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Persuasion dynamics

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Abstract

We here discuss a model of continuous opinion dynamics in which agents adjust continuous opinions as a result of random binary encounters whenever their difference in opinion is below a given threshold. We concentrate on the version of the model in the presence of few extremists which might drive the dynamics to generalised extremism. The intricate regime diagram is explained by a combination of meso-scale features involving the first interaction steps

1 Introduction

The present paper is a follow-up in a series of publications on continuous opinion dynamics and "extremism" [1].

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Social psychology is often concerned with the outcome of collective decision processes in connection with individual cognitive processes and the actual dynamics of opinion exchanges in meetings. The issue of whether extremist or moderate opinions are adopted in commissions is thoroughly discussed in Moscovici and Doise [2].

A connection with statistical physics and the Ising model was soon established, for instance by Galam [3] who collaborated with Moscovici. They considered binary opinions as in the vast majority of the literature on binary social choice [4].

The approach here is different and rests on the fact that certain choices imply continuous opinions; typical examples are the evaluation of economic profits among different possible choices [5], or how to share profits after a collective enterprise (hunt, agriculture etc.) [6]. In the early literature on committees, opinions were simply supposed to influence each other in proportion to their difference. The described dynamics was equivalent to heat diffusion, and resulted in uniformisation around some average opinion.

The notion of an interaction threshold, based on experimental social psychology, was proposed by Chattoe and Gilbert [7], and introduced in models by Deffuant et al [8] and Hegselmann and Krause [9]. Two individuals with different opinions only influence each other when their difference in opinion is lower than a threshold. The outcome of the dynamics can then be clustering rather to uniformity. (A series of models of cultural diffusion first introduced by Axelrod and followers [10] belong to the same class: cultures are represented by vectors of integers which are brought closer by interactions under certain conditions of similarity; these authors studied how these conditions influence the outcome of the dynamics, uniformity versus diversity. Integer variables facilitate analytical approaches [10],[11] via master equations).

Fascinating results were obtained in the "extremism" model of Deffuant et al [1]: when interaction thresholds are unevenly distributed, and in particular when agents with extreme opinions are supposed to have a very low threshold for interaction, extremism can prevail, even when the initially extremist agents are in very small proportion. The so-called "extremist model" can be applied to political extremism, and a lot of the heat of the discussion generated by these models relates to our everyday concerns about extremism. But we can think of many other situations where some "inflexible" agents are more sure about their own opinion than others. Inflexibility can arise for instance:

- Because of knowledge; some agents might know the answer while others only have opinions; think of scientific knowledge and the diffusion of new theories;
- Some agents might have vested interests different from others.

Although the model has some potential for many applications, we will here use the original vocabulary of extremism.

Several subsequent papers [12] checked the genericity of these results for different interaction topologies (well-mixed systems versus social networks represented by many variants between lattices and random nets) and for different variants of the distribution of interaction intensities (see further equation 3). Clustering and the possibility of extremist attractors were shown to be generic, but the phase diagrams between different dynamical regimes can be rather intricate with co-existence regions depending on parameter values.

The purpose of the present paper is to increase our understanding of these phase diagrams using simpler conditions for simulation. (Unfortunately, we are still not very advanced in formal derivations). The subsequent section describes the models, the simulation techniques and the monitoring of the results. We first deal with models where only one "extremist" is present. Full mixing and lattice topologies are then studied. More intricate situations with many extremists can be understood from the one-extremist case.

2 Models and simulations

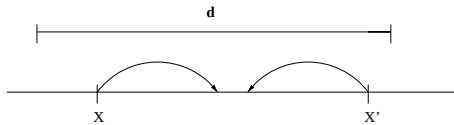
2.1 The basic model

The most basic model later called bounded confidence model was introduced by Deffuant et al [8]. It supposes an initial distribution of agents with scalar opinion x .

At each time step any two randomly chosen agents meet: they re-adjust their opinion when their difference in opinion is smaller in magnitude than a threshold d . Suppose that the two agents have opinion x and x' . If $|x - x'| < d$ opinions are adjusted according to:

$$x = x + \mu \cdot (x' - x) \tag{1}$$

$$x' = x' + \mu \cdot (x - x') \tag{2}$$



where μ is the convergence parameter whose values may range from 0 to 0.5. The rationale for the threshold condition is that agents only interact when their opinions are already close enough; otherwise they do not even bother to discuss.

The basic model uses

- a threshold d constant in time and across the whole population;
- a complete mixing hypothesis;
- and a random serial iteration mode.

The threshold can be interpreted as "openness", tolerance or as some uncertainty in opinion.

The choice of the random serial iteration mode models opinion diffusion in a large population which agents encounters each other in small groups such as pairs. By contrast Hegselmann and Krause [9] chose parallel iteration since their approach derives from earlier literature modeling formal meetings.

Computer simulations show that the distribution of opinions evolves at large times towards clusters of homogeneous opinions (both iteration modes yield similar clusters under the used conditions).

For large threshold values ($d > 0.3$) only one single cluster is observed at the average initial opinion (consensus). For lower threshold values, several large clusters are observed. Consensus is then NOT achieved when thresholds are low enough. The number of clusters varies as the integer part of $1/2d$ [8], to be further referred too as the $1/2d$ rule.

Some recent literature by Stauffer and collaborators [18] consider as clusters any group of opinions however small (even of size one). Counting all these groups yield higher figures scaling with N the number of agents. We here only monitor large clusters which size is a finite fraction of the number N of agents. We don't care about the existence of isolated "outliers". (because of the randomness of the iteration process some agents are selected at later times and remains as "outliers" outside the main clusters). The "generic" results we here refer to, such as the $1/2d$ rule, apply to the large clusters.

Rewriting the opinion updating equation as:

$$x = x + \mu \cdot f(x' - x) \cdot (x' - x), \quad (3)$$

the bounded confidence model supposes a square amplitude of the interaction function $f(x' - x)$ when $|x - x'| < d$. Smoother shapes (such as trapezoidal[1] or bell-shaped [13]) were also proposed for $f(x' - x)$. The simulations show that the main dynamical features are conserved with these smoother interaction functions.

2.2 Extremism

The model for extremism introduced by Deffuant et al [1] is based on two more assumptions.

- A few extremists with extreme opinions at the ends of the opinion spectrum and with very low threshold for interaction are introduced.
- Whenever the threshold allows interaction, both opinions and threshold are readjusted according to similar expressions.

If $|x - x'| < d$

$$x = x + \mu \cdot (x' - x) \quad (4)$$

$$d = d + \mu \cdot (d' - d) \quad (5)$$

A symmetrical condition and equations apply to the other agent of the pair with opinion x' and tolerance d' but when thresholds are different the influence can be asymmetric: the more "tolerant" agent (with larger d) can be influenced by the less tolerant (with smaller d) while the less tolerant agent is not. This "effective" asymmetry is responsible for the outcome of "extremist" attractors.

2.3 Simulation methods and displays

Computer simulations are run according to standard conditions.

- Initial conditions: uniform distribution of opinions among $[0, 1]$ among N agents with initial threshold dl . Among these a few agents are extremists, with opinions at the extreme of the opinion spectrum and with initial threshold $de < dl$.

- At each time step, one randomly selected pair is chosen and agents are updated according to equations 4-5 whenever the condition on threshold is fulfilled.
- Simulations are run until an approximate state of equilibrium is reached: we here consider that equilibrium is reached when opinion and tolerance histograms of 101 bins are stable.

The main parameters are the number and initial tolerance of extremists, and the initial tolerance dl of the other agents. Variants include different interaction networks, and different interaction functions $f(x' - x)$.

We usually first check opinion and tolerance dynamics by time plots of single simulations [1]. These time plots are clouds of points representing at each time step the opinions and tolerance of those agents chosen for eventual updating versus time along the x axis.

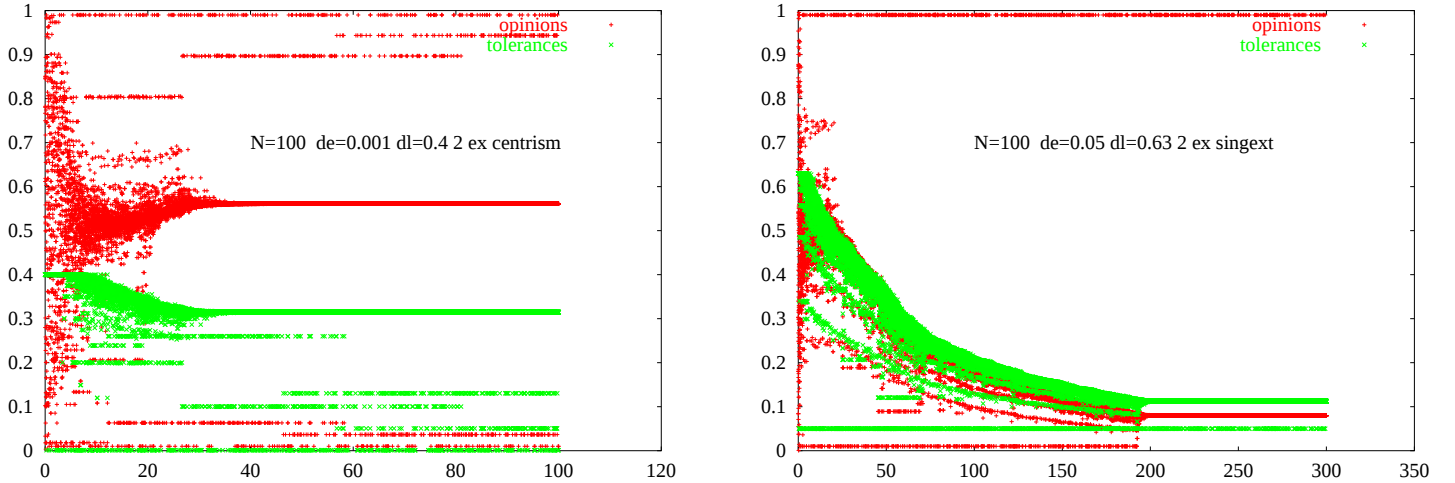


Figure 1: Time plots of opinion (red '+') and tolerance (green 'x') dynamics exhibiting a "centrism" attractor on the left frame and a single extremist cluster on the right frame. Time is given in the average number of updating per agent. The number of agents is $N = 100$, extremists' tolerance is $de = 0.001$ and two opposite extremists are initially present. Any pair of agents can a priori interact. The centrism attractor is obtained when the initial centrist tolerance is $dl = 0.4$ and the extremist attractor when $dl = 0.63$

The time plots display different dynamical regimes according to the eventual predominance of the extremists: sometime they remain

isolated and most agents cluster as if there were no extremist (e.g as represented on figure 1 left frame); otherwise extremism prevails and most agents cluster in the neighborhood of one (e.g as represented on figure 1 right frame) or both extreme. Convergence characteristic time differs: convergence is fast for the centrism attractor and slow for the extremism attractor. The ratio in convergence time is approximately the ration in the initial fraction of centrists and extremists.

Which attractor is reached depends mainly upon the parameters of the simulation (number and initial tolerance of extremists, and the initial tolerance dl of the other agents). A simplified conclusion is that some kind of extremism prevails for larger values of the tolerance of initially non-extremist agents when $dl > 0.5$, and centrism when $dl < 0.5$. In other words, the outcome of the dynamics is largely determined by the tolerance of the non-extremists agents. Systematic studies show the existence of parameter regions where several attractors can be reached depending upon the specific initial distribution of opinions and upon the specific choice of updated pairs.

Deffuant et al [1] papers are filled with two dimensional regime diagrams coded according to a variant of the Derrida-Flyvbjerg parameter [14] defined as:

$$Y = \sum_i \frac{n_i^2}{N} \quad (6)$$

This sum of the square of the fraction of number n_i of agents in each cluster i roughly represents the inverse of a weighted number of clusters. Particular choices of monitored Derrida-Flyvbjerg parameters allow to separate dynamical regimes of attraction towards center, clustering and attraction towards one or both extremes.

But these diagrams although comprehensive in terms of parameter ranges and averaging over many initial conditions are difficult to interpret and we use here a more direct approach. We only vary one parameter along the x axis, most often the initial large tolerance dl . The y axis code the histogram of attractor clusters by vertical bars. The magnitude of the bar represents how many agents are in the asymptotic cluster(s). Clusters made of one agent are most often discarded to make diagrams more readable. The position of the bar represents either the opinion or tolerance of agents in that cluster. Each bar only gives the result of one simulation.

Coexistence regions appear as dl intervals on which large fluctuations are observed in the cluster positions. Probabilities of either

regime are evaluated from their frequency of observation on any interval. By contrast, pure regimes yield regular variations of cluster positions.

We also show the asymptotic patterns of opinions and tolerance for lattice topologies with color coding.

3 Single extremist regimes

3.1 Single extremist with full mixing topology

To easily gain some insight, let us start from a rather extreme case: one single extremist agent chosen with initial opinion 0.99 and 0.001 tolerance. The topology is full mixing. Large simulation times are used (10 000 iterations per agent) to ensure convergence under every simulation condition (figure 2).

The regime diagram (figure 2) clearly shows that the centrist agents are all attracted by the extremist when their initial tolerance dl is above 0.5: they gather in a cluster of opinion 0.99 and tolerance 0.001. The interpretation is straightforward: For this low value of extremist tolerance, interaction between the extremist and centrists are asymmetric (as we checked by measuring asymmetric interactions during the simulation). The extremist acts as a fixed source of extremism, formally equivalent to a heat source at constant temperature (equations 1 and 2 can be thought as a randomly discretized version of a Euler relaxation algorithm solving a diffusion equation [15]). Opinion is here the equivalent of temperature.

Below $dl = 0.5$ the influence of the extremist decreases and agents cluster near the center opinion keeping roughly their initial tolerance. When $dl < 0.27$, the diagram shows the same increase in cluster number that can be observed in the absence of extremist (the "1/2d rule"), except for a partial extremism clustering below $dl = 0.27$ which is easily understood.

The region $0.37 < dl < 0.52$ is a co-existence region where both regimes, centrism or extremism can be observed, depending upon initial conditions and pair sampling.

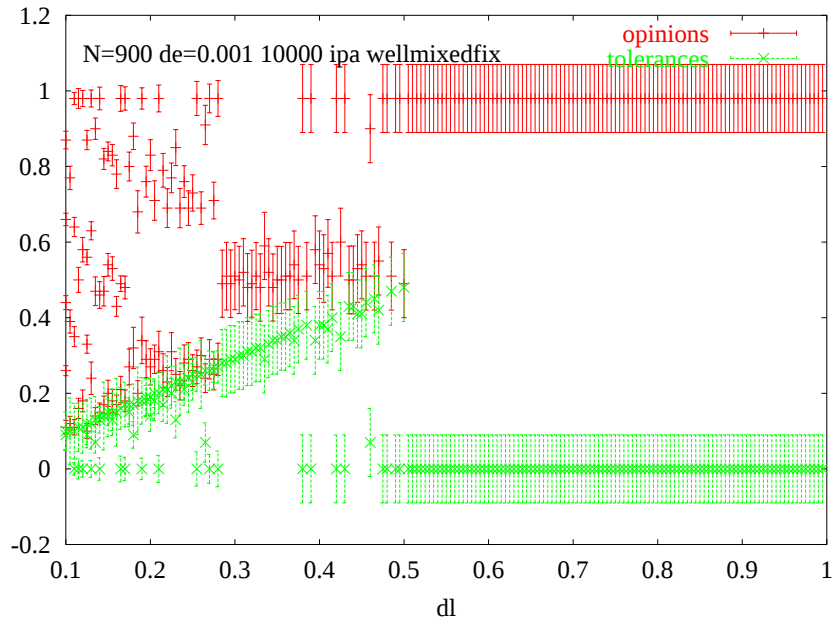


Figure 2: Histograms of asymptotic clusters. The y axis code the histogram of attractor clusters by vertical bars which magnitude represents how many agents are in the asymptotic cluster. The position of the bar represents either the opinion (red) or the tolerance (green) of the agents in that cluster. The horizontal axis gives the initial tolerance parameter of the "centrist" agents. One single extremist present, $N = 900$, $de = 0.001$, average number of iterations per agent 10 000, any pair of agents can a priori interact

3.2 Single extremist with square lattice topology

In many cases we expect interactions to occur across some social network. Such would be the case for political discussions, especially in the absence of an open discussion forum. Many model topologies of social networks have recently been proposed. We here report simulation results for square lattices, when interactions are only possible among nearest neighbours (each node can only interact with his 4 neighbours). The boundaries of the lattice are connected to each other: the diagrams represent in fact the unfolding of a torus.

Although the regularity of connections on a square lattice make it a poor candidate to model a social network, the existence of short inter-

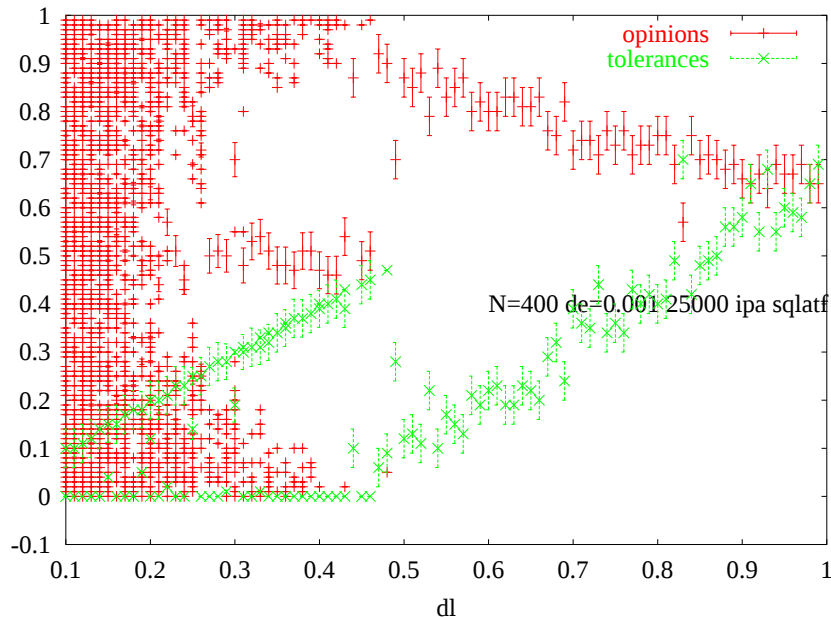


Figure 3: Histograms of asymptotic clusters for interactions across a square lattice topology. Same coding as the previous figure. One single extremist present, $N = 400$, $de = 0.001$, average number of iterations per agent 100 000. Single element clusters are exceptionnally represented on this figure, in order to check that the initial extremist himself moves towards centrism at large dl values.

action loops is shared with many empirical social nets. But again, the purpose of this paper is to increase our understanding of the dynamics of more complicated cases and the possibility to observe patterns determined our choice of lattice topology. The relevance of the results to other topologies will be further discussed.

The main difference in dynamics between well mixed systems and the square lattice structure appears in the $dl > 0.5$ region. For values of dl just above 0.5, the extremism regime seems to re-appear (see figure 3). A closer examination of the dynamics, (see figure 4) shows attraction towards extremism proceeds locally on the lattice in the neighborhood of the extremist. This spatial diffusion process is not the same as the emergence of single sided extremism in well-mixed systems as described in Deffuant et al [1]: in well-mixed systems one first observe a convergence towards a attractor with centrist opinion

and low tolerance which is often unstable and slowly evolves towards extremism.

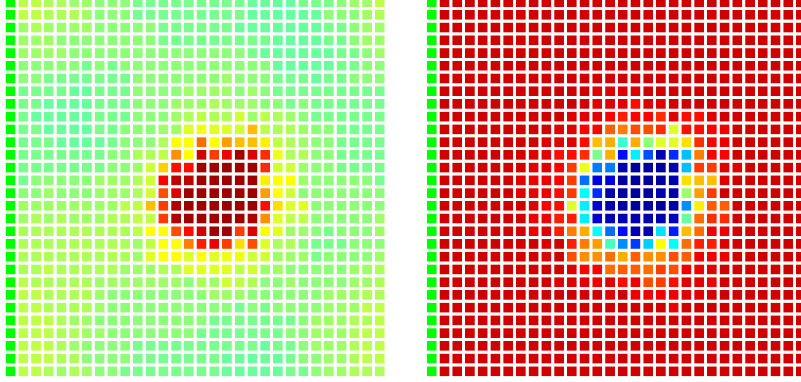


Figure 4: Propagation of extremism from a single initial extremist at the center of the lattice. Left frame: Opinions after 27 iterations per site . Color scale: deep blue 0, light green 0.5, brown 1. Right frame: Tolerances after 27 iterations per site . Color scale: deep blue 0, brown $d_l = 0.55$, initial centrist's tolerance. Initial extremist tolerance 0.001.

But for large value of dl , the influence of extremist seems to weaken. Let us see why. The propagation of extremism proceeds from the initial extremist is initially asymmetric, since the initial extremist and the new “converts” are separated from their neighbours down stream by an opinion gap intermediate between the two tolerances. But as diffusion proceeds, the opinion difference decreases below the low tolerance of extremists thus allowing symmetric interactions to occur, as we checked during the simulations. Initial and converted extremists become fully coupled by symmetric diffusion dynamics and their opinion is also influenced by those of their centrist neighbours. The position of the final cluster reflects this balance of influence. Initially more tolerant agents (large values of dl) are faster attracted towards the extremist, and their increased number favours the cluster evolution toward the center in opinion and towards dl in tolerance. (By contrast, in the case of full mixing, all agents can be attracted by the extremist when it acts as a source; there are no screening shells in the vicinity of the extremist).

The effect is density dependant: for a smaller lattice, $N = 100$, the deviation of extremism towards the center is much weaker (the opinion cluster is at 0.9 rather than 0.7 at $dl=0.99$), for the same values of the

initial tolerances. In other words, this effect is not a standard seed effect as usually observed in phase transitions where a single seed is able to drive all the system to another phase.

The same coexistence region when $0.37 < dl < 0.52$ with the occurrence of either type of attractor is observed with the lattice topology, as when all interactions are a priori possible.

4 Simulation with several extremists

4.1 Low extremist density and full mixing

Deffuant et al [1] report the existence of several dynamical regimes for the full mixing case in the presence of extremists of both kind:

- When $dl < 0.5$, extremists are not important and clustering follow the standard $1/2d$ rule.
- When $dl > 0.5$ they determine the dynamics:
 - at high extremist initial density, clusters of extremists appear at both end of the spectrum;
 - at low extremist density, instabilities often arise, and the system might evolve in a single asymmetric extreme attractor at one end of the spectrum, or even reach an attractor with centrist opinion but extremist low tolerance.

All time plots and regime diagrams are given in their paper [1].

4.2 Low extremist density on a square lattice topology

For low extremist density, we observed the same 3 regimes, centrism, polarised extremism and bi-extremism, as in the full mixing topology (figure 5).

At larger threshold, $dl > 0.5$ bi-extremism is always observed (see e.g. figure 6). In the presence of several extremists at both ends of the spectrum, the lattice is divided in extremist domains of different opinions with boundaries separated by opinion differences larger than the tolerance threshold. The size of these domains is smaller than the lattice size and the dilution of extremism in the sea of centrist as observed for single extreme dynamics at large dl values (see figure 3) does not occur. The evolution of the domains towards centrist opinion

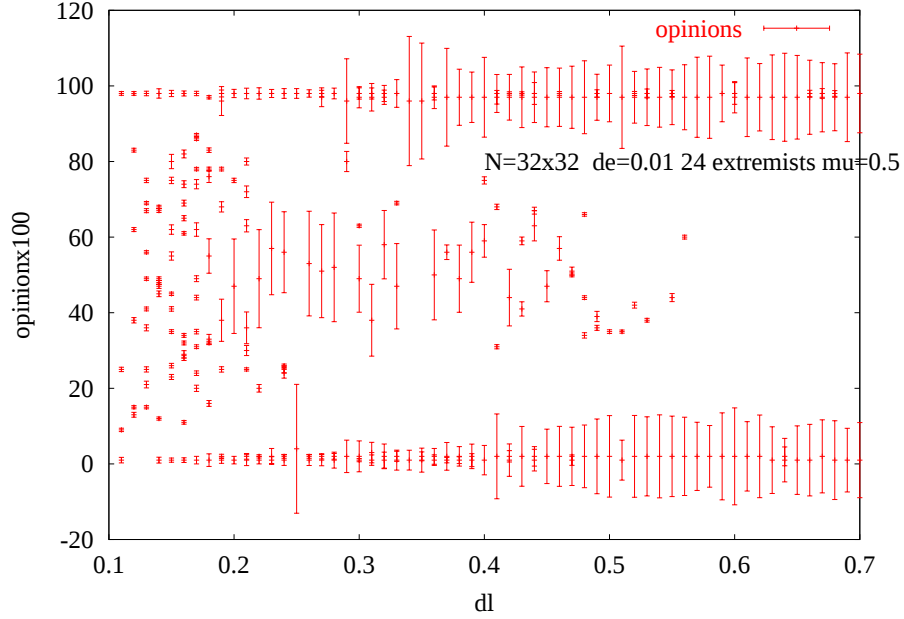


Figure 5: Clustering as a function of centrists' threshold dl . Vertical bars represent clusters: their center gives cluster's average opinion and their length give the number of agents belonging to the cluster. Note the existence of e.g. centrist attractors at $dl = 0.28$, single extreme attractors at $dl = 0.35$, double extreme attractors at $dl = 0.56$.

is limited by their size, which varies itself as the inverse of the square root of extremist densities.

As soon as the threshold is lower than 0.5, centrists position become stable. Their importance increases when threshold decreases. In the intermediate region, $0.25 < d_l < 0.5$, the 3 regimes can be observed. Which regime is observed depends of the initial sampling of the homogeneous opinion distribution. But, of course, the probability of observing a given regime depends upon the threshold.

These results apparently contradict [12] who don't report the observation of single extremism attractor: in fact this is because their simulation were done at higher extremist densities than ours.

Since evolution towards a single extreme is the most intriguing regime let us first observe the evolution towards this regime. The next figures display opinions and tolerances on a 64×64 square lattice after 300 and 2000 iterations per site on average. There were initially 12

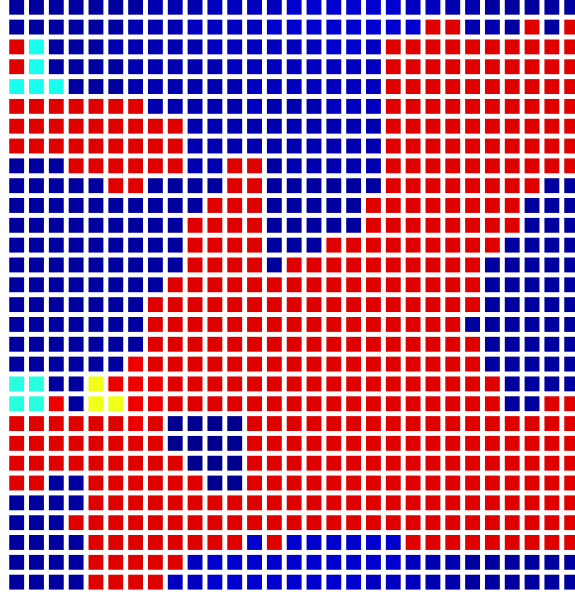


Figure 6: A bi-extremism opinion pattern observed after 100 iterations per agent for initial tolerances of $dl = 0.65$ and $de = 0.001$. Initially, twelve extremists (on each side 0 or 1) were present. Two extreme domains are seen with a few agents at the interface with centrist opinion but low tolerance.

extremists of either side, $d_l = 0.38$, $d_e = 0.01$ and $\mu = 0.5$. Extremism, both in opinions and in intolerance, clearly propagates from the lower left side of the lattice and eventually invades it.

After 2000 iterations the percolating cluster is uniform at a low, but not extreme, opinion and tolerance values.

The patterns of figure 7 exemplify the different possible influence of initial extremists, according to the first events occurring in their immediate neighborhood. One can distinguish two different “geographic” configurations:

- **Mesas** A few extremist islands, with opinion and tolerance close to the initial extremist values survive, but their influence on their neighborhood is zero: the difference in opinion at the edge between those agents on the mesa and all their neighbours is larger than $dl = 0.38$. Obviously small values of dl favour mesa which disappear whenever $dl > 0.5$.
- **Hills** The success of the extremists in the lower left corner is

due to local fluctuations in opinions: there exists in their neighborhood centrists which opinion is within the large tolerance distance. Since the dynamics results in decreasing local opinion gradients, the diffusion process once started carries on across the lattice, unless such hills collide at larger initial extremist densities as seen on figure 6.

In fact restricting interactions to the lattice structure results in two dynamics: fast local opinion clustering and eventually slow diffusion across the lattice of local fluctuations. A time plot of opinion and gradients average across the lattice allow to distinguish among the fast local averaging of opinions and the slow diffusion of extremism (figure 8). The average squared opinion gradient is evaluated by :

$$G = \sum_i (x_{i+1} - x_i)^2 \quad (7)$$

The average gradient decreases very rapidly towards low values reflecting the fact that opinions locally average very fast. This fast relaxation time does not depend upon the size of the lattice.

The slow diffusion of extremism is reflected in the slow decrease of the average opinion from 0.5 the average of the initial uniform distribution towards 0.25 corresponding to the "relative" overcome of extremism. The diffusion time varies as the square of the linear size of opinion domains.

5 The global picture and the "hopeful monster hypothesis"

Our expectation which global attractor is reached when extremists of either side are randomly scattered is then:

- Above $d_l = 0.5$, extremists are always able to influence some centrists in their immediate neighborhood and extremism prevails at large times. When extremists of both kinds are present the lattice ends up subdivided in domains of extremists of either side.
- Between $d_l = 0.5$ and $d_l = 0.25$, extremists are not always able to influence centrists in their immediate neighborhood. Chances of conversion to extremism depend upon the existence of neighbours close enough in opinion (i.e. with difference in opinion

smaller than threshold). Since an initial extremist is only one among four neighbours of its centrist neighbours, the random sampling of pairs might result in initial interactions of these neighbours with centrists (with a 0.75 probability), thus making it harder for the extremist and its neighbour to later interact.

- At small extremist density, there is a threshold region such that the probability of having only one diffusing extremist "hill" is large enough to observe single extremism convergence. This is also true if there are several "hills" on the same extremist side, either close to 0 or close to one.
- At large extremist density, one obtains several hills and bi-extremism is by far the most frequent attractor.

Chances of extremists to influence their neighbours anyway decrease with d_l and one observes mostly one centrist attractor when $d_l < 0.33$.

- Below $d_l = 0.25$, the lattice is highly divided between many clusters some of which are extremists.

The basic hypothesis is that when the density of extremists is low, the initial growth of "extremist hills" are independent events which occurrence only depends upon a restricted neighborhood of each initial extremist. These "extremist hills" can be called "hopeful monsters" since they are susceptible to grow and invade the lattice as opposed to the "mesa" configurations.

If we call P_0 the probability of occurrence of a hopeful monster, we can obtain the probabilities of observing any of the 3 attractors by simple combinatorics. In the presence of $2n_e$ initial extremists (n_e extremists close to 1, n_e close to 0) on a large lattice (to ensure independence), these probabilities are given by:

$$P_c = Q_0^{2n_e} \quad (8)$$

$$P_{bie} = (1 - Q_0^{n_e})^2 \quad (9)$$

$$P_{moe} = 2(1 - Q_0^{n_e})Q_0^{n_e} \quad (10)$$

- where: $Q_0 = 1 - P_0$ is the probability of any initial extremist to give a "sterile" mesa;
- P_c is the probability of getting a centrist cluster (i. e. du to the absence of any extremist hill);
- P_{bie} is the probability of getting clusters of extremists of both kind (two kinds of hill present);

- P_{moe} is the probability of getting a single extremist cluster (only hills of the same extreme grow);

These expressions are immediately generalised to the asymmetric case when the initial numbers of extremists close to 0 and to 1 are different. They imply that the initial number of extremists is important, not their density, at least in the limit of low densities.

The exact calculation of P_0 as a function of the threshold d_l involves a rather intricate combinatorics on the possible initial configurations of the extremist's neighborhood and on the initial sequence of iterations. But P_0 is easily evaluated by simulations. We did it on a 32x32 square lattice with a single extremist in the center.

Knowing P_0 allows to check the "independent hopeful monster hypothesis" which predicts the occurrence of attractors with probabilities given by equations (8-10). Let's take the case of $n_e = 3$. Equation 5 predicts a maximum P_{moe} probability of occurrence of a single extremist attractor of 0.5 at $Q_0^3 = 0.5$, which corresponds to $Q_0 = 0.79$ and approximately to $d_l = 0.35$ according to figure 5. The statistics plotted on figure 6 roughly confirm this prediction: The maximum of P_{moe} is around 0.5 and occurs around $d_l = 0.38$.

Figure 9 and expressions 8-10 then give a clear prediction of the succession of the most frequent attractors when centrist initial tolerance is decreased from 0.5 to 0.25.

- Bi-extremism is predominant until $(1 - P_0)^{n_e}$ is close to 0.5. How close?
- The width of the single extremist region, W_{moe} , is evaluated from equation 10. We define it as the region where the probability of the single extremist attractor is above one half of the maximum ($P_{moe} > 0.25$).

$$W_{moe} \propto (n_e)^{-1} \quad (11)$$

- Below the single extremist region, centrist attractors are predominant.

So according to the above analysis, single extreme attractors should be observable even in the presence of many initial extremists.

But large fluctuations of the statistics of "hills" and "mesa" are observed in figure 9 and 10 due to the vicinity of regime transitions (these two figures represent averages over 1000 samples, and fluctuations are still noticeable). These fluctuations reduce the occurrence of

single extreme attractors at larger n_e values. Furthermore increasing n_e decreases the distance between sources of intolerance that cannot be considered as independent anymore: the probability of a "centrist" to be early influenced by an extremist is increased by having more than one extremist neighbour.

A rapid survey of the d_l region most favourable to single extreme attractor, $0.34 < d_l < 0.40$, when the number of extremists is increased from 0.4 to 2 perc. show that the probability of observing single extreme attractors decreases from 50 perc. to 4 perc. This is consistent with Amblard and Deffuant [12] who report the absence of any single extreme attractor for extremist densities higher than 2.5 perc.

5.1 Scale free networks

What about more realistic topologies? Since the successive neighbourhood structure is preserved in all networks topologies, except fully connected networks, we expect that the same intermediate scale features which drive the dynamics, such as mesa or hills in opinions or boundaries across domains are present for different topologies. Can we expect equivalent phase diagrams, with possibly more irregularities such as outliers and co-existence phases?

We then run the extremist dynamics on scale free networks[17] to test the above prediction (equivalent phase diagram). (After small worlds networks were introduced by Watts and Strogatz [16], scale free networks became recently the strongest contenders as models of social networks). Scale free networks differ from lattices by the inhomogeneity of connectivity and by their smaller diameter.

We used a standard construction method to generate scale free networks, see e.g. Stauffer and Meyer-Ortmanns [18]:

Starting from a fully connected network of 3 nodes, we add iteratively nodes (in general up to 900 nodes) and connect them to previously created nodes in proportion to their degree. We have chosen to draw two symmetrical connections per new added node in order to achieve the same average connection degree (4) as in the 30x30 square lattice taken as reference. But obviously the obtained networks are scale free as shown by Barabasi and Albert[17].

In fact scale free networks [17] display a lot of heterogeneity in nodes connectivity. In the context of opinion dynamics, well connected nodes might be supposed more influential, but not necessarily more easily influenced. At least this is the hypothesis that we choose here.

We have then assumed asymmetric updating: a random node is first chosen, and then one of its neighbours. But only the first node in the pair might update his position according to equ.1, not both. As a result, well connected nodes are influenced as often as others, but they influence others in proportion to their connectivity. This particular choice of updating is intermediate between what Stauffer and Meyer-Ortmanns [18] call directed and undirected versions.

The cluster diagram obtained with 24 initial extremists out of 900 agents (with the same parameters as for figures 5 and 6) is represented on figure 11.

- Similarity with lattice dynamics. Below $dl = 0.45$ this cluster diagram closely resembles those we obtained for square lattice, with predominance of centrism. Above $dl = 0.45$ one also observes the predominance of some kind of extremism, with a limited final tolerance.
- Differences. But the only two kinds of observed attractors are low tolerance centrism and single sided extremism. We don't observe two sided extremism attractors as with lattices. The large inhomogeneity in nodes connectivity favour well connected nodes: most often, the best connected extremist impose his view nearly everywhere. And there are still minority clusters around the other extremists. The asymptotic clusters with central opinion are probably obtained when the initial sampling of extremists does not contain highly connected nodes.

The present result is still preliminary: the distribution of the connectivity of initial extremists is only a rough predictor of the outcome of the dynamics. More complete studies, outside the scope of the present paper are still needed.

6 Conclusions

The above series of simulations give a clearer picture of the phenomena occurring in this strongly simplified model of opinion dynamics.

The most important result, already established in Deffuant et al [1], is also true for lattice and scale free networks topologies: the existence of extremist regimes is largely due to the large tolerance of agents which were initially centrists.

One difference is observed in the dilute regime on lattices: when initial extremists are far apart in the network, their influence at large tolerance $dl > 0.5$ can be counter-balanced by centrists influence; at infinite dilution centrism would win. In some sense social networks can limit the propagation of extremism. Here is a possible explanation of the strategy of some sects which concentrate conversion efforts on a limited number of individuals by repeated interaction rather than broadcasting across whole earth.

We established that all attractors observed in the full mixing hypothesis, including single extreme, can be obtained on a square lattice for low initial extremist densities.

At higher extremist densities and large centrist tolerance, the lattice structure favours two sided extremism, while single sided extremism is favoured by scale free networks. Even our preliminary results allow to understand why extremists (or market strategists) should first convince leader figures to establish their influence on a social network.

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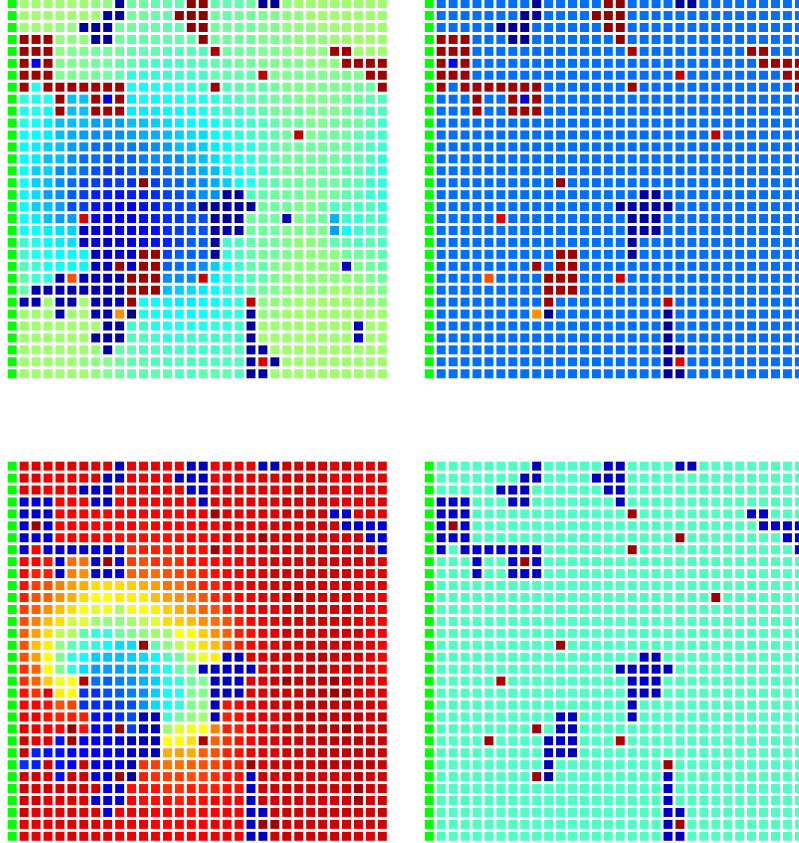


Figure 7: Upper frames: Opinions after 300 iterations per site (left panel) and 2000 (right panel). Color scale: deep blue 0, light green 0.5, brown 1. Lower frames: Tolerances after 300 iterations per site (left panel) and 2000 (right panel). Color scale: deep blue 0, brown $d_l = 0.38$, the maximum initial centrist's tolerance.

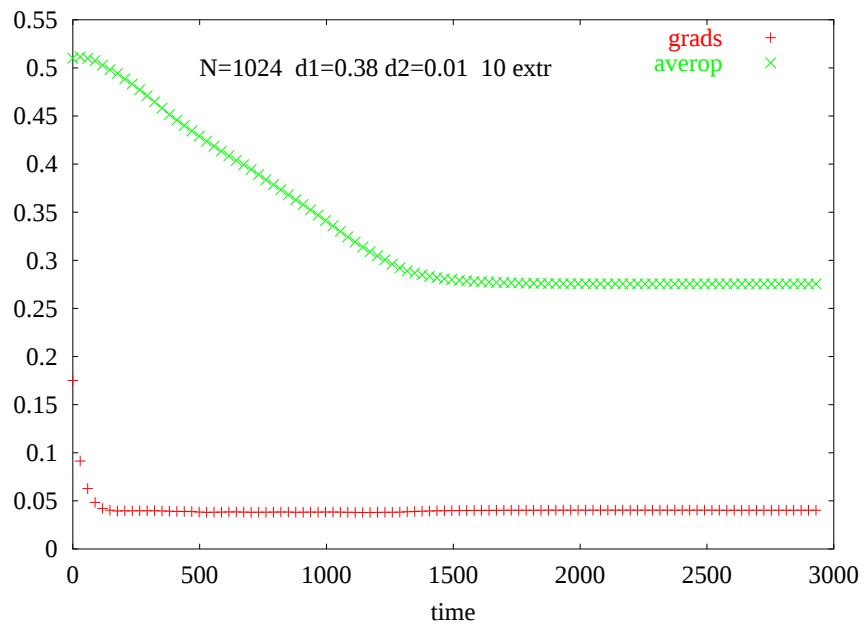


Figure 8: Time evolution of opinion and gradients average across the lattice.

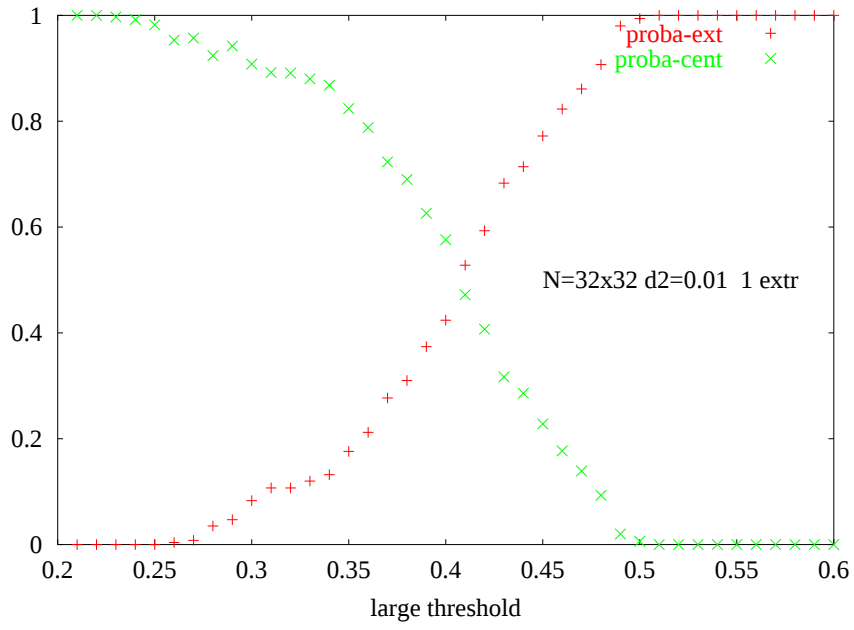


Figure 9: Statistics of extremist attractors (red '+') and centrists attractor (green x) as a function of centrists' threshold. Each point corresponds to 1000 samples on a 32x32 lattice with one central extremist.

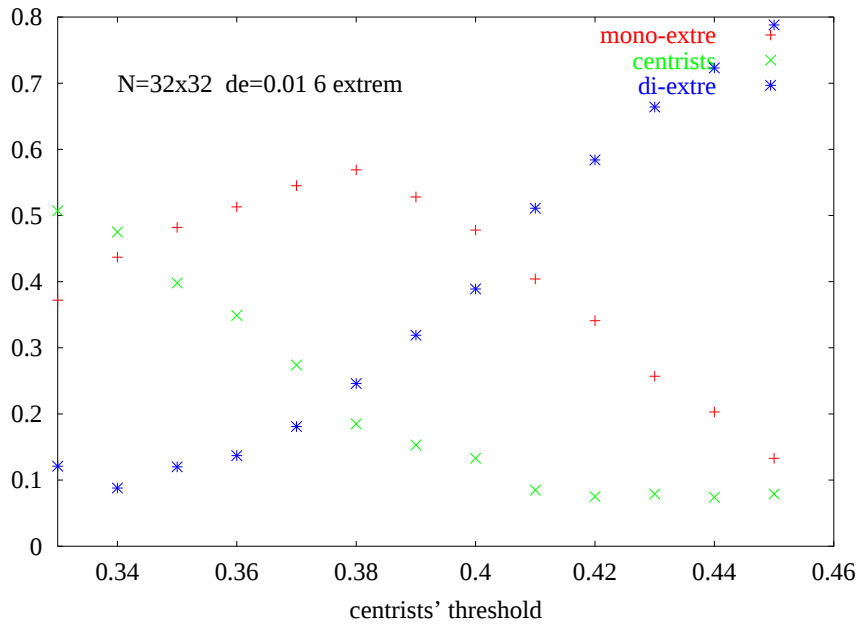


Figure 10: Statistics of attractors: red '+' are single extreme, blue '*' are double extreme and green 'x' are centrist attractors; as a function of centrist threshold. Each point corresponds to 1000 samples on a 32×32 lattice with 6 extremists.

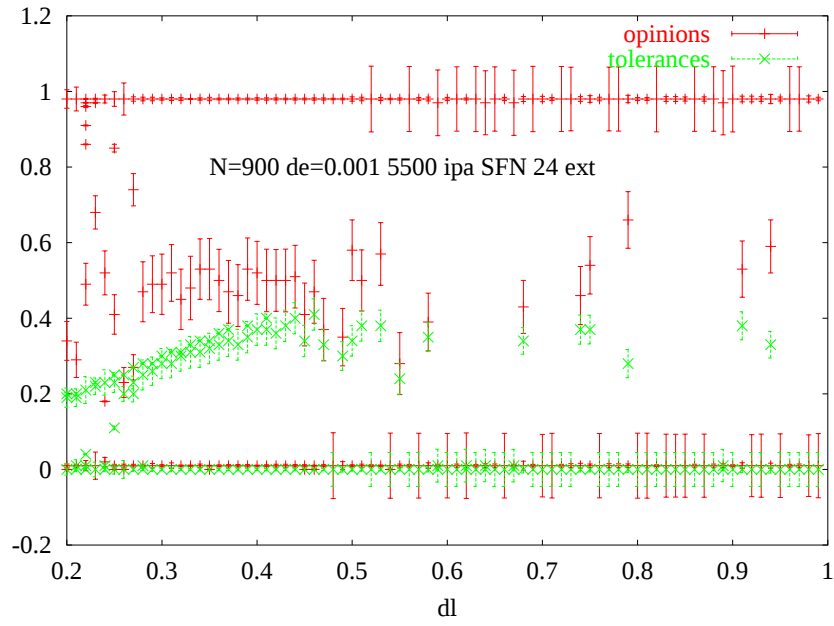


Figure 11: Clustering as a function of centrists' threshold dl for a scale free networks with the same parameters as for the diagram displayed for the square lattice on figure 5. The size of the bars representing tolerance clusters is reduced by a factor two for clarity reasons.