the leading experts went through the process of changing their minds about whether the painting was acceptable as a genuine da Vinci work or not. Section 11 presents a brief summary of the conclusions.

2. Case Outline

In this case a claim that a portrait of a young woman in a Renaissance dress could be attributed to Leonardo da Vinci was initially dismissed by art experts, but investigations were carried out and evidence was amassed on both sides of the issue. Gradually the body of evidence began to point towards acceptance of the hypothesis that the portrait was an authentic da Vinci, but controversy remained. The burden of proof rested heavily on the proponents of the hypothesis that the portrait was authentic, and there was much at stake, both financially and from the point of view of art history. Peter Silverman, an art collector, saw the portrait on sale in a

New York gallery in 2007 and bought it for $22,000. It was done using colored chalks and ink on a calfskin material called vellum. The attribution to da Vinci remained controversial in the art world during the lengthy process of assessment of the forensic evidence by art experts. For one thing, the portrait was not signed. Although the vellum on which the portrait was painted was shown with more than 95% probability by carbon dating to overlap Leonardo's life, forgers who are skilled will use original materials to make their copies and it is very common for collectors to spend millions of dollars on counterfeit works of art.

One expert claimed that the technique used in the painting showed evidence of its being made by a left-handed artist. It is well known that da Vinci was a left-handed artist. However, another expert who disagreed noted that imitators of Leonardo's work had copied this characteristic in the past. Many art scholars have expressed skepticism about the attribution to da Vinci, some saying that it is a 19th-century German painting and others saying that it is a modern forgery.

The painting was tested by another expert from Lumiere Technology in Paris, a company that offers in-depth technical analysis of paintings to authenticate masterpieces of fine art using a special high-resolution camera that can digitally scan under the surface of the painting. The founder of this company, an expert in such matters, had previously tested his technology on the Mona Lisa, and now applied it to this portrait of the woman in the Renaissance dress, sometimes called Portrait of a Young Fiancée or The Beautiful Princess. A partial fingerprint was found on the painting, and it was consistent with fingerprints found on other paintings of da Vinci, but it was too poorly detailed to support a match.

Eventually, one expert tied the painting to the Sforza family. Ludovico Sforza was a wealthy patron of da Vinci, and Leonardo lived in Milan from 1482 to 1499. The research of this expert found that Bianca, the illegitimate daughter of Ludovico, was likely the subject of the portrait. Another expert found, by using imaging technology, some unusual marks, indicating that someone had used a knife to cut along the left side of the vellum. As well he found three holes in the vellum on the same side. This evidence suggested that the painting might have been originally made as a page in a book. At that point a book, a history of the Sforza family printed on vellum, was found in the Polish National Library. It was known that some copies of the book were printed on vellum and had added illumination. One such copy was presented to the husband of Bianca at her wedding. One sheet of vellum near the front of copy of the hand-illuminated book found in the Polish National Library was missing. Further investigations showed that the stitch marks in the binding of this book matched the three holes in the portrait.[2]

The final findings of the managing of the stitch marks with holes in the portrait seemed to many to be a clincher that provided conclusive evidence to prove that the portrait was a genuine da Vinci. But despite the body of evidence that the extensive forensic investigations had amassed, there remain dissenting expert opinions.

3. What the Experts Said

When Silverman started to wonder whether Leonardo might have been the artist, he contacted Martin Kemp, Emeritus Research Professor in the History of Art at Oxford University, a specialist on Leonardo. Kemp was trained in Natural Sciences and Art History at Cambridge University and the Courtauld Institute, London. He was British Academy Wolfson Research Professor in 1993-98. Kemp studied the details of the painting carefully, examining the tiny

[2] A NOVA program 'Mystery of a Masterpiece', aired by PBS on January 25, 2012, told the story of the case up to that date. A transcript can be found at www.pbs.org/wgbh/nova/tech/**mystery-masterpiece**.html, as of 08/09/2012.

marks made by the artist's brush, and he became convinced there was a chance for attribution to Leonardo. Other experts disagreed. David Eskerdjian, Professor of Art History at the University of Leicester, said that it did not compare with the quality of other da Vinci paintings.

Silverman took the painting to a lab in Paris to be tested by an expert, Pascal Cotte, inventor of special high-resolution camera that can take pictures to probe visually under the surface of the painting. Cotte, the founder of Lumiere Technologies, is an engineer who developed a tool that enables the in-depth study of fine art paintings to reveal the true pigments for viewing and analysis without touching or damaging the paintings. He compared characteristics of alterations in the portrait to those in a sketch universally agreed to have been made by Leonardo. He found the alterations made by the artist in both paintings strikingly similar.

Giammarco Cappuzo, an art specialist and friend of Silverman, pointed out that in order to prove that the painting is genuine Leonardo, one would have to prove to the skeptics that it is not a 19th-century forgery. The question was also raised whether the portrait could have been created by one of the other artists employed in his workshop. Cristina Geddo, an art historian and expert on Leonardo and his followers, examined the portrait. She noticed that the pen marks used to create shading around the face were in an unusual direction, suggesting an artist using his left hand. It is well known that da Vinci was left handed. Geddo stated that all of Leonardo's assistants worked with the right hand. This finding suggested that either the portrait was drawn by Leonardo, or it was drawn by a forger trying to copy his left handed style.

Pascal Cotte discovered a faint fingerprint at the top left corner of the portrait. It is known that Leonardo used his hands to spread paint, and that examples of his fingerprints can be found in other paintings known to be his. Peter Paul Biro, a forensic art examiner, claimed that the partial fingerprint was comparable to a fingerprint found on St. Jerome in the Wilderness, a painting firmly attributed to da Vinci. But the match was not convincing enough to prove that the print on the Bianca portrait could definitely be attributed to him. Several forensic experts on fingerprint evidence found that the partial fingerprint was too poorly detailed to support the claim of the match. An analysis of these fingerprints was undertaken by the Institute of Criminology and Criminal Law in Lausanne, Switzerland. Professor Christoph Champaud, an expert in fingerprint identification, posted the image on a website and asked students and colleagues to analyze it. His opinion was that there was insufficient evidence to match this fingerprint with the other fingerprints known to be those of da Vinci. The characteristics of the fingerprint on the portrait could be matched with too many other non-Leonardo fingerprints to be of evidential value in linking them to those of da Vinci.

Sarah Simblet, a drawing instructor and professor at the Ruskin School of Fine Art in Oxford, was consulted by Kemp about the artistic techniques used in the portrait. She stated that the portrait was made by an exceptional draftsman and by someone who understood very well about the structure of the skull, facial bones and curvatures around the eyes in a human face. These characteristics both suggest that Leonardo could have been the artist. It is known that Leonardo dissected corpses and exposed bones, sinews and muscles in exceptional detail. She also showed that the portrait showed an unusual, experimental mix of materials put on the vellum. Such an unusual and experimental technique of painting was taken to point to Leonardo as the artist, since he was known to attempt such unusual methods. The fine painting techniques used in the portrait were consistent with the experimental painting techniques used by da Vinci, but this evidence was regarded as insufficient to prove attribution to him. At this point in the investigation, David Eskerdjian remarked that opinions were divided, and that others shared his reluctance to acceptance the hypothesis that the portrait was painted by Leonardo.

Martin Kemp then looked around to try to identify the person in the portrait. He narrowed down the candidates to Bianca, the illegitimate daughter of Ludovico Sforza. Historical evidence showed that she would have been about the right age to match the image of the girl in the portrait. The problem was that there was no record of such a person, or listing of her in the Royal Inventory. Therefore the history of the portrait remained in doubt.

At this point, Pascal Cotte opened up another line of investigation. He observed that there were three holes at the edge of the vellum, suggesting that these holes may have come from stitching of the kind used to bind a book. It had also previously been noticed that there was a knife cut along the edge of the portrait where the three holes were found. Such a knife cut could be explained by someone cutting out a single page of a book. These findings might explain why there are no accounts of the portrait, and why it was not listed among Leonardo's paintings. The line of investigation then took the direction of asking why Bianca's portrait would be put in a book. At this point, Kemp and Cotte argued that the portrait was a page in a book that celebrated the wedding of Bianca Sforza (Kemp and Cotte, 2010). However, at that point, there was no evidence of the existence of such a book. So their hypothesis was still not strongly enough supported by the evidence to meet the burden of proof required to convince the art world that da Vinci painted the portrait.

The final stage in the collection of the evidence was the discovery of a 500-year-old book called the *Sforzada* that was found in the National Library of Poland, and that was printed on vellum. Historians agreed that the book was written in commemoration of the wedding of Bianca Sforza. Pascal Cotte used a special camera enabling him to photograph details of the pages of the book. He found that the missing page would have been at the front of the book, and that the three holes on the side of the portrait match the stitching there. He found that there were originally five stitches in the book. But Polish archivists said that when it was rebound centuries ago, it was believed that two stitches were added to the original three in order to strengthen the binding. Cotte found that the alignment between the three holes and the three stitch marks were perfect.

4. Two Theoretical Instruments to be Applied to the Case

This section describes two theoretical tools that will be applied from argumentation theory to the particulars of the case to be analyzed. The first tool is called an argumentation scheme. It is a defeasible form of argument that is evaluated in a given case by critical questions that are attached to each scheme. The critical questions probe into the weak points of the argument.

The most basic version of the argumentation scheme for argument from expert opinion is given (Walton, Reed and Macagno, 2008, 310) as follows.

Major Premise: Source *E* is an expert in subject domain *S* containing proposition *A*.

Minor Premise: *E* asserts that proposition *A* is true (false).

Conclusion: *A* is true (false).

An argument from expert opinion should be evaluated by the asking of six basic critical questions.

Expertise Question: How credible is *E* as an expert source?

Field Question: Is *E* an expert in the field *F* that *A* is in?

Opinion Question: What did *E* assert that implies *A*?

Trustworthiness Question: Is *E* personally reliable as a source?

Consistency Question: Is *A* consistent with what other experts assert?

Backup Evidence Question: Is *E*'s assertion based on evidence?

If a respondent asks any one of the six critical questions, the original argument defaults unless the question is answered adequately.

One form of argumentation that this case and other instances of scientific discovery are based on is abductive reasoning, or inference to the best explanation. An abductive inference (Josephson and Josephson, 1994, 14) has the following form, where *H* is a variable representing a hypothesis and *D* is a variable representing a given set of data or (presumed) facts. This form is the argumentation scheme for abductive reasoning.

D is a collection of data.

H explains *D*.

No other hypothesis can explain *D* as well as *H* does.

Therefore *H* is plausibly true.

On this account (Josephson and Josephson, 1994, 14), one can evaluate abductive reasoning in a given case by using six critical questions.

(1) How decisively does *H* surpass the alternative explanations?

(2) How good *H* is by itself, independently of the alternatives?

(3) How reliable are the data?

(4) How much confidence is there that all plausible explanations have been considered?

(5) Are there practical considerations, including the costs of being wrong?

(6) How urgent is the need is to come to a conclusion at all before seeking further evidence?

The conclusion to be inferred using this scheme is selected as the best explanation of the data. However, abductive reasoning is taken to be defeasible, meaning that the conclusion may have to be withdrawn as new evidence is taken into account (Walton, 2004).

The second tool is the framework of the investigation that the individual arguments in the case are situated within (Hamblin, 1971). In argumentation theory, such a framework is called a type of dialogue, because it is viewed as a series of exchanges in which arguments are put forward by a proponent and then critically questioned by a respondent. There are several types of dialogue that have been studied, including persuasion dialogue, negotiation dialogue, deliberation, and information-seeking dialogue (Walton and Krabbe, 1995). The particular type of dialogue that provides the framework in which the argumentation in this case is situated is called an inquiry.

At the opening stage of an inquiry dialogue, a particular statement has to be specified, so that the object of the inquiry as a whole is to prove or disprove this statement. In discovery dialogue there is no statement set at the beginning in such a manner that the goal of the whole dialogue is to prove or disprove this statement. The aim of the discovery dialogue is to try to find something, a hypothesis that might explain the facts of a case. Such a hypothesis cannot be set as something to be proved or disproved until the dialogue has found it. Thus burden of proof is different in these two types of dialogue. In inquiry dialogue, the burden of proof is set at the opening stage, governs the conduct of the argumentation through the whole argumentation stage, and then is used at the closing stage to determine when the argumentation stage should end, and whether the argumentation in it was successful or not in fulfilling the goal of the dialogue.

In discovery dialogue, what is set at the opening stage is some set of facts that need to be explained. As evidence comes in, hypotheses are formed, and it may found that some explanations are better than others. One may then be shown to be the best explanation, the one supported by the most evidence, and least open to refutation by contrary evidence. Some anomaly or unexplained event is identified at the opening stage of a discovery dialogue, and then there is a shift to an argumentation stage where several competing explanations are evaluated.

The evidence for one explanation is weighed against the evidence for a competing explanation, or a set of competing explanations (Josephson and Josephson, 1994). In a successful discovery dialogue, sufficient evidence is brought forward to prove that one explanation is arguably better than the others. The standard of proof in inquiry dialogue tends to be set to a high level of support required to prove the hypothesis. Only if enough evidence has been put forward to satisfy the questioner, and remove his doubts to a reasonable degree, can the argument be accepted as proved.

The inquiry model applies to the marshalling of evidence in the investigation of the portrait of the young woman as outlined by the sequence of argumentation in figure 1.

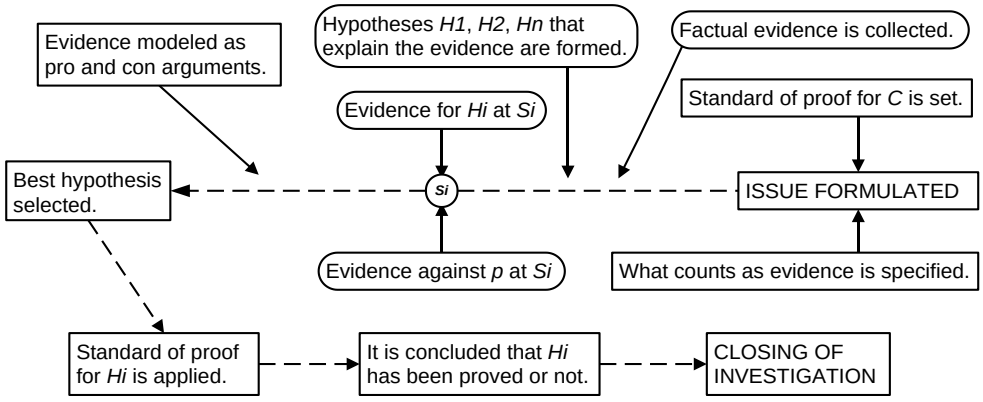

Figure 1: From the Opening to the Closing of the Investigation

As shown in figure 1, the investigation process begins with the formulation of a central claim at issue to be proved or disproved by the evidence that is brought to bear.

5. The Carneades Argumentation System

A problem with using critical questions to evaluate cases where expert opinion is used as a source of evidence is that we can no longer use an argument diagram to summarize, analyze or evaluate the basic evidence in a case and display its structure as a sequence of reasoning. The reason is that everything that appears in the text box on a standard argument diagram needs to be a statement, a proposition that is either true or false. It is harder to analyze the structure of questions, even though they are certainly very important as devices in both everyday and legal argumentation, for example in examining a witness. Using critical questions definitely takes us outside the realm of reasoning to the realm of argument, where claims are made and subjected to doubt by the asking of critical questions by an opponent.

Critical questions are modeled by the Carneades Argumentation System as additional premises corresponding to the critical questions of an argumentation scheme. Carneades is a mathematical and computational model that defines mathematical properties of arguments that are used to identify, analyze and visualize real arguments. By applying argumentation schemes, Carneades analyzes and evaluates the acceptability of arguments, based on proof standards, for example preponderance of the evidence. In the Carneades Argumentation System, critical questions matching an argument are reformulated as assumptions or exceptions (Walton and Gordon, 2005; Gordon and Walton, 2009). Assumptions are assumed to be acceptable unless called into question. Exceptions are modeled as premises that are assumed to be not acceptable,

but they can undercut an argument if found to be acceptable. Ordinary premises are assumed to be acceptable, but must be supported by further arguments if questioned. Whether or not the evidence is sufficient depends on the standard of proof, which in turn depends on the type of dialogue that is involved. During the closing stage, as shown along the bottom of figure 1, the standard of proof is applied to determine whether the proposition that was the subject of the inquiry can be said to have been proved or not.

Carneades is more than just a device for argument diagramming however. It has an open knowledge base with evidence continually streaming in that can support or defeat existing arguments (Gordon, 2011). Thus it can be used to analyze and evaluate a dynamic sequence of argumentation in a case as new evidence comes in. As a hypothesis is confirmed by new evidence, Carneades adds that evidence into the argument diagram, propagating it up the argumentation tree so it can lend support to or undermine the ultimate conclusion at the root of the tree.

An argument is defined in the Carneades Argumentation System as a directed graph consisting of text boxes and argument nodes connected by arrows (Freeman, 1991). In a Carneades argument diagram, the premises and conclusions of the argument are displayed in text boxes as leaves of a tree Scheuer et al., 2010). A proposition in a text box can be accepted or rejected, or it can be neither accepted nor rejected. If it is accepted, the text box is colored green. If it is rejected, the text box is colored red. If it is neither accepted nor rejected the text box retains a white background. The arrows joining the text boxes represent arguments. The arguments themselves are represented as nodes. A convergent argument is represented as two separate arguments supporting the same conclusion. In a linked arguments configuration, the two or more premises each lead in to the same node. The type of argument, that is, its argumentation scheme, is displayed with the node. The ultimate proposition to be proved is displayed as the root of the tree. We will see examples below, but before that it is useful to look at how the visual user interface of Carneades looks like on a computer screen. This is shown in figure 2.

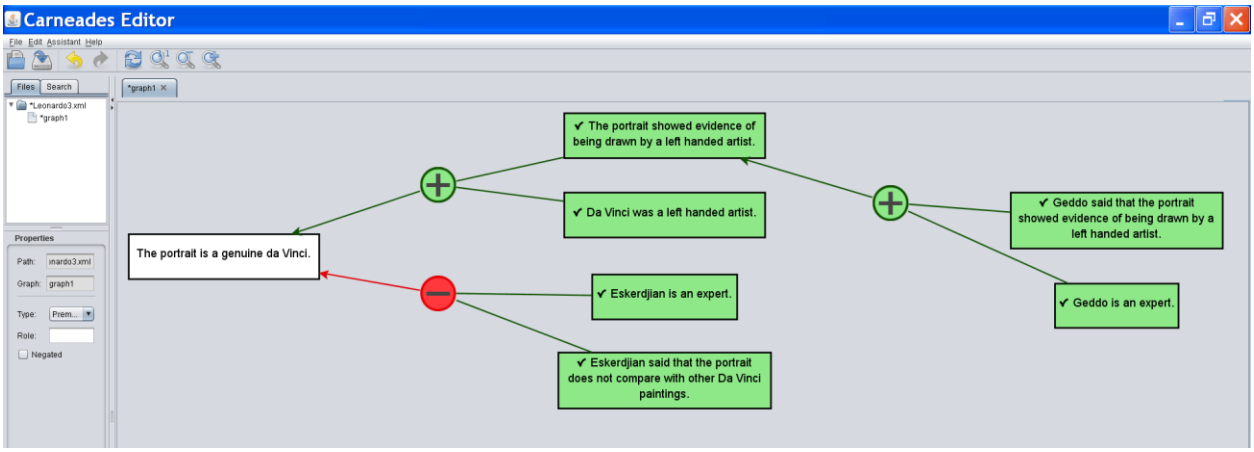

Figure 2: Screen Shot of an Example Showing the Carneades Menu

In figure 2, the ultimate conclusion to be proved, the proposition that the portrait is a genuine da Vinci, is shown at the left in a white box, indicating that it has not been accepted but only stated. On the right, we have three arguments supporting or attacking this conclusion. The argument at the top is a pro-argument, indicated by the plus symbol in its node. The argument just below it is

a contra argument, indicated by the minus symbol in its node. The third argument, at the right, supports the top premise of the top argument, since it too is shown as a pro-argument.

All six propositions making up the premises of the three arguments just mentioned are shown in green boxes containing checkmarks. The checkmarks are added for colorblind users. These notations show that all these propositions have been accepted. However, the conclusion, as noted above, is shown in a white box indicating that it is not accepted. The reason is that the standard of proof for all seven propositions (inserted into the part of the menu shown at the left) is that of beyond reasonable doubt. Even though the top argument supports the ultimate conclusion, and the argument at the right supports the premise of the top argument, the support is not enough to prove that the conclusion is true beyond a reasonable doubt. The reason is that the contra argument shown in the middle at the bottom of figure 2 raises doubt about the acceptability of the ultimate conclusion, and hence the conclusion is not drawn in a green box as being accepted.

Propositions are accepted or rejected by an audience (Tindale, 1990; Bench-Capon, Doutre and Dunne, 2007) where the audience is assumed to have a priority ordering of values (Bench-Capon and Sartor, 2003). The user inputs information into the argumentation tree indicating which propositions represented as leaves in the tree are accepted or rejected, or neither. Carneades then automatically adjusts the colors of all the leaves of the tree to show how the new information has affected a particular argument, and how it changed as this particular argument changes the other arguments it is related to. In this manner, acceptance and rejection can be propagated upwards (see figure 11) along the leaves of a tree so that any new argument can lead to either acceptance or rejection of the ultimate conclusion to be proved (Gordon, 2010).

In this paper our primary concern will not be the evaluation of the sequence of argumentation in the case of the painting attributed to da Vinci. Our concern will be with the analysis of the structure of the sequence of argumentation making up the evidence in the case. From there, once the step has been taken to see how all the pieces of evidence in the case fit together into a large structure, and the step has been taken to determine whether there could be alternative interpretations of the argumentation in case, then the step of running this sequence of argumentation through the Carneades system in order to evaluate it can be taken. The procedure will be to break the lengthy sequence of argumentation down into manageable packages at a micro level, and then take the step to a macro level analysis where the arguments in each package are chained together representing a mass of evidence supporting the ultimate conclusion in the case as a whole.

Arguments can be chained together so that one argument can affect another, either by supporting it or undermining it. There are several ways to attack arguments using Carneades. One is to present a counterargument showing that a premise of the original argument is untenable. A second way is to present a counterargument showing at the conclusion of the original argument is untenable. A third way is to undercut the original argument showing that it does not prove its conclusion. On the argument diagram this configuration is shown as one argument attacking another. That is, an arrow leads from one argument node to another. In this respect, a Carneades argument diagram is different from the traditional argument diagrams we are generally used to in logic.

Another important feature of Carneades is that whether or not a proposition is acceptable, in light of the evidence for and against it represented on an argumentation tree, is a matter of burden of proof. Burden of proof is defined in Carneades as resting on standard of proof. The four standards of proof (Gordon and Walton, 2009) are set in increasing order strictness.

- Scintilla of Evidence

    - There is at least one applicable argument
- Preponderance of Evidence
    - The scintilla of evidence standard is satisfied, and
    - the maximum weight assigned to an applicable pro argument is greater than the maximum weight of an applicable con argument.
- Clear and Convincing Evidence
    - The preponderance of evidence standard is satisfied
    - the maximum weight of applicable pro arguments exceeds some threshold α, and
    - the difference between the maximum weight of the applicable pro arguments and the maximum weight of the applicable con arguments exceeds some threshold β.
- Beyond Reasonable Doubt
    - The clear and convincing evidence standard is satisfied and
    - the maximum weight of the applicable con arguments is less than some threshold γ.

Notice that on this way of defining the standards of proof, the threshold γ is left open, and is not given a fixed numerical value.

Burden of proof is determined by two components, one of them being the standard of proof. The other is the determination of which side the burden rests on at any given point in a dialogue, as the burden shifts back and forth. As noted above, in the Carneades Argumentation System, there are two sides who take turns putting forward arguments and responding by asking critical questions, or putting forward contra arguments. A dialogue is formally defined as an ordered 3-tuple $\langle O, A, C \rangle$ where O is the opening stage, A is the argumentation stage, and C is the closing stage (Gordon and Walton, 2009, 5). Dialogue rules of the kind described in (Walton and Krabbe, 1995) define what types of moves are allowed by the parties during the three stages. The initial situation poses the issue to be resolved at the opening stage, and the dialogue moves through the opening stage toward the closing stage.

In an inquiry dialogue, the ultimate proposition to be proved or disputed is formulated at the opening stage. Using different standards of proof, for example the standard of the preponderance of the evidence, a burden of proof is assigned to each proposition (Gordon and Walton, 2009). The preponderance of the evidence standard means that in order to be proved, a proposition must have pro arguments supporting it that are stronger than the con arguments attacking it. However, there is not just one standard of proof used to define burden of proof in the system. Burden of proof is assigned in light of the type of argumentation that the participants are engaged in (Gordon, Prakken and Walton, 2007). In an inquiry dialogue to prove that a painting of questionable provenance can be attributed to Leonard da Vinci, the burden of proof would have to be set very high. For example we might assign the burden of beyond reasonable doubt. There are several reasons for the appropriateness of this kind of assignment. One is that the art world (the audience) would be highly skeptical about such a claim. Another is the monetary value of any painting attributable to da Vinci. Another is the known fact that forgers will go to great lengths to create fakes.

6. Argument Maps of Each Argument

In this section the lengthy sequence of argumentation is broken down into a sequence of five subarguments and an argument map is drawn showing the structure of each of the subarguments. The first argument map, shown in figure 3, represents a conflict of opinions between two experts,

Martin Kemp and David Eskerdjian. As is standard in argument mapping (Buckingham Shum et al., 1993) the propositions that function as premises or conclusions of the argument are displayed in text boxes as leaves of the tree. The arguments are shown as nodes connecting a set of premises to a conclusion. The argumentation scheme that a particular argument fits is shown in the node, where its name is displayed.

As shown in figure 3, Kemp became convinced after examining the details of the painting that there was a chance for attribution to Leonardo. Eskerdjian disagreed, saying that the portrait did not compare with the quality of other da Vinci paintings. In the argument map shown in figure 3, the ultimate proposition at issue, the claim that the portrait of the young woman is a genuine da Vinci, is shown at the top of the tree structure as the root of the tree. Underneath this ultimate claim the opposed arguments on both sides are presented.

To the right of the node for that argument from expert opinion there is a con argument, as indicated by the minus sign in its argument node. This con argument represents the critical question for argument from expert opinion which asks whether the opinion of the expert cited is in accord with the opinions of other experts. This critical question functions as an exception, meaning that the original argument from expert opinion is defeated if evidence can be given to back up the claim that the original argument from expert opinion is not in accord with the opinions of some other experts.

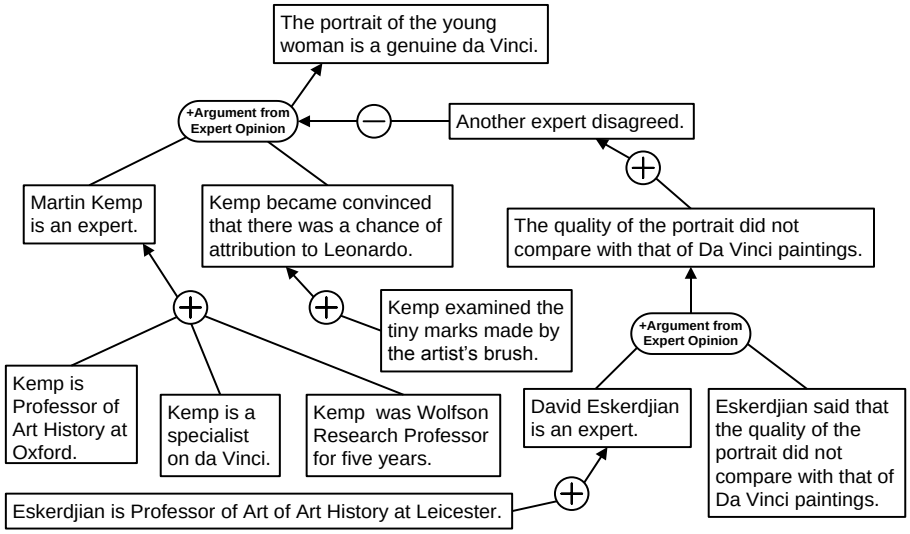

Figure 3: The First Argument Map

In this case, as shown in figure 3, evidence is given from another expert who disagreed with Kemp. This expert presented a counterargument stating that the quality of the portrait does not compare with that of other da Vinci paintings. So here we have a case of an undercutter, where the second argument is a con argument that defeats the first argument because it is backed up by evidence to support its attack. At this point then, the argumentation is inconclusive. We have the word of one expert pitted against the word of another.

In the next part of the argument some new evidence is introduced, as shown in figure 4. A third expert, Cristina Geddo, an art historian and expert on Leonardo and his followers, presented an argument for attributing the portrait to Leonardo. She found pen marks around the face

suggesting that the artist was left handed, and while it is known that da Vinci was left handed, it is also known that all of his assistants worked with the right hand (as noted above).

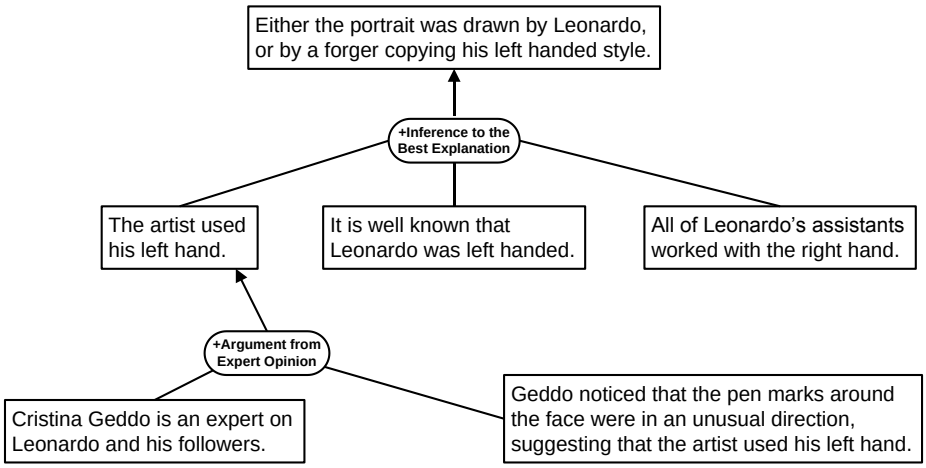

Figure 4: The Second Argument Map

This argument presents some evidence for the ultimate conclusion that the portrait can be attributed to da Vinci, but it is not conclusive by itself because it leaves open the possibility that a forger could have copied his left handed style. It remains possible that the portrait could have been painted by a 19th-century forger, because it is a known practice of forging to use original materials, for example vellum of a kind that would have been used in the Renaissance.

The next argument, shown in the argument map in figure 5, concerns fingerprint evidence.

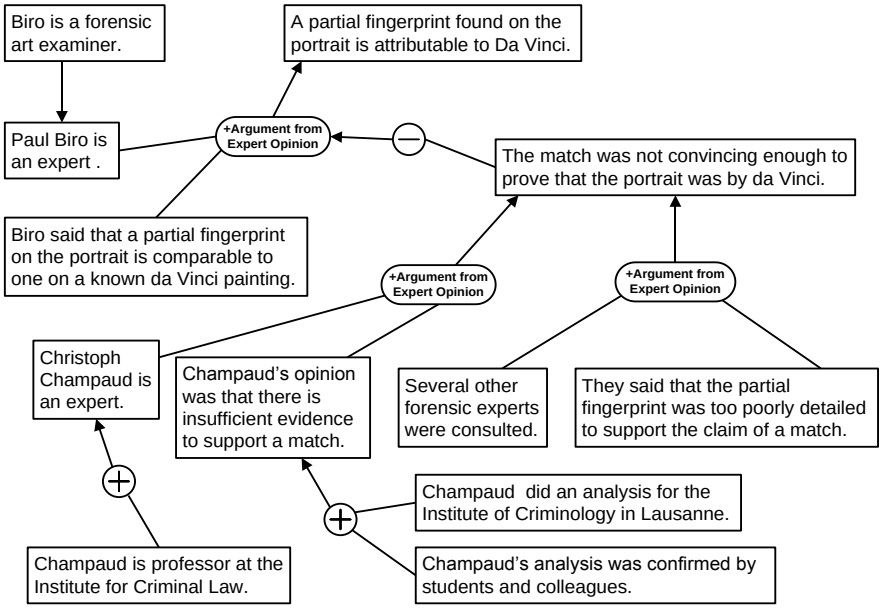

Figure 5: The Third Argument Map

Once again, this part of the argument offers some evidence to support the ultimate conclusion, but not enough to resolve the issue by meeting the burden of proof required to establish the conclusion that the portrait was painted by da Vinci. Here again we have a situation of the battle of the experts, comparable to the evidential situation shown in figure 3. We have an original argument by an expert attacked by a con argument offering evidence that other experts disagree with the claim made by the original expert.The argument map shown in figure 5 cites the expert opinion of Paul Biro, a forensic examiner, on the left of the argument map, as a pro argument supporting the ultimate claim that a fingerprint on the portrait is that of da Vinci. This third part of the argument only offers a small amount of evidence in support of the claim that the portrait is that of a genuine da Vinci. For the most part, the strength of the argument is counterbalanced by the opposing expert opinions offering evidence that the partial fingerprint is not a good enough match to offer much if any support to the ultimate conclusion.

Next we go on to draw a map representing the structure of the expert opinion evidence given by Sarah Simblet, shown in figure 6.

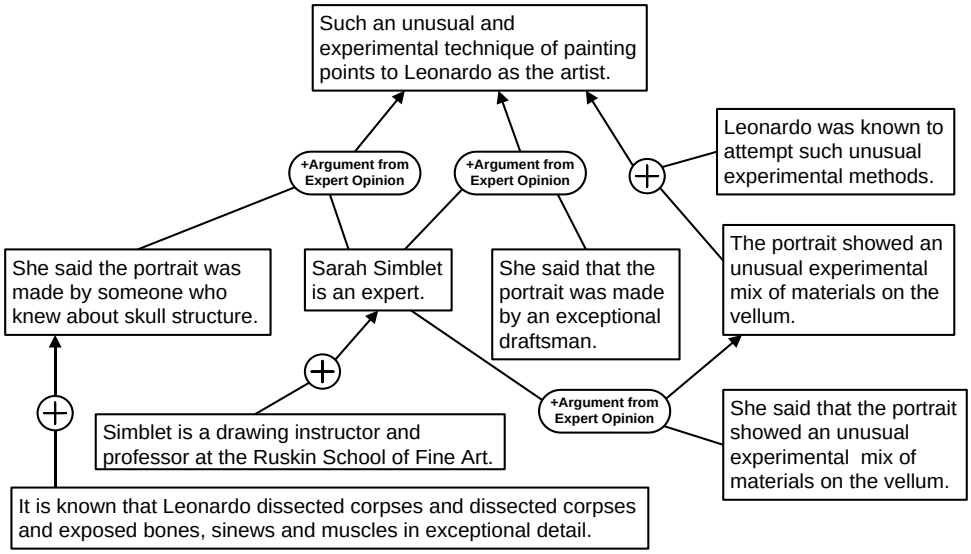

Figure 6: The Fourth Argument Map

This part of the argument shows application of three arguments from expert opinion all provided by the same expert, Sarah Simblet. It seems like a strong argument.

The next stage in the sequence of argumentation in the investigation is the point where Cotte opened up another line of investigation using hypothetical reasoning before the stage where it actually discovered the book in the library. At this prior stage, the three holes at the edge of the page suggested that these holes may have come from stitching of the kind used to bind a book. Another observation was the knife cut along the edge of the portrait where the three holes were found. Such a cut could be explained by somebody cutting out a page of a book.

This stage of the argument is conjectural, and uses inference to the best explanation to show how these observations could explain why there were no accounts of the Bianca portrait, and why it was not listed among Leonardo's paintings. At this point both Kemp and Cotte formed the hypothesis that the portrait had been a page in a book celebrating Bianca's wedding. This sequence of argumentation so far in the investigation is shown in figure 7.

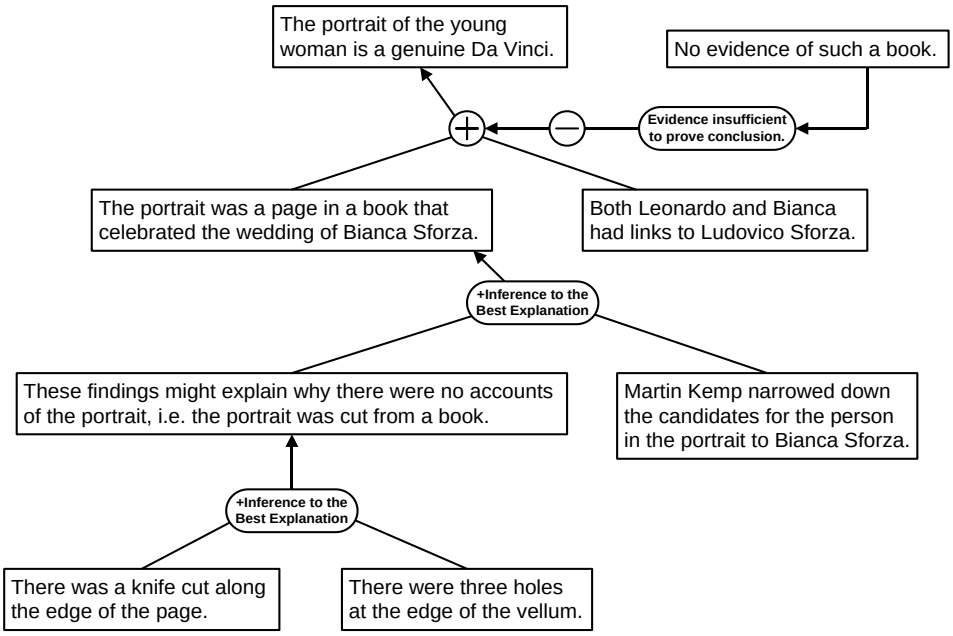

Figure 7: The Fifth Argument Map

Figure 7 shows two applications of the argumentation scheme for inference to the best explanation.

At this stage the conjecture was merely a hypothesis, because there was no evidence of the existence of such a book. This conjectural evidence is not strong enough by itself to prove the ultimate conclusion. The incompleteness of the argument at this point is shown at the top right of the diagram in figure 7 indicating that since there was no evidence of such a book at this point, the ultimate conclusion that the painting was a genuine da Vinci could not be proved.

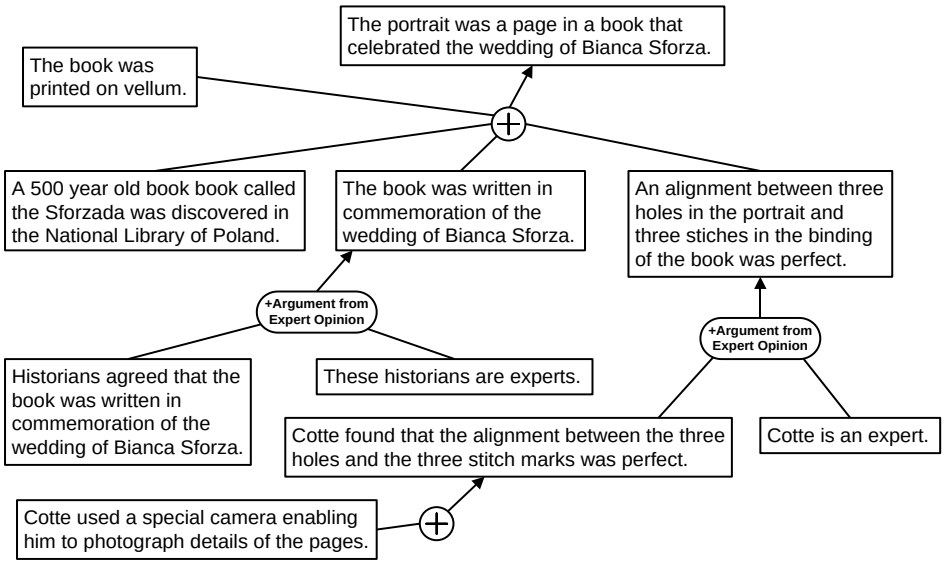

Figure 8: The Sixth Argument Map

Figure 8 takes us to the final step of the argumentation concerning the finding of the book that originally contained the portrait and the evidence of the stitching and the holes in the portrait matching. At the bottom right of figure 8 we have the expert testimony of Cotte claiming that he found a perfect alignment between the three holes in the portrait and three stitch marks in the binding of the book. This is a very strong argument from expert opinion, resting not only on Cotte's qualifications, but his use of a special camera enabling his technology to photograph the details of the pages and the portrait in a very accurate manner. On the left at the bottom of figure 8 we see a corroborating argument from expert opinion of historians who agreed that the book was a commemoration of Bianca's wedding. In this case we have a pro argument from expert opinion, and then another pro argument from expert opinion supporting a different premise of the original argument with its three linked premises leading to the ultimate conclusion shown at the top. But the main reason it is such a strong argument is the perfect match found between the three holes found in the vellum at the edge of the portrait and the three corresponding stitches in the binding of the book. The match was found by Cotte to be so close that the likelihood of its being a coincidence would be very small.

7. Fitting the Argument Maps Together

The next task is to look at the five argument maps in order and see how each one is linked to the next one so that it is possible to get a picture of the whole sequence of argumentation. Looking at figure 3, we see that it is a classic case of the battle of the experts. Kemp stated his view that the portrait is a genuine da Vinci. Using the scheme for argument from expert opinion, since Kemp is an expert, some evidence has now been shifted to support the conclusion. But there is a counterargument, also based on argument from expert opinion. Eskerdjian is also an expert, and he disagrees. Both are qualified experts, but Eskerdjian also gave some evidence to support his argument from expert opinion by stating that in his opinion the quality of the portrait did not compare with that of other da Vinci paintings. Presenting this evidence makes his argument strong, strong enough to work as an undercutter that defeats the original argument from expert opinion from Kemp. At this point then, we can sum up the evidential situation by saying that an argument from expert opinion has been put forward from Kemp to prove the ultimate conclusion at issue, but it fails to prove this proposition because it is undercut by a countervailing argument from expert opinion.

Next let's deal with the third argument map in figure 5. It too is a battle of the experts, in this case, fingerprint experts. The expert evidence put forward by a forensic examiner supports the claim that a fingerprint found on the portrait is attributable to da Vinci, but this argument from expert opinion is undercut by the testimony of other experts who claim that the fingerprint was too poorly detailed to support the claim of a match. This counterargument is strong because it is based on the testimony of several other forensic experts who were consulted, and the finding of the original expert was confirmed by tests he ran on his students and colleagues. Thus evidence was given to back up this second argument from expert opinion, and therefore it defeats the original argument from expert opinion put forward by the forensic examiner Biro. This argument too is a battle of the experts, a stalemate that does not go any further. So it can drop out of consideration as a part of the argument that is significant for the evaluation.

Next let's deal with the argument map in figure 4. This map shows the argument from expert opinion put forward by Cristina Geddo, suggesting that the artist who painted the portrait worked with his left hand. As indicated just above, this argument by itself does not prove that the portrait

is a genuine da Vinci, but it does carry some weight because it excludes the alternative explanation that the portrait could have been drawn by one of Leonardo's assistants. As indicated just above, this argument can be connected into the larger sequence of argumentation in the case by putting forward a counterargument that the portrait could have been drawn by a forger copying Leonardo's left-handed style, and then counterattacking this counterargument. Representing this argument on an argument map requires putting in an implicit counterattack and then refuting it. This is one reason for dropping it out of consideration as part of the argument taken into account when we turn to looking at the larger picture. Another reason is that once the final argument shown in figure 8 is taken into account, this argument is less important in providing additional evidence to support the ultimate conclusion. For these reasons the argument in figure 4 will not be taken into account when we come to sum up the connected sequence of argumentation in one large argument map. But it could be added in later if desired.

Next we turn to figure 7. The argumentation shown in this figure supports the argument from expert opinion put forward by Kemp in figure 3. In figure 3 Kemp did not bring forward sufficient evidence to support his claim that the portrait is a genuine da Vinci. But now, the argumentation shown in figure 7 backs up that argument from expert opinion by presenting the evidence that Bianca Sforza was a likely candidate for the person in the portrait and that both Leonardo and Bianca had links to Ludovico Sforza. These arguments narrow down the scope of the investigation considerably. Also, Kemp presented evidence that the portrait was likely cut from a book. This would explain why there were no accounts of the portrait in the literature on Leonardo's paintings. It therefore serves as evidence to rebut the argument that the absence of accounts of the portrait suggests that it is a forgery. This new argument changes the focus of the investigation, but remains purely hypothetical so far, as a proof of the ultimate claim. It is a conjecture based on inference to the best explanation, but when seen in this way it can be evaluated as a strong abductive argument, backed by physical evidence confirmed by the experts who examined that physical evidence.

Next we return to the argument map in figure 8 in order to see how the arguments displayed in the first four figures fit into it. The first thing to notice is that one of the premises shown in figure 7, supporting the ultimate conclusion that the portrait of the young woman is a genuine da Vinci, is the same proposition as the ultimate conclusion of figure 8. This proposition states that the portrait was a page in a book that celebrated the wedding of Bianca Sforza. So we can now see how the argument map in figure 7 fits into the previous argument map shown in figure 6. And so we can combine these two argument maps together to make a larger argument map. It was already shown above how the argument map in figure 6 fits into the argument map in figure 3 by supporting Kemp’s argument from expert opinion shown in figure 3. So now we can see how to connect figures 3, 7 and 8.

The argument map shown in figure 8 could be described as the clincher, because it presents strong physical evidence backed up by the technology employed by Cotte to analyze the painting and the alignment between the three holes and the three stitch marks. The finding by Cotte that the alignment was perfect is very convincing evidence. These findings, shown at the bottom of the argument map in figure 8 propagate up the tree to the root proposition that the portrait was a page in a book that celebrated the wedding of Bianca Sforza. As suggested above, this very strong argument fits into the tree shown in figure 7 by supporting the premise that the portrait was from this book. By this means the part of the argument now composed jointly of the fifth and sixth argument maps is very strong. Once these two argumentation trees are joined to the tree shown in the first argument map, the combined argument tree presents a very strong

argument supporting the ultimate conclusion that the portrait is a genuine da Vinci. To sum up, we can produce a large argument map composed of the connected trees composed of figures 3, 7 and 8 showing the whole sequence of argumentation supporting the ultimate conclusion.

Next we turn to figure 4, where a third argument from expert opinion was put forward by Cristina Geddo, an expert on Leonardo and his followers. She put forward the argument that the pen marks in the painting suggested that the artist used his left hand, even though it is known that all of Leonardo's assistants worked with the right hand. This argument would give some evidence for the conclusion that the portrait is a genuine da Vinci, but it leaves open the possibility that anyone who was working left handed could have drawn the portrait. Therefore by itself it does not prove the ultimate conclusion that the portrait is a genuine da Vinci. Still, the argument is relevant, and does carry some weight in the case as a whole. The reason is that it excludes the alternative explanation that the portrait could have been drawn by one of Leonardo's assistants, because they are all known to have worked with the right hand only. Therefore the conclusion drawn in figure 4 is disjunctive. It states only that either the portrait was drawn by da Vinci or by a forger copying his left handed style. Figure 4 remains relevant, even after the evidence put forward shown in the argument map in figure 8. The reason is that even after the portrait was shown to be taken from the commemorative book on the wedding, the possibility still remains open that it could have been painted by one of Leonardo's assistants.

It is less straightforward to connect the argument tree shown in figure 4 into this larger argument map. Nevertheless, we can connect the argument shown in figure 4 to the large argument tree composed of figures 3, 7 and 8 by putting forward a counterargument stating that the portrait could have been drawn by a forger copying Leonardo's left handed style. This argument in turn can be counterattacked by pointing out that after it was shown that the portrait came from the commemorative book connected to Leonardo, as shown by the evidence presented in figure 8, it is less likely that it was painted by a forger copying his left handed style. The reason is that once we are given the evidence presented on the large argument map, if the Bianca portrait was painted by anyone else, it would have been by one of Leonardo's assistants. However, this possibility is ruled out by the evidence shown in the argument map in figure 4.

Once we have gotten some grasp of the larger picture by seeing how the argument maps in figures 3 to 8 can all be fitted together to compose one large argument map supporting the ultimate conclusion that the portrait is a genuine da Vinci, we can see how the evidence as a whole needs to be evaluated. The main argument put forward by Kemp overcomes counter arguments put forward by other experts only once it has been supported by the very strong argument shown in figure 8 proving that the portrait was originally a page in the commemorative book with links to da Vinci.

The next task is to look at the five argument maps in order and see how each one is linked to the next one so that it is possible to get a picture of the whole sequence of argumentation. Looking at figure 3, we see that it is a classic case of the battle of the experts. Kemp stated his view that the portrait is a genuine da Vinci. Using the scheme for argument from expert opinion, since Kemp is an expert, some evidence has now been shifted to support the conclusion. But there is a counterargument, also based on argument from expert opinion. Eskerdjian is also an expert, and he disagrees. Both are qualified experts, but Eskerdjian also gave some evidence to support his argument from expert opinion by stating that in his opinion the quality of the portrait did not compare with that of other da Vinci paintings. Presenting this evidence makes his argument strong, strong enough to work as an undercutter that defeats the original argument from expert opinion from Kemp. At this point then, we can sum up the evidential situation by

saying that an argument from expert opinion has been put forward from Kemp to prove the ultimate conclusion at issue, but it fails to prove this proposition because it is undercut by a countervailing argument from expert opinion.

Next let's deal with the third argument map in figure 5. It too is a battle of the experts, in this case, fingerprint experts. The expert evidence put forward by a forensic examiner supports the claim that a fingerprint found on the portrait is attributable to da Vinci, but this argument from expert opinion is undercut by the testimony of other experts who claim that the fingerprint was too poorly detailed to support the claim of a match. This counterargument is strong because it is based on the testimony of several other forensic experts who were consulted, and the finding of the original expert was confirmed by tests he ran on his students and colleagues. Thus evidence was given to back up this second argument from expert opinion, and therefore it defeats the original argument from expert opinion put forward by the forensic examiner Biro. This argument too is a battle of the experts, a stalemate that does not take us any further. So it can drop out of consideration as a part of the argument that is centrally significant for the evaluation.

Next we turn to figure 7. The argumentation shown in this figure supports the argument from expert opinion put forward by Kemp in figure 3. In figure 3 Kemp did not bring forward sufficient evidence to support his claim that the portrait is a genuine da Vinci. But now, the argumentation shown in figure 7 backs up that argument from expert opinion by presenting the evidence that Bianca Sforza was a likely candidate for the person in the portrait and that both Leonardo and Bianca had links to Ludovico Sforza. These arguments narrow down the scope of the investigation considerably. Also Kemp presented evidence that the portrait was likely cut from a book. This would explain why there were no accounts of the portrait in the literature on Leonardo's paintings. It therefore serves as evidence to rebut the argument that the absence of accounts of the portrait suggests that it is a forgery. This new argument changes the focus of the investigation, but remains purely hypothetical so far, as a proof of the ultimate claim. It is a conjecture based on inference to the best explanation, but when seen in this way it can be evaluated as a strong abductive argument, backed by physical evidence confirmed by the experts who examined that physical evidence.

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The argument map in figure 9 is close to being complete in representing the evidence of the case presented at the beginning of this paper. The main reason it is incomplete is that it does not take into account the argumentation shown in figure 4 concerning the argument from expert opinion by Cristina Geddo. If we wanted to make it complete we could insert it into figure 9 by adding it as an additional argument that supports the ultimate conclusion of the argument in figure 9 by excluding the possibility that the portrait was painted by one of Leonardo's assistants.

We could do this by adding a counterargument to the ultimate conclusion that Leonardo painted the portrait arguing that the portrait could have been painted by one of his assistants, and countering this argument with Geddo's argument from expert opinion. This argument is not shown in the large argument that in figure 9, because of the possibility of making the diagram too complicated, and because in the end does not carry that much weight.

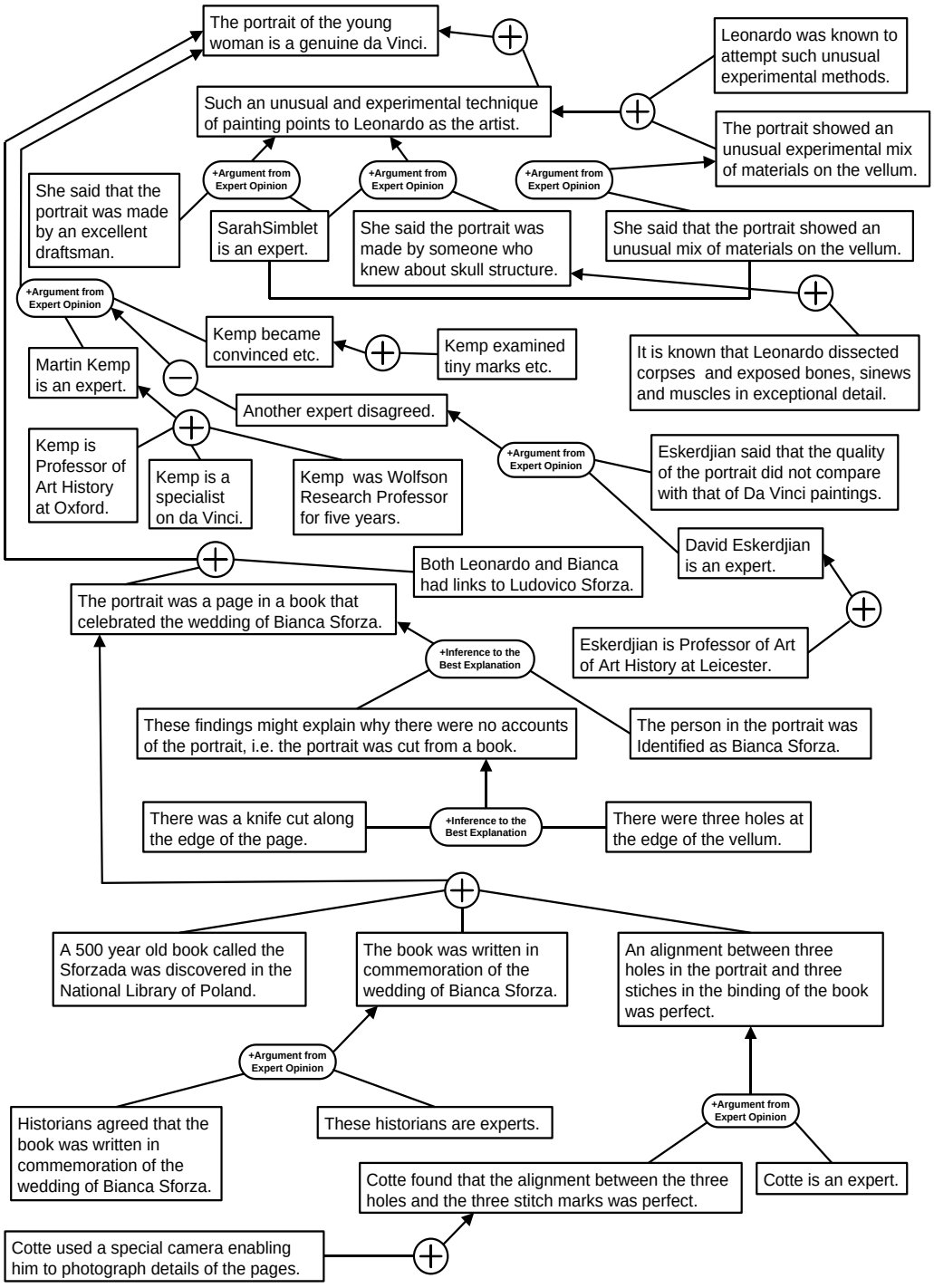

Figure 9: Large Map Connecting the Mass of Evidence in the Case

But how is it possible that we can represent the entire sequence of argumentation in the case by using the argument diagram in figure 9 in such a way that it fails to take into account the arguments shown in figure 4 and figure 5? Recall that we excluded the argument in figure 5 from the larger argument map in figure 9 for one reason, because it was susceptible to a counterargument that the portrait could have been drawn by a forger copying Leonardo's left handed style. We excluded figure 5 because the fingerprint argument in it was undercut by the testimony of other experts who claim that the fingerprint was too poorly detailed to support the claim of a match.

The formal model of burden of proof of Prakken and Sartor (2009) is an abstract argumentation formalism, and for this reason it can be used to model the exclusion of the arguments shown in figures 4 and 5 from the large argument maps shown in figures 8 and 11. The logical model of burden of proof of Prakken and Sartor (2009, 228) is based on the ASPIC+ system of Henry Prakken, which is in turn based on the abstract argumentation framework of (Dung, 1995). The theoretical basis for excluding these arguments finds its foundation in this way of modelling burden of proof. On this formal model, the proponent starts with an argument he wants to prove and then the opponent can defeat this argument by providing a counterargument. An abstract argumentation framework is defined as a pair (*Args*, *Def*), where *Args* is a set of arguments and $Def \subseteq Args \times Args$ is a binary relation of defeat. The idea is that each argument can be defeated by other arguments. If the counterargument defeats the original argument, the original argument is knocked out of consideration, and a sequence of argumentation ends that point. If there is such a deadlock, the argument can then be excluded as providing any evidence to prove the conclusion at issue.

Recent research in artificial intelligence (van Gijzel and Prakken, 2011) has shown that the structure of the Carneades argumentation system is structurally equivalent to that of ASPIC+. The two models appear to be converging toward a common conception of argumentation, and in this instance they can work together.

8. Stages of the Investigation

If we look again carefully at the way the evidence accumulated and was evaluated as shown in the large map in figure 9, we can see that the argumentation went through three main stages, the top stage, the middle stage and the bottom stage. At the top stage there were the five arguments from expert opinion. In the middle stage, there were two arguments from inference to the best explanation. At this middle stage all that was known is that there was a knife cut along the edge of the page, and three holes in the edge of the portrait, suggesting that the portrait was cut from a book. This was merely a plausible hypothesis, but it would explain why there were no accounts of the portrait known in the literature on Leonardo. At the bottom stage, a lot of new evidence came in once the 500 year old book was discovered in the National Library of Poland, and it was investigated by Cotte using his special camera. This sequence of argumentation in the buildup of evidence as a hypothesis is supported or refuted is characteristic of how scientific investigations typically work. First the hypothesis is merely a conjecture based on weak evidence, for example argument from expert opinion, that is not enough by itself to prove the ultimate conclusion, but is enough to drive the investigation forward in an effort to collect more relevant evidence. The hypothesis works at this stage as an explanation of the facts that competes with other conjectures that could explain the same facts. As new evidence comes in, the

competing explanations can be comparatively evaluated based on the arguments derived from that expanded body of evidence.

In figure 10 we see three competing explanations along the top of the argument map. The first explanation is that the portrait was painted by da Vinci. The second is that it was painted by a da Vinci follower. The third explanation is that it was painted by a modern forger, perhaps a 19th century artist. Each explanation is supported by pro and contra arguments, shown underneath the explanations. Shown here is an interesting relationship that indicates how explanations can be supported by arguments and also attacked or refuted by arguments. Which explanation is the best of the three? It depends on how well each of them can comparatively account for the evidence that supports or refutes it.

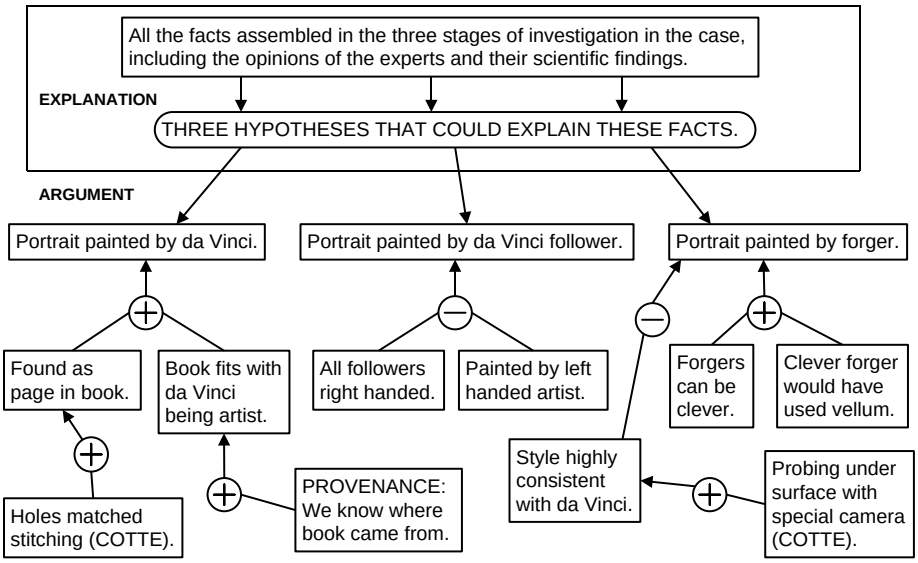

Figure 10: Three Competing Explanations of the Facts

On the right there is the argument that forgers can be clever and that a clever forger would have used vellum that came from the time and place of Leonardo. This is a very hard contra argument to overcome, because there are many known cases of extremely clever forgeries that have resisted detection for a long time, even when examined by highly knowledgeable experts. In the middle there is the explanation that the portrait was painted by a da Vinci follower. This might normally be hard to rule out, except for the evidence that not only was Leonardo left handed, but it is known that all his assistants who painted in his workshop were right handed artists. So there is strong evidence against this hypothesis, so strong that the center explanation does not compete very well with the one on the left and the one on the right. The explanation on the left is that the portrait was painted by da Vinci. This was a competing explanation from the beginning, because of the expert opinion of Kemp. And it was a reasonably strong explanation because the portrait has many of the characteristics of da Vinci as an artist. However it lacked enough strength as an explanation, by itself, to compete with the explanation that the portrait was painted by a modern forger. However, once the forensic evidence of the holes matching the stitching of the book came in, at the point where the book was discovered and examined by Cotte, suddenly this explanation became extremely powerful. The reason is that it was supported so well by the scientific evidence provided by Cotte showing that the holes in the portrait match the stitching of the book.

Once this evidence came in, the hypothesis that the portrait was painted by da Vinci explained so much of the evidence so well that it overwhelmed the two competing explanations. It was now the so-called best explanation. By inference to the best explanation, the hypothesis that the portrait was painted by da Vinci became strong enough to convincingly match the burden of proof that would be required to satisfy leading experts in the world of fine art study.

9. The Three Tasks of Evaluation

To sort out the problem of evaluation we need to distinguish three different tasks of evaluation. The first is the task of judging how the audience, in the real world so to speak, would actually evaluate the acceptability of the ultimate conclusion that the portrait was a genuine da Vinci painting. The first problem with this issue is to determine who the audience should be taken to be. The audience could be described as the art world. One needs to be careful here, however. There are two audiences that need to be distinguished, even though these audiences overlap. The first audience is the set of buyers of artworks. The second audience is the set of art experts.

It is proposed here that two factors could be used to make a judgment of this evaluation. The first is the monetary value of the painting, and how that value changes over time as new evidence on whether the painting is a genuine da Vinci or not comes forward. The second is the acceptance of the painting as a genuine da Vinci or not by the experts.

The following list of leading experts who have agreed with to attribution to Leonardo as of 06/09/2012 was given by the Wikipedia entry 'Portrait of a Young Fiancee'.[3]

*Martin Kemp, Emeritus Research Professor in the History of Art at Oxford University
*Carlo Pedretti, professor emeritus of art history and Armand Hammer Chair in Leonardo Studies at the University of California, Los Angeles
*Nicholas Turner, former curator at the British Museum and the J. Paul Getty Museum
*Alessandro Vezzosi, the director of the Museo Ideale Leonardo Da Vinci in Vinci, Italy,
*Dr. Cristina Geddo, an expert on Leonardo and his followers
*Dr. Claudio Strinati of the Italian Ministry of Culture, and
*Mina Gregori, professor emerita at the University of Florence.

This is not to say that there is universal agreement in the fine art world that the portrait is a genuine Leonardo. It is only to say that there was a sufficient mass of evidence, and absence of counter-evidence, at this point to shift the burden of proof to the side of the skeptics. The change in market value of the portrait can also be taken as an indication of such a shift. Originally, the portrait was bought in 2007 for $22,000. In 2012, it was reported in many newspapers that its estimated value would be in excess of $160 million. These monetary figures can be used to give some rough indication of general acceptance of the claim that the portrait is a genuine da Vinci.

The second task is the one addressed by this paper. It is the task of taking a particular description of the case and analyzing the argumentation specifically given in that case. We have to recognize that the issue of whether the portrait is a genuine da Vinci has been extensively investigated by forensic experts, and there is a mass of evidence that has been collected, analyzed by these experts, and communicated to other experts who are continually making judgments about whether the portrait is a genuine da Vinci or not. This body of evidence is continually changing, and is subject to change as time goes on and new evidence comes in, or as the given evidence is further discussed, analyzed and evaluated. No attempt has been made nor

[3] http://en.wikipedia.org/wiki/Portrait_of_a_Young_Fianc%C3%A9e

could it be made in this paper to use all this evidence as a basis for evaluation of the issue of whether the painting is genuine. What has been done, instead, is to designate a particular account, outlined in the first parts of the paper, as the corpus to be analyzed.

The task is the one of taking this corpus as input into the Carneades Argumentation System and allowing the system to automatically generate the decision on whether the ultimate conclusion that the painting is genuine can be proved or not, on the basis of the evidence put into Carneades. This paper has not attempted to carry out that task, but it is possible to do it, given that some agreement can be made on the input values for acceptance and rejection of the propositions in the argumentation tree used to make the calculation. This task is left as a proposed line of investigation for future research. To use Carneades to evaluate the argument, we have to determine not only which propositions are accepted and which arguments are correctly applicable. We also have to set standards of proof for each of the propositions and each of the arguments. We want to set a high standard, because of the high degree of skepticism in the art world about any unsigned portrait not mentioned in the Leonardo literature describing his paintings. The standard of preponderance of the evidence would not be nearly high enough. Probably the beyond reasonable doubt standard would be the appropriate one to use.

All three of these tasks depend on what is taken to be the appropriate Standard of Proof for proving the ultimate conclusion, and for assigning burdens of proof both to this proposition and the component arguments in the argumentation tree leading to this ultimate conclusion. Any evaluation of an argument by some normative model depends not only on the structure of the argument identified using the model, but also on the input, the initial values assigned to premises and conclusions in the sequence of argumentation. With Carneades, there are two types of input values, one for burdens of proof and one for representing whether the audience initially accepts or rejects the statements. In part three it was shown how Carneades defines burden of proof using four standards of proof set in increasing order of strictness. In defining standards for clear and convincing evidence and beyond reasonable doubt, the gamma threshold was left open and not given a fixed numerical value. The problem is that if we do assign numbers to all the propositions in the large argument map shown in figure 9 representing the mass of evidence in the case, there is a great risk of committing fallacies by assigning the numbers in an arbitrary way. Despite this difficulty, we can still apply the notions of burden of proof defined in Carneades to the case in a way that throws light on how it should be evaluated. It is up to the argument analysts to set some value for gamma, depending on the context of dialogue which the argument is part. In the Leonardo example described in case study, the context is that of a forensic investigation. According to the description of the case, there was considerable skepticism on the part of the audience, so that in order to convince this audience to reverse its initially skeptical opinion, it is necessary to set the gamma factor to a high level.

Given these limitations imposed by the specifics of the case, a highly realistic way to evaluate the case study argument analyzed in this paper is to use the notion of reversal of burden of proof. At the second to last stage of the argumentation sequence, represented in the argument map of figure 5, the burden of proof was still on the proponents of the thesis to prove that the portrait was an authentic da Vinci, because there was no evidence of the existence of a book that might have contained the portrait. With the finding of the book, and the new evidence including the perfect match between the stitch marks in the book and holes in the portrait, the burden of proof was reversed. The pro evidence outweighs the con evidence to the extent that it would now be fair to say that the burden has reversed onto the critics who claim that the portrait is not a genuine work of da Vinci.

10. A Realistic Evaluation of the Argumentation

The part of the argument map shown at the bottom of figure 9 (the part representing the evidence shown in figure 8) could be described as the clincher, because it presents strong physical evidence backed up by the technology employed by Cotte to analyze the painting and the alignment between the three holes and the three stitch marks. The finding by Cotte that the alignment was perfect is very convincing evidence. These findings, shown at the bottom of the argument map in figure 9 propagate up the tree to the root proposition that the portrait was originally a page in a book that celebrated the wedding of Bianca Sforza. As suggested above, this strong argument fits into the tree shown in figure 6 by supporting the premise that the portrait was from this book. By this means the part of the argument now composed jointly of the fifth and the fourth argument maps is very strong. Once these two argumentation trees are joined to the tree shown in the first argument map, the combined argument tree presents a very strong argument supporting the ultimate conclusion that the portrait is a genuine da Vinci.

How this propagation process works is shown in figure 11, a simplified model that can be used to illustrate to the reader in general on how the argument would be evaluated in the Carneades Argumentation System. In the Carneades diagramming tool, a text box is colored in green and a checkmark is inserted in it to show that the proposition has been accepted by the audience. To say it has been accepted by the audience means that it has an evidential value high enough to meet its required burden of proof. To represent this process in a simplified manner some of the text boxes in figure 11 have been darkened, indicating acceptance by the audience.

Notice that all the text boxes and argument nodes in the bottom part of the argument diagram in figure 11 have been darkened. This indicates that all the premises and conclusions in this part of the argument have been accepted.

Next, notice that this part of the argument supports the proposition that the portrait was a page in a book that celebrated the wedding of Bianca Sforza. Next, notice that this proposition is one premise in an inference to the best explanation in which the other premise states that both Leonardo and Bianca had links to Ludovico Sforza. This argument, in turn, goes directly to the ultimate conclusion at the root of the tree stating that the portrait of the young woman is a genuine da Vinci. Since the argument at the bottom concerning the alignment between the three holes in the three stitch marks is strong, and since both premises in the inference to the best explanation have also been strongly supported by the evidence, the argument to the ultimate conclusion is, as a whole, a very strong one.

At the top part of figure 11 the three arguments from the expert opinion of Sarah Simblet are shown. Assuming that all the premises of the argument are accepted by the audience, and that in all three instances the argumentation scheme for argument from expert opinion correctly applies to the argument, the conclusion of this argument can be accepted, namely the proposition that such an unusual and experimental technique of painting points to Leonardo as the artist. What we have here then is the first pro argument supporting the ultimate conclusion that the portrait of the young woman is a genuine da Vinci. At the next level down we have the argument from expert opinion by Martin Kemp and its attack by the contrary argument of David Eskerdjian. Because all the premises of the second argument are accepted and the argument from expert opinion is correctly applicable, the argument from Kemp's expertise is refuted, even though all its premises are accepted. This outcome is shown by the node representing Kemp's argument from expert opinion as undarkened. This notation tells us that Kemp's argument from expert opinion fails to

carry weight because of the counterattack from the opposed argument from expert opinion by Eskerdjian.

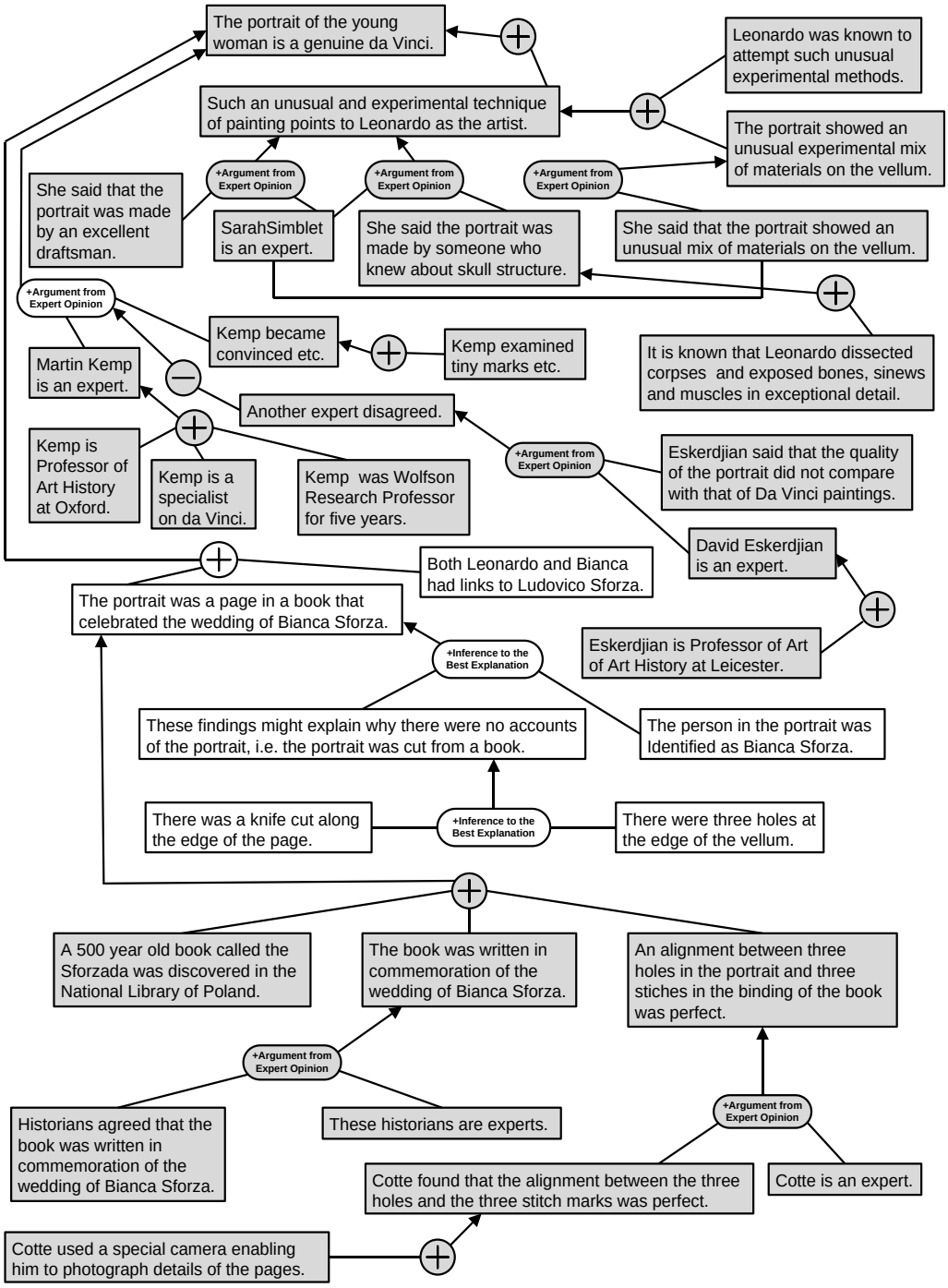

Figure 11: How the Evidence Propagates Up the Tree

In the middle of the argument map in figure 11 at the left, we have the conjectural argument from inference to the best explanation suggesting that the portrait was a page in a book that celebrated the wedding of Bianca Sforza. This argument is very strongly confirmed by the

argument at the bottom concerning the discovery of the alignment between the three holes at the edge of the portrait and the three stitch marks found in the binding of the book. Both of these arguments go together to strongly support the conclusion that the portrait was a page in a book that celebrated the wedding of Bianca Sforza. Then in turn, this premise forms the third argument going directly to the ultimate conclusion. This argument joins the conclusion that the portrait was a page in a book that celebrated the wedding of Bianca Sforza to the other premise that both Leonardo and Bianca had links to Ludovico Sforza.

The evaluation shows that first there are three complex arguments leading to the ultimate conclusion, but one of them is not strong enough, and fails to offer any support to the ultimate conclusion. Second, it shows that there are two other arguments that successfully provide support to the ultimate conclusion. One is the expert opinion from Sarah Simblet. The other is the large connected argument made up of two subarguments shown in the bottom half of figure 11. Once the bottom argument concerning the matching of the holes and the stitches is factored in, it strongly supports the conclusion that the portrait was a page in the wedding book, and this in turn strongly supports the ultimate conclusion when combined with another premise that is accepted. The two strong arguments offset the one that failed.

It needs to be made clear however, that the upwards propagation of evidence shown in figure 11 is meant to be a realistic evaluation of how this argument would be evaluated in the Carneades Argumentation System once the appropriate burdens of proof had been put into the system. Once this data has been put into the system, Carneades automatically evaluates whether the ultimate conclusion is acceptable or not based on its burden of proof, on the acceptability of all the premises that have been parts of the chain of arguments leading to the ultimate conclusion, and on the requirements of each of the argumentation schemes used in the chain of arguments. What needs to be made clear is that the argument has not yet been run through the Carneades Argumentation System, and therefore the analysis of it in this paper does not provide this sort of evaluation.

11. Conclusions

The test case modeling using the Carneades Argumentation System in this paper is of wider social interest as an investigation of how well state-of-the-art argumentation methods can be applied to modeling the aggregation of forensic evidence in controversial issues of fine art attribution. As Kemp and Cotte (2010, 9) noted, such investigations are based on “a plausible accumulation of evidence”, rather than on absolute certainty. For this reason, it is reasonable to consider the utility of an argumentation approach that evaluates proof of the claim based on weighing the arguments supporting it against the arguments opposing it. This balance of considerations technique shows the way forward in the task of modeling evidential judgments of fine art attribution in the setting of a multi-staged social inquiry.

One of the limitations of figure 11, and also of figure 9 which it was based on, is the exclusion of the consideration of figures 4 and 5. It was argued that to simplify figure 9, figures 4 and 5 could be eliminated as parts of the evidential package because both were instances where the argument was attacked by a counterargument, and therefore the evidence provided by these two parts of the argument could be considered weak. Nevertheless, it is clear that figure 9 does not take all the relevant evidence found in the investigation into account. It would be nice to have a simplified overview of the sequence of argumentation that takes the arguments of figures 4 and 5 into account as well. Such an overview is provided by the argument map in figure 12.

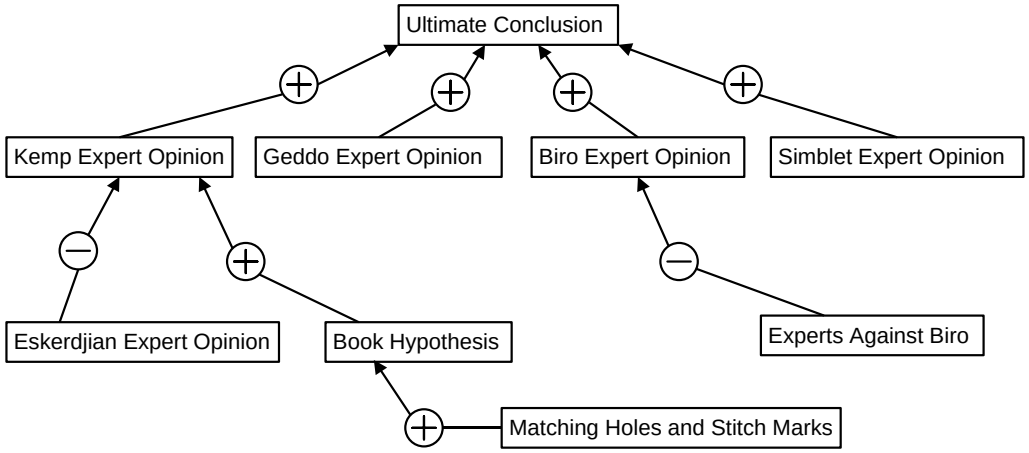

Figure 12: An Overview of the Evidence

The abstract argument framework, unlike the Carneades Argumentation System, represents each argument as a node in the tree, and does not represent the components of the argument, for example the premises and conclusion. This approach results in a simplified representation showing one argument attacking another, and another argument attacking the attacking argument, and so forth. Figure 12 is expressed in the style of an abstract argumentation framework, where each of the text boxes is taken to represent an argument. The only exception in figure 12 is the text box at the top which represents the ultimate conclusion, the statement that the portrait of the young woman is a genuine da Vinci. Also, in figure 12, supporting (pro) arguments are shown as well as attacking (con) arguments.

Looking at figure 12, we see the original conjecture of Kemp, where he became convinced that there was a chance of attribution to Leonardo, shown as the Kemp Expert Opinion on the left. This node represents the argument shown in figure 3. The next argument to the right of that one shows the argument based on the expert opinion of Cristina Geddo, represented by the argument map of figure 4. This argument presents the evidence based on the portrait being drawn by left handed artist. As noted in the discussion of figure 4, it is not a strong argument, because of the possibility of a forger copying Leonardo's left-handed style. But still, it does carry some evidential weight in the network of argumentation as a whole, and so in figure 12 is represented as a pro argument supporting the ultimate conclusion. In the next argument to the right the fingerprint evidence of Biro is represented. As noted in the discussion of figure 5, it was a weak argument because it was attacked by the contrary expert opinion argument of Champaud. In figure 12, this argument is shown as having attacking argument in which the other experts criticized the reliability of fingerprint evidence. The argument based on the expert opinion of Sarah Simblet is shown in the rightmost node at the top of figure 12. Finally, underneath the Kemp Expert Opinion Argument node, two pro arguments are shown, one supporting the other. The con argument is the contrary expert opinion of Eskerdjian. Figure 12 provides a summary of all the evidence in the case, so that the components missing in figure 11 can be taken into account. Still, figure 11 has proved useful for some significant points to be brought out.

A significant finding of the paper is shown by looking once again at figure 11, and seeing how the argumentation in that figure breaks down into three stages. There is the top stage displaying the darkened boxes, which represents the original part of the argument where Kemp

became convinced that there was a chance of attribution to Leonardo. Even though doubt was cast on Kemp's argument by the opposed argument from expert opinion of Eskerdjian, it still carried some weight because it was supported by the other argument from expert opinion of Simblet. Still, because of the attack on it, it could hardly be considered a conclusive argument by itself. It did not come close to meeting the beyond a reasonable doubt standard of proof. Then the second stage of the argument was the chain of argumentation displayed in the white boxes in the middle part of figure 11. This stage of the argument represented the two applications of the scheme for inference to the best explanation. Finally, at the bottom displayed in the argumentation sequence with the darkened boxes, we have the clincher argument provided by the forensic evidence of the stitches in the binding of the book.

This three-step sequence of development of the chain of argumentation shown in figure 11 is typical of how evidence fits together into a pattern of plausible reasoning in which there is three stages. First, there is a conjecture put forward that is interesting to investigate because it is not widely accepted, and perhaps even goes against the conventional climate of opinion. Second, some evidence is put forward that provides support for the hypothesis by means of offering an explanation of the evidence that fits the known facts of the case at that stage. Third, the existing hypotheses are tested as explanations against new stronger evidence that comes in, often by experimental findings. If the new evidence that comes in at this stage is very strong, and fits the burden of proof required to draw the conclusion that the hypothesis has been proved, then some closure is achieved. Closure does not mean that the investigation is now closed for all time, for a scientific investigation always has to be open to the possibility of new evidence, given the requirement of falsification. However, closure does mean that the ultimate conclusion can be accepted, on the basis that the evidence supporting it is strong enough to meet the burden of proof appropriate for the investigation.

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