Towards (Probabilistic)Argumentation for Jury-based Dispute Resolution

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Abstract. We propose an argumentation framework for modelling jury-based dispute resolution where the dispute parties present their arguments before a judge and a jury. While the judge as the arbiter of law determines the legal permissibility of the presented arguments the jurors as triers of facts determine their probable weights. Such a framework is based on two key components: classical argumentation frameworks containing legally permissible arguments and probabilistic spaces assigning probable weights to arguments. A juror's probability space is represented by a set of possible worlds coupled with a probabilistic measure computed by assumption-based argumentation framework using grounded semantics.

Keywords. Probabilistic argumentation, jury-based dispute resolution

Introduction

In villages throughout Asia, Africa and Latin America, disputes are often resolved by councils of elders. In modern-day population centers, much of the functions of such elder councils are practiced by trials in legal courts or various kinds of mediation bodies. There are other similar though less formal ways for dispute resolutions like debates between presidential candidates (e.g. Obama and McCain) in an election where the candidates exchange arguments and ultimately the members of audience decide the winner and loser. Committees, task forces are also common forms of dispute resolution. All of these forms of dispute resolution are arguably instances of what we will refer to in this paper as jury-based dispute resolution where the jury members weigh the credilibities of the presented arguments and collectively make their decisions. Though it seems to be recognized widely that argumentation is a key mechanism in jury-based dispute resolution, a formal model of how it is deployed is still to be developed. To clarify the problems, let us start with a simple example whose story line is borrowed from Riveret,Rotolo,Sartor,Prakken and B.Roth[8].

Example 0.1 *John sued Henry for the damage caused to him when he drove off the road to avoid hitting Henry's cow. John's argument is:*

J*: Henry should pay damage because Henry is the owner of the cow and the cow caused the accident*

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Henry countered by two arguments:

H*: John was negligent as evidences at the accident location show that John was driving fast on the hilly road. Hence the cow was not the cause of the accident*

H'*: The cow was mad and the madness of the cow should be viewed as a force-majeure*

Could John win the case ? Suppose that Henry could not put forward any evidence "proving" the madness of his cow. The judge dismisses the second argument H' *as irrelevant. Hence the probability for John to win depends on how likely the judge (as the sole juror) considers fast driving as a cause of the accident.*

Note that John's argument J is based on a common norm (or law) that owners are responsible for the damages caused by their animals while Henry's argument H *is based on a causal relation between John's fast driving and the accident.*

Example 0.2 *We give a bare-bone sketch of the argumentation at the infamous trial of OJ Simpson for the murder of his wife [10]. In a nutshell, the main argument of the prosecutor linking Simpson directly to the murder is based on DNA tests of blood found at the murder scene and on two socks and a glove found in Simpson's house. It could be presented in an informal way as follows:*

P*: Based on DNA tests showing that there is Simpson's blood at the murder scene and the victim's blood on the socks and glove, Simpson is the murder.*

The defence countered in two ways:

D_1*: By introducing Henry Lee, a respectable forensic expert who testifies that the results of DNA tests are not normal*

D_2*: By pointing out that (1) Mark Fuhrman, the police officer collecting most of the evidences at the crime scene and Simpson's house is a liar and racist who has admitted of planting evidence to help prosecutors convicting defendants in the past and (2) there are other irregularities in the evidence collecting process and (3) the glove does not fit Simpson's hand, the defence puts forwards the claim that there is a police conspiracy to frame Simpson by planting evidences against him.*

At the criminal trial, where a conviction must be beyond reasonable doubt, Simpson is not convicted though at the following civil trial where a conviction could be based on preponderance, Simpson is found guilty of murdering his wife and her guest. Interestingly, at the civil trial, "argument" D_2 *of the defence is not allowed by the trial judge. Further, the jury at the criminal trial is mostly black while it is mostly white at the civil one. It is generally accepted [10] that racial bias played a key role in the outcomes of both trials.*

The purpose of this paper is to offer an agument-based model to shed some light on these kinds of applications. The paper is structured as follows. We first introduce the notion of abstract argumentation for jury-based dispute resolution and two criteria for adjudication: beyond reasonable doubts and majority voting with preponderance. We then introduce probabilistic assumption-based argumentation as a methodolody for representing probability spaces. We illustrate the applicablity of the new framework by applying it to the infamous OJ Simpson trials. We then conclude.

1. Abstract Argumentation For Jury-Based Dispute Resolution (AAJ)

An abstract argumentation framework [3] is a pair $\mathcal{AF} = (AR, att)$, where AR is a set of arguments, and *att* is a binary relation over AR representing the attack relation between the arguments with $(A, B) \in att$ meaning A attacks B. For simplicity, we restrict ourself on frameworks with finite sets of arguments. A set S of arguments attacks an argument A if some argument in S attacks A; S attacks another set S' if S attacks some argument in S'. A set *S* of arguments is *conflict-free* iff it does not attack itself. Argument A is *acceptable* with respect to *S* iff S attacks each argument attacking A. *S* is *admissible* iff *S* is conflict-free and each argument in *S* is acceptable with respect to *S*. The semantics of argumentation could be characterized by a fixpoint theory of the characteristic function $F(S) = \{A \in AR \mid \text{A is acceptable wrt } S\}$. It is easy to see that S is admissible iff S is conflict free and $S \subseteq F(S)$. As F is monotonic,the least fixed point of F exists and is defined as the *grounded extension* of AF.

A **finite probability space** is a pair $\Pi = (\mathcal{W}, P)$ where $\mathcal{W}$ a finite set of all possible worlds and P is a mapping from $\mathcal{W}$ into the interval $[0, 1]$ such that $\Sigma_{w \in \mathcal{W}} P(w) = 1$.

There are many forms of jury-based adjudication. In a single judge trial or a three-judges appelate courts, the jury consisting of the judges themself is fully capable to introduce new legal arguments not presented by the parties in their debate. On the other hand, as lay jurors may have only the most basic education and not well-versed in the laws and norms, they should not be allowed to introduce new legal or norm-based arguments in their consideration apart from those presented by the dispute parties. In contrast, the members of audiences in presidential debates have complete freedom to introduce whatever arguments they consider fit in their "adjudication" of the debate. Understanding the fundamentals of jury-based adjudication is an enormous challenge for the research on argument-based dispute resolution. In this paper, we limit ourself to the case where the jurors are restricted to consider the probabilities of causal arguments. We follow evidence law in modeling the judge as the arbiter of law and the jurors as the triers of facts [2] [5,6,11]. In other words, the judge determines the admissibility of evidences while the jurors determine the probable weights of the evidences.

Definition 1.1 *An Abstract Argumentation framework for Jury-based dispute resolution (AAJ) is a tuple*

$$(AF, \Pi_1, \ldots, \Pi_n, \vdash_1, \ldots, \vdash_n), \qquad n \geq 1$$

satisfying following conditions:

1. $AF = (AR, att)$ *is an abstract argumentation framework with a distinct subset of arguments* $AR_c \subseteq AR$ *representing intuitively the set of arguments that are based on some causal relationships* [3].
   Abusing the notations, arguments in AR_c *are called causal arguments while arguments in* $AR - AR_c$ *are called norm-based arguments.*
   Note that the construction of AF *is under the arbitration of the judge.*

[2] This is not saying that jury members are not influenced by their biases in making their decision

[3] Note that an argument could be based on both legal norms and causal relations. Such a argument also belongs to AR_c.

2. $\Pi_i = (\mathcal{W}_i, P_i)$, $1 \leq i \leq n$ *are probability spaces where* $\mathcal{W}_i$ *consists of possible worlds of the juror i.*
   Relations $\vdash_i \subseteq \mathcal{W}_i \times AR$ *,* $1 \leq i \leq n$ *specify the legitimacy of the arguments wrt possile worlds of the jurors where for each* $A \in AR - AR_c$*, for each* $w \in \mathcal{W}_i$ *:,* $w \vdash_i A$ *holds*[4]

Intuitively, probability spaces Π_i assign weights to the arguments allowed for consideration by the judge. The condition $w \vdash_i A$ for $A \in AR - AR_c$ captures the intuition that jurors only determine the probable weights of the arguments, but do not challenge the legality of arguments.

Definition 1.2 *Let* $(AF, \Pi_1, \ldots, \Pi_n, \vdash_1, \ldots, \vdash_n)$ *be an AAJ and* $w \in \mathcal{W}_i$*.*

- *The argumentation framework wrt* w*, denoted by* $AF_w = (AR_w, att_w)$*, consists of the set of all arguments permissible wrt* w *and the attack relation between them, i.e.*

  $$AR_w = \{A \in AR \mid w \vdash_i A\} \qquad att_w = att \cap AR_w \times AR_w$$

  The grounded extension of AF_w *is denoted by* GE_w*.*
- *We define the grounded probability of argument A* [5] *for juror i, denoted by* $Prob_i(A)$*, as follows*

  $$Prob_i(A) = \sum_{w \in \mathcal{W}_i : A \in GE_w} P(w)$$

For illustration, consider the AAJ $(AF, \Pi, \vdash)$ in example 0.1 where $AF = (AR, att)$ with $AR = \{J, H\}$, $AR_c = \{H\}$ and $att = \{(H, J)\}$ and $\Pi = (W, P)$ with $\mathcal{W} = \{w_1, w_2\}$ where $w_1 = \{J, H\}$, $w_2 = \{J\}$. Define $w_i \vdash A$ if $A \in w_i$. Suppose $P(w_1) = 0.6$, $P_1(w_2) = 0.4$. As $GE_{w_1} = \{H\}$ and $GE_{w_2} = \{J\}$, the grounded probability of J is: $Prob(J) = 0.4$.

1.1. Protocol for Adjudication

How could a decision be reached in an jury-based adjudication ? There are at least two criteria: Beyond reasonable doubt and majority voting with preponderance.

An argument A is **accepted beyond reasonable doubt** by a juror i if $Prob_i(A) = 1$. A is accepted beyond reasonable doubt by the jury if A is accepted beyond reasonable doubt by each juror.

An argument A is **accepted with preponderance** by a juror i if $Prob_i(A) > 0.5$. A is accepted by majority voting with preponderance if A is accepted with preponderance by a majority of the jurors.

In example of John and Henry, as the probability of John's argument J is only 0.4, the judge would decide the case for Henry. Note that in this case, as the jury consists of only the judge, both protocols give the same result. In later chapter, we will elaborate the case of Simpson's trials for further illustrations.

[4]i.e. juror i considers all norm-based arguments legitimate in all of his possible worlds

[5]To be precise, it should be: the probability of A wrt grounded semantics

2. Assumption-based Argumentation For Jury-Based Dispute Resolution (ABAJ)

In general, definition 1.1 puts no restriction on the way probability spaces $\mathcal{W}$ are defined. It could be for example presented using statistical, probabilistic theories or calculus. But at the top level, where the audience (e.g. judges, juries or the general TV audience at large in a presidential debate) should not be expected to have formal technical knowledge, specialized theories (like theories about the probability of the outcome of a DNA test) should be encapsulated in modules whose input-output will be presented to the audience. Further lay jurors almost always employ commonsense reasoning to "compute" the probabilities of the arguments. Let us consider again example 0.1.

Example 2.1 *Argument J is represented by the following rules*[6]*:*

r_1: $henryPay \leftarrow henryOwnerOfCow,\ cowCauseAccident,\ \sim forceMajeure$

r_2: $cowCauseAccident \leftarrow \sim johnNegligent$

r_3: $henryOwnerOfCow \leftarrow$

Argument H is represented by the following rules:

r_4: $johnNegligent \leftarrow drivingFast, p_o$

r_5: $drivingFast \leftarrow p_1$

where p_0, p_1 are probabilistic assumptions with p_0 representing the probability of the accident caused by John's fast driving while p_1 representing the probability of the event that John was driving fast. Note that rules r_1, r_2, r_3 do not contain any probabilistic assumptions. It implies that argument J is norm-based.

The possible worlds in the probabilistic space of the judge when he (acting as the sole juror) reflects on the case before making a decision are represented by maximally consistent subsets of the set of probabilistic assumptions $\{p_0, \neg p_0, p_1, \neg p_1\}$ where $\neg$ is the classical negation operator. Assuming the independence of the assumptions p_0, p_1, a probability measure could be given by clauses

r_6: $[p_0 : 0.8] \leftarrow$

r_7: $[\neg p_0 : 0.2] \leftarrow$

r_8: $[p_1 : 0.75] \leftarrow$

r_9: $[\neg p_1 : 0.25] \leftarrow$

An assumption-based argumentation (ABA) framework [2,4] is a triple $(\mathcal{R}, \mathcal{A}, \overline{})$ where $\mathcal{R}$ is set of inference rules of the form $\alpha \leftarrow \sigma_1, \dots \sigma_n$ (for $n \geq 0$) over a language $\mathcal{L}$, and $\mathcal{A} \subseteq \mathcal{L}$ is a set of assumptions, and $\overline{}$ is a (total) mapping from $\mathcal{A}$ into $\mathcal{L}$, where $\overline{x}$ is referred to as the *contrary* of x. Assumptions do not appear in the heads of rules in $\mathcal{R}$.

A *(backward) deduction* of a conclusion α based on (or supported by) a set of premises Q is a sequence of sets $S_1, \dots, S_m$, where $S_i \subseteq \mathcal{L}$, $S_1 = \{\alpha\}$, $S_m = Q$, and for every i, where σ is the selected sentence in S_i: $\sigma \notin Q$ and $S_{i+1} = S_i - \{\sigma\} \cup S$ for some inference rule of the form $\sigma \leftarrow S \in \mathcal{R}$.

An *argument* for $\alpha \in \mathcal{L}$ supported by a set of assumptions Q is a (backward) deduction δ from α to Q and denoted by (Q, δ, α). An argument (Q, δ, α) attacks an argument (Q', δ', α') if α is the contrary of some assumption in Q'.

For simplicity, we often refer to an argument (Q, δ, α) by (Q, α) if there is no possibility for mistake.

[6] $\sim l$ is a negation-as-failure assumption whose contrary is l.

Given an ABA framework $\mathcal{F}$, a proposition π is said to be a *grounded consequence* of $\mathcal{F}$, denoted by $\mathcal{F} \vdash_{gr} \pi$ if there is an argument supporting π in the grounded extension.

Probabilistic spaces could be represented by probabilistic assumption-based argumentation introduced in the following definition.

Definition 2.1 *A probabilistic assumption-based argumentation (PABA) framework is a triple $\mathcal{P} = (\mathcal{A}_p, \mathcal{R}_p, \mathcal{F})$ satisfying following properties:*

1. $\mathcal{A}_p = \{p_0, \ldots, p_n\}$ *is a set of probabilistic parameters. A* **possible world** *of $\mathcal{P}$ is defined as a maximal (wrt set inclusion) consistent subset of the set $\mathcal{A}_p \cup \neg.\mathcal{A}_p$ where $\neg.\mathcal{A}_p = \{\neg p \,|\, p \in \mathcal{A}_p\}$ and $\neg$ is the classical negation operator.*
2. $\mathcal{R}_p$ *is a set of probabilistic rules of the form*

$$[\alpha : x] \leftarrow \sigma_1, \ldots \sigma_n{}^7 \qquad n \geq 0$$

where α is a probabilistic parameter or the negation of a probabilistic parameter and $0 \leq x \leq 1$ is a real number such that

   (a) *If a rule of the form $[p : x] \leftarrow \sigma_1, \ldots \sigma_n$ appears in $\mathcal{R}_p$ then $\mathcal{R}_p$ also contains the complementary rule $[\neg p : 1 - x] \leftarrow \sigma_1, \ldots \sigma_n$*

   (b) *For each probabilistic parameter p, $\mathcal{R}_p$ contains a rule of the form*

$$[p : x] \leftarrow$$

   giving the default probability of p.

   (c) *If two rules of the form $[p : x] \leftarrow \sigma_1, \ldots \sigma_n$, $[p : y] \leftarrow \sigma'_1, \ldots \sigma'_m$ appear in $\mathcal{R}_p$ and $x \neq y$ then $\{\sigma_1, \ldots \sigma_n\} \subset \{\sigma'_1, \ldots \sigma'_m\}$ or $\{\sigma'_1, \ldots \sigma'_m\} \subset \{\sigma_1, \ldots \sigma_n\}$[8] [9]*

3. $\mathcal{F}$ *is an ABA framework of the form $(\mathcal{R}, \mathcal{A}, \overline{})$ where*

   (a) *For each $\alpha \in \mathcal{A}_p$, neither α nor $\neg\alpha$ belongs to $\mathcal{A}$, and*

   (b) *No rules in $\mathcal{R}$ contain probabilistic parameters in their heads*

4. *Probabilistic sentences of the form $[l : x]$ do not appear in the bodies of rules in both $\mathcal{R}$ and $\mathcal{R}_p$.*

For illustration, consider again the example 2.1 where the PABA is defined by $\mathcal{A}_p = \{p_0, p_1\}$, $\mathcal{R}_p = \{r_6, r_7, r_8, r_9\}$ and $\mathcal{F} = (\mathcal{R}, \mathcal{A}, \overline{})$ with $\mathcal{R} = \{r_1, r_2, r_3, r_4, r_5\}$ and $\mathcal{A} = \{\sim johnNegligent, \sim forceMajeure\}$.

To define the probability measures of probability spaces associated to probabilistic argumentation, we need first to define the semantics of probabilistic argumentation.

Let $\mathcal{P} = (\mathcal{A}_p, \mathcal{R}_p, \mathcal{F})$ be an PABA framework with $\mathcal{F} = (\mathcal{R}, \mathcal{A}, \overline{})$. Let S be a consistent subset of $\mathcal{A}_p \cup \neg.\mathcal{A}_p$. *Define $\mathcal{F}_S$ to be the ABA framework $\mathcal{F}_S = (\mathcal{R}_S, \mathcal{A}, \overline{})$ where $\mathcal{R}_S = \mathcal{R} \cup \mathcal{R}_p \cup \{\alpha \leftarrow \ | \ \alpha \in S\}$. An argument of $\mathcal{P}$ wrt S is defined as an argument of the ABA $\mathcal{F}_S$.*

[7] stating that the probability of α is x if $\sigma_1, \ldots, \sigma_n$ hold

[8] Note that $X \subset Y$ implies that $X \neq Y$

[9] In general, we could also allow the case of $\{\sigma_1, \ldots \sigma_n\} \cup \{\sigma'_1, \ldots \sigma'_m\}$ being inconsistent without causing any problem apart from a somewhat more complicated notion of attack between probabilitic arguments. But to get the conceptual idea across to the readers, we restrict ourself to the simpler case.

Arguments with conclusion of the form $[\alpha : x]$ are referred to as *probabilistic arguments*.

Definition 2.2 *Let $A = (Q, \delta, [\alpha : x])$, $A' = (Q', \delta', [\beta : y])$ be probabilistic arguments of $\mathcal{P}$ wrt possible world w of $\mathcal{P}$ and $\delta = S_1, \ldots, S_m$ and $\delta' = S'_1, \ldots, S'_n$. Further let the probabilistic rules used to derive S_2 from S_1 and S'_2 from S'_1 are r_1, r'_1 respectively. We say that A* **attacks** *A' by* **specificity** *if r_1, r'_1 are respectively of the form*

$$[\alpha : x] \leftarrow \sigma_1, \ldots \sigma_k, \sigma_{k+1}, \ldots, \sigma_{k+j}$$
$$[\beta : y] \leftarrow \sigma_1, \ldots \sigma_k$$

such that $j > 0$ and α, β contain the same probabilistic parameter.

Definition 2.3 *Let $A = (Q, \alpha)$, $A' = (Q', \alpha')$ be arguments of a PABA $\mathcal{P}$ wrt a possible world w of $\mathcal{P}$. We say A* **attacks** *A' if one of the following conditions is satisfied:*

1. *A is a non-probabilistic argument and α is the contrary of some assumption in Q'. This attack is called type 1 attack.*
2. *A, A' are probabilistic arguments and A attacks A' by specificity. This attack is called type 2 attack.*
3. *α is a probabilistic parameter, $A = (\emptyset, \alpha)$ [10] and A' is a probabilistic argument with $\alpha' = [\neg\alpha : x]$ for some x. This attack is called type 3 attack.*

Note that probabilistic arguments do not attack non-probabilistic ones.

Intuitively, the probability of a possible world w of a PABA $\mathcal{P} = (\mathcal{A}_p, \mathcal{R}_p, \mathcal{F})$ is determined by $P(w) = \prod_{(Q,[\alpha:x]) \in GE} x$ where GE is the grounded extension of the ABA framework $\mathcal{F}_w$. Unfortunately this idea does not work in general as the following example illustrates.

Example 2.2 *Consider a PABA $(\mathcal{A}_p, \mathcal{R}_p, \mathcal{F})$ with $\mathcal{A}_p = \{p\}$ and $\mathcal{R}_p$ consisting of the following rules:*

$[p : 0.5] \leftarrow$
$[\neg p : 0.5] \leftarrow$
$[p : 0.1] \leftarrow \sim a$
$[\neg p : 0.9] \leftarrow \sim a$

and $\mathcal{F}$ is represented by

$a \leftarrow \sim a$

where $\sim a$ is the only assumption in $\mathcal{F}$ whose contrary is a. Let $w = \{p\}$. $\mathcal{F}_w$ contains the rules in $\mathcal{R}_p$, $\mathcal{F}$ and the extra rule $p \leftarrow$. The arguments of $\mathcal{F}_w$ are $\{a_0, a_1, a_2, a_3, a_4, a_5\}$ where $a_0 = (\emptyset, [p : 0.5])$, $a_1 = (\emptyset, [\neg p : 0.5])$, $a_2 = (\{\sim a\}, [p : 0.1])$, $a_3 = (\{\sim a\}, [\neg p : 0.9])$, $a_4 = (\{\sim a\}, a)$ and $a_5 = (\emptyset, p)$. The attack relation is: i) a_5 attacks a_1, a_3, ii) a_2, a_3 attacks a_0, a_1 by specificity, iii) a_4 attacks itself and attacks also a_2, a_3. The grounded extension GE of $\mathcal{F}_w$ contains exactly one argument $(\emptyset, p)$. Hence $P(w) = 1$. Similarly $P(w') = 1$ for $w' = \{\neg p\}$. Hence $(\{w, w'\}, P)$ is not a probability space.

We introduce now a natural condition guaranteeing the probabilistic coherence of PABA generalizing the idea of acyclic logic programming and also of Baysian nets.

[10] i.e. $\alpha \in w$. Note that A is not a probabilistic argument

The **dependency graph** of a PABA $\mathcal{P} = (\mathcal{A}_p, \mathcal{R}_p, \mathcal{F})$ consists of atoms as nodes and there is a link from atom α to atom β if there is a rule in $\mathcal{R}_p$ or in $\mathcal{F}$ containing α in its head and β in its body. A PABA framework is said to be **probabilistic acyclic** if there is no infinite path starting from a probabilistic parameter in its dependency graph.

It is not difficult to see that the PABA frameworks in example 2.2 is not probabilistic acyclic while the PABA in example 2.1 is. Note that each PABA framework with empty set of probabilistic rules is probabilistic acyclic.

Lemma 2.1 *Let $\mathcal{P} = (\mathcal{A}_p, \mathcal{R}_p, \mathcal{F})$ be a probabilistic acyclic PABA framework and W be the set of all possible worlds of $\mathcal{P}$. For $w \in W$, let GE_w be the grounded extension of the ABA $\mathcal{F}_w$. Further define*

$$P(w) = \prod_{(Q,[\alpha:x]) \in GE_w} x$$

Then $\sum_{w \in W} P(w) = 1$.

Proof We prove the lemma by induction on n.

1. Base Case: n = 0. Obvious.
2. Inductive Step: Suppose the lemma holds for $n-1$. We first prove a couple of support propositions.
   Let $\mathcal{A}_p = \{p_1, \ldots, p_n\}$ such that there is no path from p_i to p_j in the dependency graph for any pair $i < j$. Such enumeration exists due to the probabilistic acyclicity of $\mathcal{P}$.
   From definition 2.3, there are three types of attacks denoted by att_1, att_2, att_3. Let the set of arguments of $\mathcal{P}$ wrt w be denoted by AR_w. Let the grounded extension of AR_w wrt att_1 be GE_1. Further let the grounded extension of (GE_1, att_2) be GE_2 and the grounded extension of (GE_2, att_3) be GE_3.
   Proposition 1 $GE_w = GE_3$.
   Proof As probabilistic arguments do not attack non-probabilistic arguments, the set of non-probabilistic arguments in GE_3 and GE_w coincide. Let this set be NG. It is not difficult to see that GE_1 is the set of all arguments acceptable wrt NG wrt att_1. It follows that GE_2 is the set of arguments acceptable wrt NG wrt $att_1 \cup att_2$. Therefore there are no probabilistic arguments in GE_2 that are more specific than other probabilistic arguments in GE_2. Applying att_3 eliminate arguments with head $[\neg\alpha : x]$ if $\alpha \in w$. Hence $GE_3 = GE_w$.
   From the existence of rules assigning default values to for probabilistic parameters and proposition 1, it follows
   Proposition 2 For each probabilistic parameter p, there exists exactly one argument of the form $(Q, \delta, [p : x])$ (resp $(Q, \delta, [\neg p : 1 - x])$) in GE_w if $p \in w$ (resp $\neg p \in w$).

   From the structures of rules in $\mathcal{R}_p$, it follows:
   Proposition 3 For each probabilistic parameter p, there are exactly two arguments of the form $(Q, \delta, [p : x])$ and $(Q, \delta', [\neg p : 1 - x]))$ in GE_2 where δ, δ' differ only in their first elements.

Let $v = w \setminus \{p_n, \neg p_n\}$. Let GE_v be the grounded extension of $\mathcal{F}_v$. From the probabilistic acyclicity of $\mathcal{P}$, it follows

Proposition 4 For each probabilistic literal $\alpha \in v$, each probabilistic argument of the form $A = (Q, [\alpha : x])$, $A \in GE_v$ iff $A \in GE_w$.

Let $w_0 = w \cup \{\beta\}$ where $\beta \in \{p_n, \neg p_n\} \setminus w$.

Proposition 5 Let $(Q, \delta, [\alpha : x])$ with $\alpha \in \{p_n, \neg p_n\}$ be a probabilistic argument belonging to GE_w. Then the complementatry argument $(Q, \delta', [\neg p : 1 - x])$[11] belongs to GE_{w_0}.

From propositions 4,5, it follows: $P(v) = P(w) + P(w_0)$. Hence the lemma follows from the induction hypothesis.

We can now introduce the notion of assumption-based argumentation for jury-based dispute resolution.

Definition 2.4 *An assumption-based argumentation framework for jury-based dispute resolution (ABAJ) is a tuple*

$$(\mathcal{F}, \mathcal{P}_1, \ldots, \mathcal{P}_n), \qquad n \geq 1$$

satisfying following conditions:

1. *$\mathcal{F}$ is an ABA of the form $(\mathcal{R}, \mathcal{A}, \overline{})$ where $\mathcal{A}$ contains a special subset $\mathcal{A}_p$ of positive probabilistic assumptions such that for each $\alpha \in \mathcal{A}_p$, $\neg\alpha \in \mathcal{A}$ and $\overline{\alpha} = \neg\alpha$ and $\overline{\neg\alpha} = \alpha$.*
   Arguments in $\mathcal{F}$ containing no probabilistic assumptions are norm-based arguments while causal arguments are represented by arguments containing probabilistic assumptions.
2. *$\mathcal{P}_i = (\mathcal{A}_p, \mathcal{R}_{i,p}, \mathcal{F}_i)$ are PABA frameworks with $\mathcal{F}_i = (\mathcal{R}_i, \mathcal{A}_i, \overline{})$ such that $\mathcal{R} \subseteq \mathcal{R}_i$ and $\mathcal{A} \setminus \mathcal{A}_p \subseteq \mathcal{A}_i$* [12].
   Note that the probabilistic assumptions in $\mathcal{F}$ are probabilistic parameters in $\mathcal{P}_i$.

Given a probabilistic assumption-based argumentation framework for jury-based dispute resolution $(\mathcal{F}, \mathcal{P}_1, \ldots, \mathcal{P}_n)$, $n \geq 1$ with $\mathcal{A}_p$ denoting the set of probabilistic assumptions in $\mathcal{F}$, the corresponding abstract argumentation framework for jury-based dispute resolution is $(AF, \Pi_1, \ldots, \Pi_n, \vdash_1, \ldots, \vdash_n)$, $n \geq 1$ where

1. AF is the argumentation framework defined by $\mathcal{F}$ and
2. $\Pi_i = (W_i, P_i)$ where W_i is the set of possible worlds of $\mathcal{P}_i$ and P_i is the associated probability measure, and
3. for each possible world $w \in W_i$, each argument $A = (Q, \alpha)$ in AF, define $w \vdash_i A$ iff $Q \cap (\mathcal{A}_p \cup \neg.\mathcal{A}_p) \subseteq w$ where $\neg.\mathcal{A}_p = \{\neg p \mid p \in \mathcal{A}_p\}$.

One may ask what happens in the case where the set of probabilistic assumptions in $\mathcal{F}$ in an ABAJ is empty. Hence each PABA $\mathcal{P}_i$ has only one possible world, the emptyset. Therefore for each i, $Prob_i(A) = 1$ iff A belongs to the grounded extension of $\mathcal{F}$. This

[11] i.e. δ' differs from δ only in its first element

[12] It follows immediately that norm-based arguments from $\mathcal{F}$ are also arguments in each $\mathcal{F}_i$.

implies that all arguments in $\mathcal{F}$ are norm-based. In this case, the judge will simply decide the case without giving it to the jurors. An argument $\mathcal{F}$ is then accepted if it belongs to the grounded extension of $\mathcal{F}$.

Jury's decisions are often biased. Such bias may have deep historical roots and constitute parts of the social fabric. The juries in OJ Simpson trials made their decisions along social lines where black jurors favored Simpson. In PABA frameworks representing the probability spaces of jurors, their biases are captured by the probabilitic rules together with norm-based rules that are not contained in the ABA framework representing the arguments of the dispute parties.

2.1. OJ Simpson again

For illustration, consider again the OJ Simpson example 0.2. For simplification, let us focus only on the blood sample collected at the murder scene. Argument P is simplified to argument P' stating that Simpson is the murder as the DNA test of blood sample collected at the murder scene show that it is Simpson's blood. Argument P' is based on the following rules:

r_0: $simpsonMurder \leftarrow bloodSample(B), SimpsonBlood(B),$
$\qquad CollectedAtMurderScence(B),\ p_1$

r_1: $bloodSample(B) \leftarrow$

r_2: $collectedAtMurderScene(B) \leftarrow p_2$

r_3: $simpsonBlood(B) \leftarrow dnaTest(B)\ \sim improperDNATest$

where B is the blood sample shown as physical evidence at the trial. The probabilistic assumption p_1 specifies the causal probability to jump from the premisses to the conclusion of rule r_0. Prosecutor needs to *convince the jury* that p_1 is very high, basically equivalent to 1.0 to be able to convict Simpson. This is often done by producing evidences showing that Simpson has the motivation and capability to carry out the murder. We will discuss more about how to influence this probability later.

Probabilistic assumption p_2 specifies the probability that the blood sample used for DNA test is collected at the murder scene. Rule r_3 intuitively means that if the DNA test is carried out properly then the blood sample used in such tests is indeed Simpson's blood.

The defence strategy is based on two tracks. First attacking the trustability of the DNA test by using expert's testimony to raise doubts about the way it is conducted. This argument (D_1) is based on the following rules:

r_4: $improperDNATest \leftarrow drHenryTesttimony, p_3$

r_5: $drHenryTesttimony \leftarrow$

where probabilistic assumption p_3 specifies the probability that Henry is right in his testimony.

The second line of defence is to raise reasonable doubt in prosecutor's argument P' by producing evidences to establish that the probabilities of assumptions p_1, p_2 are well below 1.

Imagine the time point during the trial where the prosecution had presented their arguments and evidences but the defence had not started their defence yet. As there is in general no reason to doubt the integrity of the police and the precision of DNA tests, it is sensible to expect that the jury is impressed by the prosecution's presentation. Their impression could be represented by following probabilistic rules:

pr_1: $[p_1 : 1.0] \leftarrow$
pr_2: $[p_2 : 1.0] \leftarrow$ [13]

As it turned out that Dr Henry Lee was quite an influence to the jury in his testimony about the improperity of the DNA tests. The PABA frameworks of black jury members could sensibly contain the rule:

pr_3: $[p_3 : 0.4] \leftarrow$

Further, by exposing police officer Fuhrman as a liar and racist who could go to any length to convict black defendants, the defence managed to reduce the probability of pa_2 in the eyes of the black jurors to an important degree. We could sensibly represent this by a rule like:

pr_4: $[p_2 : 0.95] \leftarrow fuhrmanLiarRacist$

Adding other irregularities in evidence collection and the "fact" that the glove does not fit, we could sensibly imagine yet another rule:

pr_5: $[p_2 : 0.9] \leftarrow fuhrmanLiarRacist, otherIrregularities, gloveNotFit$

To summarize, we can sensibly model the probability spaces of black jurors by a PABA framework $(\mathcal{A}_p, \mathcal{R}_p, \mathcal{F})$ with $\mathcal{F} = (\mathcal{R}, \mathcal{A}, \overline{})$ where $\mathcal{R} = \{r_0, \ldots, r_5, r_6, r_7, r_8\}$ with r_6, r_7, r_8 representing facts introduced by the defence:

r_6: $fuhrmanLiarRacist \leftarrow$ r_7: $otherIrregularities \leftarrow$ r_8: $gloveNotFit \leftarrow$

$\mathcal{A} = \{\sim improperDNATest\}$, with $\mathcal{A}_p = \{p_1, p_2, p_3\}$ and $\mathcal{R}_p = \{pr_1, \ldots, pr_5\}$ together with complementary rules.

The ABA framework representing arguments presented by both parties is $(\mathcal{R}, \mathcal{A}, \overline{})$.

Suppose the probability spaces of the black jurors are represented by the above PABA framework. The only possible world of these PABAs in which Simpson is a murder is $w = \{p_1, p_2, \neg p_3\}$. It follows $P(w) = 1.0 \times 0.9 \times 0.6 = 0.54$. It is obvious that black jurors have serious "reasonable doubt" about the conclusion that Simpson is a murder. Hence using the criteria of beyond reasonable doubt, Simpson is acquitted.

In the civil trial both probabilistic rules pr_4, pr_5 are not included in the PABA frameworks of the jury members as Fuhrman is not called as witness and the plaintiff's lawyer does not make the mistake of trying the glove. Testimony about the improper conduct of DNA tests did not raise much doubts. So rule pr_3 could sensibly be replaced by something with a probability of say 0.2.

It is not difficult to see that the probability of "Simpson is the murder" for a whie juror is now 0.8, much higher than 0.5. As most jurors in the civil trial of OJ are white, this explains his conviction by majority vote using preponderance.

2.2. Modelling Rhetoric and Emotional Arguments

Rhetorics and emotions play key roles in trials and decision makings of humans. A good lawyer is often one who could play to the emotions and biases of the jury. This could also be seen at the Simpson's trial. For example, to demonstrate that Simpson is a caring family man, the defence had put a spin on Simpson's life during a visit to his house by the jury, judge and the media by putting a Bible and pictures of his mum and other black people on his table [10]. This seemed to have a good effect at reducing the probability of pa_1, i.e. weakening the conclusive force of the DNA test results. The effects of rhetorics

[13] For short, we do not write down explicitly the complementary rules

could be naturally represented in our PABA by probabilistic rules like some rule stating that seeing the Bible reduces the probability of probabilistic parameter p_1.

3. Conclusion and Discussion

We have proposed an argumentation framework for jury-based dispute resolution by incorporating probabilistic reasoning into abstract argumentation as well as assumption-based argumentation. We in fact have provided a theory to measure the strength of arguments and their "accrual". The separation between argumentation and probabilities spaces in probabilitic argumentation offers a very high degree of modularity and encapsulation. There is for example no constraints that the different components of the framework must be based on the same language.

Though our notion of PABA is related the independent choice logic of Poole [7] and the probabilistic logic programming of Baral,Gelfond and Rushton [1], the conceptual idea underlining our work is different to theirs. Unlike in [7,1], we do not consider the (stable or preferred or some other kind of) extensions as possible worlds of the probability spaces represented by a PABA. Note that a PABA with emptyset of probabilistic rules may have many stable extensions but only one possible world consisting of the emptyset of probabilistic parameters. Further, as we use the PABA with grounded semantics as a vehicle to "compute" the probability measure of possible worlds that are defined externally to the PABA, it does not matter whether the concerned PABA has stable semantics or not. In difference to [7,1,9], we are not interested in the probabilities of queries concerning the PABA of the jurors. We are interested in the probabilities of the queries concerning the "non-probabilistic" knowledge base set up by the judge.

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