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Mass Media and Polarisation Processes in the Bounded Confidence Model of Opinion Dynamics

Journal of Artificial Societies and Social Simulation vol. 9, no. 1
<http://jasss.soc.surrey.ac.uk/9/1/11.html>

For information about citing this article, click here

Received: 17-Jun-2005 Accepted: 27-Oct-2005 Published: 31-Jan-2006

Abstract

This paper presents a social simulation in which we add an additional layer of mass media communication to the social network 'bounded confidence' model of Deffuant et al (2000). A population of agents on a lattice with continuous opinions and bounded confidence adjust their opinions on the basis of binary social network interactions between neighbours or communication with a fixed opinion. There are two mechanisms for interaction. 'Social interaction' occurs between neighbours on a lattice and 'mass communication' adjusts opinions based on an agent interacting with a fixed opinion. Two new variables are added, polarisation: the degree to which two mass media opinions differ, and broadcast ratio: the number of social interactions for each mass media communication. Four dynamical regimes are observed, fragmented, double extreme convergence, a state of persistent opinion exchange leading to single extreme convergence and a disordered state. Double extreme convergence is found where agents are less willing to change opinion and mass media communications are common or where there is moderate willingness to change opinion and a high frequency of mass media communications. Single extreme convergence is found where there is moderate willingness to change opinion and a lower frequency of mass media communication. A period of persistent opinion exchange precedes single extreme convergence, it is characterized by the formation of two opposing groups of opinion separated by a gradient of opinion exchange. With even very low frequencies of mass media communications this results in a move to central opinions followed by a global drift to one extreme as one of the opposing groups of opinion dominates. A similar pattern of findings is observed for Neumann and Moore neighbourhoods.

Keywords:
Opinion Dynamics, Mass Media, Polarisation, Extremists, Consensus

Introduction

1.1

The model of opinion dynamics presented in this paper is an extension of the model presented by Deffuant, Neau, Amblard and Weisbuch (2000). Their model of opinion dynamics utilized a grid of agents interacting with each other and adjusting their opinion on the basis of these interactions. The model in this paper similarly uses a continuous real variable (from 0 to 1 or -1 to 1) to describe the agents opinions rather than the alternative binary (Snzajd-Weron 2003; Galam 1997; Galam 2000; Holyst 2000; Kacperski 2000), or multi-valued integer model of opinions (Hegselmann 2002). Like Deffuant, Amblard, Weisbuch and Faure (2002) and Deffuant, Amblard, Weisbuch (2004) we view the gradation of opinion as important so that the progressive drift of opinions may be monitored. The model is based on a simple lattice/grid and agents possess bounded confidence in that an agent only enters into an opinion exchange with a neighbouring agent if the neighbouring agent's opinion is within a certain confidence threshold from the original agent (Deffuant et al. 2000; Dittmer 2001; Hegselmann 2002).

1.2

The Deffuant et al. (2000) basic model later called the bounded confidence model consists of a pair of agents interacting at any given time step, an interaction involves a comparison of the agents opinions and if they are sufficiently similar then the opinions change to become closer to a central position by some weighted factor. If the opinions are too different no exchange of opinion occurs and the opinions remain at the same level.

1.3

Deffuant et al. (2000) explore three variations on their model. In the basic model pairs of agents are randomly chosen at each time step and engage in an opinion exchange. A social network model attempts to simulate the conditions of social interaction in which communication only takes place between agents with a pre-existing social relationship defined by communication with neighbours on a lattice. Their final model examined vectors of opinions and adopted a binary approach this model is not of interest in the current paper.

1.4

There are two important parameters in the Deffuant et al. (2000) model. First, the magnitude of a threshold d the difference between the opinions of two agents, below which opinions would be re-adjusted, above which no change in opinion would occur. Second, the convergence parameter (μ) which determines the degree to which the two opinions would converge if opinions were to be re-adjusted.

1.5

They found that with the basic model convergence of opinion occurred but this opinion was only uniform with larger values of d. They determined that the threshold d was the most important determinant of the qualitative dynamics of the model. The convergence (μ) and size of population N only influenced the convergence time and the width of the distribution of final opinions. With smaller values of d the number of peaks of final opinions increases.

1.6

The social network model added a further level of realism in which agents no longer interacted randomly across populations (full mixing) but interacted along the basis of pre-existing social relations. The social network connects an agent with its four immediate neighbours on the lattice (a Neumann neighbourhood as opposed to a Moore neighbourhood of eight neighbours). At each time step a pair of connected agents is randomly selected from the grid, and the same opinion adjusting procedure is applied.

1.7

The results showed a similar pattern of behaviour for larger values of d ($d > 0.3$) in which uniform distributions of opinion are observed with the exception of isolated extremists. When the value of d is smaller ($d < 0.3$) the findings are more interesting as several values are available to form clusters of opinions. In a Neumann neighbourhood (connectivity 4) only one cluster of opinion can percolate across the lattice which contains smaller non-connected clusters of homogenous opinion.

1.8

Stauffer (2005) describes three outcomes in the Deffuant model and similar models (Hegselmann 2002; Sznajd-Weron 2000), given sufficient time these models all show one of three types of result, consensus, polarisation or fragmentation. The model presented in this paper adds a mass communication component to the social network bounded confidence model of Deffuant et al. (2000). In the following section, section 2, we present the mass communication model and the new parameters that are involved in adding a mass communication component to the model. Section 3 reports some simulations in detail at certain parameters in the model. Section 4 explores the parameter space and some broader parameters of the model.

The Mass Communication Model

2.1

The goal of the model presented in this paper is to integrate some elements of mass communication into the social network model presented by Deffuant et al. (2000). The social network model accepts only one mode of opinion exchange in which opinions only travel through neighbour to neighbour communication in a word of mouth style process. This creates a model that would be good at modeling early human societies or some modern but isolated societies. However since the invention of the Gutenberg press it has become possible to convey opinion in a more efficient and one sided manner. The model in this paper while still very limited and idealized acknowledges that there is more than one mechanism by which opinions are transmitted in society. Other studies have adopted approaches that try to simulate the processes of mass communication in a binary model. For example, Schulze (2003) suggests that the influence of advertising can be simulated in a binary model by a probability to change opinion irrespective of the normal convincing process. Use of a binary model however does not allow the analysis of opinion drift under the influence of mass communication.

2.2

The model presented here (the code, written using the Swarm library, is here) attempts to include the effect of mass communication in the form of newspaper and broadcast media on top of a pre-existing social network. We make the assumption that the process of adjustment of opinion in a mass communication is not dissimilar to that in a social network, but the delivery mechanism of the communication is what differs. The model presents two mechanisms for delivery of communication. The first is the social network method of communication which is the same as that presented by Deffuant et al (2000). The second is the mass media type of communication, which is delivered from a particular opinion to an agent selected from the lattice. So the current model is very similar to the Deffuant et al (2000) models except that it has an additional mechanism of communication, the opinion adjustment process itself is identical in each of the two mechanisms, and is the same as that used in Deffuant et al. (2000). If two agents have the opinions x and x' and $|x- x'| < d$, then the opinions are adjusted according to:

$$\begin{aligned} x &= x + \mu \cdot (x' - x) \\ x' &= x' + \mu \cdot (x - x') \end{aligned} \qquad (1)$$

where μ is the convergence parameter (Deffuant et al., 2000). Like the original model all initial opinions are randomly generated across a uniform distribution between 0 and 1 (or later -1 and 1).

2.3

The mass media mechanism uses either one or two poles of opinion from which an opinion is delivered. These poles of opinion represent the opinions used in the mass media communications, normally there are two poles of opinion which in the case of a fully polarised extreme mass media would be placed at 0 and 1, representing each extreme of opinion, as polarisation becomes less extreme the poles of opinion move closer to the central opinion and remain equidistant with a mean opinion of 0.5. There can be one pole in the special instance in which both poles combine to form a central mass media opinion at 0.5. In a mass media communication an agent is chosen from the lattice and exchanges opinion with one of the two poles using exactly the same mechanism as the social network communication, that is, if their opinions differ by more than the threshold no change in opinion occurs however if their opinions are within the threshold their opinions are adjusted by an amount dependent on the convergence parameter.

2.4

This model adds two important variables to the Deffuant et al. (2000) model, a polarisation variable and a ratio of social network communications to mass media communications termed the broadcast ratio. The polarisation variable ranges from 0 to 1. At 0 both poles of opinion occupy the central opinion of 0.5 so there is effectively one pole, if the polarisation variable is 1 then the two poles of opinion are diametrically opposed at 0 and 1. The broadcast ratio defines how many social network communications there are for each mass media or broadcast communication.

2.5

The model has some similarities to the Deffuant et al. (2002) Relative Agreement model and other later versions of the model (Amblard and Deffuant 2004; Weisbuch, Deffuant and Amblard 2005). When there are two mass media poles with extreme values (polarisation = 1) the poles have a similar role to extremists with low levels of uncertainty. The relative agreement model involves full mixing in the communications of its agents whereas in the current model the poles of opinion act globally in the same manner as the extremists in the relative agreement model and the social network acts locally; it is the dual mechanism approach that distinguishes this model. The later models involve similar types of social network however the action of extremists is embedded within the network and therefore is also very different from the mass media communications in this model which exhibit a random influence spread globally across the agents. The relative agreement model also seeks to make a more realistic continuity of opinion change in which there is a more gradual shift in opinion rather than the sharp drop off that reliance on a strict threshold brings. The current model stays with the less desirable steep drop off in the influence of an opinion once the threshold has been crossed. However, Weisbuch et al. (2005) note that the main dynamical features are conserved between the sharp drop off in the bounded confidence model and those models with smoother interaction functions.

2.6

The model accesses every agent in each iteration and each agent is given a broadcast ratio defined opportunity to be chosen for a mass media exchange. If they are chosen for a mass media exchange then an exchange of opinions occurs between the agent and one of the two poles which is chosen at random. If there is no mass media exchange then the agent engages in a social network exchange in which one of their four neighbours is chosen at random and an exchange takes place.

2.7

Any pole of opinion may be thought of as an attractor limited in its reach by the threshold parameter, that is, it can only communicate directly and influence the opinion of those agents that fall within its threshold, those outside its threshold will ignore it. However it may exert an indirect influence over these agents if they happen to communicate with a neighbour that was influenced on the previous timestep by the mass media opinion, so at time t the pole can only directly influence those that fall within its threshold however at time t+1 local social interactions of opinion are influenced by its effects.

Simulations

Mass media with no Polarisation

3.1

The first simulations conducted looked at the most basic form of mass media communication that with no polarisation (p = 0). In other words all the exchanges between a mass media communication and an agent come from a central opinion. This scenario is the same as the social network models of Deffuant et al. (2000) with the addition of the mass media communication acting as an attractor from a central point. Figure 1 shows the case where the threshold (*d*) is greater than 0.5 and therefore agents from all possible starting opinions can be influenced by the mass media communication and the result is a rapid shift towards a consensus at the central opinion.

3.2

The following figures are graphs of opinion change. For each iteration of the model each agent gets a chance to communicate but may not if their opinion differs by too much from their neighbour's opinion or the mass communication opinion. The figures are a sample of the opinions of 100 agents drawn from a model with 2500 interacting agents. The time frame is

1000 iterations, so each graph displays 100,000 exchanges sampled from 2,500,000 exchanges. Other common parameters are a convergence of 0.3, and a broadcast ratio of 1:5, that is, 1 mass media communication for every five social network communications.

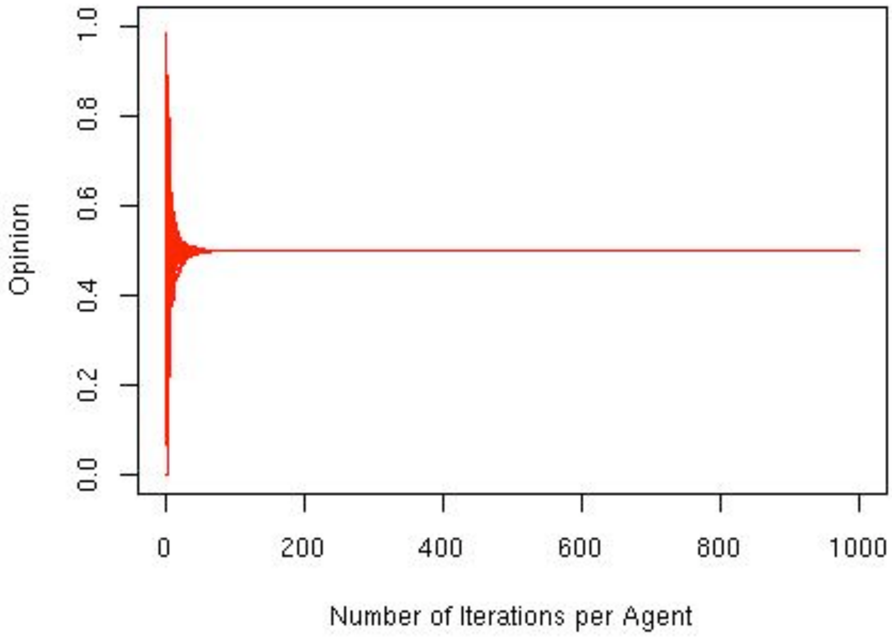

Figure 1. Convergence to a Central Opinion. p = 0, d = 0.5, μ = 0.3, n = 100, N = 2500

3.3

The situation differs when the threshold is less than 0.5 and the agents that start out with extreme opinions are beyond the influence of the central mass media opinion. Figure 2 shows the same parameters as Figure 1 except with a threshold of 0.25. In this situation those agents with an initial starting opinion that is sufficiently similar to the central mass media opinion are once again rapidly drawn to a central consensus however there is room for alternative opinions at the extremes of opinion. Those agents that fall outside the central mass media attractor quickly settle down to a number of more extreme positions in which they are isolated from other extreme groups by the main core consensus and there is therefore no possibility of further exchange of opinion and the model settles on a steady pattern.

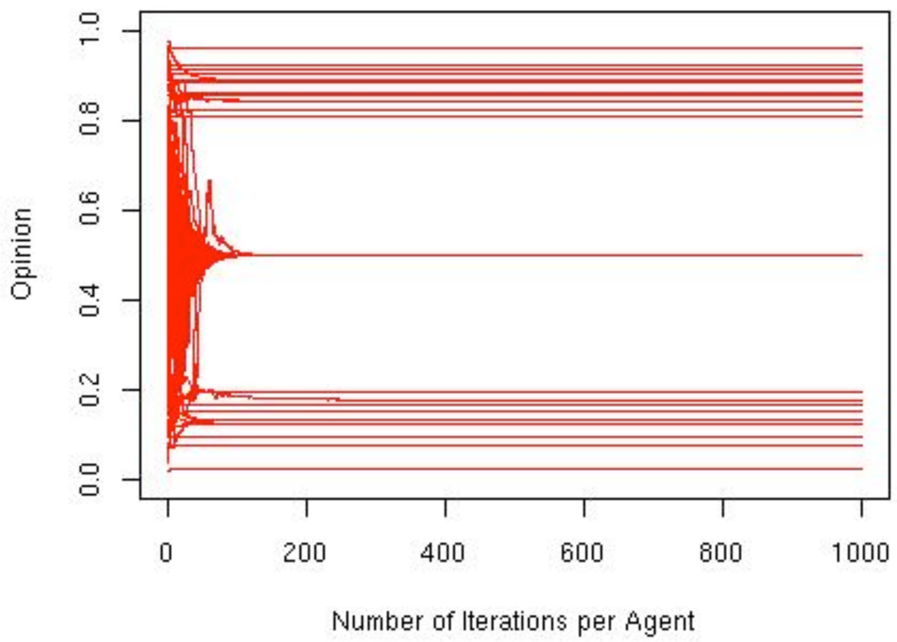

Figure 2. Central Convergence with Isolated Extremes. p = 0, d = 0.25, μ = 0.3, n = 100, N = 2500

3.4

At threshold below 0.15 there is very little movement from the initial opinions and therefore this results in a fragmented distribution of opinions.

Mass media with Full Polarisation

3.5

The situation is quite different when we move to full polarisation of the mass media (polarisation = 1). In this state four separate dynamical regimes are observable in the model. Starting with a high level of threshold in which opinion exchange is very likely, a state of constant change is observed around a central core of opinion and there is very little activity at the extremes of opinion. Figure 3 shows opinions of 100 agents with the threshold at 0.7.

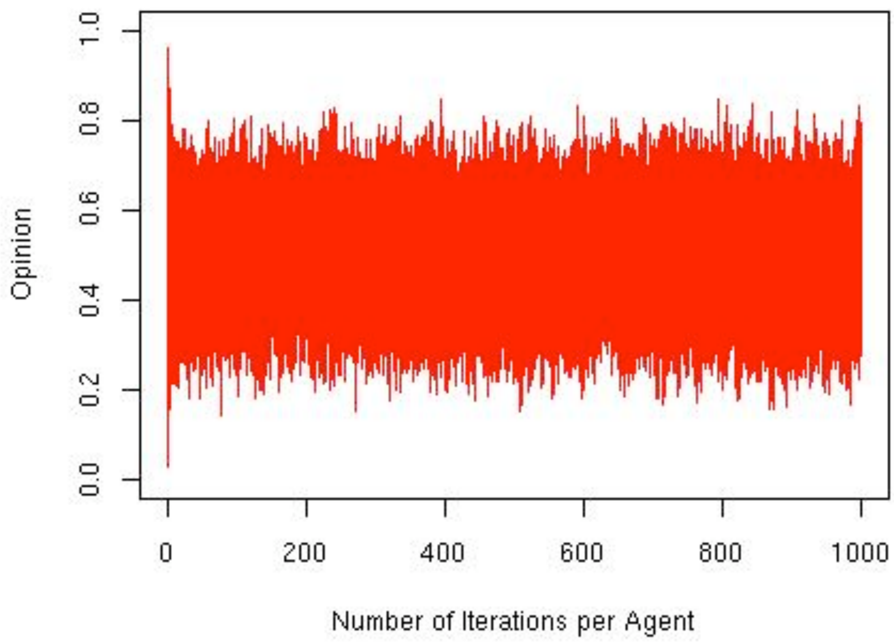

Figure 3. Opinion in a state of constant change around a Central Opinion. p = 1, d = 0.7, μ = 0.3, n = 100, N = 2500

3.6

This regime is characterised by a state of constant change of opinion in which the threshold is large enough to allow an exchange of opinion between an agent at one extreme and those closer to the opposite pole of attraction. The mass media communications still act as attractors of opinion and agents with opinions that are far from an extreme pole will converge towards it. These attractions are balanced by the consensus forming actions of a social network in which the willingness to talk to agents with other opinions is high and therefore interactions occur between neighbours of disparate opinions. This results in a disordered regime in which opinions are in a constant state of change around a central opinion. The movements of opinion are driven by the opposing forces of polarisation and social network consensus formation in which the social network has the stronger attraction forces with a broadcast ratio of 1 mass media communication to every 5 social network communications.

3.7

The next dynamical regime occurs between thresholds of about $0.2 < d < 0.42$ when the broadcast ratio is 1:5. In this regime the agents interact and quickly form into two stable groups of opinion resulting in a double extreme convergence similar to those in Deffuant et al. (2004). Figure 4 displays opinions of 100 agents that settle into two groups or double extreme convergence.

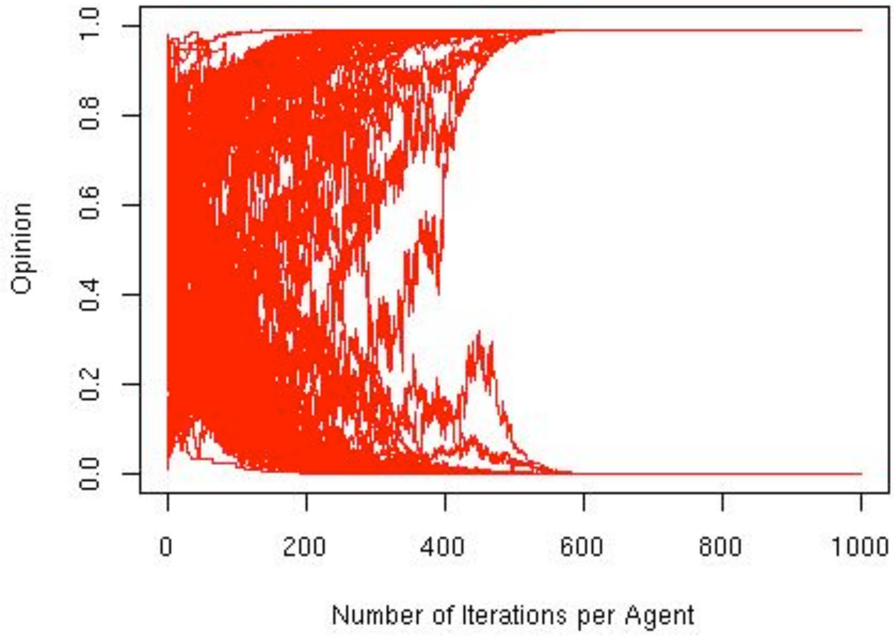

Figure 4. Opinion settles in two extreme groups. *p* = 1, *d* = 0.4, μ = 0.3, *n* = 100, N = 2500

3.8
The third dynamical regime occurs between threshold of about $0.42 < d < 0.63$. In this regime local initial differences result in the formation of groups taking one opinion or the other which coalesce and the borders between are comprised of a gradient of opinion exchange. The gradients persist until one group of opinion gives way to the other group and all agents have an opinion at one extreme or the other, a state of single extreme convergence. These gradients of opinion exchange can exist for a considerable number of iterations and have been observed to be stable after an average of greater than 50000 iterations per agent. Figure 5 displays the opinions of 100 agents that settle at one extreme, single extreme convergence, after a relatively short period of opinion exchange.

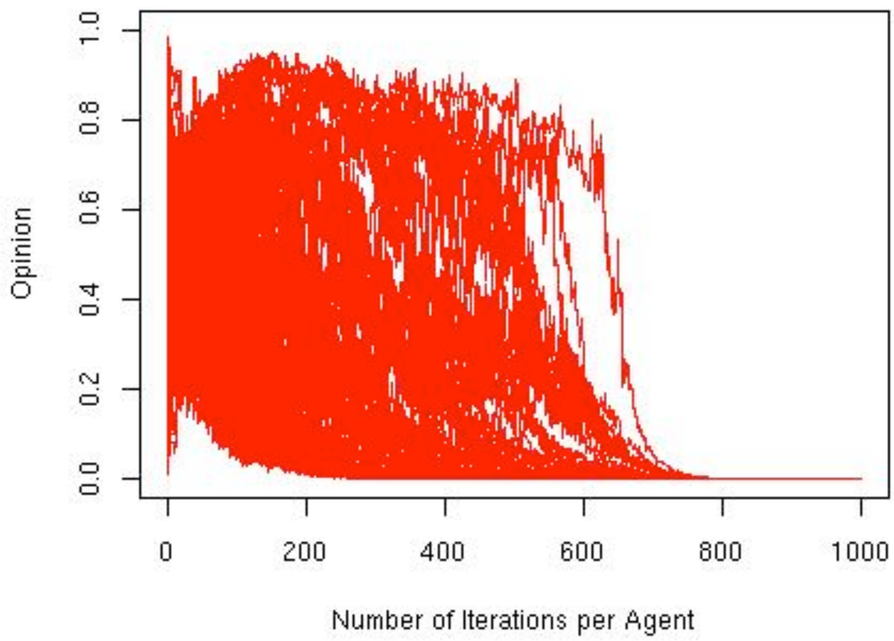

Figure 5. Opinion settles at one extreme after a period of persistent opinion exchange. *p* = 1,

d = 0.5, μ = 0.3, n = 100, N = 2500

3.9

Figure 6 displays a sequence of screenshots of the model with a polarisation of 1 and a threshold of 0.5. There are two clear groups of opinion and gradients of opinion exchange separating them with a number of isolated extremists. The red opinion is slowly dominating, and will eventually lead to single extreme convergence at the red pole of opinion.

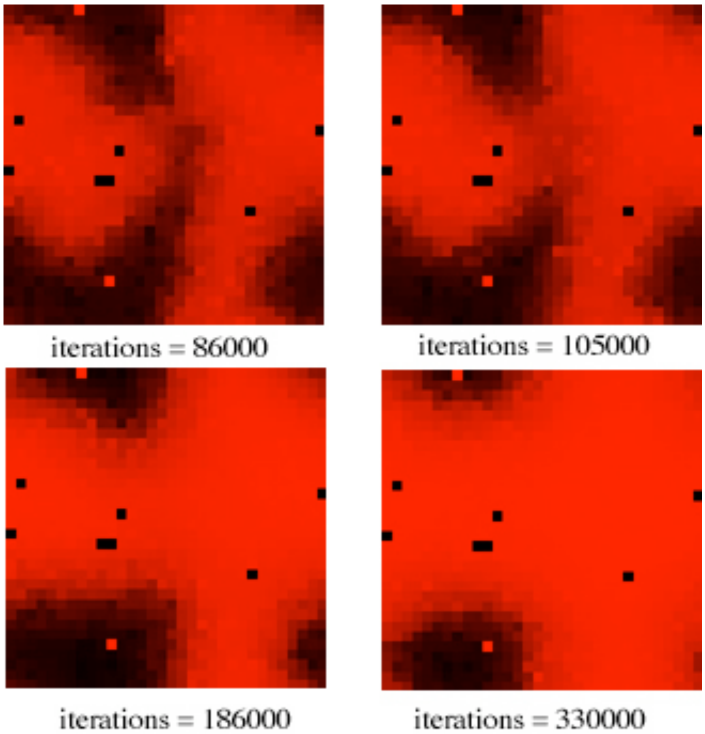

Figure 6. A sequence of screenshots showing two groups of opinion and with gradients of opinion exchange. p = 1, d = 0.5, μ = 0.3, n = 100, N = 2500, Red = 1, Black = 0, one iteration = a single opinion exchange

3.10

What seems to be occurring in this regime is that the social network interactions possess consensus forming quality whereas the mass media communications are attractors to either of the two extremes. Groups of neighbours quickly form into small local groups of consensus converging with each other; and to whichever of the polar attractors first exerts its influence in that local region or to which the local region is initially biased. These polar groups are reinforced by local internal social interactions in which all the neighbours communicate with each other as they have opinions below the threshold. They are also reinforced by only one of the two mass media communications as they will modify their opinion to whichever pole they are closest too and will ignore the other pole. In between these two groupings is a gradient in which the agents are constantly in a state of opinion change. Agents in this gradient possess neighbours that are closer to different poles and therefore the social network exchanges will be drawing them in different directions. In a Neumann neighbourhood this means the topology of the neighbourhood has an effect in which there is a tendency towards gradients in which either there are lines of neighbours in which north-south or east-west neighbours have opinions which are closer to opposite extremes. This results in two separate groups of opinion coalescing with a gradient of opinion exchange between them in which the opinions of agents may change back and forth between the two poles in a "swinging voter" style phenomenon.

3.11

At lower levels of threshold there is still a level of attraction to the two extremes. However the strength of the attractors is weakened and there exists a situation which is in some ways the opposite of that shown in Figure 2: the attractors are now at the extremes and isolated opinions exist in the central areas. Figure 7 displays an opinion graph of this type of behaviour.

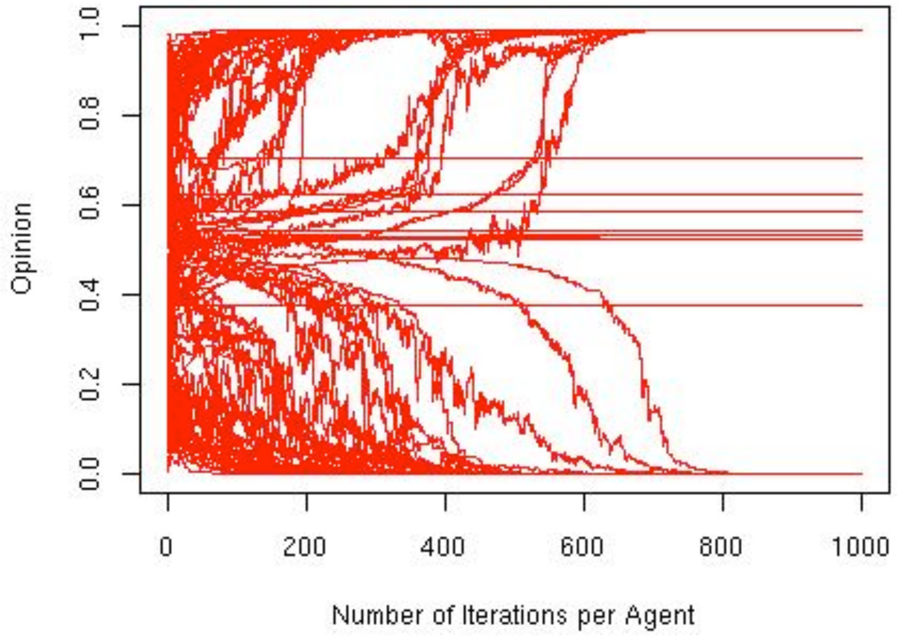

Figure 7. Convergence at extremes with Isolated Moderate Opinions. p = 1, d = 0.25, μ = 0.3, n = 100, N = 2500

3.12

This situation is characterised by an attraction to and spreading of the two extreme opinions and a more localized spread to a number of central opinions. The smaller level of threshold creates a situation in which the attractors have influence over a smaller area in which they can directly attract agents through the process of mass communication so they can only attract agents outside this zone of direct influence indirectly through a combination of mass media communication and social network processes using what Weisbuch et al. (2005) term "active intermediates". This leads to the spread of the extreme opinions outside the central area. Opinions in the centre ground are also formed. These are outside the attraction of the poles and do not get indirectly drawn to the poles by the social network once these opinions are formed. Since there are no neighbours within the threshold of communication they persist as isolated opinions.

Parameter space exploration

4.1

In these explorations of the parameters we have kept convergence constant (μ = 0.3). We explore the threshold and broadcast ratio parameter space and the threshold and polarisation parameter space using two measures. The first measure, standard deviation, is a measure of the consensus between agents, so where there is consensus there will be a small or zero standard deviation and where there is polarisation or fragmentation there will be a larger standard deviation. Using standard deviation to measure the different regimes is useful in presenting the larger picture between the broader types of behaviour. However, standard deviation is not as useful when discriminating between single extreme convergence and double extreme convergence (illustrated in Figure 4, 5 and 6) and masks the picture somewhat. These behaviours can be examined more clearly if we make some adjustments to the model so that we can use the indicator suggested by Deffuant et al. (2004). The indicator takes a final state of the population which has k clusters of opinion x_i, including the proportion p_i of agents within the cluster (the proportion of initially moderate agents in the original formulation of the indicator). As the opinions were continuous real numbers they were rounded to three decimal places when judging cluster membership.

$$y = \sum_{i=1}^{k} p_i^2 \cdot |x_i| \quad (2)$$

4.2

This indicator was designed to produce a *y* close to zero when there is central convergence on a number of opinions, close to 0.5 when there is double extreme convergence, and close to 1 when there is single extreme convergence. It does not serve well in distinguishing between the fragmented regime and the disordered regime. The indicator requires opinions between −1 and 1 so the model has to be adjusted somewhat to accommodate this requirement. The figures that follow are derived from a model with opinions −1 to 1 and the threshold and polarisation are doubled. Convergence remains the same (μ = 0.3).

Broadcast Ratio

4.3

In the following figures the broadcast ratio is presented from 1 to 100 (i.e. these are the number of social interactions for each broadcast interaction). Each point represents one simulation of the parameters after 1000 or 10000 iterations for each agent. Polarisation is held constant at 1. Figure 8a and 8b display the parameter space for threshold and broadcast ratio using standard deviation as a measure of consensus.

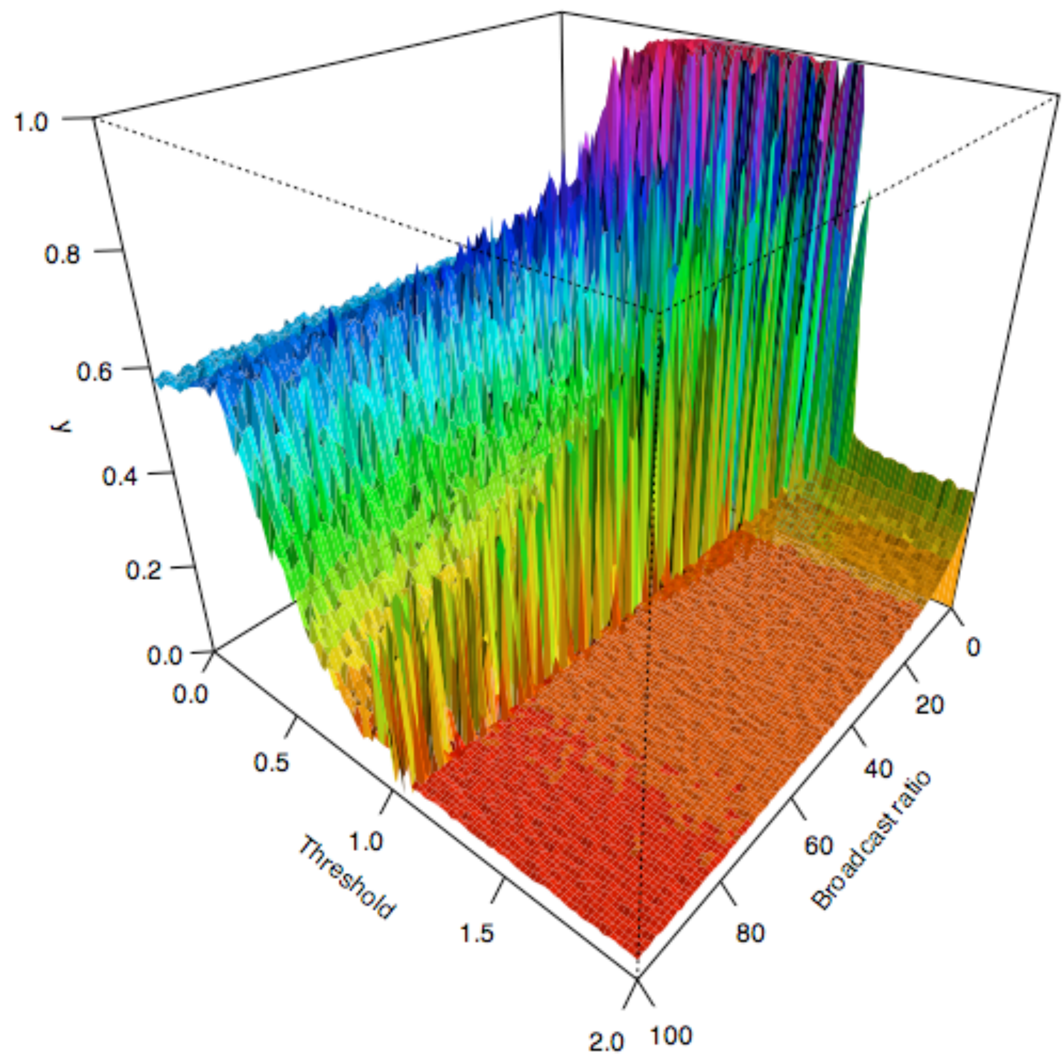

Figure 8a. Standard Deviations for Threshold and Broadcast Ratio after an average of 1000 iterations per agent

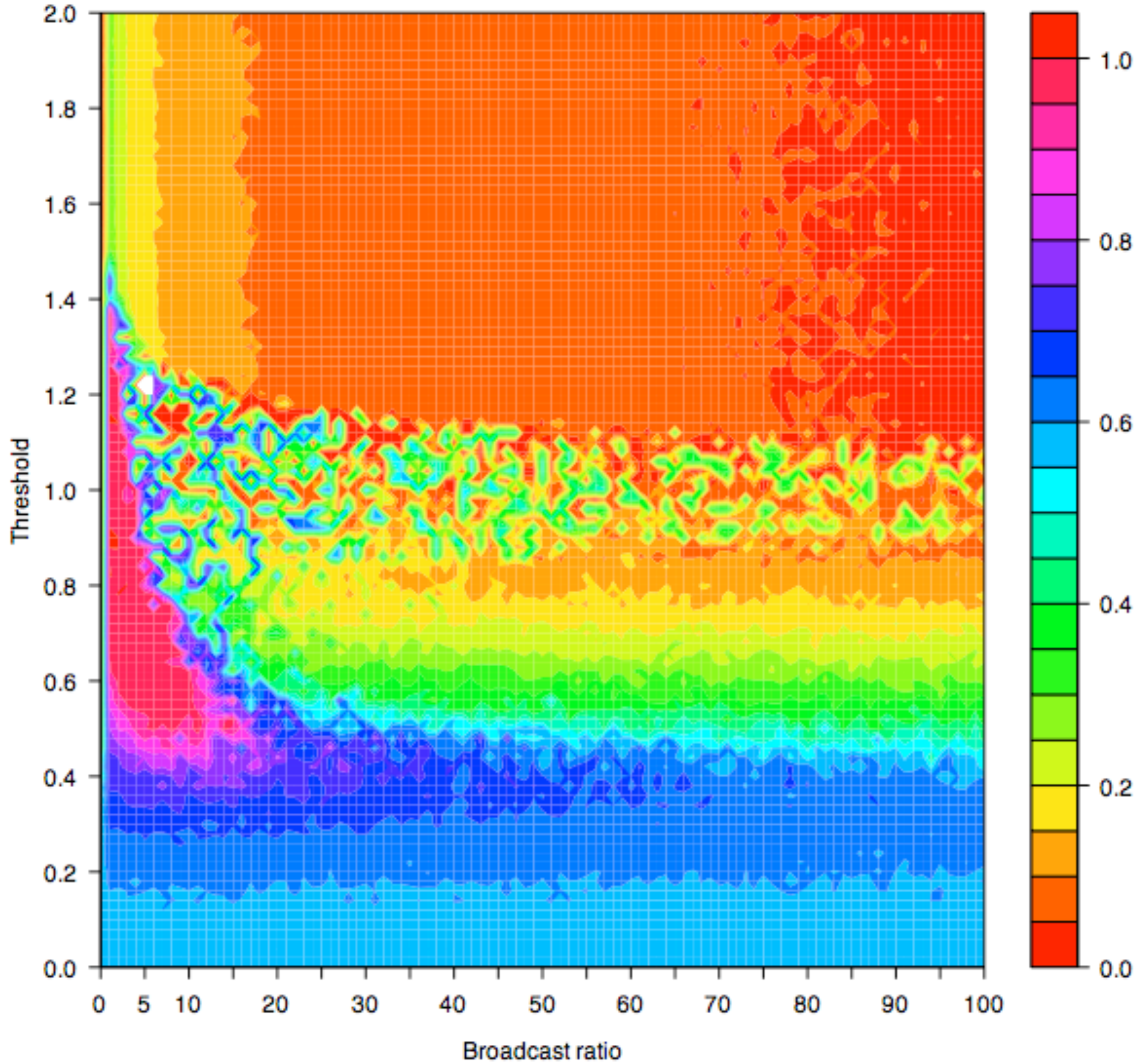

Figure 8b. Contour graph showing Standard Deviations for Threshold and Broadcast Ratio after an average of 1000 iterations per agent

4.4

The four dynamical regimes are clearly distinguished at a broadcast Ratio of 1:5. The fragmented regime is shown by a larger standard deviation around 0.6 and is found when the threshold is lower than about 0.5 or 0.4. With a broadcast ratio of 5 the double extreme convergence regime exists with thresholds about $0.5 < d < 0.8$. The regime of persistent opinion exchange followed by single extreme convergence exists from threshold of about $0.8 < d < 1.3$. Thresholds higher than this are the disordered regime illustrated in Figure 3. The broader picture is a little different and more clearly banded. Around the threshold $0.9 < d < 1.1$ there exists a zone in which the standard deviation varies considerably depending on the initial conditions of a simulation. It is presumed that in this zone single extreme convergence will be reached if the simulation is left running for a longer period of time. It is interesting that in this zone a relatively small number of broadcast communications is needed to form a consensus. On the slope that characterizes the area between the fragmented regime and the zone in which single extreme convergence will be reached there is convergence towards a central opinion. Some isolated extremists are left where the central attractors of the social networks can no longer reach them, as illustrated in Figure 2. The slope is created by an increasing volume of isolated extremists as the threshold decreases. Double extreme convergence only appears where there is a standard deviation greater than about 0.7 so it is a feature of a quite small area in the parameter space.

4.5

Figure 9a and 9b display the second measure which is designed to distinguish between double extreme and single extreme convergence and the parameter space of broadcast ratio and threshold.

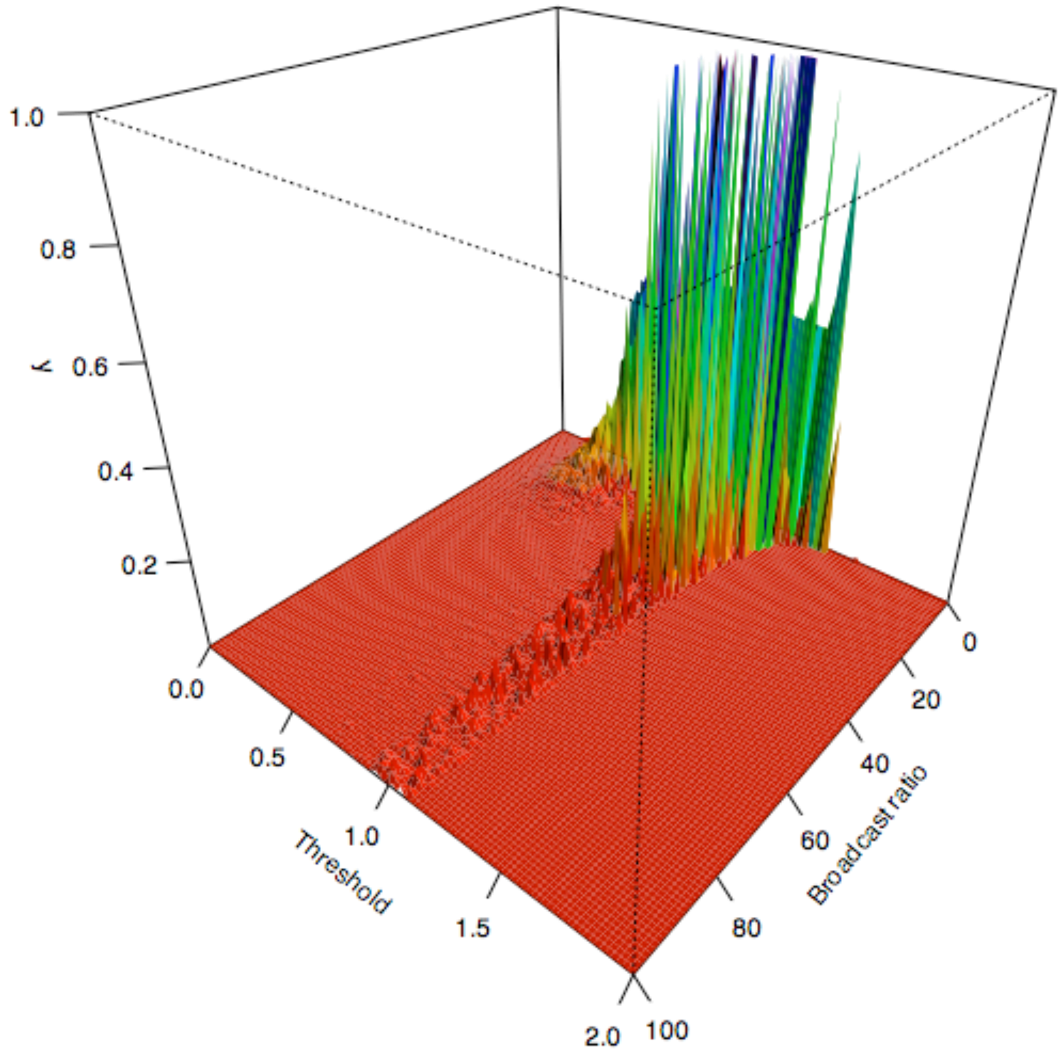

Figure 9a. The indicator *y* for Threshold and Broadcast Ratio after an average of 1000 iterations per agent

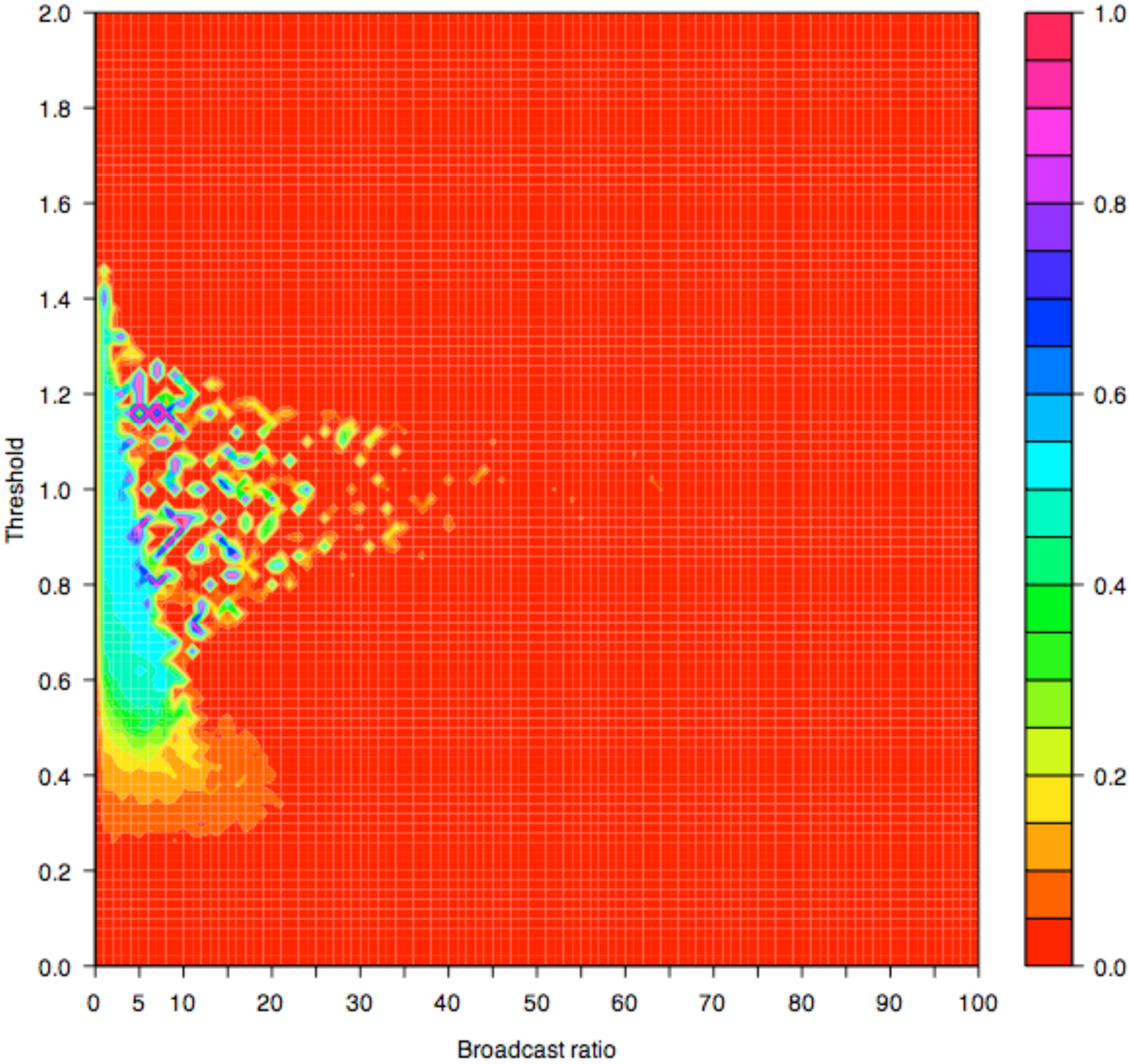

Figure 9b. Contour graph showing the indicator *y* for Threshold and Broadcast Ratio after an average of 1000 iterations per agent

4.6

Where the *y* indicator is around 0.5 one can clearly discern an area of double extreme convergence. The area around a threshold of $0.9 < d < 1.1$ that was clear in Figure 8b is less evident here. It may be that this is because the simulations have not been given enough time (i.e. an average of 1000 iterations per agent is insufficient) to arrive at a single consensus and agents are still largely in a state of persistent opinion exchange. Thus, whereas the zones in which there is double extreme convergence the convergence is quickly realized, single extreme convergence can take much longer to achieve. Figure 9c illustrates the same parameter space in which agents have been given an average of 10000 iterations. It is clear that the situation has changed. The area of double extreme convergence is a little larger and more pronounced, however, the area of persistent opinion exchange leading to single extreme convergence is clearly visible.

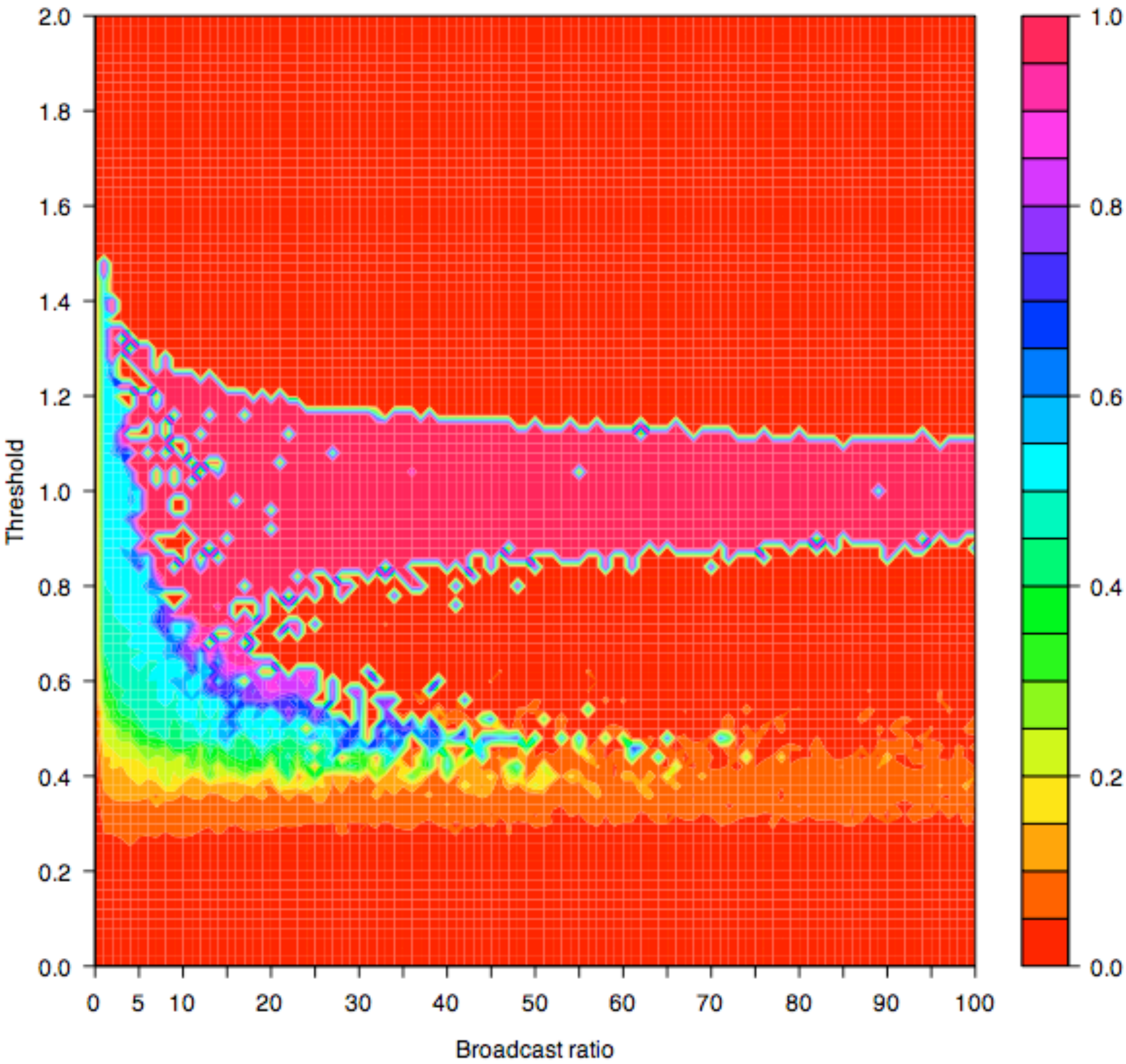

Figure 9c. Contour graph showing the indicator *y* for Threshold and Broadcast Ratio after an average of 10000 iterations per agent

4.7

These findings illustrate a difference in the nature in which double extreme and single extreme convergence occur. Where double extreme convergence is found it occurs rapidly and without long periods of deliberation, mostly in less than 1000 iterations per agent. Figure 9c shows that when the agents are given sufficient time in the central zone surrounding thresholds of $0.9 < d < 1.1$ they will eventually arrive at single extreme convergence. This finding suggests that when agents are moderately open minded (thresholds around 1) their opinions can be influenced greatly by consistent and not necessarily frequent broadcast media opinions from the poles which, given enough time will result in a consensus at one extreme or another. Furthermore there is a difference in the manner in which agents achieve a consensus as the number of broadcast media communications decreases. Figure 5 displays the arrival at consensus for a sample of agents when the number of broadcast communications is similar to the number of social communications. Figure 10 shows the same sample when the number of broadcast communications is low. When there is a lower broadcast ratio agents arrive at opinions around a central opinion when both poles still function as attractors. Eventually one of the two poles is favoured and there is a gradual global drift towards the favoured pole when the opposite pole no longer exerts an attractive influence. Note that the number of iterations in Figure 10 are a factor of ten greater than those in Figure 5.

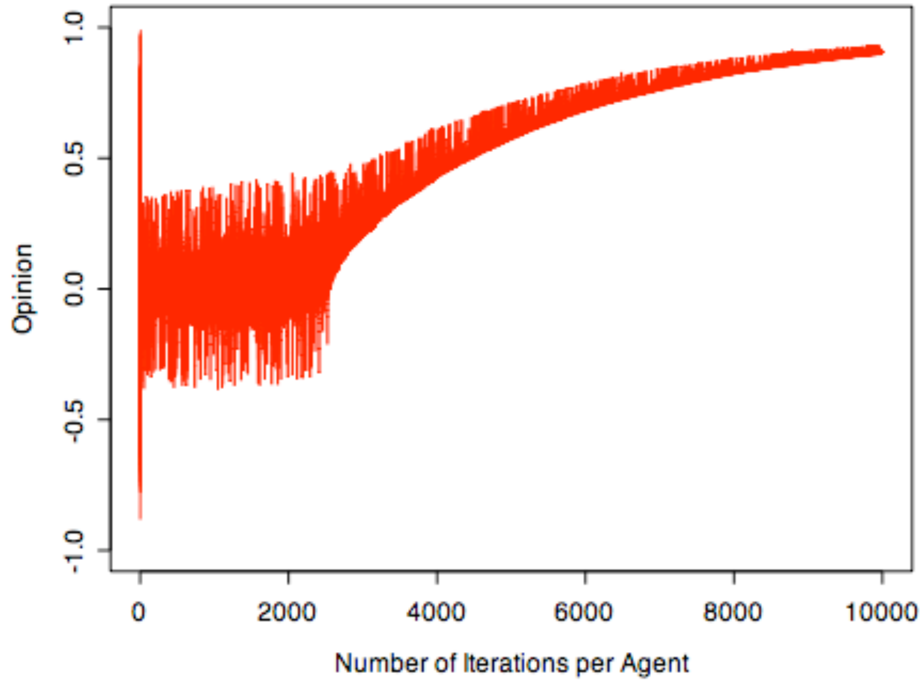

Figure 10. Single extreme convergence with a broadcast ratio of 1:100 for 10000 iterations. *p* = 1, *d* = 1, *μ* = 0.3, *n* = 100, N = 2500

Polarisation

4.8

When the space of threshold and polarisation are looked at as a whole the four regimes can be clearly seen. Figure 11 displays the parameter space for threshold and polarisation using standard deviation as a measure of consensus whenever the broadcast ratio is held constant at 1:5. Each point represents one simulation of the parameters after 10000 iterations for each agent. The four regimes can be clearly seen.

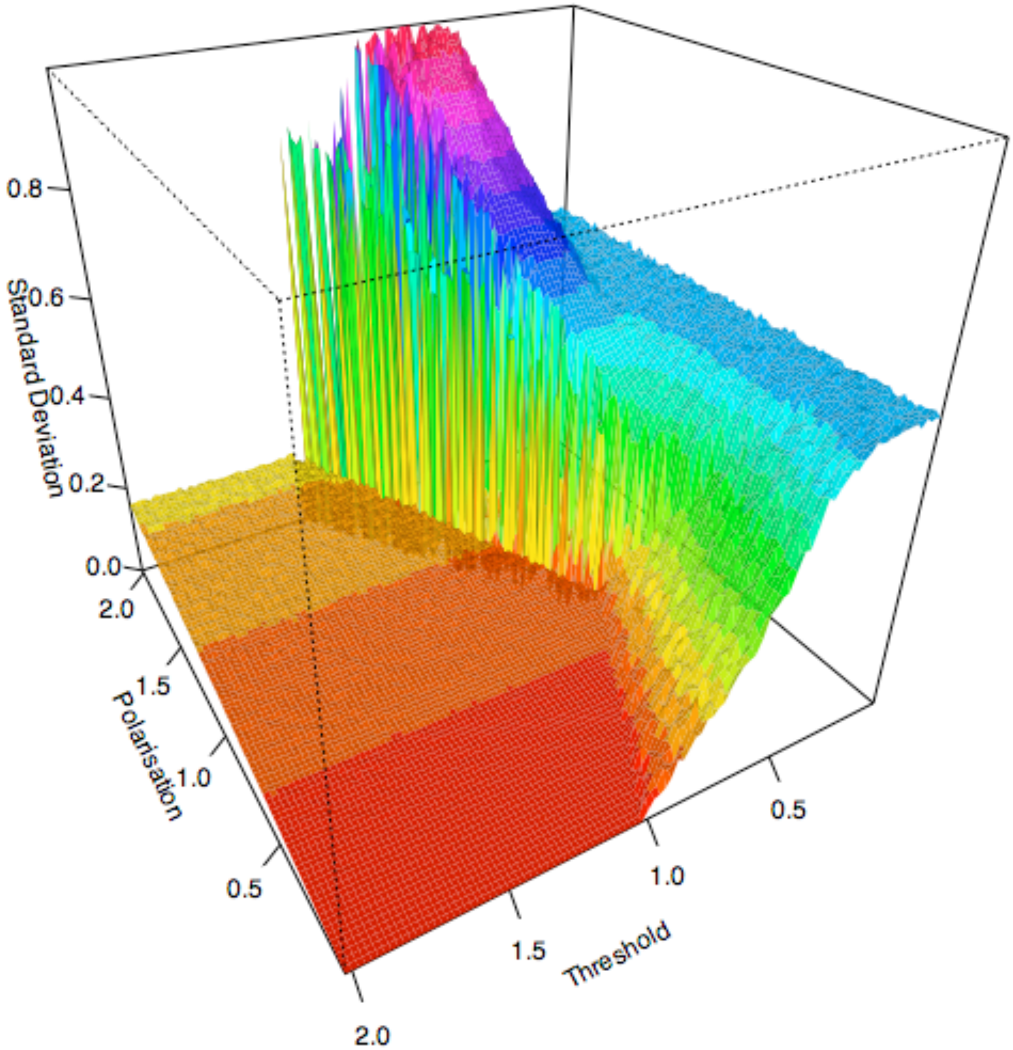

Figure 11a. Standard Deviations for Threshold and Polarisation after an average of 10000 iterations per agent

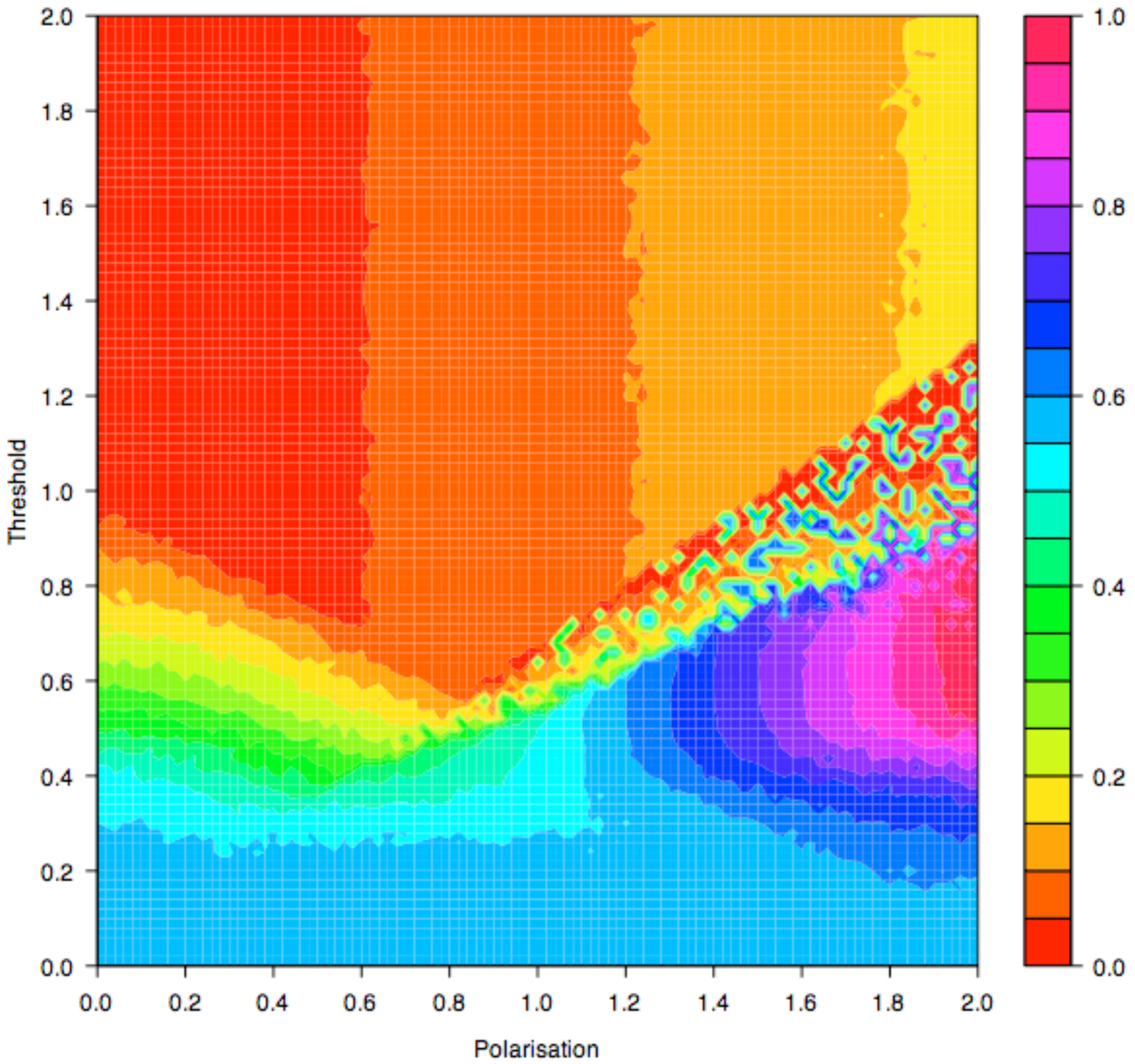

Figure 11b. Contour graph showing Standard Deviations for Threshold and Polarisation after an average of 10000 iterations per agent

4.9

The disordered regime is the sloped flat area which starts between threshold of $0.6 < d < 1.2$ and continues as the threshold d increases. In this regime the standard deviation also steadily rises as polarisation increases, this is due to the contrasting effect of polarisation and the consensus created by social communications. As polarisation increases the contrast between these effects becomes stronger and the level of disorder in the regime increases.

4.10

The trough with spikes is the area of persistent exchange of opinions leading to single extreme convergence. The trough occurs when there is single extreme convergence and there are no extremists and therefore a very low or zero standard deviation. The spikes are where the simulation has not yet converged and there remains a persistent exchange of opinions. Where standard deviation rises close to one is the area of double extreme convergence in which there is rapid bipolar convergence with approximately half of the agents move to one extreme and the other half to the other.

4.11

The arched smoother area is the fragmented regime. There is a plateau of fragmentation for all levels of polarisation and a threshold up to about $d = 0.25$ where there are so few exchange of opinions there is little change from the initial distribution of opinion. This changes above $d = 0.25$, for polarisations at 0: with one central pole of opinion, there is a gradual change as fragmentation gives way to an overall consensus with isolated groups of extremists with homogenous opinions and eventually to strong majority consensus with individual isolated extremists. This is the situation observed in Figures 1 and 2. As polarisation increases the situation is similar. However, instead of complete consensus there exists a disordered state with islands of extremists with homogenous opinions so the fragmented regime and the disordered regime can co-exist within the same simulation. Figure 12 displays this behaviour, there is a constantly changing area of consensus around a central opinion with extremists at the edges of opinion.

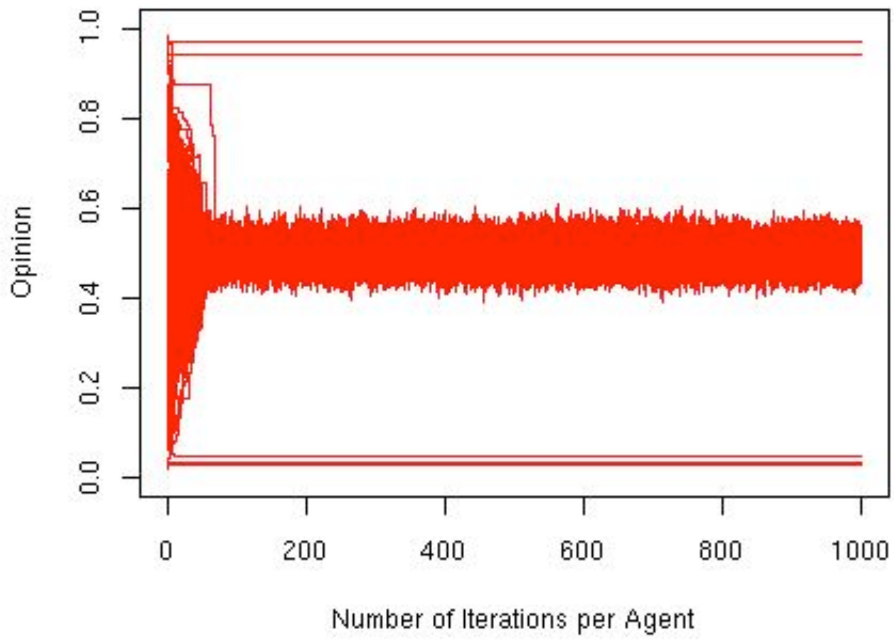

Figure 12. Constant change of central opinions with islands of extremists with homogenous opinions. p = 0.3, d = 0.25, μ = 0.3, n = 100, N = 2500

4.12
In this central area other regimes co-exist too, Figure 13 displays a more complex example in which there is a combination of the fragmented regime and a regime of persistent exchange in which islands of extremists are left isolated at an early stage of the simulation and the remaining active agents engage in persistent exchange eventually settling at one or other pole. There is the equivalent of single extreme convergence at one of the two poles for the majority of agents but there also exist a number of smaller regions of consensus.

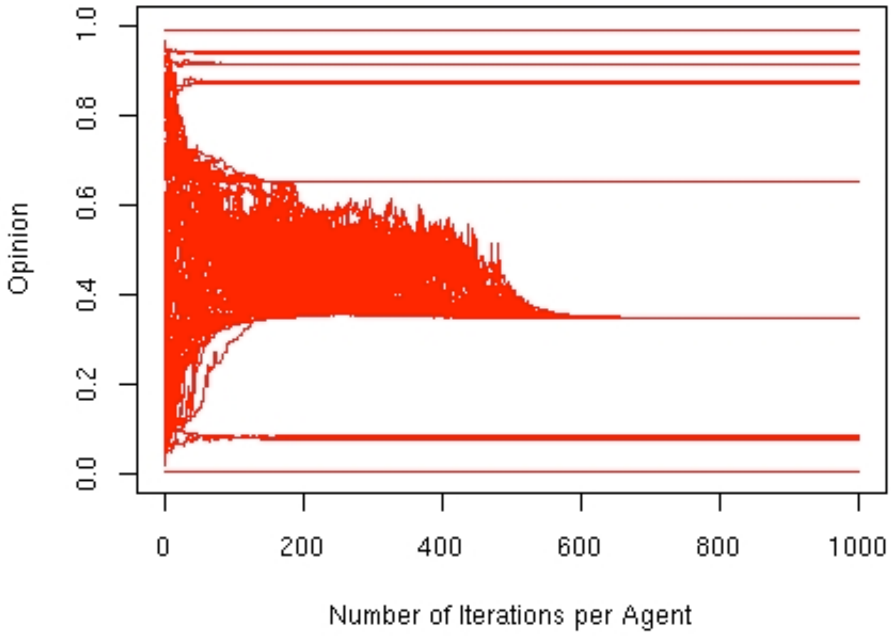

Figure 13. Constant change of central opinions with islands of extremists with homogenous opinions. p = 0.3, d = 0.25, μ = 0.3, n = 100, N = 2500

4.13

The parameter space exploration of threshold and polarisation reveals that the relationship between regimes is not quite as clearly divided for smaller thresholds and polarisations. Where agents are less willing to communicate there is room for a coexistence of behaviours from more than one dynamical regime within the same simulation.

4.14

Using standard deviation again masks the differences between the two convergence regimes that of double extreme convergence and persistent opinion exchange leading to single extreme convergence. Using the Deffuant et al. (2004) indicator we get a much clearer picture of the delineation of these two regimes in the parameter space of threshold and polarisation.

4.15

Figure 14a and 14b show the results of the simulation after an average of 1000 social iterations per agent. These show that the two dynamical regimes resulting in either double extreme convergence or where single extreme convergence is reached resulting in the spikes in Figure 12a or where it is not yet reached and persistent opinion exchange continues. This results in the regions between the spikes in which the indicator suggests that there is central convergence around a number of opinions.

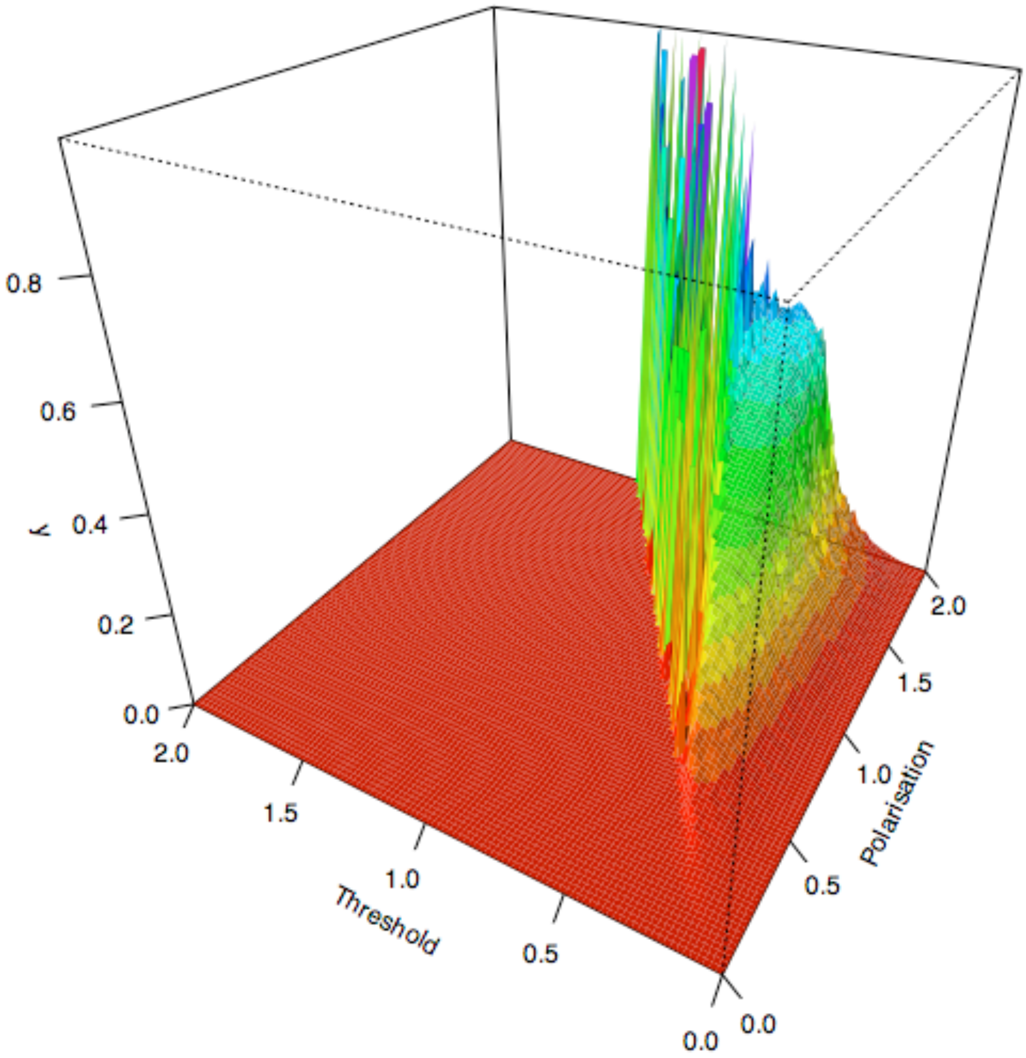

Figure 14a. The indicator *y* for Threshold and Polarisation after an average of 1000 iterations per agent

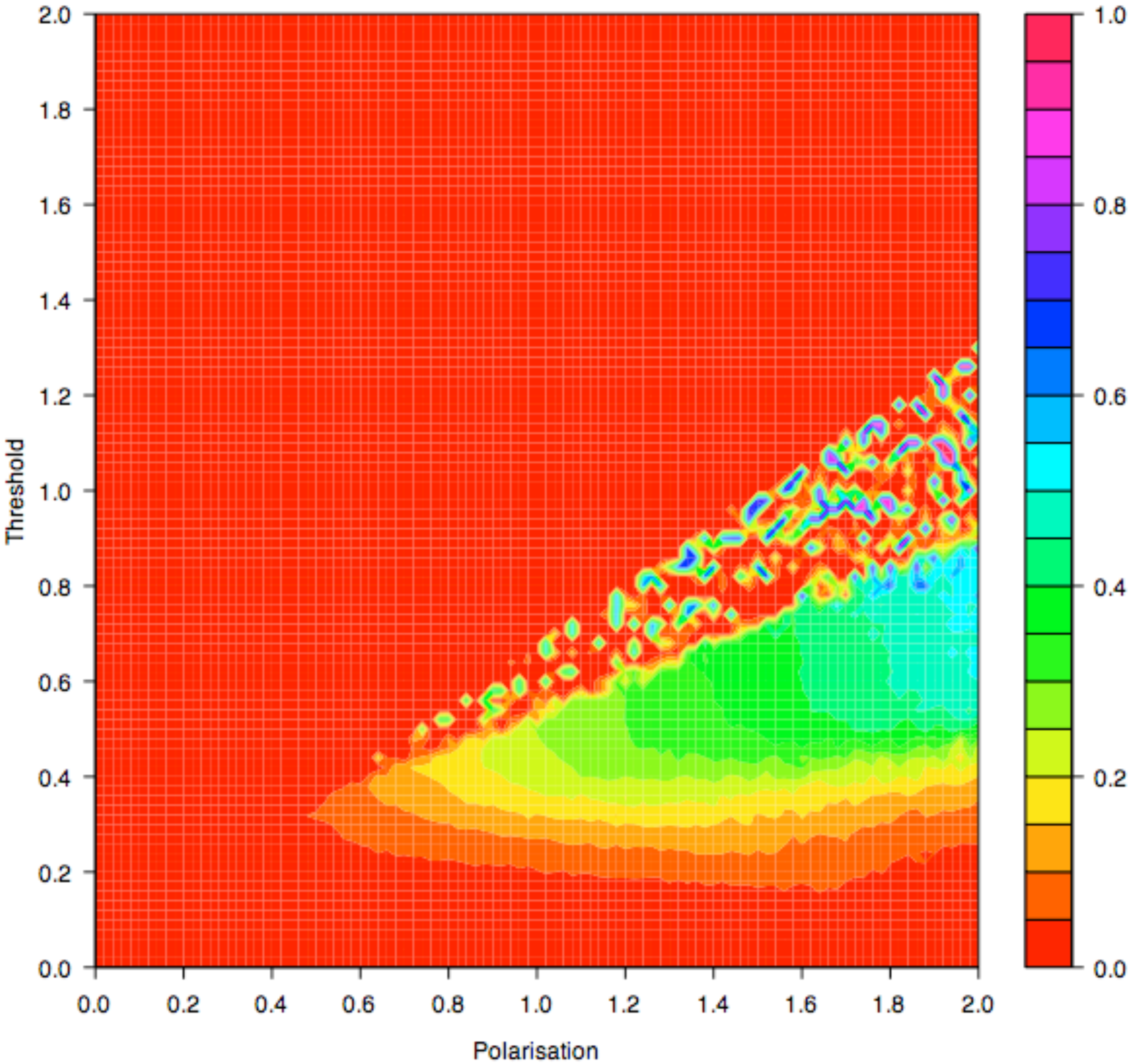

Figure 14b. Contour graph showing the indicator *y* for Threshold and Polarisation after an average of 1000 iterations per agent

4.16

The behaviour of the model that results in 0 in each of the disordered, fragmented and single extreme convergence regimes is quite different. The fragmented regime is most similar to that envisaged by Deffuant et al. (2004) and there is central convergence around a number of opinions. In the disordered regime there is a wide variety of opinions around a central core but never settling on any type of convergence. The areas close to zero within the single extreme convergence regime are a result of the number of clusters of opinion that are created by a gradient of opinion separating the two extremes before either one of the extremes has convinced the other. The existence of these is due to the amount of time that the model has been left to run and given sufficient time these would settle on one extreme or the other. Figures 13a and 13b, represent the same graphs but after the model has run until each agent has had an average of 10000 iterations. They show that given enough time a large number of the simulations within this regime will reach single extreme convergence however there are still many that will not. Simulations in which there is a stable gradient of opinion exchange can persist for many iterations.

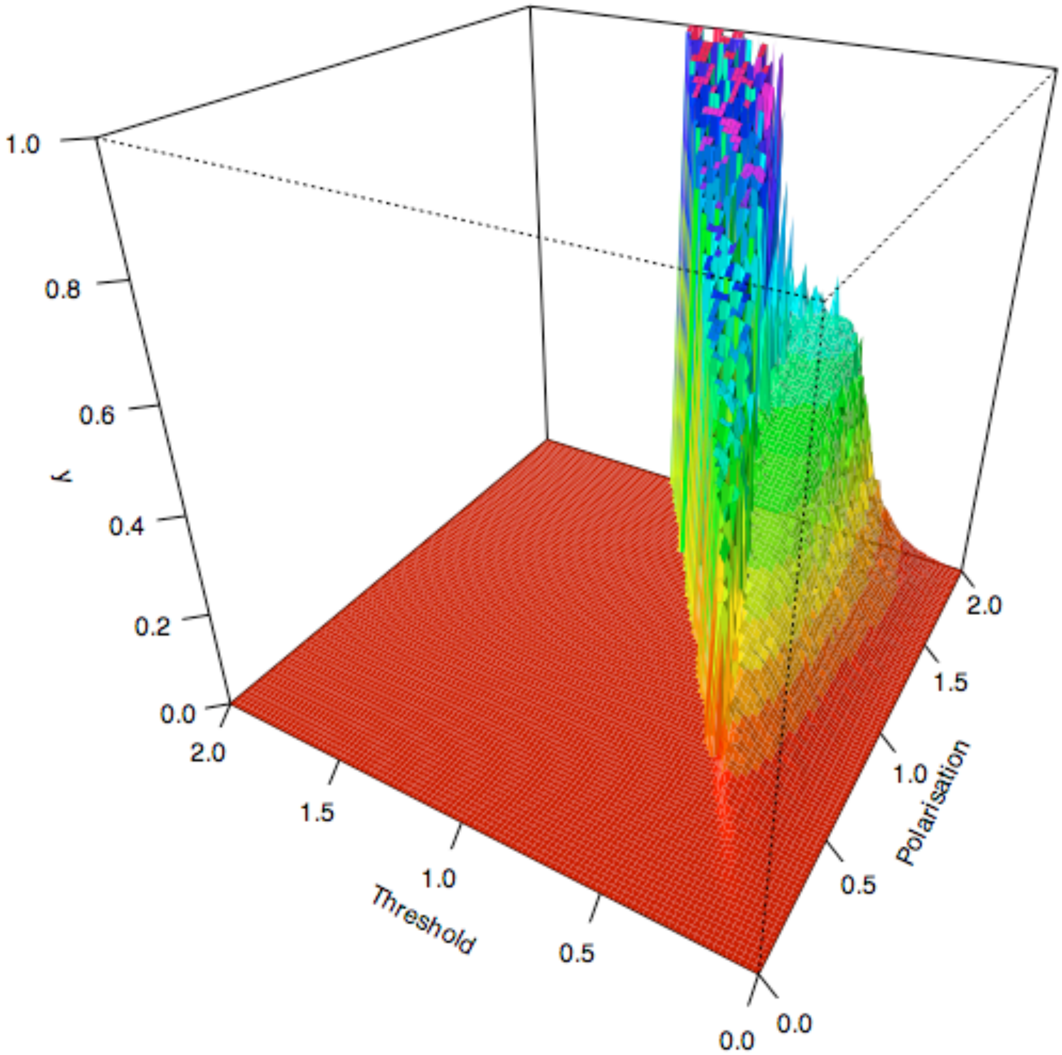

Figure 15a. The indicator *y* for Threshold and Polarisation after an average of 10000 iterations per agent

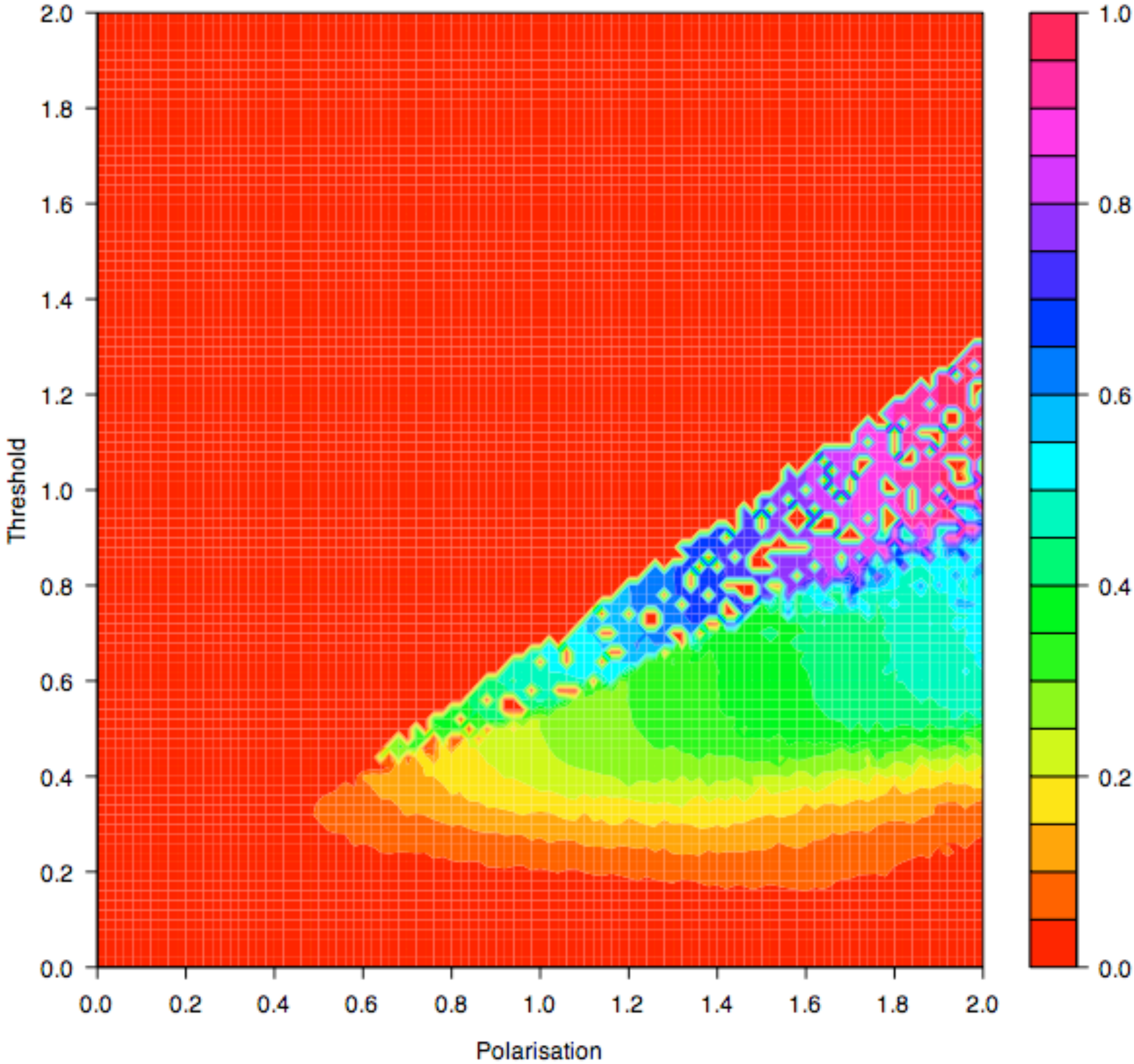

Figure 15b. Contour graph showing the indicator *y* for Threshold and Polarisation after an average of 10000 iterations per agent

4.17

There is also interesting behaviour at the boundary between regimes. When the threshold is at the boundary between the disordered regime and the regime of single extreme convergence it can result in a simulation that starts in a fashion similar to the disordered regime and ends in the regime of single extreme convergence. Figure 16 provides an example of the progression of opinions in such a case.

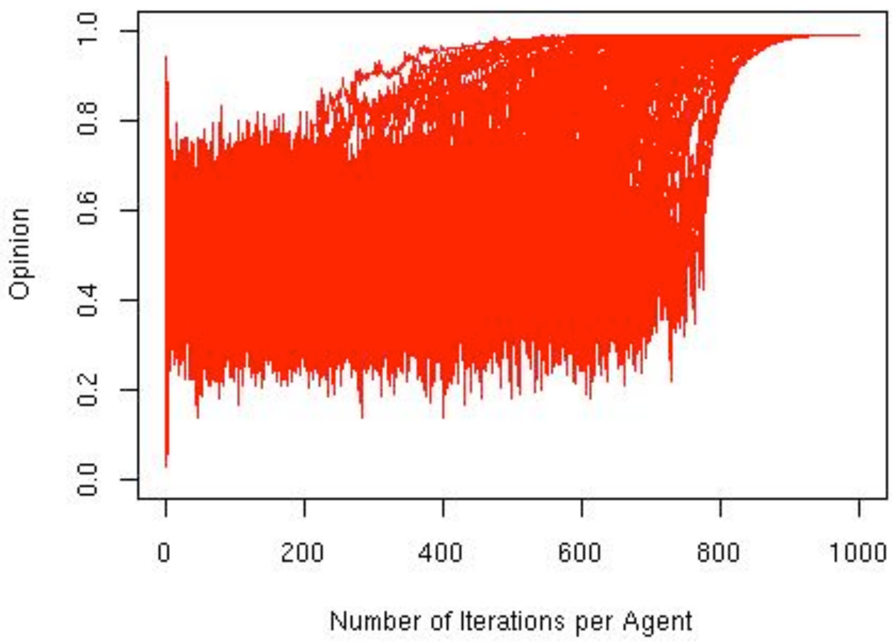

Figure 16. Straying from one regime to another. p = 1, d = 0.64, μ = 0.3, n = 100, N = 2500

Moore Neighbourhood

4.18

Using a Moore neighbourhood yeilds a similar pattern of results which suggests that these processes are quite robust. A Moore neighbourhood uses all eight possible neighbours on the lattice in contrast to the North, East, South, West distribution of neighbours used in the Neumann neighbourhood. This only effects the social network method of communication and not the mass media communications. Figures 17a and 17b show the standard deviation across the parameters using a Moore neighbourhood (these figures were derived using the original model with a 0 to 1 range of opinions). There is very little difference between these results and those obtained from the Neumann neighbourhood displayed in Figure 11a and 11b.

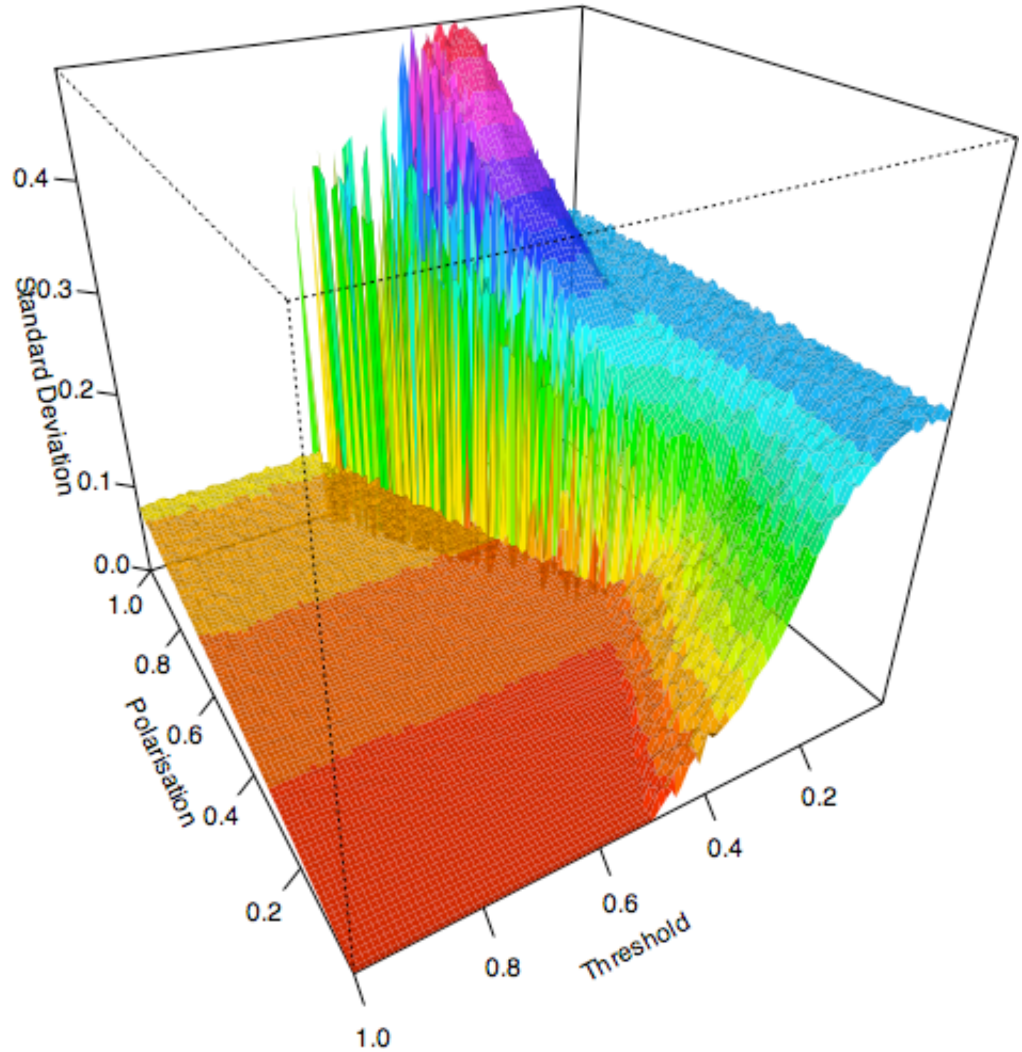

Figure 17a. Standard Deviations for Threshold and Polarisation using a Moore nieghbourhood with 8 neighbours after an average of 1000 iterations per agent

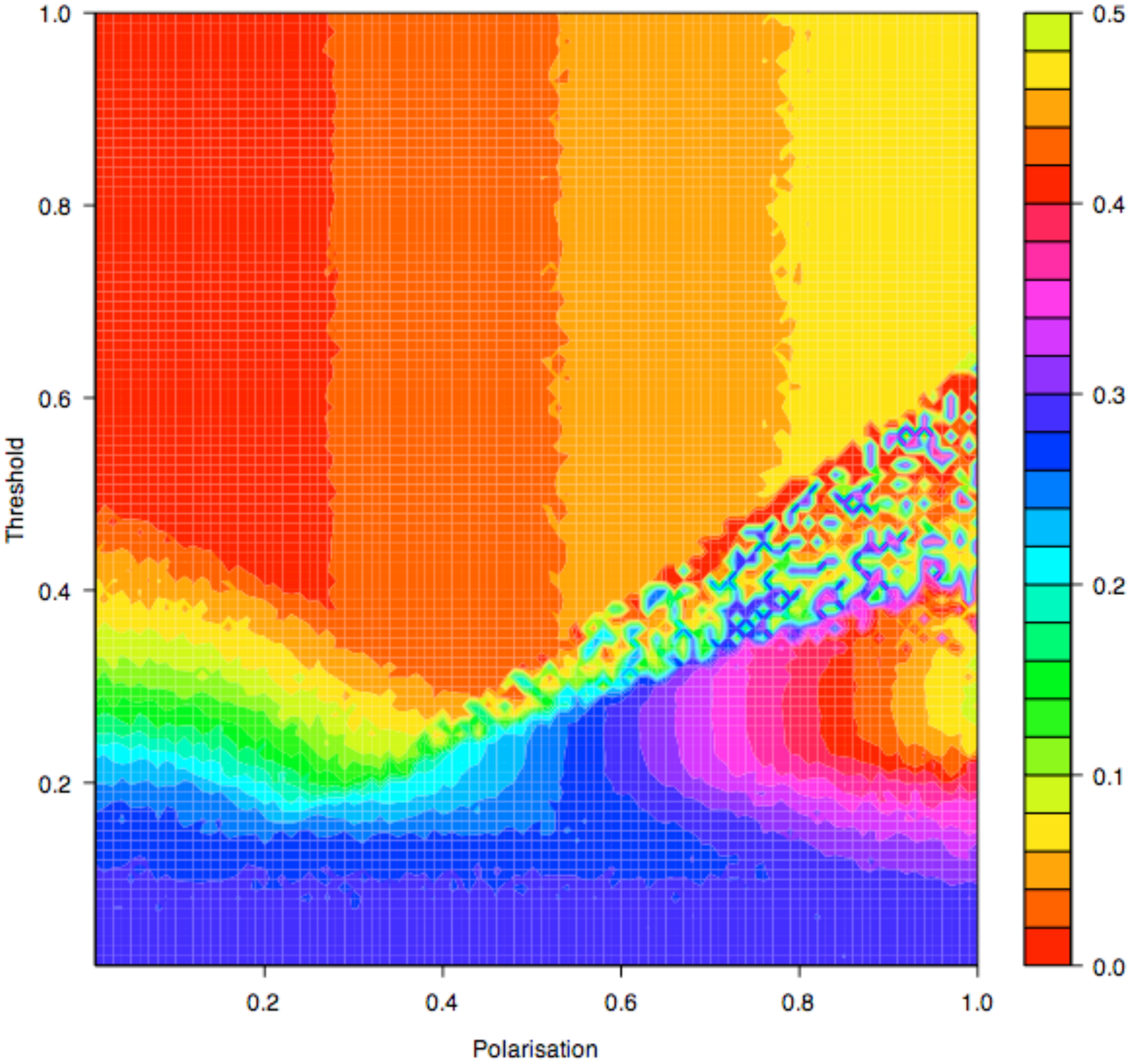

Figure 17b. Standard Deviations for Threshold and Polarisation using a Moore neighbourhood with 8 neighbours after an average of 1000 iterations per agent

Conclusions

5.1

There exists a combination of polarising mass media communications and a ratio of mass communications to social communications that can result in four possible dynamical regimes: the three types suggested by Stauffer (2005), consensus, polarization and fragmentation and an additional dynamical regime in which there is a disordered state of opinions. For certain parameters these dynamical regimes can coexist within the same simulation. Social network communications tend to lead to the formation of a consensus and when there are opposing mass media communications these create a tendency to polarisation. These forces interact with the threshold or bounded confidence levels to create the four dynamical regimes; the disordered regime, a persistent state of opinion exchange leading to single extreme convergence, double extreme convergence and a fragmented state in which many states of opinion can exist. This model shows that considerably more complex behaviour is observed when a second method of communicating opinion is introduced, and an additional level of realism is added when an agent's communications are influenced by factors additional to social interactions with neighbouring agents.

5.2

Social communications have a consensus forming influence on the agents. Conversely a polarised mass media draws agents away from a consensus and towards the extremes. The mass media poles of opinion are attractors that exert their influence both directly by direct opinion exchange with an agent and indirectly by influencing the opinion of neighbours that have social network based communications with an agent at a later timestep. This can have the effect of drawing agents with initially different opinions to the pole furthest from their initial condition. This depends largely on the arbitrary sequence of communications that occur between an agent's neighbours and the agents that receive mass communications. These conflicting attractions result in the four dynamical regimes given different parameters.

5.3

The fragmented regime occurs when there is little willingness to communicate among agents and as such this regime is static and short lived. The disordered regime represents the opposite: there is so much willingness to change opinion there is no possibility that a stable pattern will result and opinions remains in constant flux. More interesting is the regime of double extreme convergence in which the conflicting attractions of mass media polarisation and social communication forming a consensus create a regime in which agents are forced, relatively rapidly, to one pole or the other. Although there is sufficient willingness to change opinion so that the agents will be drawn to one pole or the other, the consensus forming social communications do not seem to be sufficiently powerful to force the agents away from the poles once they have fallen into a basin of attraction to one or the other. The most interesting regime however is the persistent opinion exchange followed by single extreme convergence. In this regime, the willingness to change opinion is greater than in the double extreme convergence regime. In addition the attractions of consensus forming and polarisation are balanced in such a way as to cause agents to form a local consensus around initial asymmetries in opinion with a "swing voter" style gradient of opinion exchange separating areas of differing consensus. These gradients can persist for a considerable time before one pole or the other eventually dominates and a single extreme consensus is formed. The pattern of inter-agent communication is reminiscent of the Ising model (Galam 1997).

5.4

When we examine the threshold and broadcast ratio parameter space we find these last two regimes occupy quite different regions. Double extreme convergence is found in a smaller area of this space in which agents are less willing to communicate and the number of broadcast communications is similar to the number of social communications. Double extreme convergence is a function of two factors: frequent influence of the polarising forces of the extreme mass media, and a lower willingness to change opinion. The combination of these two factors results in agents taking an entrenched position at the extreme closest to their original position. However, double extreme convergence can occur in situations of moderate willingness to change opinion when the level of mass media opinion is very high. The situation in the single extreme convergence regime is quite different. This regime occurs where agents have a moderate threshold close to half way between the extreme opinions and are therefore likely to change their opinion when this is the case the consensus forming processes are strong. The mass media polarising forces pull some of the agents towards the extremes and thus keep the debate animated. In the initial stages the consensus forming properties stop the formation of opinion at the extremes and the mass media communications stop a central consensus forming. Instead the opinions move towards a central consensus but do not settle. Opinion exchange continues until one of the attractors pulls a critical number of the agents towards its pole and away from the influence of the other attractor and there is a gradual global drift towards consensus at the extreme that exerted the most influence. Interestingly in these moderate thresholds the amount of broadcast communication to social communications can be very small and this effect will still occur, only the drift of opinion to the extreme will be slower.

5.5

In relation to the relative agreement model (Deffuant et al., 2002), the three dynamical regimes found in the relative agreement model were also found in this model although there is no equivalent in the relative agreement model to the disordered regime. The early version of the relative agreement model (Deffuant et al., 2002) had full connectivity between agents and therefore cannot be directly compared to this model as full mixing connectivity does not permit two methods of communication. The closest comparison is Amblard and Deffuant's (2004) examination of the relative agreement model on a Moore neighbourhood. Uncertainty in the relative agreement model plays a similar role to threshold in that at low levels of uncertainty agents are less likely to change their opinion and with higher levels they will be likely to change their opinion more readily. Extremists can be seen as similar to the broadcast media in the current model, the crucial difference is that extremists form part of the social network in the relative agreement model and as such cannot communicate indiscriminately with a variety of agents. When the simulations were run on the Moore neighbourhood Amblard and Deffuant found two dynamical regimes: fragmented when uncertainty was low, and double extreme convergence when uncertainty was high. They did not see either the disordered state or single extreme convergence. They attribute the lack of single extreme convergence to high local propagation of extremism which allows each extremist to disseminate its opinion rapidly within its local area. When there is full connectivity the weight of the majority acts as an attractor back to the majority and opinions can then drift globally to either extreme. Our model possesses some of these features but in a different combination: the social network that draws the agents towards the majority opinion, whereas the broadcast mechanism acts a little like extremists with full connectivity in that they can have a communication at random with any agent and draw agents opinion closer to the extreme. However, broadcast communications are not bounded by a social network and so do not have the local constraints found by extremists in the Moore neighbourhood version of the relative agreement model. The broadcast communication mechanism creates random reinforcement of local initial asymmetries that provides the mechanism for the different dynamical regimes seen in the current model. The small world model of Amblard and Deffuant (2004) displayed single extreme convergence at a critical level of connectivity between agents, whereby the population groups at the center before disconnecting with one extreme and drifting to the other. This situation appears similar to that displayed in Figure 10. It may be that at this critical level of connectivity extremists behave like the broadcast communications, they can have a wide random reinforcing influence on a sufficient number of agents acting as a polarising force, in contrast to the consensus forming interactions of the majority of agents who possess moderate opinions. Further analysis would be required to confirm or refute this.

5.6

Weisbuch et al. (2005) look at single and multiple extremists on a Neumann lattice. In the case of the single extremist the majority of agents quickly reach a consensus however those surrounding the extremist are influenced by the extremists opinion and there is propagation of the single extremists opinion towards a consensus. After a sufficient number of iterations an equilibrium is reached and a static gradient of opinions results. This is as if a broadcast communication was repeatedly delivered to the same agent in a lattice. The propagation of the extreme opinion is similar to the gradient of opinion exchange seen in the current model, the difference being that the gradient of opinion exchange is dynamic and constantly fluctuating whereas this gradient is static. As there is only one extremist in this example there is no opportunity for initial asymmetries to cause fluctuations in other parts of the lattice and so consensus forms everywhere other than around the extremist. When there are multiple extremists the situation is closer still to that observed in this model and the 'hills' of opinion referred to by Weisbuch et al (2005) are also similar to the gradients of opinion in our model. Once again the difference is that they become static once they reach a state of equilibrium. Their "hopeful monster" hypothesis suggests that there are extremists who, given a large enough threshold will always influence a local neighbourhood, and given sufficient density of extremists these will eventually combine to create situations of double extreme convergence situations. This model intimates "hopeful monsters" that pick agents at random and drag their opinion towards an extreme before social consensus draws them back. The hopeful monsters communications often fall on deaf ears but have a strong effect on local neighbourhoods when they are heard.

5.7

The observed effects are robust and similar patterns of results appeared in two types of neighbourhood (Neumann and Moore) where agents had either four or eight neighbours. An interesting further simulation would examine the two mechanisms of communication using more realistic social network topologies such as small world (Watts and Strogatz 1998) and scale-free (Albert and Barabasi 2002) social network topologies as used in Stauffer, Sousa and Schulze (2004) and Weisbuch et al. (2005).

5.8

A more realistic model would have different weightings for mass media communications and social network communications. In addition the ratio of mass media communications to social communications could take more realistic levels. There may be a lower threshold amongst mass media communications than amongst social network communications as people try to minimize cognitive dissonance and seek reinforcing messages through newspapers, television channels, radio channels or internet sites to which they choose to pay attention. Almost certainly differing levels of credibility would lead to different thresholds for each source. We may also receive a larger number of opinionated pieces of communication through the internet, newspaper and broadcast media so this would need to be taken into account in broadcast ratio parameters. It is also important to take into account that polarisation may come from more than one or two sources and the spread of poles would be much more complex than the simple spread presented in this model. Variations in these elements may make the model more realistic. Nevertheless, the model shows that when more than one mechanism for communicating opinions is introduced the picture becomes a lot more complex than that indicated by previous explorations which have concentrated on just one type of transmission with different weightings.

5.9

The model implies that extreme and divided societies (double extreme convergence) are likely to be found in circumstances in which individuals show little willingness to communicate outside of the point of view favoured by the community (low threshold) and where there are strong attempts by the broadcast media to convince people to move towards extreme positions. One example is Northern Ireland where there is little willingness to consider the point of view of the opposing community and where well-established local newspapers often reaffirm the views of extremists. Strong internet and video based propaganda, as used by religious extremists such as al-qaeda, may exert an influence which is similar to that of a large quantity of broadcast events and thus induce those less willing to change opinion to adopt more extreme views. We would also expect to find the strong divisions of double extreme convergence in societies containing individuals holding moderate views but receiving high concentrations of mass media communications on one issue. The media hype and constant publicity that surround elections and national referenda may be a causal factor in creating strong societal divisions along party lines or around a contested issue rather than encouraging a more reasoned debate. In situations in which we find single extreme convergence, issues in which there is a lower concentration of broadcast events over a longer period of time may lead to a more central discussion and a slower pace of social movement on a particular issue. Examples of contested issues which were once open for discussion (amongst those who were permitted to have a voice) but which, in Western Society, have lead the majority to adopt one extreme include slavery, and women's suffrage. Currently similar debates are taking place on controversies such as animal rights, stem cell usage and genetically modified foods. These debates have lower volume broadcast impacts and are often about new issues on which opinions have yet to be formed and the willingness to change opinion may be greater. We may receive many broadcast opinions every day but often they concern a range of different issues thereby assuaging the impact of any individual broadcast event on a single issue. However when broadcast events increase in volume or level of impact on a particular issue then societies are more likely to be forced into dual extreme convergence.

5.10

As it stands the model supports arguments for including a diverse range of mass media treatments of various opinions in order to better understand how isolated extremes of opinion might be avoided and how those with extreme opinions might be drawn into the debate. It provides conditions which allow for gradients of opinion exchange in which agents opinions may sway in one direction and then another in a "swinging voter" style phenomenon, modeling longer term social movements.

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