Moving Targets: How Consumers Change Value Systems Through Interaction With Designed Products And Other Consumers

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1 INTRODUCTION[1]

In the eyes of a designer, consumers often react to a new product introduction in surprising and unexpected ways. These unexpected reactions are both a source of risk—products may fail in the marketplace—and a source of innovation as new uses or new utility are discovered. These in turn create opportunities for new directions in product design. Both designers and consumers form their expectations before and during the design process, including their experience with previous designs. Their behaviours and interactions in the post-design phase are not simply a matter of having those expectations met or not. Consumers can engage creatively with new and existing products, and therefore designers must constantly re-evaluate their strategic choices. This might mean abandoning existing competencies and preferred design strategies in favour of new and untried paths. It might also mean that the designer might benefit from serendipitous events—e.g. product characteristics that were previously not valued by consumers suddenly come into favour, allowing a marginal producer to rise to market leadership. Designers that successfully observe and learn from consumers in the post-design phase can then adapt their strategies and plans in subsequent design cycles, including the possibility of making fundamental changes in strategy or architecture. In other words, successful design involves the interplay between cognition, value systems, and social interactions that reshape the design landscape and, thus, cause designers to re-evaluate their plans and strategies for future designs.

In this paper we report on investigating phenomenological patterns of collective behaviour due to social influence among consumers of designed artefacts where the consumers' value systems change in response to their experience with artefacts and their social interactions with other consumers. This is part of a larger research goal of investigating innovation processes and policies across complex ecosystems of researchers, innovators/designers, funding organizations, and consumers.

Systems of innovation can exhibit stability without convergence. They are capable of stable averages in aggregate activity but without stasis in micro-level dynamics. By definition, systems of innovation produce a stream of new product types. Consumers in the system must react and adapt to this stream of novelty, and in some sense master it.

The attention is on heuristic search processes when there is no clear global maximum in the landscape and there is no consumer-accessible metric for collective utility, and where collective behaviour is emergent. To emphasize the role of social interactions, consumers are not endowed with spatial reasoning or spatial memory, nor are signalling or overt coordination capabilities provided. Search and learning is also hampered by local competition between consumers and also by a bias

[1] This paper draws on the preprint Thomas & Gero (2012).

toward consuming (to avoid frustration). These influences tend to cause consumers to move away from local maxima even if they have found them. This can be characterized as a ‘frustrating search problem’ for consumers in that they might never be able to master the problem from an observer viewpoint.

The theoretical lens in this paper on collective behaviour is situated cognition (Clancey 1997). Any cognitive system operates within its own worldview and that worldview affects its understanding of its interactions with its environment (Clancey 1997; Gero 2008). In essence, what you think the world is about affects what it is about for you.

A person or group of people is “situated” because they have a worldview that is based on their experience. Situated cognition involves three ideas: situations, constructive memory and interaction. Situations are mental constructs that structure and hence give meaning to what is observed and perceived based on a worldview. Constructive memory makes memory a function of the situation and the past. Memory is not laid down and fixed at the time of the original sensate experience. What is remembered is constantly being recreated and reframed. Interactions between consumers trigger changes in situations and memories.

Through the lens of situated cognition, collective behaviour is an emergent phenomenon that arises from the interplay of situations, constructive memory, and social interactions at the level of consumers and networks of consumers. We claim that situated cognition is at the heart of social processes of creativity and inventiveness. This is why it is so important in the study of innovation (Gero 2011).

To facilitate this research, a computational laboratory using agent-based modelling with rich agents and rich artefacts is being built. The phenomena of interest arise through the dynamic social interactions between agents, and between agents and artefacts, far from equilibrium. Therefore, it is important that the system includes endogenous processes for learning (direct and indirect), social interactions and network formation, and be capable of rich emergent phenomena.

1.1 Consumer and Designer Values

Our research draws on previous research regarding values of consumers and designers/producers and how those values influence behaviour. Saviotti (1996) presents a formal model of technological evolution through design space, where the space is defined by dimensions for each technical and service characteristic associated with a particular product or technology. ‘Characteristics’ are formalized as a vector of variables that specify both a product’s internal structure (‘technical characteristics’) or services performed for its users (‘service characteristics’) (Saviotti and Metcalfe, 1984). This “twin characteristics framework” is useful for understanding both designer’s values, which centre on technical characteristics and associated learning, and the consumer’s values, which centre on the service characteristics.

There is an extensive literature consumer preferences, opinions, and consumer behaviour. Liggett (2010) evaluates alternative methods for mapping consumer preferences as a population using perceived product characteristics and their `ideal product' that can be formalized as a vector of values for each service characteristic of the product. Liggett also uses Multi-dimensional Scaling (MDS) to create a 2D map of a population of consumers' ideal vectors relative to the available products. There is also extensive research on how consumers influence each other's values and opinions through social interactions, e.g. Friedkin and Johnsen (1999). This literature guided our design decisions for social influence mechanisms and patterns, including topology of consumer social networks, the behaviour of opinion leadership, susceptibility to social influence, and homophily as a primary factor in the determining strength of social ties and thus the degree of influence between any two consumers.

2 ARCHITECTURE AND IMPLEMENTATION

2.1 Functional Overview

There is one type of active agent in the current implementation of the system – Consumers – and one type of artefact – Products. Consumers are seeking to consume Products on a geographic Consumption Space with micro-behaviour similar to foraging, but with social interactions. The Consumption Space is a bounded rectangular grid with von Neumann neighbourhoods. In each clock cycle consumers can move to any neighbouring point on the grid within the boundaries. Only one Consumer can occupy a given grid location at a given time.

Products have both surface characteristics and functional characteristics. During their search and evaluation process, Consumers can only sense and perceive a Product's surface characteristics (its "signature"). The functional characteristics are only experienced through the process of consumption. During consumption, Consumers gain utility based on the functional characteristics, relative to expectations. Higher than expected evaluations of functional characteristics yield positive utility, while lower than expected evaluations of functional characteristics yield negative utility. The surface characteristics of Products are related to their functional characteristics, but not identical. Consumers cannot directly perceive the value of products.

The space of possible Product signatures, along with the utility of each Product, is called the Value Space. The value system for each Consumer centres on a single vector that represents the signature of its ideal product type. Consumers learn and adapt by adjusting this vector through experience and social interaction. Each Consumer's value system can be represented as a point in Value Space, and their changing values as paths through Value Space. All consumers have the same utility function that does not change during a run.

Consumers choose to consume based on their perception of product signature, perception of proximity to their ideal type, and a rough expectation of utility. Generally, Consumers choose to consume when the Product they encounter is close to their ideal type.

In summary, at the task level the Consumer's problem is to find relatively more desirable Products to consume by searching the Consumption Space and adjusting their ideal product type. If they become dissatisfied during this process or if they are not able to find products to consume, they interact socially to either modify their value system or to move toward another agent in the Consumption Space.

At a social level, Consumers create and maintain social relationships through physical contact in the Consumption Space or through social interactions. However, if a Consumer is close to losing social connections, that Consumer interacts socially to build new connections through a referral process ('friends of friends').

2.2 Architecture Overview

2.2.1 Consumers

A block diagram of the agent architecture is shown in Figure 1. Compared to other agents in the social network influence literature, these agents have a rich architecture that includes both symbolic and sub-symbolic reasoning. This was necessary to implement situated cognition, which was one the primary research goals. For brevity only perception, conception, situation, and social interaction functions are described.

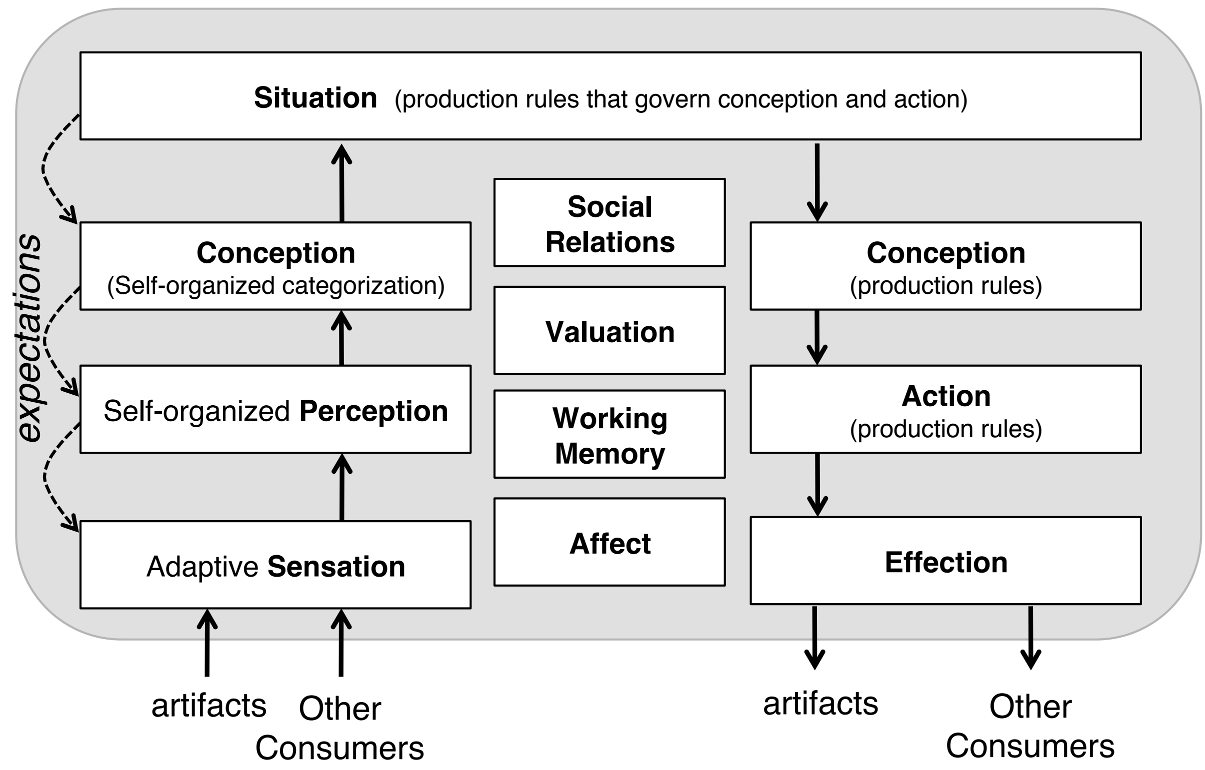


Figure 1. Agent Architecture

Perception is the collection of functions that enables the agent to focus and organize their sensations according to their current situation, their expectations, and past experiences. Consumers perceive Product signatures using a self-organizing map (SOM, also known as Kohonen Networks). SOMs are a type of neural network that are trained via unsupervised learning. Essentially they perform a mapping from the sensed Product Signature to a condensed 2D internal representation of the Products. This is functionally equivalent to conceptual spaces, as described in Gardenfors (2000). Perception is updated every clock cycle, but is only processed when new sensations arrive.

Perception of other agents is performed through a categorization and comparison procedure, where agents with direct social connections are labelled 'most similar', 'most dissimilar', 'most admired', 'least admired', etc.

Conception is the highest level of reasoning, including both tacit and explicit capabilities. Tacit conceptual reasoning is focused on deciding whether a given product should be considered attractive or not. This is implemented using a SOM that essentially creates a one-dimensional map of products that it has experienced and the value and/or utility that is perceived or realized from those products. A threshold value is used to trigger a decision that the product being inspected is attractive. The threshold value is adapted through learning by experience. Conception also includes explicit reasoning about actions, social interactions and goals. These are implemented symbolically as production rules.

Situation has the function of cognitive orientation and focus. We implemented it using production rules that tested for conditions that would change a Consumer's situation, and then fired actions to change their concepts according. Overlapping situations can be active at the same time. Situations act as conditions on other conception rules so that each conception rule fires only when one of its applicable situations is active. Situation also activates other reasoning functions, as appropriate. We implemented the following generic situations:

1. Consume-locally	Local foraging
2. Interact-socially	Interact with social neighbours.
3. Bored	Decide what to change to end boredom
4. Dissatisfied	Stop current actions, reverse expectations, and decide what to do instead
5. Change-location	Use available information to pick a target destination
6. Change-values	Make incremental changes in value system and selection criteria
7. Search-for-a-friend	No social network, so find a friend

Social interactions are implemented using production rules. Generally, social interaction only occurs when the Consumer is both not in the act of consumption and is also frustrated by its consumption experiences. The exception to this occurs when a Consumer's social ties have been reduced to two or fewer and their strength has fallen below a threshold value. Here, conception rules fire that cause the agent to create new social ties. This is necessary experimentally in order to sustain social networks and avoid disconnections. This was essential to maintain the distinction between "social" and "non-social" runs in the paired experiment design.

The targets of social actions and influences interactions are always defined by the perceptual categories mentioned earlier. In these experiments, Consumers are only influenced by one neighbour at a time. They do not poll their local social network or perform any reasoning based on the range of values of other agents.

The utility function for all agents is the same and is fixed. It is a logistic function of the number of edges in the Product structure (see below) relative to an expected value of 8. Edge counts above 8 yield positive utility while counts below yield negative utility.

The valuation function is also fixed and identical. It is the Euclidean distance between the Consumer's ideal product and the Product signature (6-element real valued vectors).

2.2.2 Products

Products are constructed as a graph structure with six nodes. During the construction process, edges between the nodes are formed at random, creating a single connected graph with between 5 and 14 edges. The Product's utility is a function of its topology, while its signature (external appearance) is a metric of its physical layout. Physical layout is constructed on a circle with a relaxation method to equalize the length of edges. Distance from the centroid of this layout produces a signature in the form of a 6-element vector.

This construction process produces a non-obvious relationship between the surface characteristics and the functional characteristics of Products. Products that are very close in surface characteristics (i.e. close in Value Space) may have very different utilities. This allows for rugged search landscapes, though any particular realization of 10 product types may or may not be rugged. When we generated a sample of 2000 product types, the resulting landscape was extremely rugged with no global maximum.

2.3 Design Choices

The following is an explanation of the most salient design choices we have made and their effect on system behaviour and experiment results.

In contrast to other social influence networks research (e.g. Friedkin & Johnsen 1999), the Consumers are situated in two environments: the task environment of consumption and the social environment of agent-to-agent interaction. Thus, the social network is endogenous and dynamic and has a contextual influence over agent behaviour in the task environment and their behaviour on tasks influences their social world. This is a cornerstone in theory of situated cognition and, therefore, was a necessary choice given the objectives.

The agents are cognitive and adaptive rather than rational or even bounded rational. Specifically, the agents were not endowed with explicit preference ordering or utility maximization processes or capabilities. We claim the cognitive-adaptive model is more appropriate for innovation studies.

Deterministic rules are used for reasoning and acting whenever possible, especially for activities related to Product evaluation and consumption, and also related to social influence processes. This is in contradistinction with research approaches that use probabilistic rules for action decisions and influences. This has experimental benefits. The system is already endowed with several sources of randomness and mixing through agent interactions. Adding randomness into the agent architecture would have made it difficult to determine experimentally the cause-effect relationships. The system would have become essentially a large stochastic processes dominated by the Central Limit Theorem, producing statistically homogenous output.

Because the focus is on social influence involving value systems, Consumers have rather simple and reflexive capabilities for navigating in the Consumption Space. In contrast to insect or animal foraging models, the agents do not leave pheromone trails and do not use energy in the consumption process. We endowed the Consumption space with a proximity gradient for Products, so that moving toward or away from Products could be reduced to gradient ascent/decent. These choices are parsimonious because Consumer search in the space still resembles foraging, which was the intent. The main effect of this choice is that we need to control for density in the Consumption space so that it is neither too sparse nor too crowded.

3 HYPOTHESES

In this research, we test three hypotheses:

H1. Consumers that adapt their values through social and Product interaction will have higher aggregate consumption of the available Products, compared to Consumers who only form their values through Product interaction alone.

H2. Consumers that adapt their values through social and Product interaction will explore a much larger region in Value Space, compared to Consumers who only form their values through Product interaction alone.

H3. Consumers that adapt their values through social and Product interaction are more likely to form stable clusters in Value Space, compared to Consumers who only form their values through Product interaction alone.

The first hypothesis is important because it points to the overall importance of Consumer social interaction from the point of view of Designers. If there were no difference in aggregate consumption (i.e. consumption of any available product), then social interaction among Consumers would not have much economic significance to Designers.

The second hypothesis is important because it helps to elucidate the mechanism of collective adaptation, especially to Products that a given Consumer may not have encountered before. Exploring a larger region in the Value Space also means that Consumers with social interaction will be more receptive and responsive to products that are very different from the existing Products.

Finally, clustering behaviour by Consumers is very significant for Designers because stable clusters of value provide an opportunity for Designers to find a receptive market for Products that are far from the mainstream.

4 EXPERIMENT DESIGN AND METHODS

To evaluate the effect of social capabilities we ran a series of randomized paired simulations – social agents vs. non-social agents – and then analyzed the results using statistical methods to test hypotheses related to the differences in patterns of behaviour. This experimental method is well suited to the objective of identifying significant and theoretically important differences for the system under test, given the particular nature of the agent architecture and the design choices described above. Readers are cautioned about assuming that the results apply generally to any social network of situated cognitive agents. Context matters.

4.1 Initial conditions

The following initial conditions apply to all runs. The Consumption Space grid measured 165 X 165, and it was populated with 40 Consumers and 50 Products of 10 types with random uniform distribution. All Consumers started with identical initial conditions except for their location in Consumption Space. Their ideal product signature was set to be the average of all product types. To initialize the SOMs for perception and conception, Consumers were primed by exposing them to each of the product types, allowing all of the reasoning functions to be performed on each product, followed by a learning step in between each evaluation. The social network between Consumers was initialized as a fully connected small world network, randomly generated using the Watts-Strogatz method.

For Products, we generate 10 types with a random construction technique, and retained types that were at least a minimum distance in their signatures. This minimum distance allowed us to maintain sufficient product variety and distribution in Value Space. In contrast, when we generated products using random construction rules with no constraints, the resulting distribution in Value Space tended to be clustered in one to three regions. While this is not a difficultly in general, it did make agent cluster analysis difficult. By requiring minimum distances in Value Space for each product, we could ensure that the distribution of product types would allow Consumer clustering but not dictate it.

Each Product type was replicated five times to yield 50 Products. Even though Products are consumed during a run, the population of Products and types is static. This is accomplished by replacing the consumed Product in a new location at a random distance from its previous location, with Gaussian distribution.

Prior to running these experiments, we ran several tests over a range of parameters (number of Consumers, number of Products, size of Consumption Space, etc.). We found that the results described below were not sensitive to the number of Consumers or Products above 15 of each. However, the results were sensitive to the size of the to the density of Consumers and Products in Consumption Space. Therefore, we chose parameter ratios that maintained constant spatial density.

4.2 Experiment design

The experiment consisted of 30 paired runs (social vs. non-social) of 10,000 clock cycles each. Pairs in a run were given the same random number generator seed, which created identical initial conditions for the pair, and also statistical independence between runs. Agent behaviour and consumption results were tabulated over 20-clock-cycle periods. For each period, we collected data on consumption and changes in Consumer value. We did not analyze Consumer paths through Consumption Space or the dynamics of the social network.

Test statistics were generally mean value for population aggregates or mean value for individuals in the population for a given metric.

4.3 Statistical methods

To evaluate transients and trends in the time series, we performed linear regressions and examined the slope parameters. Histograms and Q-Q plots were used to evaluate sample distributions, particularly to identify modes and deviations from normality.

Hypothesis testing was done using the paired t-test when sample distributions appeared normal and signed rank test when sample distributions did not appear normal. In most cases we performed both tests.

To quantify the difficulty of the heuristic search problem, we used the fitness difficulty correlation (FDC) from Jones & Forrest (1995). This metric is defined as follows.

Given a set $U = \{u_1, u_2 ..., u_n\}$ of n individual utilities and a corresponding set $D = \{d_1, d_2, ..., d_n\}$ distances to the nearest local or global maximum, the correlation coefficient is:

$$r = \frac{c_{UD}}{s_U s_D} \tag{1}$$

where

$$c_{UD} = \frac{1}{n}\sum_{i=1}^{n}(f_i - \overline{f})(d_i - \overline{d}) \tag{2}$$

is the covariance of U and D, and $s_U, s_D, \overline{f}, \overline{d}$ are the standard deviations and means of U and D, respectively. The ideal landscape to search is one where utility is perfectly correlated to the inverse of distance, which is -1 (i.e. locally smooth landscapes). A very rough landscape has an FDC of zero.

5 RESULTS

5.1 Level of Difficulty

The statistic for the difficulty of the heuristic search problem in the 30 experimental runs, using the FDC metric described above, is

H4. FDC mean = -0.23
H5. FDC standard deviation = 0.08

Because FDC is closer to 0 than -1, the results show that the level of difficulty was relatively high and that it was similar in all runs. The distribution of difficulty values appears to be Normal.

5.2 Aggregate Consumption

We performed time series analysis of aggregate unit consumption for individual runs for both social and non-social agents. The steady state trend is essentially flat, which we confirmed with linear regression, and the distribution of values is approximately normal. In some runs there was a noticeable transient period of roughly 1,000 to 1,500 clock cycles. Since the experimental runs were 10,000, this transient did not affect the results described below.

Aggregate unit consumption was significantly higher for social agents than non-social agents. The smoothed kernel density estimate of the distribution over 30 runs is shown in Figure 2. Both the paired t-test and signed rank test reject the null hypothesis of no difference at the 0.1% significance level.

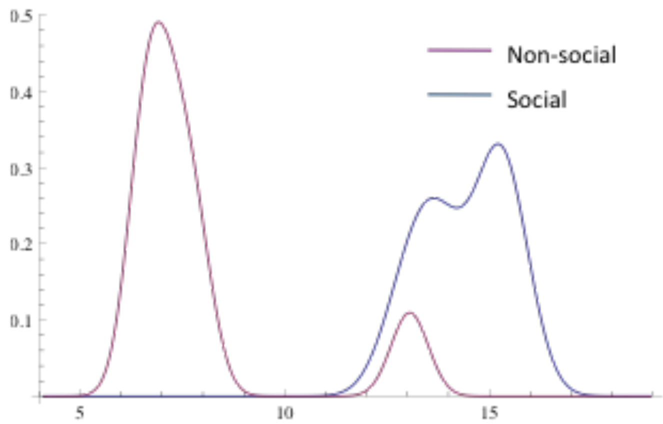


Figure 2 Aggregate unit consumption means

The same relationship holds for aggregate utility, also statistically significant at 0.1% level using the same tests. However, the higher level of aggregate utility for social agents was due to the higher rate of unit consumption. Average utility per unit consumed was lower for social agents compared to non-social agents.

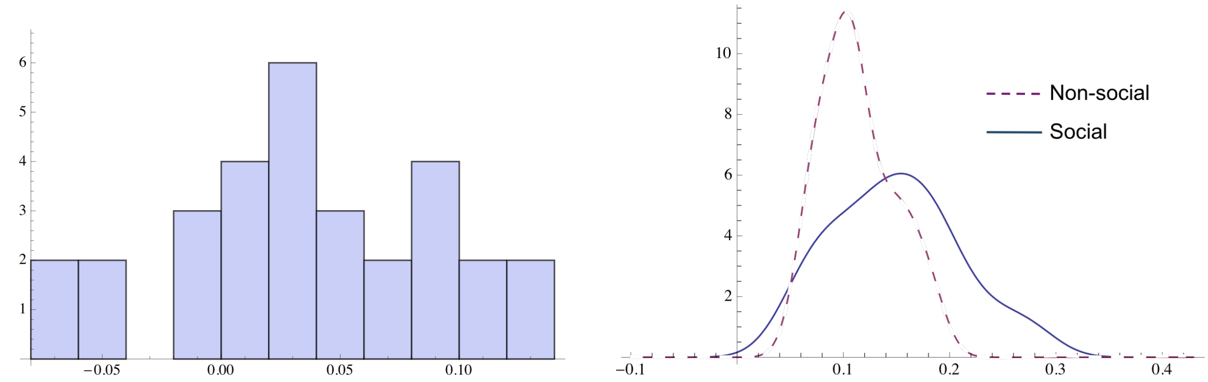
5.3 Behaviour in Value Space

Another class of time series data is the movement of Consumer ideal product signatures (i.e. their “values”) in Value Space. While all Consumers’ values start at the same location in Value Space, we did not observe any cases of single point convergence as a steady state, either to global or local maxima in the Value Space, or to any other point. We did observe temporary clustering at or near the location of Products in Value Space, but neither social nor non-social Consumers showed any tendency toward long-term stability in clustering.

There was a statistically significant difference in the Value Space area covered by individuals during a run. The paired differences between social and non-social Consumers, where the difference is between mean areas covered by individuals in the population is shown in Figure 3. Paired t-test and signed rank test both reject the null hypothesis that there is no difference in means at the 1% significance level.

However, the histogram of paired differences is tri-modal. Investigation of individual runs indicates that this distribution structure is informative and not just due to random variation. For an analysis of this and possible implications, see the Discussion section, below.

We also examined path length in Value Space for individual agents. The smoothed kernel density estimate of means of path lengths I shown in Figure 4. Social Consumers had longer paths in Value Space than non-social Consumers. Paired t-test and signed rank test both reject the null hypothesis that there is no difference at 0.1% significance level.



a. Paired differences of means *b. Means*

Figure 3. Spatial coverage area in Value Space, population means

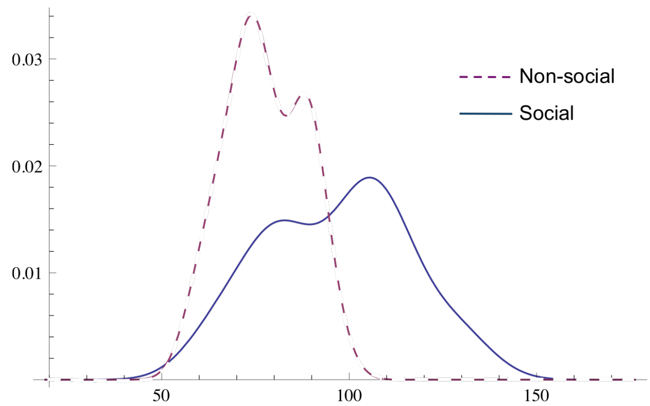


Figure 4. Value Space coverage area means

Combining these two results, the data shows that social Consumers adjust their values more than non-social Consumers and that they adjust them over a wider range of values.

6 DISCUSSION

The experiment results confirm that social interactions influence agent value systems in a way that changes their individual and collective performance in a frustrating task environment. The experiment results support two hypotheses – H1 and H2 – but not H3 (clustering). Higher aggregate consumption for social agents is a result of moving individual values (ideal product signatures) away from favourable positions in Value Space. The social influence 'lowered the standards' of individuals that then allowed them to make more frequent consumption choices. Thus, aggregate consumption in units and utility was increased at the expense of average utility for individual Consumers.

The lack of clustering and lack of selectivity in Product consumption choices was surprising. But this goes to show that emergent phenomena cannot be always anticipated based on micro-level specifications. This is one of the virtues of computational models of social phenomena, and of rich agent-based models in particular. Neither social nor non-social Consumers were able to collectively optimize or converge on local or global maxima in Value Space. This result is a consequence of the design choices regarding the difficulty of heuristic search and also limitations on agent capabilities.

Trendless steady-state aggregate consumption rates were achieved in both cases, with approximately normal distribution. Consistent with the design goals, Consumers did not reach any static equilibrium in terms of 1) values (i.e. their ideal product signature), 2) consumption pattern by Product type, or 3) social network structure. This indicates that in both cases the system was both stable and also far from equilibrium. This is important for the future research because we are interested in the emergence of equilibria or stable patterns that result from agent-agent interactions across agent types, and also agent-artefact interactions across different levels.

We believe the tri-modal histogram of Value Space coverage in Figure 3a merits further investigation. It appears that there are underlying relationships between the distribution of Products in Value Space and the behaviour of social Consumers, specifically related to the formation of stable subgroups that specialize. This is an important result because it shows the potential for interesting and informative emergent phenomena in this type of computational model.

In summary, the experiment results support the assertion that an social agents endowed with situated cognition to have meaningful influence over the values of other agents and demonstrate forms of collective behaviour. From the viewpoint of product designers, these experimental results demonstrate how consumer values can change endogenously through their social interactions. This is not just convergence to a consensus, though that may happen. It can also lead to divergence of values and greater exploration of the Value Space. While it may not be possible for designers to understand these emergent processes completely, it certainly is possible for designers to inquire into the cognitive and conceptual foundations of consumer values and to have some understanding of how their consumers interact socially. When these insights are combined with traditional product requirements analysis, designers will have much better ability to hit the ‘moving target’ of consumer demand in successive design cycles.

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