Gero JS and Brazier FMT (eds) (2002) *Agents in Design 2002*
Key Centre of Design Computing and Cognition, University of Sydney, pp. 165-180.

COMPUTATIONAL MODELS OF CREATIVE SITUATIONS

Towards multiagent modelling of creativity and innovation in design

RICARDO SOSA and JOHN S GERO
Key Centre of Design Computing and Cognition
University of Sydney Australia

Abstract. This paper presents a series of computational models based on the cellular automata voter model as applied to the study of social influence as a model of creative situations. Preliminary findings related to creativity and innovation in design and their possible implications in agent modelling are presented.

1. Introduction

In considering designers as change agents in society (Gero 1996) this paper presents a series of experiments derived from a cellular automata (CA) approach that aims to provide a better understanding of change agency in design and related social phenomena. In these experiments simulated agents interact with each other and with their environment following a set of simple principles that may represent certain aspects of designing. The resulting simulations provide at times rather unexpected outcomes that challenge some of the current beliefs and assumptions about creativity and innovation. The preliminary results presented suggest a series of issues that could contribute towards the modelling of agent-based creative design systems.

One of the chief characteristics that associates design activity to social change is the role of creativity in designing and the associated collective processes of innovation in our society, a relation between individual activity and social structures that is only partially understood (Rogers 1995). It has been suggested that the study of creativity should be approached from a systemic view that includes the individual as well as the environmental and social dimensions (Csikszentmihalyi 1997; Findlay and Lumsden 1988). The six models presented here focus on this link in phenomena related to:

a) social influence,

b) social and individual learning,
c) cultural drift,
d) abilities of influential individuals,
e) community formation, and
f) increasing abilities and prominence.

These models depart from a CA approach and further implement basic agency at the individual and the collective levels, the objective is to provide empirical support for the specification and development of multi-agent systems (MAS) of creative design.

2. Model of social influence

The model of social influence that lays the foundation for subsequent extensions is based on the well-researched CA voter model (Liggett 1999) as applied by Axelrod (1997) to address one of the simplest notions of social influence, namely, who we are affects whom we interact with, and whom we interact with shapes who we become. This is considered a mechanism of social interaction and culture formation (where *culture* is defined as a set of shared values reached by the interaction of individual members of a population) that deals with how individuals become more similar as they interact. This takes into account the fundamental principle of human communication that the transfer of ideas tends to occur most frequently between individuals who are similar in certain attributes such as beliefs, education, social status, and the like. The study of the designing of artefacts and their subsequent impact in society could benefit from findings of such simulation models if these artefacts are considered as a population of agents interacting within a shared environment.

This approach to the simulation of change phenomena could be valuable for agent-based modelling of designing because it enables experimentation with fundamental principles and conditions that may play a key role in designing and its impact in society, constructs not easily accessed through other research methods. The model describes a population of agents with individual cultures defined by a list of *features* each with a set of possible *traits*. Two individuals have compatible cultures if they share at least one trait of a common feature, and would share the same culture if they have the same traits for each feature. Individuals are distributed in a two dimensional grid with four adjacent neighbours each: east, west, north, and south sites. Although Axelrod (1997) presents a grid with boundaries where sites on the edge have three neighbours and sites in the corners only two, equivalent results are observed in a torus grid where sites on the edge interact with the

neighbouring site in the opposite edge of the grid. A system run is based on a sequence of events where a site and one of its neighbours are randomly selected. Both sites have a probability of interacting that is proportional to their similarity, i.e., two entirely different sites have probability 0 of interacting, whilst two identical sites have probability 1 of interacting. A process description is:

1. pick a site and one of its neighbours at random
2. pick a common feature at random, if they share the same trait then
3. pick a feature where both sites differ, if any
4. copy the trait from the neighbour into the site

More formally:

1. Let culture c at a site change as
2. select a random site s, a random neighbour of that site n, and a random feature f
3. let $G(s,n)$ be the set of features g such that $c(s,g) \neq c(n,g)$
4. if $c(s,f) = c(n,f)$ and G is not empty, then select a random feature g and set $c(s,g)$ to $c(n,g)$.

3. Results from Running the Model

The results presented by Axelrod (1997) are confirmed in our replication of this model of simple social convergence. In essence, at all times the population converges presenting *regions* or contiguous sites with identical values after around 80,000 iterations. At times the final configuration shows a single dominant region, whereas often two or more incompatible regions become stable since neighbouring sites have no common features and hence cannot interact. Figure 1 illustrates the convergence trend of a Monte Carlo run of 20 cases of 100 individuals with 5 features and 10 traits where culture variety is plotted over time.

In exploring the implications of this convergence structure, a feasible extension for the study of creative agents in design proposes that faced with routine and uniformity a few individuals would try to dissent by introducing a new value. Such models assist in studying how agents could introduce a social change and the change rate needed for a population of agents to be able to give rise to a culture. Presumably, different rates of innovation would not allow culture formation or would not cause sufficient impact on the population to contest group convergence. The social influence algorithm is complemented with the following procedure: given a global novelty probability any individual is able to generate a random trait in a random feature. One way of probing such probability is inspired by the ratio of designers to the rest of society. Consider the U.S. Census Bureau data of the Decennial Census 2000 where the Standard Occupational Classification shows that 0.177% of the population works

in the creative design professions (SOC codes 27-1021 to 27-1027). The model is thus set with a stochastic condition that enables the trigger of a random change equivalent to a 0.177% rate.

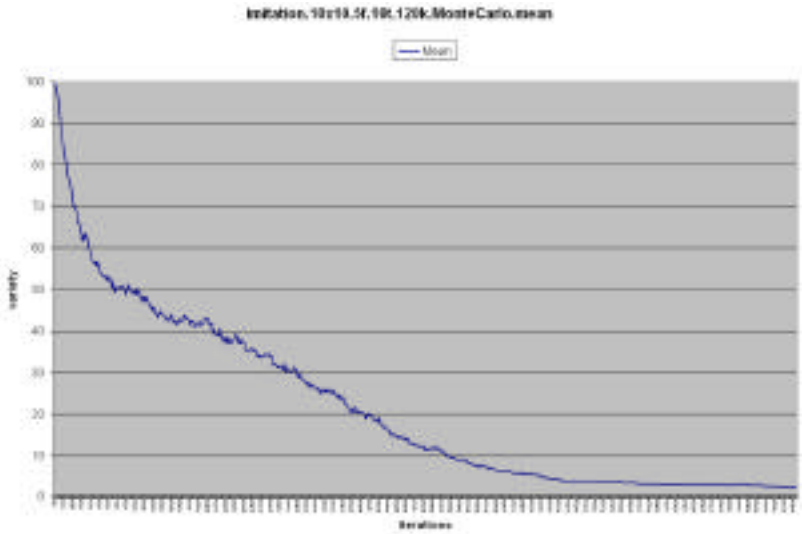
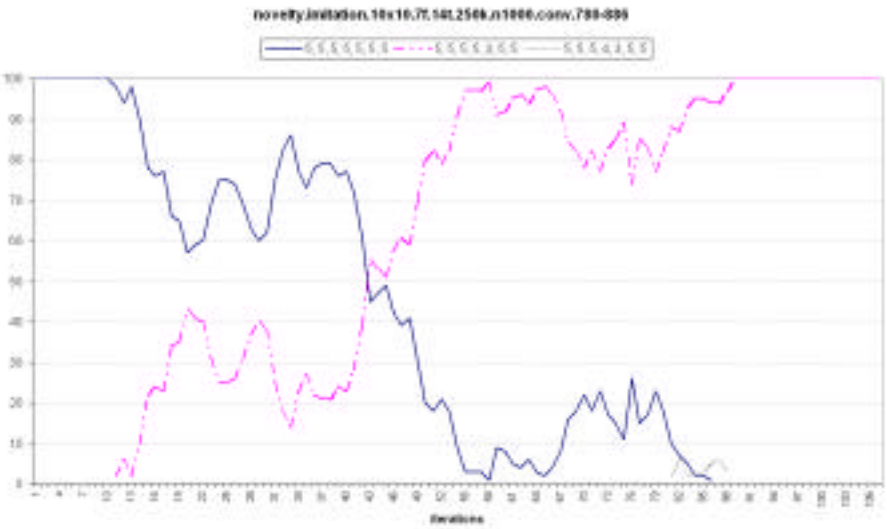


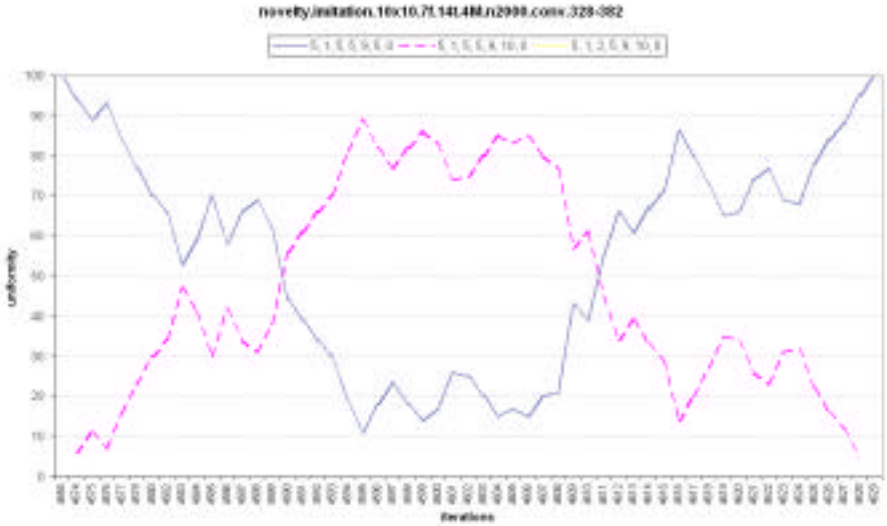
Figure 1. Monte Carlo run of imitation model 10 x 10 sites, 5 features and 10 traits, convergence trend from a group variety of 100 to a mean of 2 final cultures.

A typical run shows that such marginal innovation rate in fact generates culture formation and social change in a population of agents, which could be counter-intuitive since a probabilistic analysis of the social influence model suggests that large cultures would inevitably take over marginal compatible cultures. This is even offered as an explanation for the development of regions and the fact that often only one culture dominates (Axelrod 1997). The response to this contradiction represents a key insight for a situated approach to creativity (Gero and Sosa 2002) by suggesting that individual agency has an entirely different group impact according to the particular global structures at the time of the action.

Figure 2 shows a set of episodes where the dominant collective value faces the increasing spread of one or more alternative cultures, in some cases being replaced by the new culture and in others reverting to dominance. Figure 2(a) shows a nascent culture becoming dominant, while Figure 2(b) shows the dominant culture reasserting itself and becoming dominant. These examples show group structure as an emergent result of the sum of every interaction among individuals at particular time steps and indicate that a small perturbation has a potential major effect on the development of shared values.



(a)



(b)

Figure 2. Two episodes are shown where dominant and nascent cultures interact with different outcomes, (a) a nascent culture becomes dominant; (b) a dominant culture retakes control. Dashed line indicates nascent culture.

Within this model of global convergence, local divergent behaviour is observed in a kind of crossover process, whilst it is clear that change agency is *situated* since the effect of any individual local action is bounded by the ensuing global conditions. To better appreciate this

consider the cases where a control case, shown in Figure 3, is repeatedly run introducing the same individual action at four different time steps.

Figure 3. Control case where no individual novelty action is introduced, only imitation is possible. The vertical axis is a measure of variety of cultures over 120,000 steps.

Figure 4 shows the same setup but with novelty introduced at step 108,000. This results in a new culture developing between that step and step 120,000 bringing the total resulting dominant cultures to three. However, it cannot be assumed that this variety will continue since the simulation stops just after the introduction of novelty action and as the following simulations show the introduction of novelty actions further from the end of the simulation does not result in mire dominant cultures.

Similarly, Figure 5 shows the same original setup but with novelty introduced at step 90,480. This results in new cultures developing but these die out and by step 120,000 there are again only two dominant cultures.

Figure 6 shows the same original setup but with novelty introduced at step 61,200. This results in new cultures developing but these die out and by step 120,000 there are again only two dominant cultures.

We can notice that although the action is the same in all cases, the global impact largely depends on the overall dynamic social structure at the time of execution.

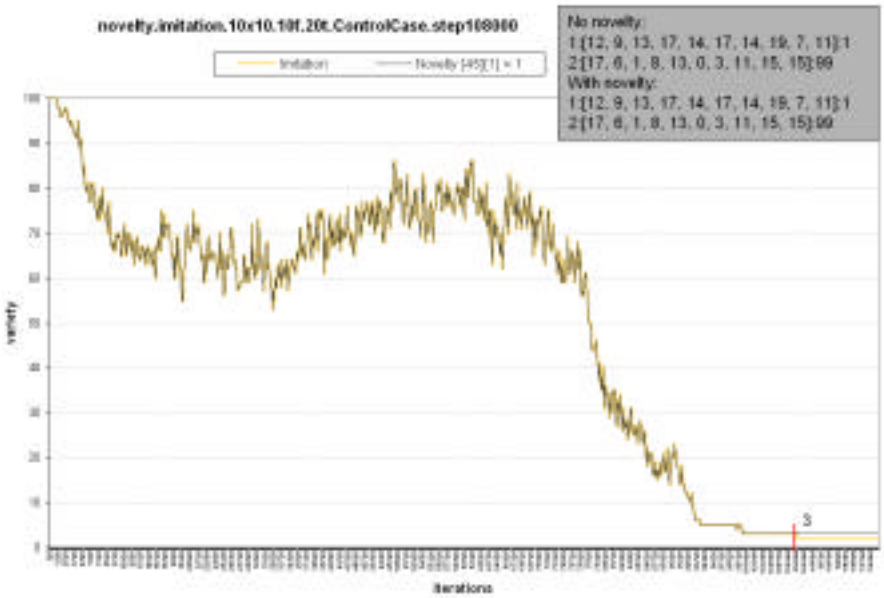


Figure 4. Case where novelty action is introduced at step 108,000. The vertical axis is a measure of variety of cultures over 120,000 steps.

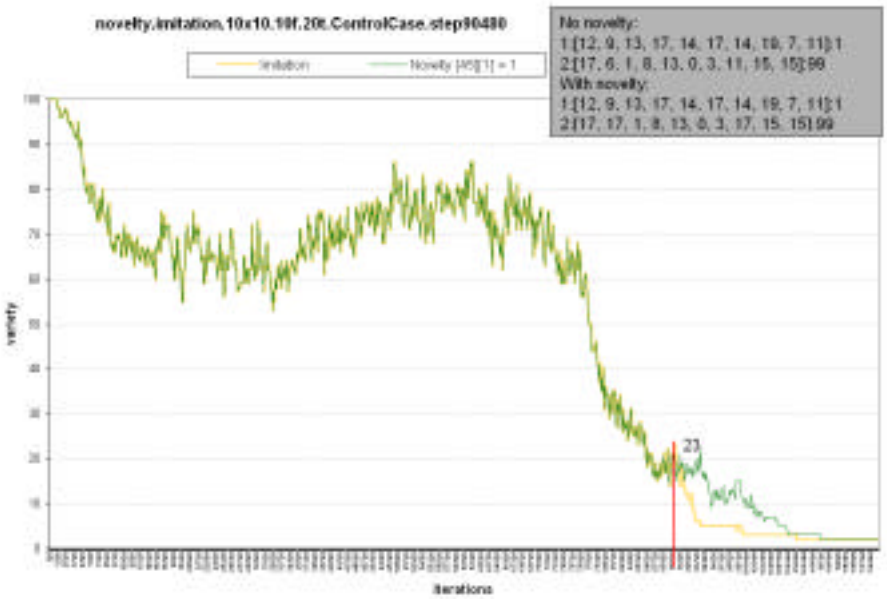


Figure 5. Case where novelty action is introduced at step 90,480. The vertical axis is a measure of variety of cultures over 120,000 steps.

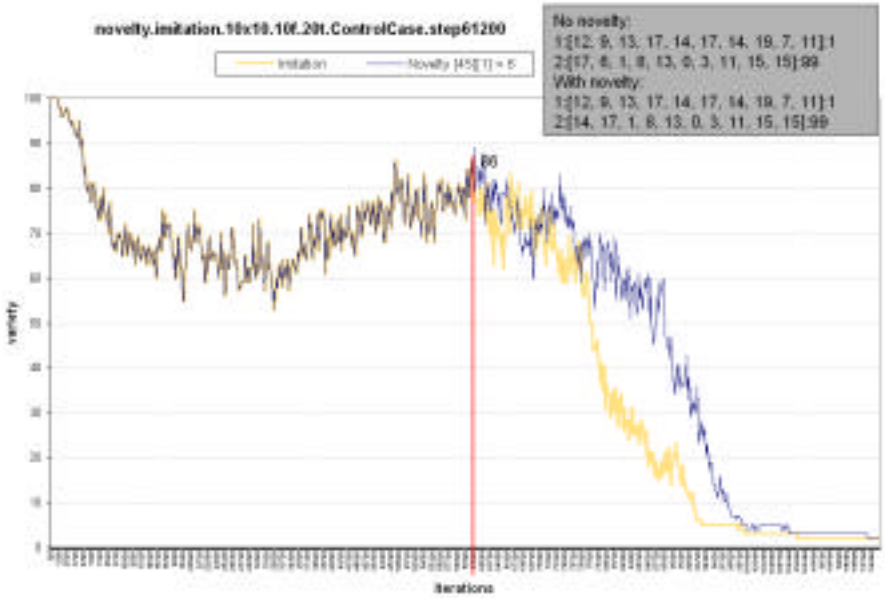


Figure 6. Case where novelty action is introduced at step 61,200. The vertical axis is a measure of variety of cultures over 120,000 steps.

Figure 7 further exemplifies this with a case where two different individual actions are executed at the same time step by the same individual producing the same global effect on the dominant culture. This unanticipated finding suggests that influencing society may be seen as a function not only of *what* action an agent executes but sometimes more importantly of *where* and *when*.

4. Individual and social learning

The model of social influence presented is extended to incorporate a notion of environment and a series of agency mechanisms of imitative and learning behaviour in order to further experiment within a situated approach to creative design. Preliminary findings of this model show that populations that produce shared values adapt more rapidly to their environment and their members are able to cope with changing environments in a noticeably better way than populations where individuals have to learn independently. By introducing a cycle of environmental change, it is observed that populations with imitative behaviour are able to adapt more rapidly to such changes. These are preliminary findings since further experiments show that high levels of imitative behaviour may hinder group adaptation as well.

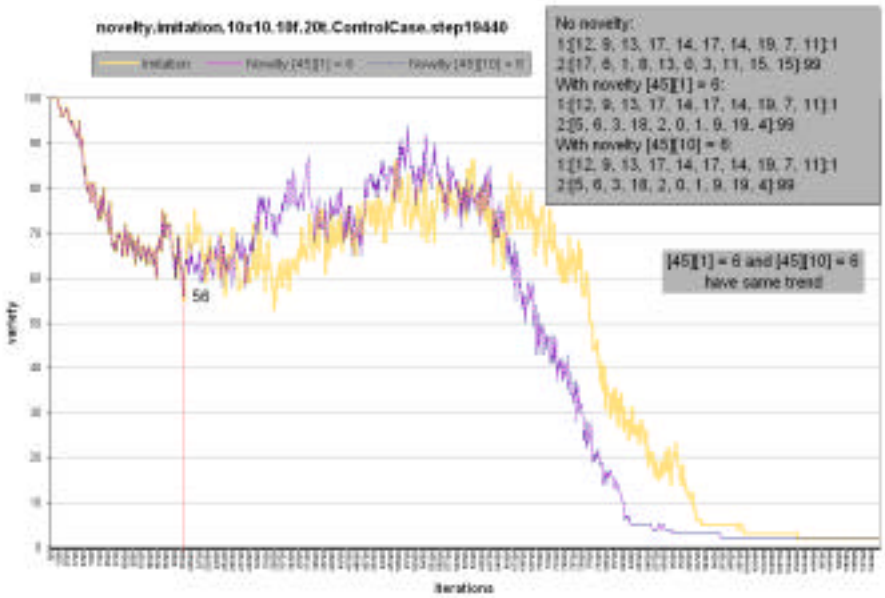


Figure 7. Two runs of a control case where two different individual actions are executed at the same time step causing the same final global structure.

When the cumulative number of adopters is plotted, the process of collective adaptation follows an S-shaped curve, confirming observations from studies of diffusion of innovations where the number of adopters per unit of time takes off once enough early adopters act as opinion leaders adopting a change and influencing others. The process tends to slow down again towards the end, as late adopters take longer to accept change (Rogers 1995).

Experiments with this model put forward the idea that a situation may not only determine the effect of an individual action but also, and more importantly, its content. Consider a population where individuals have the same ability to learn and imitate, i.e. a probability of 0.5 for each behaviour. In such a social situated model, the action of an individual at every time step is shaped by at least four components that interact with each other: the internal state of the individual, the state of adjacent neighbours, the environment state, and the interaction channels through which individuals interrelate. These four components combine at every time step shaping the situation that determines the actual action executed by an individual. This illustrates that two individuals with the same abilities may carry out different behaviours depending on their situation and in general, that social change phenomena of the kind involved in creative design need to be modelled from a situated viewpoint.

Current creativity research appears to disregard the fact that individual actions and their group impact are shaped conjointly by the characteristics of individuals and by the collective structures created through their interaction. Personality and problem solving ability tests associated with creative performance take no account of the notion that individual characteristics and their group impact are importantly shaped by external, situated factors. Under this view, the modelling of creative designing can be seen as a twofold activity of individual and social dimensions with creativity and innovation being the respective agency processes of interest. Paraphrasing the discussion of the previous model, in influencing society *where* and *when* an individual executes an action strongly determines *what* action that would be.

5. Cultural drift

The model of cultural drift extends the social learning model in order to include structural change cycles that are not externally imposed but triggered from endogenous processes of the system. Cultural drift is thus defined as the population's recurring self-organisation process of developing collective shared elements as it adapts to a changing environment, which is conversely changed as a result of the interaction of its individuals. Such adaptation and transformation mechanisms are two social aspects largely related to culture formation and may represent fundamental tenets of design activity. For instance, Eco (1965) defines culture as being "shaped as a continuous dialectic between innovative proposals and homologising adaptations", a definition pertinent to design activity.

Experiments show that the aggregation of individual adaptive and transformative behaviour facilitates effective cultural drift and group re-adaptation, a process repeatedly observed as a population of agents adapts to changing conditions of the environment. These re-adaptation cycles occur as a global effect of the sum of individual actions entirely based on local conditions. Individuals are enabled with agency mechanisms to transform their environment based only on local information and as a result activate a self-sustaining global mechanism that generates continuous cultural drift within the population. These adaptation cycles are more effective in this model when the probability of environmental change causes marginal transformation (change triggering in the order of 0.1% of individual actions). By effective is meant that a population of agents exhibits culture formation stages that often reach a vast majority of the agents before any agent is able to trigger a change in the environment and consequently start a new adaptation cycle. This is interesting when compared to the occupational

classification of the U.S. Decennial Census 2000 previously mentioned that shows that 0.177% of the population works in the creative design professions.

Varying the probability of environmental change it is observed that when individuals have less chances of transforming their environment there is more global stability with fewer changes occurring in a given period of time although these changes have greater impact in larger segments of the population. In contrast, when individuals have better access to transform their environment, the global behaviour is less stable and more changes are observed in a period of time and such changes have a lesser impact in the population reaching fewer individuals. Populations where individuals imitate less and thus rely less on shared elements present slower adaptation processes but respond more effectively to changes in the environment, whereas populations that heavily depend on collective values adapt faster but take longer to react to changes.

The results of a system run of this model cannot be fully explained by considering individual conditions only. Instead, in order to explain agent behaviour at any time step it is necessary to take into account external factors at that step that remain out of the individual's control such as: the state of its neighbours, the environment state, as well as the interaction channels among individuals and between these and the environment. The combination of such factors shapes the individuals' situations determining the corresponding action. This model of social change and adaptation reinforces the inadequacy of modelling creative or influential agents in a society and instead draws attention to *situations* within which each agent acts and can potentially play the role of change agent in its society.

6. Individual abilities

The objective of modelling individual abilities is to focus on the role of agent characteristics in determining environmental transformations and group impact. According to predominant studies of creativity, one would only need to measure individual abilities in order to assess creativity. However, not only *what* to measure and *how* to measure, in order to determine this ability, represents a major problem in the field, but it is argued that even if this were known, that would not be sufficient to define creativity since this is largely a social phenomenon and thus situated factors need to be considered.

The major finding of this simple model is unexpected in that there appears to be no direct correlation between an individual's ability to influence its society and its actual social impact. Non-linearity causes individuals with very high abilities to fail to produce collective change

whilst others with very low abilities have major impact on their social group. We argue that the difference is to be found not in individual characteristics alone but rather in their situation, defined as the result of their interaction with other individuals, and with their environment in a certain time step. What this finding represents appears counter-intuitive and to challenge some of the dominant views of creativity research.

Individual abilities appear to be only part of the equation in becoming a change agent in society but they are not fully responsible and often not the most important factor. In order to model creative design, a situated view is necessary where agents cannot be defined as creative a priori and then released into a social group but need to be embedded in a socio-environmental system shaped through their interaction. Modelling creative agency thus seems to involve individual and social dimensions jointly shaping situations that define the potential creativeness of agents within the particular conditions of the system at a time step.

7. Community formation

The model of individual abilities is extended to allow for a richer environment that supports the formation of more than one valid interpretation, and thus more than one valid culture can form and co-exist within a population. This accounts for the observation that some disciplines (i.e., design) are multi-paradigmatic, i.e. alternative paradigms and cultures support different communities (defined as groups of population members with shared values) within a population (Kuhn 1974).

The first observable consequence of this model is that whilst previously any individual could become influential, now a further situated factor is in play. Those individuals that are located at the border between two incompatible cultures cannot be influential independently of their abilities since they fail to comply with the first condition for transforming the environment, i.e. that the individual and its four adjacent neighbours present the same culture. In this model, only those individuals that are found in key positions (i.e., surrounded by alike neighbours) at the time when the population reaches consensus, are potentially influential. And because border formation is an emergent phenomenon collectively determined, this model further illustrates the key non-linear role of situated factors in determining individual characteristics and their ultimate impact in a social group. Effectively, in addition to the difference between individual abilities (which was shown to be only a partial determinant of group impact in the previous model), by modifying an environmental factor it is seen that individual activity and social structures are importantly affected. In a phenomenon like

creativity where individual and group behaviour are assumed to closely interact, it is seen how inadequate it appears to consider individual action dissociated from its situation. This variant shows how a change in an environmental factor affects the emergent definition of influential individuals and their group impact.

The second major role of this model is subtler and requires further tuning. Consider that the first feature of the environment is not only ambiguous but also remains unchangeable by individuals. That is, at any time step influential individuals are able to transform the environment in only the last four of its five features. The outcome is very interesting and can be called the 'change without a change' phenomenon or *stagnation of communities* where a community is defined as a subgroup of the population that presents a common culture or set of shared values. This phenomenon occurs in a population where individuals keep changing whilst adapting and transforming their environment but this happens within an unvarying social structure where borders repeatedly form identical communities with a constant group configuration but with evolving environmental and individual features. Figure 8 shows a run of a control case where a recurring border configuration is observed. Note that this social structure of community formation is not programmed but is an emergent feature of the interaction among individuals and between these and an ambiguous partially inaccessible environment.

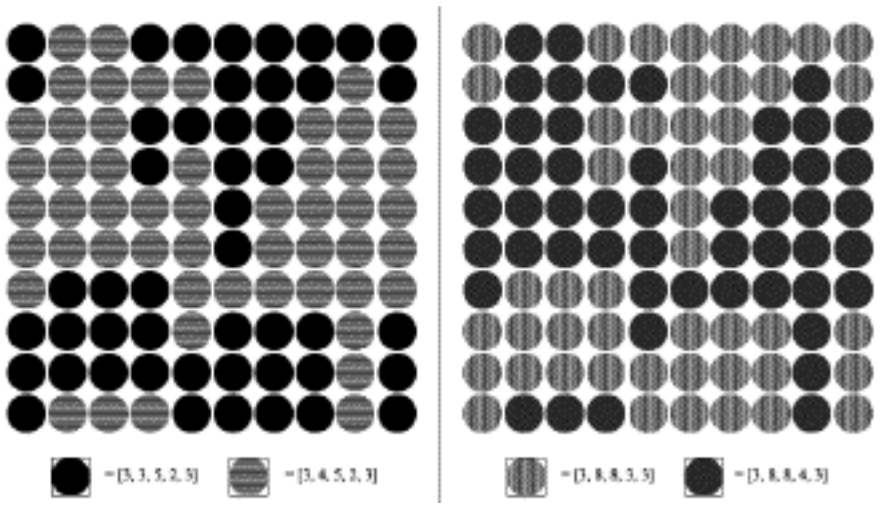


Figure 8. Run of control case where a population self-organises into two cultures that reappear after every cycle of adaptation.

8. Increasing abilities

Sociality and individual intelligent behaviour are regarded as essential to each other and often considered to co-evolve (Edmonds and Dautenhahn 1999). Likewise, creativity and innovation may be seen as a indivisible processes that take place jointly at the individual and social levels respectively. This approach is to some extent present in the study of diffusion of innovations but in design studies investigation into the relation of novelty and utility co-evolution at the individual and social levels is scarce. To experiment with these joint change processes is key to modelling creative design.

In this model agents build up from their change behaviour whilst their societies self-define prominent influential individuals. Assuming that when an individual triggers an environmental change its ability to repeat the action in the future is likely to increase, the main objective of this model of increasing abilities is to assess the social structures that arise from such individual behaviour as well as the evolution of agent characteristics during a period of time.

The foremost finding relates to the social self-definition of influential individuals. Unexpectedly, over long time periods the standard deviation of the population's ability starts to decrease after having increased from the initial step. To understand this consider that initially all individuals have identical probabilities of transforming their environment, however social, temporal, and environmental (i.e., situated) conditions determine a small group of individuals that become favoured significantly improving their abilities and thus dominating the changes of their social group and concentrating prominence. Notice that as members of such elite group reach the maximum ability (for instance triggering a change every time they try), their prominence increases abruptly. At the same time, as this selected group controls the change processes of its society, their abilities tend to converge. What this finding suggests is that:

a) a social group where agents influence each other tends to favour an elite group of change agents and
b) b) such a definition process cannot be understood in individual terms only but needs to acknowledge situated factors such as social and environment interaction. Equivalent results are observed in populations with initial random distribution of abilities. It is significant that in both scenarios an elite group of around 10% of the population is repeatedly observed to gain high ability levels and that the influence of such minority is disproportionate to the rest of their society.

When a system makes available a higher individual ability limit, fewer individuals become influential and higher inequality arises in a population.

Under such conditions a few individuals rapidly tend to reach the highest possible ability and thus take control over most environmental changes causing the majority of the population to remain without access to the transformation process.

Lastly, prominence is used as a measure of social influence. In this model it is defined by the number of times that an individual transforms an environmental feature thus causing the rest of the population to resume adaptation to the new conditions. Studies of creativity and innovation tend to individualise such change processes and to designate exceptional persons. Findings of this model could suggest that the real difference between such individuals and 'the rest of us' need not be as vast as we have been made to believe since small individual differences of abilities coupled with favourable situated factors can effectively give rise to substantial differences of prominence over time. As shown, even in a population of initially identical able agents, social structures favour certain individuals that may be within influential situations from which they gain control of the change processes. A natural step for future work is situation awareness, a process by which an agent is expected to identify elements of its situation that it tries to change with the aim of improving the creativeness of its situation.

9. Implications for agent-based models of creative design

This paper has emphasised that in studying change processes in society not only individual factors of the members of a population should be considered but possibly more importantly, the non-linear effects of their situated conditions in an environment, a society, and time. Failure to account for such situated factors could lead agent-based modelling of creative design to the belief that predominates in much creativity research in human designers, i.e., that creativity can be studied and measured only in terms of individual dimensions such as personality or problem solving skills. The findings of these models point towards creative agents in design that are not defined a priori but that necessarily co-evolve with their social group and environmental settings, self-defined by their society through a grounded process.

Acknowledgements

This research is supported by an International Postgraduate Research Scholarship and a University of Sydney Postgraduate Award. Computer support is provided by the Key Centre of Design Computing and Cognition.

References

Axelrod, R: 1997, *The Complexity of Cooperation, Agent-based Models of Competition and Collaboration*, Princeton University Press, New York.

Csikszentmihalyi, M: 1997, *Creativity, Flow and the Psychology of Discovery and Invention*, HarperCollins, New York.

Eco, U: 1965, *Apocalipticos e Integrados*, Lumen, Barcelona.

Edmonds, B and Dautenhahn, K: 1998, The contribution of society to the construction of individual intelligence, *in* Edmonds, B. and Dautenhahn, K. (eds), *Socially Situated Intelligence SAB'98*, University of Zürich, Zürich, pp. 42-60.

Findlay, CS and Lumsden, CJ: 1988, *The Creative Mind*, Academic Press, Orlando.

Gero, JS: 1996, Creativity, emergence and evolution in design: concepts and framework, *Knowledge-Based Systems* **9**(7): 435 -448.

Gero, J S and Sosa, R: 2002, Creative design situations, *in* Eshaq, A, Khong, C, Neo, K, Neo, M and Ahmad, S (eds), *CAADRIA 2002,* Prentice Hall, New York, pp. 191-198

Kuhn, T: 1974, Second thoughts on paradigms, *in* Suppe, F. (ed), *The Structure of Scientific Theories*, University of Chicago Press, Chicago, pp. 459 –482.

Liggett, TM: 1999, *Stochastic Interacting Systems: Contact, Voter, and Exclusion Processes*, Springer-Verlag, Berlin.

Rogers, EM: 1995, *Diffusion of Innovations*, The Free Press, New York.