

The Quantum Inspired Modelling of Changing Attitudes and Self-Organising Societies

Kirsty Kitto¹ and Fabio Boschetti^{2,3}

¹ School of Information Systems, Queensland University of Technology
kirsty.kitto@qut.edu.au

² Marine Research, Commonwealth Scientific and Industrial Research Organisation

³ School of Earth and Geographical Sciences, The University of Western Australia
fabio.boschetti@csiro.au

Abstract.

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1 Introduction

The Quantum inspired modelling of human decision making has become quite advanced in recent years [1–4], and could now be regarded as relatively mature. In this paper we propose that this theory can be ‘scaled up’ into the realm of social modelling. In particular, we will show that the notion of an *attitude* as it arises in Social Psychology [5] provides a natural candidate for a quantum state, and introduce a simple extension to the quantum approach which allows for a consideration of the way in which a society of decision making agents will form attitudes which are influenced by both their natural disposition and their social context. We shall conclude with a brief consideration of the extension of the formalism that was introduced in this approach, and discuss its implications for the broader Quantum Interaction community.

Social psychology defines *attitudes* as referring to a person’s overall evaluation of people (including themselves), objects and issues [6]. Even when writing the first *Handbook of Social Psychology* in 1935, Allport claimed that the attitude construct was the most indispensable concept in the field [7]. Attitudes play a critical role in the

choices people make regarding their own health and security as well as those of their families, friends, and nations. From purchase decisions provoked by liking for a product to wars spurned by ethnic prejudices, attitudes help to determine a wide variety of potentially consequential outcomes. [6]

However, this very potentiality of attitudes makes them extremely difficult to model. How will a given person think about ‘global warming’ vs ‘climate change’? What if their daughter has just had her house flooded? Or if they are about to

make a very large tax payment that includes a carbon component? People’s attitudes are not static immutable objects, but change in response to persuasion [8], and the demands of cognitive consistency [9]. We often express different attitudes and opinions in accordance with the social scenario we find ourselves in [10, 11], and it is frequently the case that an explicitly expressed attitude is quite different from an internally held one [12].

Two proposals of attitude change arose in the 1970’s; the Elaboration Likelihood Model (ELM) [13]; and the Heuristic-Systematic Model (HSM) [14]. Both of these models utilise a dual-process approach that takes a form of mental effort as its key switching variable. mosler.schwarz.ea.computer Thus some processes of attitude change require relatively high amounts of mental effort, resulting from situations where individuals are motivated to pay attention to a message, or have the cognitive capacities to consider it carefully. In these high effort or high elaboration processes, people’s attitudes will be determined by an effortful examination of all relevant information, and so changing them will expend high amounts of cognitive energy. In contrast, other processes of persuasion require relatively little mental effort on the part of the persuadee, resulting in attitudes that are determined by factors like emotions, ‘gut feeling’, liking, and reference to authority. Similar amounts of attitude change can be produced via either process, however, the changes induced by the high mental effort processes are postulated to be more persistent, resistant to counterpersuasion, and predictive of behavior than low effort attitude changes. The difference between these two processes has a number of implications for public policy. In an era of high-frequency press reporting periods (i.e. the 24 hour news cycle) we have entered a climate where low effort attitudes appear to predominate [15, 16], and the transitional nature of this process could be seen to result in the apparent increase in undecided or swinging voters in the modern age. However, few mathematically oriented or computationally implementable models of these low effort processes exist, and those that do tend to make unrealistic commitments to the ontological status of attitudes which imply that these are held in some objective sense and have a well defined setting [17].

We have recently proposed [18] that the very contextuality of the low effort processes makes them prime candidates for a quantum inspired model. This paper will summarise that model in section 2 before moving onto a consideration in section 3 of the implications that this model has for the QI community, emphasising its divergence from the more direct application of the quantum formalism that tends to be utilised.

2 A Geometric Model of Attitude Change

The social model that we shall present here is a large scale agent based model (ABM), roughly based upon the quantum decision theory (QDT) presented by Busemeyer et. al [2]. In this section we shall briefly introduce the notion of an agent, A , making a decision to act that is affected by their attitude within a particular social context. Thus, our agent might be answering a question, they

might be voting for a particular politician, perhaps they need to work out if they should immunise their child, or drive to work. In order to maintain generality in the model that follows we shall term all of these different decisions as *actions*. However, the agent has not yet made their decision, and how they eventually do choose to act will depend upon both their own attitudes (implicit and explicit), and on the attitudes of those that surround them (i.e. their social context). Note that an agent with the same initial cognitive state may choose a different course of action if they find themselves in a different context, and this uncertainty should lie in the mind of the agent. However, seating uncertainty in the mind of the agent implies that even if the same agent is presented with the same context then they might choose something different, a situation that we feel reflects the true uncertainty of human decision making (and its modelling). Finally, we draw attention to the recursive nature of attitudes within a system of this form; the actions of our agent will likely affect the social context of other agents in the system, so changing their attitudes and hence their decisions.

2.1 A Quantum-like Decision

We shall begin with a consideration of the cognitive state of our agent, represented as $|A\rangle$, which A may not have direct access to (i.e. A may not be aware of this state for reasons of context to be explained below). If A has decided to act then we shall denote this state of action using the symbol $|1\rangle$, to represent a situation where it is *true* that they have *chosen to act* (in contrast to a state of inaction which we denote as $|0\rangle$). However, a decision to act (or not) depends on the context in which it is made; we are immediately faced with the dilemma that our social agent cannot be described as making a decision without reference to a context. Thus, we must specify that *within a given context*, termed p say, our agent will have a certain probability of acting, and note that a change in context might change this probability.

In what follows, we shall represent both the current state of an agent, and that of their context explicitly. This is done by expanding the notion of a state from that of a point in a space, to that of a vector in a Hilbert space, which is a real or complex inner product space that is also a complete metric space with respect to the distance function induced by the inner product [19]. At this point we can start to ask what the state of our undecided agent might be. Requiring that they have a probability of acting in any way whatsoever that is equal to 1 (as is standard), then there is one obvious choice for the representation of the current state of our agent, $|A\rangle$, in some context p :

$$|A\rangle = a_0|0_p\rangle + a_1|1_p\rangle, \text{ where } |a_0|^2 + |a_1|^2 = 1, \quad (1)$$

a situation that is illustrated in Figure 1(a). Here, $\{|0_p\rangle, |1_p\rangle\}$ are taken to define an orthonormal basis, the inner product (denoted in the quantum formalism as $\langle \cdot | \cdot \rangle$) of which returns 0 or 1: $\langle 0_p | 0_p \rangle = \langle 1_p | 1_p \rangle = 1$ and $\langle 1_p | 0_p \rangle = \langle 0_p | 1_p \rangle = 0$. Thus, we have used the orthonormal basis $\{|0_p\rangle, |1_p\rangle\}$ to represent the set of ‘not act’ or ‘act’ decisions to be made by our agent in the context p . We note that

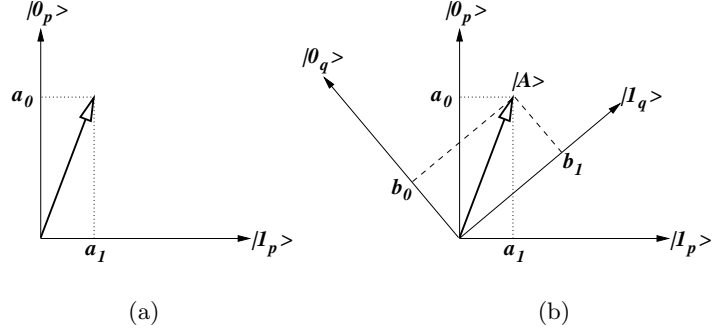


Fig. 1. An agent attempts to decide whether or not to act. (a) Their probability of action is proportional to the length squared of the projection of their state onto the axes labelled $|0_p\rangle$ (no action) and $|1_p\rangle$ (action); (b) The changing context of a decision. The probability of the agent acting changes between the two contexts p and q .

in this case orthogonality is entirely appropriate as an agent cannot do both, however, before they make their decision, the agent can be genuinely undecided; in a different context their probability of choosing an action may change quite significantly. QDT extracts this probability from the cognitive state of an agent using a notion of measurement.

When a person responds to a survey they could be said to be undergoing a social measurement of their attitudes, and the same can be said of all actions as they were defined above. The decision to act (or not) entails the measurement of a state of an agent, but this very act of measurement may itself affect the decision to act. For example, consider the manner in which the framing of a question in a positive or negative light can lead to risk averse or risk taking behaviour [20]. Such results suggest that the act of measurement can itself influence the outcomes that are obtained, but the geometric formulation of decisions that is used by QDT can easily incorporate such effects [2].

Measurement of the state (1) is defined in this approach with respect to a projection operator V , where

$$V = |0_p\rangle\langle 0_p| + |1_p\rangle\langle 1_p| = V_0 + V_1. \quad (2)$$

Thus, the basis vectors $\{|0_p\rangle, |1_p\rangle\}$ define the current context p of our agent, which in turn affects their decisions about whether or not to perform an action during the process of measurement. This effect is reflected in the probability of our agent acting in a given context p is given by

$$P = \langle A|V_1|A\rangle \quad (3)$$

$$= \langle A|1_p\rangle\langle 1_p|A\rangle \quad (4)$$

$$= (a_0^*\langle 0_p|1_p\rangle + a_1^*\langle 1_p|1_p\rangle) \times (a_0\langle 1_p|0_p\rangle + a_1\langle 1_p|1_p\rangle) \quad (5)$$

$$= |a_1|^2 \quad (6)$$

and similarly, their probability of inaction is given by $|a_0|^2$.

Perhaps the most important feature of this new model arises from a consideration of context itself; it is not just a label. We can immediately develop a far richer notion of context by asking: what would happen if the social context of our agent A changed? QT provides us with a particularly elegant mechanism for dealing with this scenario via a change of basis. Consider figure 1(b), which is an elaboration of figure 1(a), and represents the changing probabilities of action that arise in the case of two different contexts, p and q . With reference to figure 1(b) we can quickly see that while our agent is highly likely to act in context q , this is not the case in context p , where A is much less likely to act (since by examination of the figure we can see that while $|a_0| > |a_1|$ in context p , $|b_1| > |b_0|$ in context q).

2.2 Social Agents Minimise Cognitive Loads

We shall now extend the framework of QDT with a consideration of the *uncertainty* that an agent experiences. An agent who has decided to act has reduced their uncertainty about a situation, as has one who has decided not to act. In contrast, an agent who is most undecided (i.e. has a current state that forms a 45° angle between choosing to act and choosing not to act in the context p) is highly uncertain about their future action in that context, and this is not a state that people tend to enjoy. Indeed, there is a history of literature in psychology suggesting that people preferentially tend to not to make decisions in situations of uncertainty [21, 3].

This leads us to introduce a minimisation principle which takes as its basis the desire of people to be ‘decided’. That is, we assume that people tend not to enjoy living in states of uncertainty, and that they will preferentially seek a state in which they can maximise their chances of being decided about an action. In order to model this behaviour we require a measure of the uncertainty that an agent experiences in their current context. *Binary entropy* provides a suitable measure for of this uncertainty. Defined as the entropy of a Bernoulli trial (e.g. a two-outcome random variable such as a coin toss), with a probability of success given by P , it is specified as:

$$H_b(P) \equiv -P \log_2 P - (1 - P) \log_2(1 - P), \quad (7)$$

which is a concave function taking its minimum values at $P = 0$ and $P = 1$, and its maximum at $P = 1/2$.

An agent who is uncomfortable with uncertainty will seek to minimise the binary entropy associated with their current attitude over time by aligning their state with the context in which they are currently making a decision to act. Thus, we require that agents seek to minimise the binary entropy associated with their current state or attitude, in whatever frame is currently relevant to the agent. This means that the time evolution of $|A\rangle$ will seek to reduce $H_b(P)$ for the context p by moving towards either of the basis states $\{|0_p\rangle, |1_p\rangle\}$. Referring to figure 1(a), we can rewrite the binary entropy (7) for our agent within the

context p as


$$H_b(P) = -|a_1|^2 \log_2(|a_1|^2) - |a_0|^2 \log_2(|a_0|^2) \quad (8)$$

$$= -\cos^2\theta \cdot \log_2(\cos^2\theta) - \sin^2\theta \cdot \log_2(\sin^2\theta) \quad (9)$$

where θ is the angle between the $|1_p\rangle$ basis state and the state of the agent $|A\rangle$. Rewriting (7) in this manner makes obvious the way in which the entropy of the agent will change if either (a) the agent undergoes a change in state, or (b) finds themselves in a changed context. However, we are yet to propose the manner in which the social context of our agent might emerge.

2.3 The Local and Global Framing of an Issue

A final extension of QDT is required; we shall assume that multiple frames (i.e. contexts) can be used by a society to understand an issue, and that these can work at two different scales. Thus, agents in a society will make decisions to act in both *local* and *global* contexts, that represent both their individual and private attitude towards an issue and their collective and global attitudes respectively.

For example, each member of a society will have an attitude towards a public issue (e.g. the need for a  tax, or the ‘pro-life’ lobby) but this will quite often remain local and un-shared. When an agent is exposed to an argument about that issue, they will frequently form an opinion, or choose to act, according to that argument but we will consider such decisions to be local and broadly unshared with the other agents in the society. A local context might depend upon a wide range of both external and internal factors, such as their socio-economic status, educational background, race etc. and so is a highly complex, and multidependent variable, although the implementation in this paper takes a simple two dimensional form.

In addition to these local and private decisions, we note that sometimes agents interact, or make decisions of a more global form (e.g. they might be asked to vote in an election, or be polled). In this situation, issues are considered in a frame that is somehow aggregated from the attitudes of each member in the society (such as the spin of a major political party, or a voting card that represents all of the candidates in an election and their policies). We note here that a society frequently understands an issue from a small number of broadly definable perspectives (e.g. capitalism vs socialism, or pro-green vs pro-development etc.), and so it seems likely that more than one global frame may exist in a society at any one time (and these will not necessarily be orthogonal). This leads us to surmise that for every issue confronting a society, a set of global frames will spontaneously emerge. Agents would then align their understanding of an issue with a particular global frame, and make their choices on this basis.

The model presented below considers the orientation of each agent’s local frame as resulting from an attempt to navigate two different drives for cognitive consistency:

1. A desire for internal cognitive consistency. This results in a drive to minimise the binary entropy that applies to their decisions through a choice of local frame that results in their current state being maximally decided.
2. A desire to ‘fit in’ with the society and its current norms. This desire is expressed by a pull of their local frame towards the current global frame to which they belong.

These two drives may prove to compete with one another in the mind of the agent, and indeed, they might have a different pull for agents of different personality types (e.g. a ‘conformist’ agent vs a highly ‘individualistic’ one). In what follows, we shall define Θ as the angle between the agent’s current state $|A\rangle$ and $|1\rangle$ axis in the global context to which they currently belong, and take θ to perform a similar function in their local frame. This allows us to an individual entropy measure for each agent

$$H(|A\rangle, \theta) = w_i(A)H_b(p(\theta)) + w_s(A)H_b(p(\Theta)) \quad (10)$$

where the weights $w_i(A)$ and $w_s(A)$ refer to agent A ’s need for internal consistency and social conformity respectively. These weights can be set to range over a population of agents, indicating a rough parameterisation of a societies social make-up.

2.4 Updating the State and the Local Frame

An agent who has chosen to act in a certain context will feel a certain amount of *cognitive dissonance*, meaning that this decision will not reflect the agent’s perceived internal state, and this will result in psychological discomfort [9]. This gives people a drive to either alter their existing cognitions, or to alter their interpretation of a situation, through a re-orientation of their local frame. We note that since an agent has no direct control over the global frame they may not always be able to minimise their uncertainty as represented by (10), however, depending upon their personality type, they may be able to reduce it over time if the global frame is relatively stable.

Rather than positing a collapse of the agent’s cognitive state to whichever axis represents their decision, this model updates $|A\rangle$ after a decision by shifting it towards the axis representing the decision by a certain amount. The size of this shift will depend upon the agent’s personality variables (w_i and w_s), and upon the angle θ between the state at time t , $|A_t\rangle$, and the frame in which the decision is being made (as represented by context p , $\{|0_p\rangle, |1_p\rangle\}$). Writing θ_0 for the angle between the agent’s state and the $|0_p\rangle$ axis, and θ_1 for the angle between their state and the $|1_p\rangle$ axis, the new angle between the agent’s state and the relevant frame is defined to become:

$$\text{if } A \text{ decides to } \begin{cases} \text{act: } \theta_1(|A\rangle_{t+1}, w(A)) = \theta_1(|A_t\rangle) \times (1 + w(A)) \\ \text{not act: } \theta_0(|A\rangle_{t+1}, w(A)) = \theta_0(|A_t\rangle) \times (1 - w(A)) \end{cases} \quad (11)$$

where $w(A)$ depends upon the comfort of A with holding two dissonant attitudes. If A ’s decision is being made in a global frame then $w(A) = w_s(A)$, whereas if

it is being made in their local frame then $w(A) = w_i(A)$. Agents who decide to act will thus rotate by a certain distance towards the $|1_p\rangle$ axis, and agents who decide not to act will rotate in the opposite direction.

Thus, in this model, agents who are comfortable with dissonance will likely be able to maintain attitudes that do not conform to their actions, while those who prefer a consistent cognitive state will experience significant swings in attitude as a result of actions that they choose to take.

Over time, we expect the agents to self-organize towards a scenario where they are highly aligned within groups. This process will be measured by the total entropy of the system, given by a summation of each agent's individual entropy

$$H = \sum_{i=1}^N H(|i\rangle, \theta_i). \quad (12)$$

The next section will briefly discuss a computational implementation of this social model of low effort attitude change, the interested reader can find far more details in the longer paper [18].

2.5 Computational Implementation

A computational implementation of this model has been performed using MATLAB. A simple two dimensional space was used for this implementation, which is at the proof of concept stage, and will be further developed in a higher dimensional space in future work. Simulations can be run with a varying collection of agents, with varying weightings of personality variables, and different numbers of global frames. Clustering was utilised to find a specified number of global frames in this implementation. In this case the vertex substitution heuristic (VSH) algorithm was used [22]. It is also important to note that the current model is obviously symmetric, with agents who are at precisely 180° to one another will exhibit the same probabilities of action in the one global frame. This should be remembered when considering the figures below.

In figures 2 and 3 we see a society of 100 agents, with their current states represented by long black lines, the global frames in the system by large red dots, and the local frames of each agent by the shot red lines. These are seen to evolve over 100 timesteps, and even with this particularly simple implementation we can illustrate two key effects that are of interest to social modelling.

Firstly, the vast majority of runs have demonstrated the anticipated gradual minimisation of the total entropy of the system. Thus, over time the system minimises (12), which represents a lessening of the uncertainty of most agents in the system about their actions. In figure 2 we see a typical system run with one global frame specified, which starts from a random distribution of states, but quickly settles into a scenario where clusters of agents are centred around the global frame, with a couple of other groupings also in existance. The total entropy of this system is seen to quickly settle down to a low value, but we note that some runs have seen well defined spikes arise in this measure of system

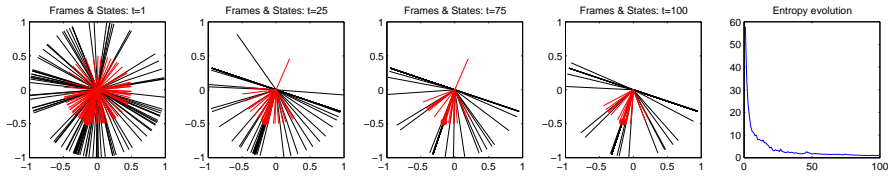


Fig. 2. The time-wise behaviour of a typical run with only one global frame.

uncertainty, denoting a scenario where an unstable global frame undergoes a marked shift, which requires the agents to re-evaluate their current attitudes.

This shift in global frames suggests that it may be possible for a policy maker or interested party to identify places where they might be able to interfere in a system of this form. Indeed, entropy measures might be utilised to identify ‘tipping points’ from which a social system might be manipulated towards a desired outcome. We have briefly investigated such a scenario in figure 3, where a perturbation of one global frame at step 51 causes the system to reconfigure and eventually settle down into a new stable position. The entropy mapped in figure 3(e) shows the spike in entropy that results from this manipulation, so linking the entropy to such shifts in global frame.

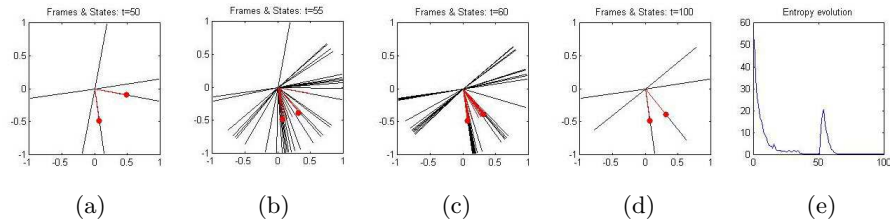


Fig. 3. Guided Self-Organisation example. Time evolution patterns for a system of 100 agents all characterised by the same personality values (consistency and conformity =.5). After 50 iterations the system reaches a stable state with 2 global frames and all agents aligned to their local frames as well as to one of the global frame. At iteration 51 an external perturbation rotates one of the global frames of 30 degrees clockwise. At iteration 55 and 60 we see the system re-organising. After 100 iterations the system reaches a new, different stable state. The rightmost panel shows the time evolution of the total entropy measure, clearly displaying the effect of the intervention at iteration 51.

3 New Time Evolution Paradigms

At this point it is worth taking a step back from the model itself and considering its implications for the broader QI paradigm. This is because while the model is quantum inspired, it has characteristics that do not keep with a pure quantum model. Specifically, no continuous time evolution satisfying the Schrödinger

equation takes place, and while agents change their state in response to measurement they do not exhibit complete collapse.

We note that the evolution operator given in equation (11) can be defined in such a manner that it is invertible by setting $\theta_1^{-1} = \theta_0$ and vice versa. This has the result of implying that the time evolution in this system is unitary [19]:

$$U_\theta U_\theta^\dagger = 1, \quad (13)$$

However, this time evolution equation is different to all other operations so far considered in a quantum framework, and so provides us with a genuinely new form of probability conserving time evolution. We anticipate that many other forms of evolution exist, and propose that the QI community should strive to identify them and classify their behaviour.

We have designated this model as a geometric model rather than a quantum one due to its reliance upon Pythagoras theorem in the extraction of probabilities, and suggest that it forms part of a class of non-classical models which do not exhibit completely quantum behaviour.

4 Conclusions, Shortcomings and Projected Future Work

The model presented in section 2 is obviously very simplistic, and has many deficiencies. For example, a genuine model of attitude change must be implemented in more than a two dimensional plane. A current project involves trying to identify a suitable set of socially relevant variables from social psychology that could take the role of basis states. However, this higher dimensional setting would entail significant new complexities, for measurement in particular, which would require the specification of some sort of plane or cut through the higher dimensional space before a frame could be suitably defined.

We note that this model has not been designed to exhibit either interference, or non-separability effects at this stage, although this is not in principle ruled out, although they may arise in a slightly different form due to the different time dynamics of this system. The design of the system behaviour is such that interference effects between competing decisions to be made by an individual should be evident, with choices made in one frame affecting choices in another etc. A more novel phenomenon would centre around interference effects between different agents in a society. Indeed, depending upon how a global frame is defined, we could anticipate scenarios where the decisions of one agent might have pronounced effects upon other agents in the system. For example, it would not be difficult to define a ‘presidential’ agent, whos decisions shape one global frame in the system, so interfering with the decisions of all other agents. We might then ask what would be signified by the emergence of a new global frame — perhaps the emergence of a new set of political ideologies? The ended time dynamics of this model leaves us with the hope that such behaviour would be more theoretically stified and emergent from the evolution of the system rather than postulated.

In conclusion, much has been learned from this new model, even at this preliminary stage. We believe that the geometric representation employed in this paper allows natural scientists and engineers to model, and thus more easily accept, a set of models that social scientists hold particularly dear. Similarly, the adoption of our proposed framework may in some cases provide social scientists with some confidence that important aspects of social theory can be considered within quantitative models, so making them relevant to the real world problems that they are seeking to address. For the QI community, we see a new way forwards, towards a class of quasi-quantum systems displaying contextualised probabilistic behaviour, but within a new set of measurement paradigms. This further opens up the field towards a new broader class of formalisms able to treat context in a sophisticated manner, of which quantum mechanics is only one example.

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