

A Bargaining Agent Model's Its Opponent with Entropy-based Inference

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Abstract

A negotiating agent engages in multi-issue bilateral negotiation in a dynamic information-rich environment. The agent aims to make informed decisions. The agent uses maximum entropy inference and minimum relative entropy inference to construct complete distributions in its world model from sparse observation data. The agent makes no assumptions about the internals of its opponent — it focuses only on the signals that it receives.

Keywords: uncertainty, information, belief, probability distribution, induction, entropy.

1 Introduction

A *Negotiating Agent*, *NA*, engages in bilateral bargaining with an opponent, *OP*. It strives to make informed decisions in an information-rich environment that includes information drawn from the Internet by bots. Its design was provoked by the observation that agents are not always utility optimisers, and may not know their utility function with certainty. In the presence of realistic uncertainties, *NA* is more concerned making sensible, informed decisions than with attempting to optimise an unknown utility function. *NA* attempts to fuse the negotiation with the information generated both by and because of it. It reacts to information derived from its opponent and from the environment, and proactively seeks missing information that may be of value.

NA draws on ideas from information theory. Game theory tells us what to do, and what outcome to expect, in many well-known negotiation situations, but these strategies and expectations are derived from assumptions about the internals of the opponent. Game theoretic analyses of bargaining are founded on the notion of agents as utility optimizers in the presence of complete and incomplete information about their opponents [9].

NA may not have a von Neumann-Morgerstern utility function. *NA* makes no assumptions about the internals of *OP* in particular whether it has a utility function. *NA* does make assumptions about: the way in which the integrity of information will decay, preferences that its opponent may have for some deals over others, and conditions that may lead to breakdown. It also assumes that unknown probabilities can be inferred using *maximum entropy probabilistic logic* [8] that is based on random worlds [4]. The maximum entropy probability distribution is “the least biased estimate possible on the given information; i.e. it is maximally noncommittal with regard to missing information” [5]. In the absence of knowledge about *OP*'s decision-making apparatus, *NA* assumes that the “maximally noncommittal” model is the correct model on which to base its reasoning.

A *preference relation* is an assumption that *NA* makes about *OP*'s preferences for some deals over others. For example, that she prefers to pay a lower price to a higher price. A *single-issue preference relation* assumes that she prefers deals on the basis of one issue alone, independent of the values of the other issues. A preference relation may be assumed prior to the negotiation, or dur-

ing it based on the offers made. For example, the opponent may display a preference for items of a certain color; [3] describes a basis for ordering colors. The preference relations illustrated here are single-issue orderings, but the agent's reasoning operates equally well with any preference relation as long as it may be expressed in Horn clause logic.

Under some circumstances bilateral bargaining has questionable value as a trading mechanism. Bilateral bargaining is known to be inherently inefficient [10]. [1] shows that a seller is better off with an auction that attracts $n + 1$ buyers than bargaining with n individuals, *no matter what* the bargaining protocol is. [11] shows that the weaker bargaining types will fare better in exchanges leading to a gradual migration. These results hold for agents who aim to optimize their utility and do limit the work described here.

2 The Negotiating Agent: NA

NA operates in an information-rich environment. The integrity of its information, including information extracted from the Internet, will decay in time. The way in which this decay occurs will depend on the type of information, and on the source from which it is drawn. Little appears to be known about how the integrity of information, such as news-feeds, decays.

One source of NA's information is the signals received from OP. These include offers to NA, and the acceptance or rejection of NA's offers. If OP rejected NA's offer of \$8 two days ago then what is NA's belief now in the proposition that OP will accept another offer of \$8 now? Perhaps it is around 0.1. A linear model is used to model the integrity decay of these beliefs, and when the probability of a decaying belief approaches 0.5¹ the belief is discarded. This choice of a linear model is independent of the bargaining method. The model of decay could be exponential, quadratic or what ever.

¹A sentence probability of 0.5 represents "maybe, maybe not".

2.1 Interaction Protocol

The agents communicate using sentences in a first-order language $\mathcal{L}$. This includes the exchange, acceptance and rejection of offers. $\mathcal{L}$ contains the following predicates: $Offer(\delta)$, $Accept(\delta)$, $Reject(\delta)$ and $Quit(.)$, where $Offer(\delta)$ means "the sender is offering you a deal δ ", $Accept(\delta)$ means "the sender accepts your deal δ ", $Reject(\delta)$ means "the sender rejects your deal δ " and $Quit(.)$ means "the sender quits — the negotiation ends".

Two negotiation protocols are described. First, negotiation *without decay* in which all offers stand for the the entire negotiation. Second, with *with decay* in which offers stand only if accepted by return — NA represents OP's offers as beliefs with sentence probabilities that decay in time.

NA and OP each exchange offers alternately at successive discrete times [7]. They enter into a commitment if one of them accepts a standing offer. The protocol has three stages:

1. Simultaneous, initial, binding offers from both agents;
2. A sequence of alternating offers, and
3. An agent quits and walks away from the negotiation.

The negotiation ceases *either* in the second round if one of the agents accepts a standing offer *or* in the final round if one agent quits and the negotiation breaks down.

2.2 Agent Architecture

Incoming messages from all sources are time-stamped and placed in an "In Box", $\mathcal{X}$, as they arrive. NA has a knowledge base $\mathcal{K}$ and a belief set $\mathcal{B}$. Each of these two sets contains statements in $\mathcal{L}$. $\mathcal{K}$ contains statements that are generally true, such as $\forall x(Accept(x) \leftrightarrow \neg Reject(x))$ — i.e. an agent does one thing or the other. The belief set $\mathcal{B} = \{\beta_i\}$ contains statements that are each qualified with a *given sentence probability*, $B(\beta_i)$, that represents an agent's belief in the truth of the statement. These sentence probabilities may decay in time.

The distinction between the knowledge base $\mathcal{K}$ and the belief set $\mathcal{B}$ is simply that $\mathcal{K}$ contains unqualified statements and $\mathcal{B}$ contains statements that are qualified with sentence probabilities [14]. $\mathcal{K}$ and $\mathcal{B}$ play different roles in the method described in Sec. 3.

NA 's actions are determined by its "strategy". A *strategy* is a function $S : \mathcal{K} \times \mathcal{B} \rightarrow \mathcal{A}$ where $\mathcal{A}$ is the set of actions. At certain distinct times the function S is applied to $\mathcal{K}$ and $\mathcal{B}$ and the agent does something. The set of actions, $\mathcal{A}$, includes sending *Offer*(.), *Accept*(.), *Reject*(.) and *Quit*(.) messages to OP . The way in which S works is described in Sec. 4. Momentarily before the S function is activated, a "revision function" R is activated: $R : (\mathcal{K} \times \mathcal{K} \times \mathcal{B}) \rightarrow (\mathcal{K} \times \mathcal{B})$. R clears the "In Box", and stores the messages *either* in $\mathcal{B}$ with a given sentence probability *or* in $\mathcal{K}$.

A *deal*, δ , is a commitment for the sender to do something, τ (the sender's "terms"), subject to the receiver committing to do something, ω (the receiver's "terms"): $\delta = (\tau, \omega)$. NA may have a real-valued *utility* function: $U : \mathcal{T} \rightarrow \mathbb{R}$, where $\mathcal{T}$ is the set of terms. If so, then for any deal $\delta = (\tau, \omega)$ the expression $U(\omega) - U(\tau)$ is called the *surplus* of δ . An agent may be unable to specify a utility function either precisely or with certainty.² A predicate $NAAcc(\cdot)$ represents the "acceptability" of a deal to NA .

NA uses three things to make offers: an estimate of the likelihood that OP will accept any offer [Sec. 3], an estimate of the likelihood that NA will, in hindsight, feel comfortable accepting any particular offer, and an estimate of when OP may quit and leave the negotiation [Sec. 4.2].

2.3 Random worlds

Let $\mathcal{G}$ be the set of all positive ground literals that can be constructed using the predicate, function and constant symbols in $\mathcal{L}$. A *possible world* is a valuation function $v : \mathcal{G} \rightarrow \{\top, \perp\}$. $\mathbf{V}$ denotes the set of all possible worlds; and $V_{\mathcal{K}}$ denotes the set of possible worlds that are consistent with a knowledge base $\mathcal{K}$ [4].

²The often-quoted oxymoron "I paid too much for it, but its worth it." attributed to Samuel Goldwyn, movie producer, illustrates that intelligent agents may choose to negotiate with uncertain utility.

A *random world* for $\mathcal{K}$ is a probability distribution $W_{\mathcal{K}} = \{p_i\}$ over $V_{\mathcal{K}} = \{v_i\}$, where $W_{\mathcal{K}}$ expresses an agent's degree of belief that each of the possible worlds is the actual world. The *derived sentence probability* of any $\sigma \in \mathcal{L}$, with respect to a random world $W_{\mathcal{K}}$ is:

$$P_{W_{\mathcal{K}}}(\sigma) \triangleq \sum_n \{p_n : \sigma \text{ is } \top \text{ in } v_n\} \quad (1)$$

A random world $W_{\mathcal{K}}$ is *consistent* with the agent's beliefs $\mathcal{B}$ if: $(\forall \beta \in \mathcal{B})(B(\beta) = P_{W_{\mathcal{K}}}(\beta))$. That is, for each belief its derived sentence probability as calculated using Eqn. 1 is equal to its given sentence probability.

The *entropy* of a discrete random variable X with probability mass function $\{p_i\}$ is [8]:

$H(X) = -\sum_n p_n \log p_n$ where: $p_n \geq 0$ and $\sum_n p_n = 1$. Let $W_{\{\mathcal{K}, \mathcal{B}\}}$ be the "maximum entropy probability distribution over $V_{\mathcal{K}}$ that is consistent with $\mathcal{B}$ ". Given an agent with $\mathcal{K}$ and $\mathcal{B}$, its *derived sentence probability* for any sentence, $\sigma \in \mathcal{L}$, is:

$$(\forall \sigma \in \mathcal{L}) P(\sigma) \triangleq P_{W_{\{\mathcal{K}, \mathcal{B}\}}}(\sigma) \quad (2)$$

Using Eqn. 2, the derived sentence probability for any belief, β_i , is equal to its given sentence probability. So the term *sentence probability* is used without ambiguity.

3 Estimating $P(OPAcc(\cdot))$

NA does two different things. First, it reacts to offers received from OP . Second, it sends offers to OP . This section describes the estimation of $P(OPAcc(\delta))$ where the predicate $OPAcc(\delta)$ means "the deal δ is acceptable to OP ".

In the four sub-sections following, NA is attempting sell something to OP . In Secs. 3.1 and 3.2 NA 's terms τ are to supply a particular good, and OP 's terms ω are money — in those examples the amount of money ω is the subject of the negotiation. In Secs. 3.3 and 3.4 NA 's terms are to supply a particular good together with some negotiated warranty period, and OP 's terms are money — in those examples the amount of money p and the period of the warranty period w are the subject of the negotiation.

3.1 One Issue — Without Decay

The unary predicate $OPAcc(x)$ means “the amount of money $\$x$ is acceptable to OP ”. NA is interested in whether the unary predicate $OPAcc(x)$ is true for various values of $\$x$. NA assumes the following preference relation on the $OPAcc$ predicate:

$$\kappa_1 : \forall x, y ((x > y) \rightarrow (OPAcc(x) \rightarrow OPAcc(y)))$$

Suppose that NA 's opening offer is $\bar{\omega}$, and OP 's opening offer is $\underline{\omega}$ where $\underline{\omega} < \bar{\omega}$. Then $\mathcal{K}$ now contains two further sentences: $\kappa_2 : \neg OPAcc(\bar{\omega})$ and $\kappa_3 : OPAcc(\underline{\omega})$. There are now $\bar{\omega} - \underline{\omega}$ possible worlds, and the maximum entropy distribution is uniform.

Suppose that NA knows its true valuation for the good, u_{na} , and that NA has decided to make an “expected-utility-optimizing” offer: $x = \frac{\bar{\omega} + u_{na}}{2}$. This offer is calculated on the basis of the preference ordering κ_1 and the two signals that NA has received from OP . The response is in terms of only NA 's valuation u_{na} and the signal $Reject(\bar{\omega})$ — it is independent of the signal $Offer(\underline{\omega})$ which implies that $\underline{\omega}$ is acceptable.

In the standard game theoretic analysis of bargaining [9], NA assumes that OP has a utility, u_{op} , that it lies in some interval $[\underline{u}, \bar{u}]$, and that the expected value of u_{op} is uniformly distributed on that interval. On the basis of these assumptions NA then derives the expected-utility-optimizing offer: $\frac{\bar{u} + u_{na}}{2}$. These two offers differ by $\bar{u}$ in the game-theoretic result and $\bar{\omega}$ in the maximum entropy result. The game theoretic approach relies on estimates for $\underline{u}$ and $\bar{u}$:

$$E([\underline{u}, \bar{u}] | Reject(\bar{\omega}) \wedge Accept(\underline{\omega}))$$

If OP has a utility, and it may not, then if OP is rational: $\underline{u} \leq \underline{\omega} \leq \bar{u}$. The inherent inefficiency of bilateral bargaining [10] shows for an economically rational OP that u_{op} , and so consequently $\bar{u}$, may be greater than $\bar{\omega}$. There is no reason to suspect that $\bar{u}$ and $\bar{\omega}$ will be equal.

3.2 One Issue — With Decay

As in the previous example, suppose that the opening offers at time t_0 are taken as given and are $\underline{\omega}$ and $\bar{\omega}$. Then $\mathcal{K}$ contains κ_1 , κ_2 and κ_3 . Suppose $\mathcal{L}$ contains n consecutive, integer constants in the interval $[\underline{\omega}, \bar{\omega}]$, where $n = \bar{\omega} - \underline{\omega} + 1$, that

represent various amounts of money. κ_1 induces a total ordering on the sentence probabilities for $OPAcc(x)$ on the interval $[\underline{\omega}, \bar{\omega}]$, where the probabilities are ≈ 0 at $\bar{\omega}$, and ≈ 1 at $\underline{\omega}$.

Suppose that at time t_1 NA makes an offer ω_{na} which is rejected by OP , who has replied at time t_2 with an offer of ω_{op} where $\underline{\omega} \leq \omega_{op} \leq \omega_{na} \leq \bar{\omega}$. At time t_3 $\mathcal{B}$ contains $\beta_1 : OPAcc(\omega_{na})$ and $\beta_2 : OPAcc(\omega_{op})$. Suppose that there is some level of integrity decay on these two beliefs: $0 < B(\beta_1) < 0.5 < B(\beta_2) < 1$. Then $V_{\mathcal{K}}$ contains $n + 1$ possible worlds ranging from “all false” to “all true” each containing n literals. So a random world for $\mathcal{K}$ will consist of $n + 1$ probabilities $\{p_i\}$, where, say, p_1 is the probability of “all true”, and p_{n+1} is the probability of “all false”. $P_{\{\mathcal{K}, \mathcal{B}\}}$ will be the distribution that maximizes $-\sum_n p_n \log p_n$ subject to the constraints: $p_n \geq 0$, $\sum_n p_n = 1$, $\sum_{n=1}^{\bar{\omega}-\omega_{na}+1} p_n = B(\beta_1)$ and $\sum_{n=1}^{\bar{\omega}-\omega_{op}+1} p_n = B(\beta_2)$.

The optimization of entropy, H , subject to linear constraints is achieved by the introduction of Lagrange multipliers. $P_{\{\mathcal{K}, \mathcal{B}\}}$ is:

$$p_n = \begin{cases} \frac{B(\beta_1)}{\bar{\omega}-\omega_{na}+1} & \text{if } 1 \leq n \leq \bar{\omega} - \omega_{na} + 1 \\ \frac{B(\beta_2) - B(\beta_1)}{\omega_{na} - \omega_{op}} & \text{if } \bar{\omega} - \omega_{na} + 1 < n < \bar{\omega} - \omega_{op} + 2 \\ \frac{1 - B(\beta_2)}{\omega_{op} - \underline{\omega} + 1} & \text{if } \bar{\omega} - \omega_{op} + 2 \leq n \leq \bar{\omega} - \underline{\omega} + 2 \end{cases}$$

Using Eqn. 2, for $\omega_{op} \leq x \leq \omega_{na}$:

$$P(OPAcc(x)) = B(\beta_1) + \frac{\omega_{na} - x}{\omega_{na} - \omega_{op}} (B(\beta_2) - B(\beta_1)) \quad (3)$$

These probability estimates are used in Sec. 4 to calculate NA 's next offer.

The values for $P(OPAcc(x))$ in the region $\omega_{op} \leq x \leq \omega_{na}$ are derived from only two pieces of information that are the two signals $Reject(\omega_{na})$ and $Offer(\omega_{op})$ each qualified with the time at which they arrived, and the decay rate on their integrity. The assumptions in the analysis given above are: the choice of values for $\underline{\omega}$ and $\bar{\omega}$ — which do not appear in Eqn. 3 in any case — and the choice of the “maximally noncommittal” distribution.

If the agents continue to exchange offers then new beliefs will be acquired and the integrity of old beliefs will decay. If the next pair of offers lies within the interval $[\omega_{op}, \omega_{na}]$ and if the integrity of β_1 and β_2 decays then the sentence probabilities of β_1 and β_2 will be inconsistent with those of the two new beliefs due to the total ordering of sentence probabilities on $[\underline{\omega}, \bar{\omega}]$ induced by κ_1 . This inconsistency is resolved by the revision function R that here discards inconsistent older beliefs, β_1 and β_2 , in favor of more recent beliefs. If the agents continue in this way then the sentence probabilities for the $OPAcc$ predicate are given simply by Eqn. 3 using the most recent values for ω_{na} and ω_{op} .

The analysis given above requires that values be specified for the opening offers $\underline{\omega}$ and $\bar{\omega}$. The only part of the probability distribution that depends on the values chosen for $\underline{\omega}$ and $\bar{\omega}$ are the two "tails" of the distribution. So the choice of values for these two opening offers is unlikely to effect the estimates. The two tails are necessary to "soak up" the otherwise unallocated probability.

3.3 Two Issues — Without Decay

The above approach to single-issue bargaining generalizes without modification to multi-issue bargaining, it is illustrated with two issues only for ease of presentation. The problem considered is the sale of an item with $0, \dots, 4$ years of warranty. The terms being negotiated specify an amount of money p and the number of years warranty w . The predicate $OPAcc(w, p)$ now means " OP will accept the offer to purchase the good with w years warranty for $\$p$ ".

NA assumes the following two preference orderings, and $\mathcal{K}$ contains:

$$\begin{aligned}\kappa_{11} : & \forall x, y, z ((x > y) \rightarrow \\ & (OPAcc(y, z) \rightarrow OPAcc(x, z))) \\ \kappa_{12} : & \forall x, y, z ((x > y) \rightarrow \\ & (OPAcc(z, x) \rightarrow OPAcc(z, y)))\end{aligned}$$

As in Sec. 3.1, these sentences conveniently reduce the number of possible worlds. The number of possible worlds will be finite as long as $\mathcal{K}$ contains two statements of the form: $\neg OPAcc(4, a)$ and $OPAcc(0, b)$ for some a and b . Suppose that NA 's initial offer was "4 years warranty for \$21" and OP 's initial offer was "no warranty for \$10".

$\mathcal{K}$ now contains:

$$\kappa_{13} : \neg OPAcc(4, 21) \quad \kappa_{14} : OPAcc(0, 10)$$

These two statements, together with the restriction to integers only, limit the possible values of w and p in $OPAcc(w, p)$ to a 5×10 matrix.

Suppose that NA knows its utility function for the good with $0, \dots, 4$ years warranty and that its values are: \$11.00, \$11.50, \$12.00, \$13.00 and \$14.50 respectively. Suppose that NA uses the strategy $S^{(n)}$ which is described in Sec. 4.2 — the details of that strategy are not important now. If NA uses that strategy with $n = 2$, then NA offers $Offer(2, \$16)$ which suppose OP rejects and counters with $Offer(1, \$11)$. Then with $n = 2$ again, NA offers $Offer(2, \$14)$ which suppose OP rejects and counters with $Offer(3, \$13)$. $P(OPAcc(w, p))$ now is:

$p =$	$w = 0$	$w = 1$	$w = 2$	$w = 3$	$w = 4$
20	0.0000	0.0000	0.0000	0.0455	0.0909
19	0.0000	0.0000	0.0000	0.0909	0.1818
18	0.0000	0.0000	0.0000	0.1364	0.2727
17	0.0000	0.0000	0.0000	0.1818	0.3636
16	0.0000	0.0000	0.0000	0.2273	0.4545
15	0.0000	0.0000	0.0000	0.2727	0.5454
14	0.0000	0.0000	0.0000	0.3182	0.6364
13	0.0455	0.0909	0.1364	1.0000	1.0000
12	0.0909	0.1818	0.2727	1.0000	1.0000
11	0.1364	1.0000	1.0000	1.0000	1.0000

and the expected-utility-optimizing offer is: $Offer(4, \$18)$. If NA makes that offer then the expected surplus is \$0.95. The matrix above contains the "maximally non-committal" values for $P(OPAcc(w, p))$; those values are recalculated each time a signal arrives. The example demonstrates how the NA is able to conduct multi-issue bargaining in a focussed way without making assumptions about OP 's internals, in particular, whether OP is aware of a utility function [12].

3.4 Two Issues — With Decay

Following from the previous section, suppose that $\mathcal{K}$ contains κ_{11} , κ_{12} , κ_{13} and κ_{14} . The two preference orderings κ_{11} and κ_{12} induce a partial ordering on the sentence probabilities in the $P(OPAcc(w, p))$ array [as in Sec. 3.3] from the top-left where the probabilities are ≈ 0 , to the bottom-right where the probabilities are ≈ 1 . There are fifty-one possible worlds that are consistent with $\mathcal{K}$.

Suppose that $\mathcal{B}$ contains: $\beta_{11} : OPAcc(2, 16)$, $\beta_{12} : OPAcc(2, 14)$, $\beta_{13} : OPAcc(1, 11)$ and $\beta_{14} : OPAcc(3, 13)$ — this is the same offer sequence as considered in Sec. 3.3 — and with a 10% decay in integrity for each time step: $P(\beta_{11}) = 0.4$, $P(\beta_{12}) = 0.2$, $P(\beta_{13}) = 0.7$ and $P(\beta_{14}) = 0.9$. Belief β_{11} is inconsistent with $\mathcal{K} \cup \{\beta_{12}\}$ as together they violate the sentence probability ordering induced by κ_{11} and κ_{12} . Resolving this issue is a job for the belief revision function R which discards the older, and weaker, belief β_{11} .

The distribution $W_{\{\mathcal{K}, \mathcal{B}\}}$ has just five different probabilities in it. $P(OPAcc(w, p))$ now is:

$p =$	$w = 0$	$w = 1$	$w = 2$	$w = 3$	$w = 4$
20	0.0134	0.0269	0.0286	0.0570	0.0591
19	0.0269	0.0537	0.0571	0.1139	0.1183
18	0.0403	0.0806	0.0857	0.1709	0.1774
17	0.0537	0.1074	0.1143	0.2279	0.2365
16	0.0671	0.1343	0.1429	0.2849	0.2957
15	0.0806	0.1611	0.1714	0.3418	0.3548
14	0.0940	0.1880	0.2000	0.3988	0.4139
13	0.3162	0.6324	0.6728	0.9000	0.9173
12	0.3331	0.6662	0.7088	0.9381	0.9576
11	0.3500	0.7000	0.7447	0.9762	0.9978

In this array, the derived sentence probabilities for the three sentences in $\mathcal{B}$ are shown in bold type; they are exactly their given values.

4 Negotiation Strategies

Sec. 3 estimated the probability distribution, $P(OPAcc)$, that OP will accept an offer. Estimation of the probability distribution, $P(NAAcc)$, that NA should be prepared to accept an offer, is not described here. These two probability distributions represent the opposing interests of the two agents NA and OP . $P(OPAcc)$ will change every time an offer is made, rejected or accepted. $P(NAAcc)$ will change as the background information changes. This section discusses NA 's strategy S . Sec. 4.2 considers the risk of breakdown.

Bargaining can be a game of bluff and counter-bluff in which an agent may even not intend to close the deal if one should be reached. A basic conundrum in any offer-exchange bargaining is: it is impossible to force your opponent to reveal information about their position without revealing information about your own position. Further,

by revealing information about your own position you may change your opponents position — and so on.³ This infinite regress, of speculation and counter-speculation, is avoided here by ignoring the internals of the opponent and by focussing on what is known for certain — that is: *what* information is contained in the signals received and *when* did those signals arrive.

A fundamental principle of competitive bargaining is “never reveal your best price”, and another is “never reveal your deadline — if you have one” [13]. It is not possible to be prescriptive about what an agent *should* reveal. All that can be achieved is to provide strategies that an agent may choose to employ. The following are examples of such strategies.

4.1 Without Breakdown

An agent's strategy S is a function of the information $\mathcal{I}_t$ that it has at time t . That information will be represented in the agent's $\mathcal{K}$ and $\mathcal{B}$, and will have been used to calculate $P(OPAcc)$ and $P(NAAcc)$. Simple strategies choose an offer only on the basis of $P(OPAcc)$, $P(NAAcc)$ and α . The greedy strategy S^+ chooses $\arg \max_{\delta} \{P(NAAcc(\delta)) \mid P(OPAcc(\delta)) \gg 0\}$, it is appropriate for an agent that believes OP is desperate to trade. The *expected-acceptability-to-NA-optimizing* strategy S^* chooses $\arg \max_{\delta} \{P(OPAcc(\delta)) \times P(NAAcc(\delta)) \mid P(NAAcc(\delta)) \geq \alpha\}$, it is appropriate for a confident agent that is not desperate to trade. The strategy S^- chooses $\arg \max_{\delta} \{P(OPAcc(\delta)) \mid P(NAAcc(\delta)) \geq \alpha\}$, it optimizes the likelihood of trade — it is a good strategy for an agent that is keen to trade without compromising its own standards of acceptability.

An approach to issue-tradeoffs is described in [3]. The bargaining strategy described there attempts to make an acceptable offer by “walking round” the iso-curve of NA 's previous offer (that has, say, an acceptability of $\alpha_{na} \geq \alpha$) towards OP 's subsequent counter offer. In terms of the machinery described here, an analogue is to use the strategy S^- : $\arg \max_{\delta} \{P(OPAcc(\delta)) \mid P(NAAcc(\delta)) \geq \alpha\}$.

³This is reminiscent of Werner Heisenberg's indeterminacy relation, or *unbestimmtheitsrelationen*: “you can't measure one feature of an object without changing another” — with apologies.

$\mathcal{I}_t \succsim \alpha_{na} \}$ for $\alpha = \alpha_{na}$. This is reasonable for an agent that is attempting to be accommodating without compromising its own interests. Presumably such an agent will have a policy for reducing the value α_{na} if her deals fail to be accepted. The complexity of the strategy in [3] is linear with the number of issues. The strategy described here does not have that property, but it benefits from using $P(OPAcc)$ that contains foot prints of the prior offer sequence — see Sec. 3.4 — in that distribution more recent offers have stronger weights.

4.2 With Breakdown

A negotiation may break down because one agent is not prepared to continue for some reason. p_B is the probability that the opponent will quit the negotiation in the next round. There are three ways in which NA models the risk of breakdown. First, p_B is a constant determined exogenously to the negotiation, in which case at any stage in a continuing negotiation the expected number of rounds until breakdown occurs is $\frac{1}{p_B}$. Second, p_B is a monotonic increasing function of time — this attempts to model an impatient opponent. Third, p_B is a monotonic increasing function of $(1 - OPAcc(\delta))$ — this attempts to model an opponent who will react to unattractive offers.

At any stage in a negotiation NA may be prepared to gamble on the expectation that OP will remain in the game for the next n rounds. This would occur if there is a constant probability of breakdown $p_B = \frac{1}{n}$. Let $\mathcal{I}_t$ denote the information stored in NA 's $\mathcal{K}$ and $\mathcal{B}$ at time t . S is NA 's strategy. If NA offered to trade with OP at $S(\mathcal{I}_1)$ then OP may accept this offer, but may have also been prepared to settle for terms more favorable than this to NA . If NA offered to trade at $S(\mathcal{I}_1 \cup \{Accept(S(\mathcal{I}_1))\})$ then OP will either accept this offer or reject it. In the former case trade occurs at more favorable terms than $S(\mathcal{I}_1)$, and in the latter case a useful piece of information has been acquired: $Reject(S(\mathcal{I}_1))$ which is added to $\mathcal{I}_1$ before calculating the next offer. This process can be applied twice to generate the offer $S(\mathcal{I}_1 \cup \{Reject(S(\mathcal{I}_1 \cup \{Accept(S(\mathcal{I}_1))\}))\})$, or any number of times, optimistically working backwards on the assumption that OP will remain in the game for n rounds. The strategy $S^{(n)}$,

where $S^{(1)} = S^*$ the expected-acceptability-to- NA -optimizing strategy defined in Sec. 4.1. $S^{(n)}$ is the strategy of working back from $S^{(1)}$ ($n-1$) times. At each stage $S^{(n)}$ will benefit also from the information in the intervening counter offers presented by OP . The strategy $S^{(n)}$ is reasonable for a risk-taking, expected-acceptability-optimizing agent. This strategy was used to generate the offer sequence in the example in Sec. 3.3.

Define the value of making an offer $Offer(\delta)$ to be: $\Upsilon(Offer(\delta)) = P(NAAcc(\delta))$ if δ is accepted, and zero otherwise. The expected value of making an offer is then: $E(\Upsilon(Offer(S(\mathcal{I}_t)))) = P(OPAcc(S(\mathcal{I}_t))) \times P(NAAcc(S(\mathcal{I}_t))) + (1 - P(OPAcc(S(\mathcal{I}_t)))) \times (1 - p_B) \times E(\Upsilon(Offer(S(\mathcal{I}_{t+1}))))$ where $\mathcal{I}_{t+1} = \mathcal{I}_t \cup \{Accept(S(\mathcal{I}_t))\}$. This is of little help in finding the “best” S , but two approximations are interesting. Either replace the S in the final term by a simple strategy such as S^- . Or assume that $E(\Upsilon(Offer(S(\mathcal{I}_{t+1})))) = \theta \times E(\Upsilon(Offer(S(\mathcal{I}_t))))$ — for some $\theta < 1$ — then:

$$E(\Upsilon(Offer(S(\mathcal{I}_t)))) = \frac{P(OPAcc(S(\mathcal{I}_t))) \times P(NAAcc(S(\mathcal{I}_t)))}{1 - (1 - P(OPAcc(S(\mathcal{I}_t)))) \times (1 - p_B) \times \theta}$$

in either case the expression can be optimized numerically, even if p_B is a function of $P(OPAcc(S(\mathcal{I}_t)))$.

The preceding considers the possibility of OP quitting. NA may choose to quit and cause the negotiation to break down if the negotiation appears to be leading nowhere. One measure of convergence is to monitor the sequence: $\max_{\delta} (P(OPAcc(\delta)) \mid P(NAAcc(\delta)) \geq \alpha)$ — ie: the greatest likelihood of acceptable trade. If this sequence is not increasing in time to a “reasonable” value then NA may choose to quit.

5 Conclusions

The negotiating agent achieves its goal of reaching informed decisions whilst making no assumptions about the internals of its opponent [6]. NA has five ways of leading a negotiation towards a positive outcome. First, by making more attractive offers to OP . Second, by reducing its threshold α . Third, by acquiring information to hopefully increase the acceptability of offers received.

Fourth, by encouraging *OP* to submit more attractive offers. Fifth, by encouraging *OP* to accept *NA*'s offers. The first two of these have been described. The third has been implemented but is not described here. The remaining two are the realm of argumentation-based negotiation. The integrated way in which *NA* manages both the negotiation and the information acquisition should provide a sound basis for an argumentation-based negotiator.

[4] discusses problems with the random-worlds approach, and notes particularly representation and learning. Representation is particularly significant here — for example, the logical constants in the price domains could have been given other values, and, as long as they remained ordered, and as long as the input values remained unchanged, the probability distributions would be unaltered. Learning is not an issue now as the distributions are kept as simple as possible and are re-computed each time step. The assumptions of maximum entropy probabilistic logic exploit the agent's limited rationality by attempting to assume "precisely no more than is known". But, the computations involved will be substantial if the domains in the language $\mathcal{L}$ are large, and will be infeasible if the domains are unbounded. If the domains are large then preference relations such as κ_1 can simplify the computations substantially.

The following issues are presently being investigated. The random worlds computations are performed each time the knowledge, $\mathcal{K}$, or beliefs, $\mathcal{B}$, alter — there is scope for using approximate updating techniques interspersed with the exact calculations. The offer accepting machinery operates independently from the offer making machinery; this may mean that better deals could have been struck under some circumstances.

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- and all those who helped / *et tous ceux qui s'y sont associés.*

The IPMU conference was organized for the first time twenty years ago and has been held every two years since then in six different locations in Europe apart from Paris: Urbino, Palma de Mallorca, Granada, Madrid, Annecy, Perugia.

Each of these events was successful thanks to the hard work and dedication of the organizers, particularly the co-chairpersons and organizing committee chairs. We would like to acknowledge our debt and gratitude to those colleagues who helped over the past twenty years. We would especially like to thank all past members of program and organizing committees, those who have organized special sessions and those who served as referees for helping maintain the high quality of the IPMU Conferences.

All of them deserve many thanks for having helped IPMU attain its goal of providing a high level of scientific exchange in a pleasant environment

La conférence IPMU, organisée pour la première fois à Paris il y a vingt ans, l'a été tous les deux ans depuis, dans six différents lieux en Europe à part Paris : Urbino, Palma de Mallorca, Granada, Madrid, Annecy, Perugia.

Chacun de ces événements a été un succès grâce à l'énorme travail et au dévouement de ses organisateurs, en particulier les co-présidents et les présidents des comités d'organisation. Nous voudrions exprimer notre reconnaissance et notre gratitude à tous les collègues qui ont contribué à l'organisation de la conférence IPMU pendant les vingt dernières années. Nous aimerions en particulier remercier tous les membres des comités de programmes et comités d'organisation successifs, les organisateurs de sessions spéciales et les relecteurs, pour avoir aidé à maintenir la grande qualité de la conférence IPMU.

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Bernadette BOUCHON-MEUNIER & Ronald R. YAGER

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