Agents, Information and Negotiation

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A suite of ideas for agent building in Digital Ecosystems

Motivation

- Intelligent agents have been around for a while
- Game theory is 50 years old
  - with Nobel prizes all over the show
- Electronic business is ten years old, and has survived its first "boom and bust"
- But the number of deployed negotiating agents, in say eProcurement, is ≈ 0
- What has gone wrong, or rather, not gone right?
- Challenge for AI — I can do it — can't you?

What we want to achieve

We would like to understand negotiation in the broad context of the evolution of business relationships.

Business relationships may:

- start by two agents aggressively trading
- lead to a desire to establish reliable trade in the context of a solid, trusting relationship
- lead to the formation of a partnership in which resources are deployed for the benefit of the partnership

The negotiation machinery must evolve across this *relationship spectrum*.

Foundations for Negotiation

Two are:

- Microeconomics / game theory
- Psychology

It is perhaps odd that the Artificial Intelligence community has become so pre-occuppied with game theory, and has largely ignored the principles from psychology.

Particularly as game theory has failed to deliver a sound basis for real-world negotiation in, say, eProcurement.

Game Theory & Utility

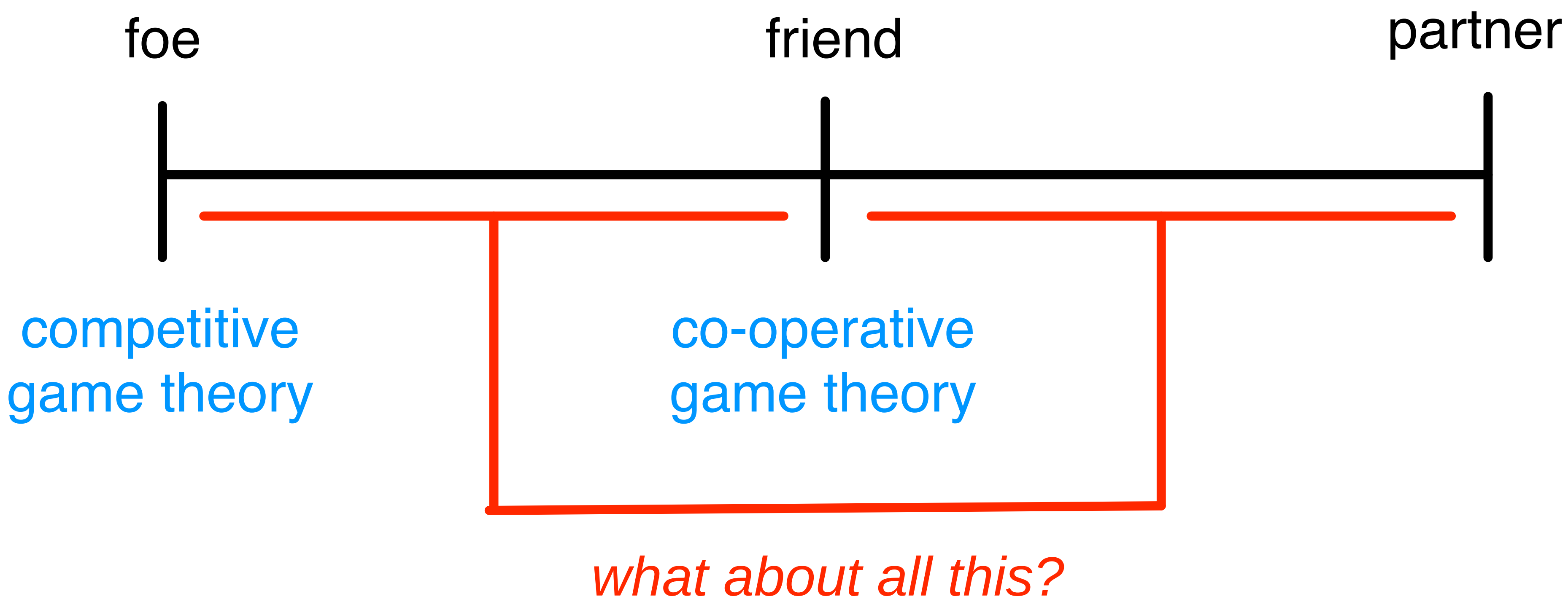
It isn't 'wrong' — it is a theory. It will work when its postulates are satisfied.

Game Theory assumes that you know your preferences (ie; utility), and that you either want to optimise your utility (in competitive game theory) or want to reach a fair allocation (in co-operative game theory).

So if this is precisely where you are at then Game Theory is what you need.

In multi-issue negotiation (*ALL* eProcurement is multi-issue) we may know our preferences along each direction, but not across the whole space. *That is, we may not know our preferences!*

Game Theory & Relationship Evolution



The 'two game theories' have no obvious generalisation that enable us to understand the business relationship spectrum.

Negotiation that works . . .

Nathan Rothschild and his pigeons

Walter Wriston on becoming CEO of Citicorp in 1967:

> "Banking is not about money; it is about information"

Benjamin Disraeli:

> "As a general rule, the most successful man in life is the man who has the best information"

Insight

Negotiation is an information exchange process *as well as* a proposal exchange process *ie: two different things are going on*

Information exchange is primitive

Anything that an agent says, or does not say, conveys valuable information to the opponent

To speak, or not to speak — the eBay 'fib'

Conclusion: negotiating agents need machinery to value information as information, as well as machinery to evaluate proposals

Information-based Agency based on information theory

Five dimensions

- Legitimacy. What information is relevant to the negotiation process? What are the persuasive arguments about the fairness of the options?
- Options. What are the possible agreements we can accept?
- Goals. What are the underlying things we need or care about? What are our goals?
- Independence. What will we do if the negotiation fails? What alternatives have we got?
- Commitment. What outstanding commitments do we have?

Our two primitives

Two primitive concepts:

intimacy (degree of closeness), and

balance (degree of fairness).

- The *intimacy* is a pair of matrices that evaluate both an agent's contribution to the relationship and its opponent's contribution each from an information view and from a utilitarian view across the five LOGIC dimensions.

- The *balance* is the difference between these matrices.

Intimacy and Balance

There is evidence from psychological studies that humans seek a *balance* in their negotiation relationships.

Recent studies show that humans follow a rich set of norms of distributive justice depending on their *intimacy* level: equity, equality, and need.

- *Equity* being the allocation proportional to the effort,
- *Equality* being the allocation in equal amounts, and
- *Need* being the allocation proportional to the need for the resource.

Information-Based Agency

Successful negotiators look beyond a purely utilitarian view.

We propose a new agent architecture that integrates the utilitarian, information, and semantic views allowing the definition of strategies that take these three views into account.

Information-based agency values the information in dialogues in the context of a communication language based on a structured ontology and on the notion of commitment.

This abstraction unifies measures such as trust, reputation, and reliability in a single framework, and enables us to understand the evolution of business relationships in a rich sense.

The Multiagent System

An agent α interacts with other intelligent agents $\{\beta_1, \ldots, \beta_o\}$. α has two languages: $\mathcal{C}$ an illocutionary-based language for communication, and $\mathcal{L}$ is a language for internal representation.

These agents also interact with a collection of information sources $\{\theta_1, \ldots, \theta_t\}$ that may include data mining and text mining agents that retrieve information from the multiagent system and from general news sources.

A single *Institution Agent* ξ completes the multiagent system, it reports honestly, promptly and confidentially on all that occurs, and enables α to evaluate the enactment of commitments. ξ also manages the system inventory — ie: "who owns what". In this way, ξ enables α to negotiate and trade by simple message passing.

Communication Language $\mathcal{C}$

$\mathcal{C}$ is defined by:

$$
\begin{aligned}
a ::= & \; illoc(\alpha, \beta, \varphi, t) \mid a; a \mid a \cup a \mid a^* \mid \\
& \; \textbf{Let } \text{context } \textbf{In } a \textbf{ End} \\
\varphi ::= & \; term \mid Done(a) \mid Commit(\alpha, \varphi) \mid \varphi \wedge \varphi \mid \\
& \; \varphi \vee \varphi \mid \neg\varphi \mid \forall v.\varphi_v \mid \exists v.\varphi_v \\
context ::= & \; \varphi \mid id = \varphi \mid \text{prolog\_clause} \mid context; context
\end{aligned}
$$

where φ_v is a formula with free variable v, $illoc$ is any appropriate set of illocutionary particles, and $context$ represents either previous agreements, or illocutions, or code that aligns the ontological differences between the speakers.

Ontology

An *ontology* is a tuple $\mathcal{O} = (C, R, \leq, \sigma)$ where

1. C is a finite set of concept symbols (including basic data types);
2. R is a finite set of relation symbols;
3. $\leq$ is a reflexive, transitive and anti-symmetric relation on C (a partial order)
4. $\sigma : R \to C^+$ is the function assigning to each relation symbol its arity

Agent Architecture

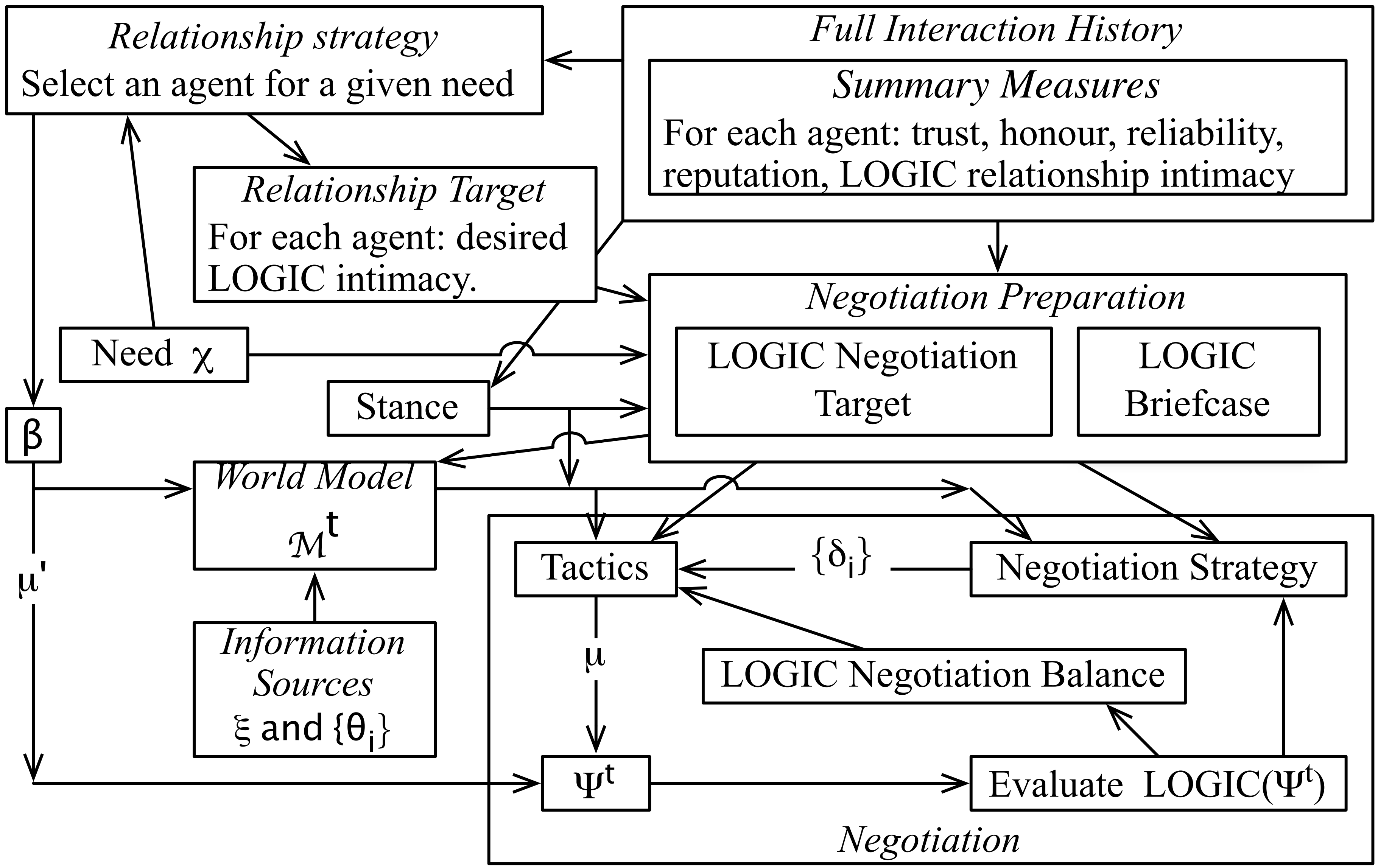
Agent α receives all messages expressed in $\mathcal{C}$ in an in-box $\mathcal{X}$ where they are time-stamped and sourced-stamped.

A message μ from agent β (or θ or ξ) is then moved from $\mathcal{X}$ to a *percept repository* $\mathcal{Y}^t$ where it is appended with a subjective belief function $\mathbb{R}^t(\alpha, \beta, \mu)$ that normally decays with time. α acts in response to a message that expresses a *need*.

A need may be exogenous such as a need to trade profitably or may be triggered by another agent offering to trade, or endogenous such as α deciding that it owns more wine than it requires.

Each plan contains constructors for a *world model* $\mathcal{M}^t$ that consists of probability distributions, (X_i), in first-order probabilistic logic $\mathcal{L}$. $\mathcal{M}^t$ is then maintained from percepts received using *update functions* that transform percepts into constraints on $\mathcal{M}^t$

Our Agent Architecture



Proactive Reasoning

If α is negotiating some contract δ in satisfaction of need χ then it may require the distribution $\mathbb{P}^t(\text{eval}(\alpha, \beta, \chi, \delta) = e_i)$ where for a particular δ, $\text{eval}(\alpha, \beta, \chi, \delta)$ is an evaluation over some complete and disjoint *evaluation space* $E = (e_1, \ldots, e_n)$ that may contain hard (possibly utilitarian) values, or fuzzy values such as "reject" and "accept", leading to a probability of acceptance $\mathbb{P}^t(\text{acc}(\alpha, \beta, \chi, \delta))$.

$\mathbb{P}^t(\text{eval}(\alpha, \beta, \chi, \delta) = e_i)$ could be derived from the subjective estimate $\mathbb{P}^t(\text{satisfy}(\alpha, \beta, \chi, \delta) = f_j)$ of the expected extent to which the *execution* of δ by β will satisfy χ, and an objective estimate $\mathbb{P}^t(\text{val}(\alpha, \beta, \delta) = g_k)$ of the expected valuation of the *execution* of δ possibly in utilitarian terms.

Proactive Reasoning /contd

α's plans may construct various other distributions such as:

- $\mathbb{P}^t(\mathrm{trade}(\alpha, \beta, o) = e_i)$ that β is a good person to sign contracts with in context o
- $\mathbb{P}^t(\mathrm{confide}(\alpha, \beta, o) = f_j)$ that α can trust β with confidential information in context o
- $\mathbb{P}^t(\mathrm{acc}(\beta, \alpha, \delta))$ that estimates the probability that β would accept δ

Integrity Decay

α may have background knowledge concerning the expected integrity of a percept as $t \to \infty$ — the *decay limit distribution*.

Given a distribution, $\mathbb{P}(X_i)$, and a decay limit distribution $\mathbb{D}(X_i)$, $\mathbb{P}(X_i)$ decays by:

$$\mathbb{P}^{t+1}(X_i) = \Delta_i(\mathbb{D}(X_i), \mathbb{P}^t(X_i))$$

where Δ_i is the *decay function* for the X_i satisfying the property that $\lim_{t\to\infty} \mathbb{P}^t(X_i) = \mathbb{D}(X_i)$. For example, Δ_i could be linear: $\mathbb{P}^{t+1}(X_i) = (1 - \nu_i) \times \mathbb{D}(X_i) + \nu_i \times \mathbb{P}^t(X_i)$, where $\nu_i < 1$ is the decay rate for the i'th distribution.

Either the decay function or the decay limit distribution could also be a function of time: Δ_i^t and $\mathbb{D}^t(X_i)$.

Reactive Reasoning

This procedure updates $\mathcal{M}^t$ for all percepts expressed in $\mathcal{C}$.

Suppose that α receives a message μ from agent β at time t. Suppose that this message states that something is so with probability z, and suppose that α attaches an epistemic belief $\mathbb{R}^t(\alpha, \beta, \mu)$ to μ — this probability reflects α's level of personal *caution*. Each of α's active plans, s, contains constructors for a set of distributions $\{X_i\} \in \mathcal{M}^t$ together with associated *update functions*, $J_s(\cdot)$, such that $J_s^{X_i}(\mu)$ is a set of linear constraints on the posterior distribution for X_i.

Denote the prior distribution $\mathbb{P}^t(X_i)$ by $\vec{p}$, and let $\vec{p}_{(\mu)}$ be the distribution with minimum relative entropy with respect to $\vec{p}$: $\vec{p}_{(\mu)} = \arg\min_{\vec{r}} \sum_j r_j \log \frac{r_j}{p_j}$ that satisfies the constraints $J_s^{X_i}(\mu)$.

Reactive Reasoning /contd

Then let $\vec{q}_{(\mu)}$ be the distribution:

$$\vec{q}_{(\mu)} = \mathbb{R}^t(\alpha, \beta, \mu) \times \vec{p}_{(\mu)} + (1 - \mathbb{R}^t(\alpha, \beta, \mu)) \times \vec{p}$$

and then let:

$$X_{i(\mu)} = \begin{cases} \vec{q}_{(\mu)} & \text{if } \vec{q}_{(\mu)} \text{ is more interesting than } \vec{p} \\ \vec{p} & \text{otherwise} \end{cases}$$

A general measure of whether $\vec{q}_{(\mu)}$ is more interesting than $\vec{p}$ is: $\mathbb{K}(\vec{q}_{(\mu)} \| \mathbb{D}(X_i)) > \mathbb{K}(\vec{p} \| \mathbb{D}(X_i))$, where $\mathbb{K}(\vec{x} \| \vec{y}) = \sum_j x_j \ln \frac{x_j}{y_j}$ is the Kullback-Leibler distance between two probability distributions $\vec{x}$ and $\vec{y}$.

Reactive Reasoning /contd /contd

Finally merging the above we obtain the method for updating a distribution X_i on receipt of a message μ:

$$\mathbb{P}^{t+1}(X_i) = \Delta_i(\mathbb{D}(X_i), \mathbb{P}^t(X_{i(\mu)}))$$

This procedure deals with

- integrity decay
- two probabilities:
  - the probability z in the percept μ that will appear in the constraints
  - the belief $\mathbb{R}^t(\alpha, \beta, \mu)$ that α attached to μ.

Note on Entropy-based Inference

Given a probability distribution $\vec{q}$, the *minimum relative entropy distribution* $\vec{p} = (p_1, \ldots, p_I)$ subject to a set of J linear constraints $\vec{g} = \{g_j(\vec{p}) = \vec{a_j} \cdot \vec{p} - c_j = 0\}, j = 1, \ldots, J$ (that must include the constraint $\sum_i p_i - 1 = 0$) is: $\vec{p} = \arg\min_{\vec{r}} \sum_j r_j \log \frac{r_j}{q_j}$.

This may be calculated by introducing Lagrange multipliers $\vec{\lambda}$: $L(\vec{p}, \vec{\lambda}) = \sum_j p_j \log \frac{p_j}{q_j} + \vec{\lambda} \cdot \vec{g}$. Minimising L, $\{\frac{\partial L}{\partial \lambda_j} = g_j(\vec{p}) = 0\}, j = 1, \ldots, J$ is the set of given constraints $\vec{g}$, and a solution to $\frac{\partial L}{\partial p_i} = 0, i = 1, \ldots, I$ leads eventually to $\vec{p}$.

Entropy-based inference is a form of Bayesian inference that is convenient when the data is sparse and encapsulates common-sense reasoning.

An Example

In a simple multi-issue contract negotiation α may estimate $\mathbb{P}^t(\text{acc}(\beta, \alpha, \delta))$, the probability that β would accept δ, by observing β's responses.

Using shorthand notation, if β sends the message $\text{Offer}(\delta_1)$ then α may derive the constraint: $J^{\text{acc}(\beta,\alpha,\delta)}(\text{Offer}(\delta_1)) = \{\mathbb{P}^t(\text{acc}(\beta, \alpha, \delta_1)) = 1\}$, and if this is a counter offer to a former offer of α's, δ_0, then: $J^{\text{acc}(\beta,\alpha,\delta)}(\text{Offer}(\delta_1)) = \{\mathbb{P}^t(\text{acc}(\beta, \alpha, \delta_0)) = 0\}$.

In the not-atypical special case of multi-issue bargaining where the agents' preferences over the individual issues *only* are known and are complementary to each other's, maximum entropy reasoning can be applied to estimate the probability that any multi-issue δ will be acceptable to β by enumerating the possible worlds that represent β's "limit of acceptability".

Empirical estimate of $\mathbb{R}^t(\alpha, \beta, \mu)$

Suppose that μ is received from agent β at time u and is verified by ξ as μ' at some later time t. Denote the prior $\mathbb{P}^u(X_i)$ by $\vec{p}$. Let $\vec{p}_{(\mu)}$ be the posterior minimum relative entropy distribution subject to the constraints $J_s^{X_i}(\mu)$, and let $\vec{p}_{(\mu')}$ be that distribution subject to $J_s^{X_i}(\mu')$.

The *observed reliability* for μ and distribution X_i:

$$\mathbb{R}^t_{X_i}(\alpha, \beta, \mu)|\mu' = \arg\min_k \mathbb{K}(k \cdot \vec{p}_{(\mu)} + (1-k) \cdot \vec{p} \parallel \vec{p}_{(\mu')})$$

If $\mathbf{X}(\mu)$ is the set of distributions that μ affects, then the *observed reliability* of β on the basis of the verification of μ with μ' is:

$$\mathbb{R}^t(\alpha, \beta, \mu)|\mu' = \frac{1}{|\mathbf{X}(\mu)|} \sum_i \mathbb{R}^t_{X_i}(\alpha, \beta, \mu)|\mu'$$

Commitment and Enactment

Denote $\mathbb{P}^t(\text{Observe}(\varphi')|\text{Commit}(\varphi))$ simply as $\mathbb{P}^t(\varphi'|\varphi) \in \mathcal{M}^t$ Set of possible enactments be $\Phi = \{\varphi_1, \varphi_2, \ldots, \varphi_m\}$ with prior distribution $\vec{p} = \mathbb{P}^t(\varphi'|\varphi)$. We estimate the posterior $\vec{p}_{(\mu)}$.

First, if $\mu = (\varphi_k, \varphi)$ is observed estimate the posterior $\vec{p}_{(\varphi_k)} = (p_{(\varphi_k)j})_{j=1}^m$ satisfying the single constraint: $J^{(\varphi'|\varphi)}(\varphi_k) = \{p_{(\varphi_k)k} = d\}$.

Second, we consider the effect that the enactment ϕ' of another commitment ϕ, also by agent β, has on $\vec{p}$. Given the observation $\mu = (\phi', \phi)$, define the vector $\vec{t}$ by

$$t_i = \mathbb{P}^t(\varphi_i|\varphi) + (1- \mid \text{Sim}(\phi', \phi) - \text{Sim}(\varphi_i, \varphi) \mid) \cdot \text{Sim}(\varphi', \phi)$$

for $i = 1, \ldots, m$. $\vec{t}$ is not a probability distribution. The posterior $\vec{p}_{(\phi', \phi)}$ is defined to be the normalisation of $\vec{t}$.

Ideal enactments

A distribution of enactments that represent α's "ideal". This distribution will be a function of β, α's history with β, anything else that α believes about β, and general environmental information including time — denote all of this by e, then we have $\mathbb{P}^t_I(\varphi'|\varphi, e)$. For example, if α considers that it is unacceptable for the enactment φ' to be less preferred than the commitment φ then $\mathbb{P}^t_I(\varphi'|\varphi, e)$ will only be non-zero for those φ' that α prefers to φ. Trust is the relative entropy between this ideal distribution, $\mathbb{P}^t_I(\varphi'|\varphi, e)$, and the distribution of expected enactments, $\mathbb{P}^t(\varphi'|\varphi)$. That is:

$$T(\alpha, \beta, \varphi) = 1 - \sum_{\varphi'} \mathbb{P}^t_I(\varphi'|\varphi, e) \log \frac{\mathbb{P}^t_I(\varphi'|\varphi, e)}{\mathbb{P}^t(\varphi'|\varphi)}$$

where the "1" is an arbitrarily chosen constant being the maximum value that trust may have.

Preferred enactments

Given a predicate $\text{Prefer}(c_1, c_2, e)$ meaning that α prefers c_1 to c_2 in environment e. An evaluation of $\mathbb{P}^t(\text{Prefer}(c_1, c_2, e))$ may be defined using $\text{Sim}(\cdot)$ and the evaluation function $\vec{w}(\cdot)$ — but we do not detail it here. Then if $\varphi \leq o$:

$$T(\alpha, \beta, \varphi) = \sum_{\varphi'} \mathbb{P}^t(\text{Prefer}(\varphi', \varphi, o))\mathbb{P}^t(\varphi' \mid \varphi)$$

and:

$$T(\alpha,\beta, o) =$$

$$\frac{\sum_{\varphi:\varphi\leq o} \mathbb{P}^t_\beta(\varphi) \left[\sum_{\varphi'} \mathbb{P}^t(\text{Prefer}(\varphi', \varphi, o))\mathbb{P}^t(\varphi' \mid \varphi)\right]}{\sum_{\varphi:\varphi\leq o} \mathbb{P}^t_\beta(\varphi)}$$

Certainty in enactment

The idea here is that α will trust β more if variations, φ', from expectation, φ, are not random. The trust that an agent α has on agent β with respect to the enactment of a commitment φ is:

$$T(\alpha, \beta, \varphi) = 1 + \frac{1}{B^*} \cdot \sum_{\varphi' \in \Phi_+(\varphi, o, \kappa)} \mathbb{P}^t_+(\varphi'|\varphi) \log \mathbb{P}^t_+(\varphi'|\varphi)$$

where $\mathbb{P}^t_+(\varphi'|\varphi)$ is the normalisation of $\mathbb{P}^t(\varphi'|\varphi)$ for $\varphi' \in \Phi_+(\varphi, o, \kappa)$,

$$B^* = \begin{cases} 1 & \text{if } |\Phi_+(\varphi, o, \kappa)| = 1 \\ \log |\Phi_+(\varphi, o, \kappa)| & \text{otherwise} \end{cases}$$

Valuing negotiation dialogues

α estimates the *value* of the negotiation dialogue, Ψ^t, to itself as a 2×5 array $V_\alpha(\Psi^t)$ where:

$$V_x(\Psi^t) = \begin{pmatrix} I_x^{\mathrm{L}}(\Psi^t) & I_x^{\mathrm{O}}(\Psi^t) & I_x^{\mathrm{G}}(\Psi^t) & I_x^{\mathrm{I}}(\Psi^t) & I_x^{\mathrm{C}}(\Psi^t) \\ U_x^{\mathrm{L}}(\Psi^t) & U_x^{\mathrm{O}}(\Psi^t) & U_x^{\mathrm{G}}(\Psi^t) & U_x^{\mathrm{I}}(\Psi^t) & U_x^{\mathrm{C}}(\Psi^t) \end{pmatrix}$$

where the $I(\cdot)$ and $U(\cdot)$ functions are information-based and utility-based measures respectively.

α estimates the *value* of this dialogue to β as $V_\beta(\Psi^t)$ by assuming that β's reasoning apparatus mirrors its own.

The $I(\cdot)$ and $U(\cdot)$ functions

The information-based valuations measure the reduction in uncertainty, or information gain, that the dialogue gives to each agent, they are expressed in terms of decrease in entropy that can always be calculated.

The utility-based valuations measure utility gain are expressed in terms of "some suitable" utility evaluation function $\mathbb{U}(\cdot)$ that can be difficult to define.

This is one reason why the utilitarian approach has no natural extension to the management of argumentation that is achieved here by our information-based approach.

Intimacy

The *intimacy* between agents α and β, $I^{*t}_{\alpha\beta}$, is the pattern of the two 2×5 arrays V^{*t}_{α} and V^{*t}_{β} that are computed by an update function as each negotiation round terminates, $I^{*t}_{\alpha\beta} = \left(V^{*t}_{\alpha}, V^{*t}_{\beta}\right)$.

If Ψ^t terminates at time t:

$$V_x^{*t+1} = \nu \times V_x(\Psi^t) + (1 - \nu) \times V_x^{*t}$$

where ν is the learning rate, and $x = \alpha, \beta$. Additionally, V_x^{*t} continually decays by: $V_x^{*t+1} = \tau \times V_x^{*t} + (1 - \tau) \times D_x$, where $x = \alpha, \beta$; τ is the decay rate, and D_x is a 2×5 array being the decay limit distribution for the value to agent x of the intimacy of the relationship in the absence of any interaction. D_x is the *reputation* of agent x.

Balance

The *balance* in a negotiation dialogue, Ψ^t, is defined as: $B_{\alpha\beta}(\Psi^t) = V_\alpha(\Psi^t) \ominus V_\beta(\Psi^t)$ for an element-by-element difference operator $\ominus$ that respects the structure of $V(\Psi^t)$.

The *relationship balance* between agents α and β is: $B^{*t}_{\alpha\beta} = V^{*t}_\alpha \ominus V^{*t}_\beta$.

The notion of balance may be applied to pairs of utterances by treating them as degenerate dialogues. In simple multi-issue bargaining the *equal balance* strategy generalises the tit-for-tat strategy in single-issue bargaining, and extends to a tit-for-tat argumentation strategy by applying the same principle across the LOGIC framework.

Stance

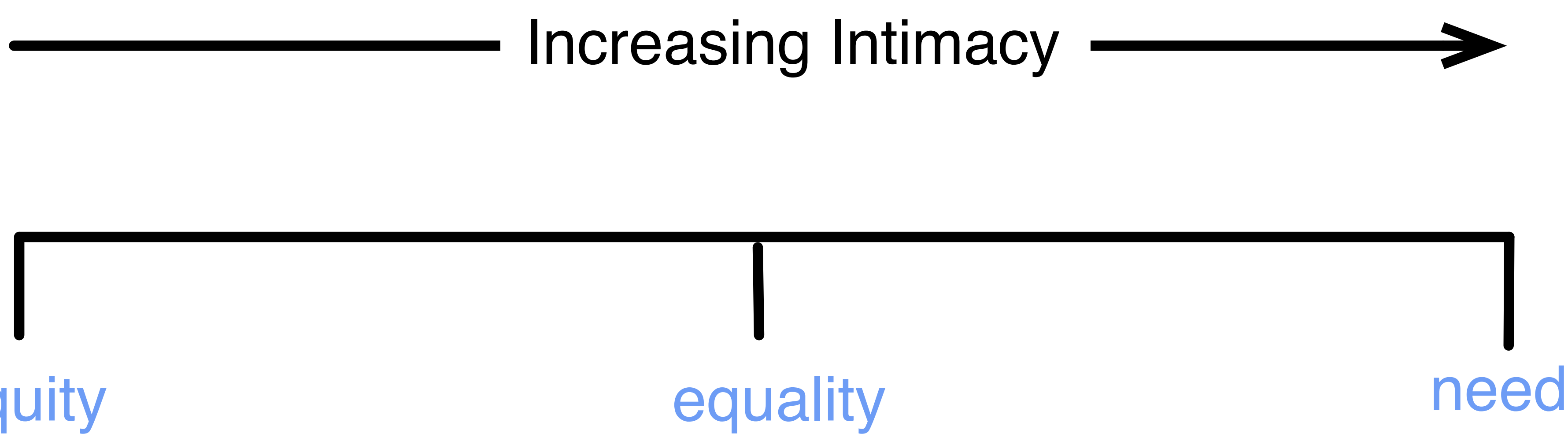
The negotiation literature consistently advises that an agent's behaviour should not be predictable even in close, intimate relationships. The required variation of behaviour is normally described as varying the negotiation *stance* that informally varies from "friendly guy" to "tough guy".

The stance injects bounded random noise into the process, where the bound tightens as intimacy increases. The stance, $S^t_{\alpha\beta}$, is a 2×5 matrix of randomly chosen multipliers, each ≈ 1, that perturbs α's actions. The value in the (x, y) position in the matrix, where $x = I, U$ and $y = \mathrm{L}, \mathrm{O}, \mathrm{G}, \mathrm{I}, \mathrm{C}$, is chosen at random from $[\frac{1}{l(I^{*t}_{\alpha\beta}, x, y)}, l(I^{*t}_{\alpha\beta}, x, y)]$ where $l(I^{*t}_{\alpha\beta}, x, y)$ is the bound, and $I^{*t}_{\alpha\beta}$ is the intimacy.

Accepting a proposal

The predicate $\mathbb{P}^t(\mathrm{acc}(\alpha, \beta, \chi, \delta))$ estimates the probability that α should accept proposal δ in satisfaction of her need χ, where $\delta = (a, b)$ is a pair of commitments, a for α and b for β. α will accept δ if: $\mathbb{P}^t(\mathrm{acc}(\alpha, \beta, \chi, \delta)) > c$, for level of certainty c.

$\mathbb{P}^t(\mathrm{acc}(\alpha, \beta, \chi, \delta))$ is a function of the intimacy and the stance:



Strategy

The negotiation *strategy* is concerned with maintaining a working set of Options. If the set of options is empty then α will quit the negotiation. α perturbs the acceptance machinery and may decide to inflate her opening Options.

Set the Options to the empty set, let $D_s^t = \{\delta \mid \mathbb{P}^t(\text{acc}(\alpha, \beta, \chi, \delta)) > c\}$, then:

- repeat the following as many times as desired: add $\delta = \arg\max_x\{\mathbb{P}^t(\text{acc}(\beta, \alpha, x)) \mid x \in D_s^t\}$ to Options, remove $\{y \in D_s^t \mid \text{Sim}(y, \delta) < k\}$ for some k from D_s^t

By using $\mathbb{P}^t(\text{acc}(\beta, \alpha, \delta))$ this strategy reacts to β's history of Propose and Reject utterances.

Tactics

Negotiation *tactics* select some Options and wrapp them in argumentation. Prior interactions with agent β will have produced an intimacy pattern expressed in the form of $\left(V_\alpha^{*t}, V_\beta^{*t}\right)$. Suppose that the relationship target is $(T_\alpha^{*t}, T_\beta^{*t})$, and that α wants to achieve a *negotiation target*, $N_\beta(\Psi^t)$ such that: $\nu \cdot N_\beta(\Psi^t) + (1-\nu) \cdot V_\beta^{*t}$ is "a bit on the T_β^{*t} side of" V_β^{*t}:

$$N_\beta(\Psi^t) = \frac{\nu - \kappa}{\nu} V_\beta^{*t} \oplus \frac{\kappa}{\nu} T_\beta^{*t} \tag{1}$$

for small $\kappa \in [0, \nu]$ that represents α's desired *rate of development* for her relationship with β. $N_\beta(\Psi^t)$ is a 2×5 matrix containing variations in the LOGIC dimensions that α would like to reveal to β during Ψ^t (e.g. I'll pass a bit more information on options than usual, I'll be stronger in concessions on options, etc.).

Closing the circle: β's response

It is reasonable to expect β to progress towards her target at the same rate and $N_\alpha(\Psi^t)$ is calculated by replacing β by α in Equation 1. $N_\alpha(\Psi^t)$ is what α hopes to receive from β during Ψ^t.

This gives a *negotiation balance target* of: $N_\alpha(\Psi^t) \ominus N_\beta(\Psi^t)$ that can be used as the foundation for reactive tactics by striving to maintain this balance across the LOGIC dimensions.

A cautious tactic could use the balance to bound the response μ to each utterance μ' from β by the constraint: $V_\alpha(\mu') \ominus V_\beta(\mu) \approx S^t_{\alpha\beta} \otimes (N_\alpha(\Psi^t) \ominus N_\beta(\Psi^t))$, where $\otimes$ is element-by-element matrix multiplication, and $S^t_{\alpha\beta}$ is the stance. A less neurotic tactic could attempt to achieve the target negotiation balance over the anticipated complete dialogue.

Conclusions

- Information-based agency as an integration of utilitarian, information and semantic views

- Information based agency as a sound method for building relationships in DE

- Ontology and semantics are central in DE

- Trust, reputation, negotiation [and argumentation] in a single (LOGIC) framework

Future uses in Digital Ecosystems

- Information-based social network analysis for reputation
- Coalition and team formation
- Supply-chain formation and evolution

Questions?