Supplementary Material: Ideology, Communication, and Polarisation

Yoshihisa Kashima, Andrew Perfors, Vanessa Ferdinand, and Elle Pattenden

Melbourne School of Psychological Sciences

The University of Melbourne

R code for simulations and figures (CogCompRewire_friendly_full.R) are deposited at https://github.com/ccsmelbourne/ideology.

S1. The Hebbian learning rule used in the connectionist model of the ideological mind

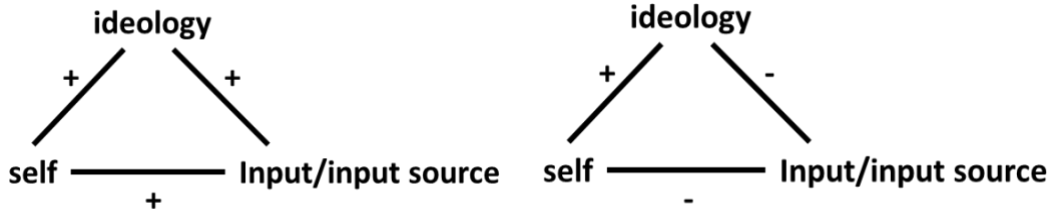
In modelling the memory mechanism, we assumed that an episodic memory is constructed by $\mathbf{E_{ti}} = \mathbf{s_{ti}}\mathbf{e_{ti}}^{\mathbf{T}}$. Recall that $\mathbf{s_{ti}}$ and $\mathbf{e_{ti}}$ are both a column vector with *n* elements. The activation levels for *p*th proposition is indicated by the *p*th element in $\mathbf{e_{ti}}$, $e_{ti}(p)$. Let $s_{ti}(q)$ be the activation level for the *q*th unit in a source representation, $\mathbf{s_{ti}}$. $\mathbf{E_{ti}} = \mathbf{s_{ti}}\ \mathbf{e_{ti}}^{\mathbf{T}}$ yields an *n* x *n* matrix whose element at the *p*th row and the *q*th column, $E_{ti}(q,p) = s_{ti}(q)e_{ti}(p)$, i.e., the product of the activation levels of the *p*th unit in the opinion later and the *q*th unit in the source layer. The pre-existing memory, $\mathbf{M_{(t-1)i}}$, is updated by a weighted average of E(q,p) and $M_{(t-1)i}(q,p)$. This is a form of Hebbian learning rule.

S2. Type 1 process

Type 1 always encodes an input as $\alpha\mathbf{e_{0i}}$, where $\mathbf{e_{0i}}$ represents an ideology as learned by the individual prior to receiving any inputs and $\alpha = \mathbf{e_{0i}}^{\mathbf{T}}\mathbf{input}$ is a cosine similarity between the learned ideology and the input. Further, Type 1 encodes the input source as $\alpha\mathbf{s_{0i}}$, i.e., the self representation as scaled by how similar the input is to the learned ideology. This is because $\mathbf{M_{0i}}$

= $\mathbf{e_{0i}s_{0i}^T}$ for Type 1. As a consequence, the input is represented as $\mathbf{E_t} = \alpha^2\mathbf{e_{0i}s_{0i}^T}$, and $\mathbf{M_t}$ is updated as a weighted average of $\mathbf{E_t}$ and $\mathbf{M_{t-1}}$. Because α^2 is always positive, every new input $\mathbf{E_t}$ starting from $\mathbf{M_0}$ always reinforces the association between the learned ideology, $\mathbf{e_{0i}}$, and one's identity, $\mathbf{s_{0i}}$, and $\mathbf{M_t = e_{0i}s_{0i}^T}$ for all t.

This is akin to Heider's balance principle. If $\alpha = \mathbf{e_{0i}^T input} > 0$, one's self is positively associated with the ideology, the input supports the ideology, and the input source is similar to the self as shown in the left panel of Fig. 1. Likewise, If $\alpha = \mathbf{e_{0i}^T input} < 0$, one's self is positively associated with the ideology, but the input contradicts the ideology, and the input source opposes the self as shown in the right panel of Fig. 1. Either way, this is a balanced triad.



S3. Communication models between ideological minds

Fig. S1 depicts the communication model developed in section **4(a)**, **Communication and Social Influence in Multi-dimensional Opinion Space**, and Equation (2). Also note that there are other models of social influence that incorporate multiple opinions [1-3].

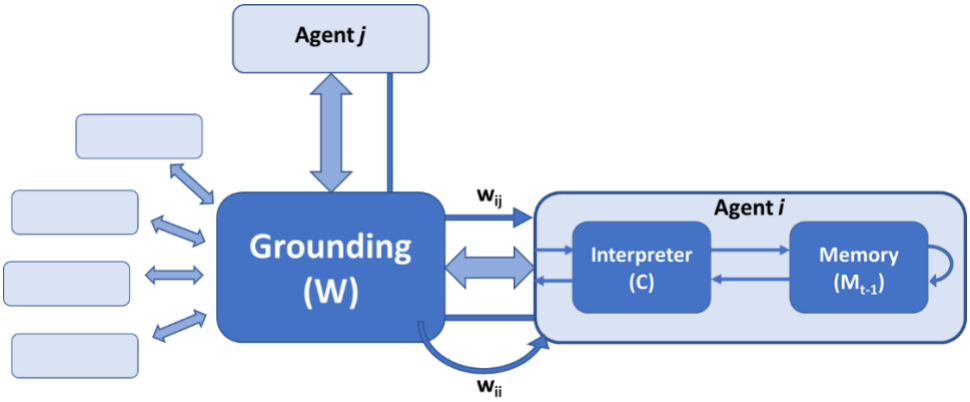


Fig. S1. A schematic representation of agent *j*'s influence on agent *i* (w_{ij}), including agent *i*'s influence on itself, i.e., it's stubbornness (w_{ii}).

Here, we modelled stubbornness, w_{ii}, as follows. First, we assumed that each agent has different levels of "status" within the population, and that a higher status agent had a greater influence on a lower status agent in social interaction [4]. More specifically, we assumed that agent *i* has Status[i], where Status ~ $N(0,1)$, and the unstandardized influence of agent *j* over agent *i*, by a sigmoid function: $uw_{ij} = e^{-2(Status[i]-Status[j]}$. Because Parsegov, Friendkin, and their colleagues' model of social influence [5, 6] stipulates that $\sum w_{ij} = 1 \; over \; all \; j$, we standardised this: $w_{ij} = uw_{ij} / \sum uw_{ij}$.

S4. Simulations of ideological minds reported in section 4(a)

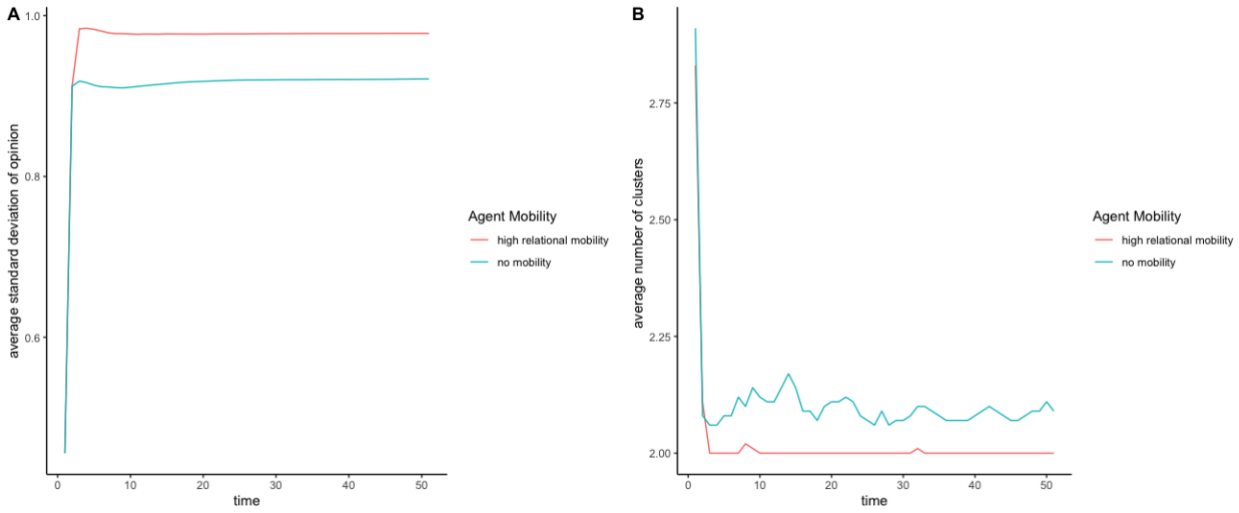
An ideology was assumed to have 5 propositions and the ideology prototype, **a**, was generated by normalizing a random vector with 5 elements with each element sampled from a uniform random distribution between -1 and 1. Unless otherwise stated, we call a vector generated by this process a random vector. For each agent, $\mathbf{s_0}$ was a normalized random vector; $\mathbf{e_0}$ was generated by adding a small Gaussian noise of mean 0 and standard deviation of .1 to each element of **a** and normalizing it; and $\mathbf{e_u}$ was a normalized random vector. Each input was a random vector generated at each time step. The weight for memory process, w_i, was set at .5.

S5. Simulations of communicating Type 2 and Type 4 cognitive agents with and without relational mobility

For each simulation, we computed the cosine similarities of all pairwise opinion vectors at each time step and recorded (1) their standard deviation and (2) the number of opinion clusters. To estimate (2), we constructed a graph that represents the relationships between the agents' opinions and ran a clustering algrorithm, walktrap, in the igraph package of R. We regarded two agents as having a tie if their opinion vectors' cosine similarity was positive, but as having no tie otherwise. These measures yield an estimate of how polarised the population is at that time step. The results are shown in Fig. S2 (Type 2 agents) and Fig. S3 (Type 4 agents).

Fig. S2 reports the standard deviations and estimated numbers of clusters for Type 2 agents (ideological Interpreters). Consistent with the qualitative observation, with mobility the opinion distribution becomes more variable quickly and remains more variable than when there is no mobility. In addition, when there is mobility the dynamics settle down to two opinion clusters quickly; the process is more variable over time without mobility.

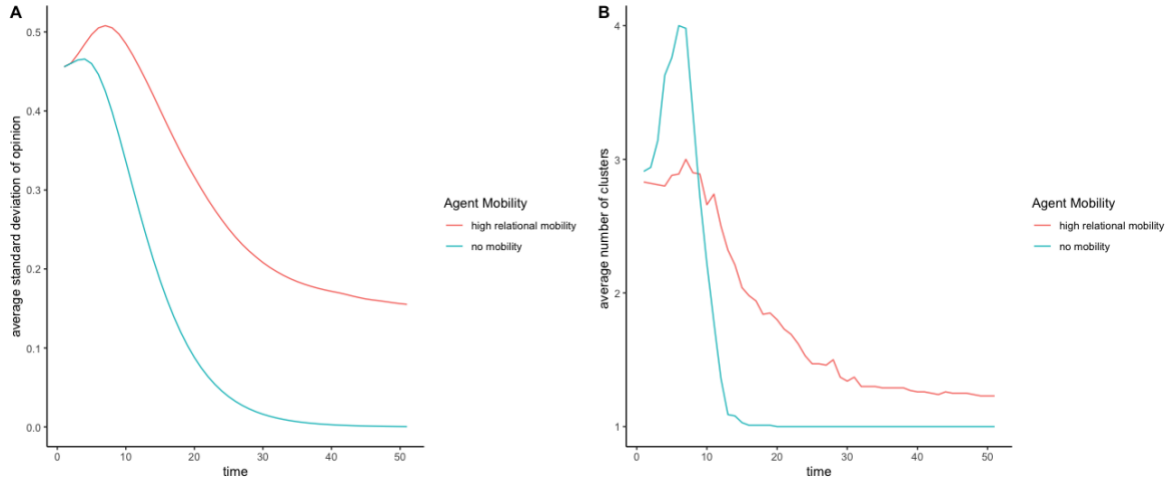
Fig. S2. Mean number of opinion clusters and standard deviation of opinion similarities in simulated opinion dynamics for Type 2 (Ideological Interpreter)



Variation in Type 2 populations. The left panel shows the average standard deviation of opinion similarities. Agents with high mobility, who could seek out who to talk to, showed a higher standard deviation, reflecting more individual variation. The right panel shows the mean number of opinion clusters. The high mobility agents always ended up with two clusters, whereas those who had lower mobility had slightly more on average; either way, there was substantial polarisation whether mobility was high or low. Error bars indicate 95% confidence intervals.

Fig. S3 reports the mean standard deviations and estimate number of clusters for Type 4 agents that have no ideological mindset. With or without mobility, these agents tend to form a single consensual opinion as indicated by low standard deviations and a single cluster. However, with mobility, the mean number of clusters is slightly above 1 and the mean standard deviation above zero, indicating that in occasional runs polarisation is maintained (3 of 100 runs). When there is no mobility, opinion variability is reduced to zero much more quickly and forms a single opinion cluster 100% of the time.

Fig. S3. Mean number of opinion clusters and standard deviation of opinion similarities in simulated opinion dynamics for Type 4 (No Ideological Mindset)



Variation in Type 4 populations. The top panel shows the standard deviation of opinion similarities. Unlike for Type 2 agents, variability diminished over time; as with Type 2 agents, those with high mobility, who could seek out who to talk to, showed a higher standard deviation, reflecting more individual variation. The bottom panel shows the mean number of opinion clusters. Unlike for Type 2 agents, they generally (although not always) converged onto one cluster, but the process took longer and showed more variation when agents had more mobility. Error bars indicate 95% confidence intervals.

S6. Neoliberalism and ieological climate

We justify our claim that neoliberalism may have been a dominant ideology of the late 20th and early 21st century. First of all, neoliberalism as an ideology appears to include multiple dimensions. Bay-Cheng et al. [7] identified at least four dimensions: system inequality (e.g., Affirmative action is an outdated policy now that people are generally treated as equals), competition (e.g., Competition is a good way to discover and motivate the best people), personal wherewithal (e.g., Anybody can get ahead in the world if they learn to play the game), and government interference (e.g., A problem with government social programs is that they get in the way of personal freedom). They reported that these four dimensions correlated in expected ways (i.e., positively) with measures like belief in just world and social dominance orientation, which

correlate very strongly with political conservatism in general. They also reported that their neoliberalism subscales correlated with measures of feminism and perceived sexism.

As Beattie [8] noted, the US-UK led trade liberalization in the 1980s and 1990s has strongly entrenched neoliberal orientations (both Ronald Regan and Margaret Thatcher were clearly neoliberals), and neoliberalism became a mainstream model of governance, which people either took for granted (e.g., Conservatives) or others opposed (e.g., Progressives/Liberals). Other Republican American presidents who followed them (e.g., George Bush, Sr, and George W. Bush, Jr), or even a Democrat president, Bill Clinton, could not ignore a neoliberal ideology (recall "It's the economy, stupid", a statement famously made by James Carville, a Clinton strategist). There was no clear alternative in public discourse after the collapse of the Eastern Bloc and a more "capitalist" turn in People's Republic of China. In many ways, this has led Francis Fukuyama [9] to declare the end of history, prematurely, as noted by Lorenz and his colleagues [10]. For an excellent collection of papers on these topics, see a special issue on neoliberalism in the *Journal of Social Issues* (2019, Issue 1).

References

1. Huet, S., G. Deffuant, and W. Jager, *A rejection mechanism in 2D bounded confidence provides more conformity.* Advances in Complex Systems, 2008. **11**(04): p. 529-549.
2. Lorenz, J., *Fostering consensus in multidimensional continuous opinion dynamics under bounded confidence*, in *Managing complexity: insights, concepts, applications*. 2008, Springer. p. 321-334.
3. Schweighofer, S., F. Schweitzer, and D. Garcia, *A Weighted Balance Model of Opinion Hyperpolarization*, in *56q12sdswx8daaggo3jb0ek2mxts6ndn*. 2019.

4. Correll, S.J. and C.L. Ridgeway, *Expectation states theory*, in *Handbook of social psychology*. 2006, Springer. p. 29-51.
5. Friedkin, N.E., et al., *Network science on belief system dynamics under logic constraints.* Science, 2016. **354**(6310): p. 321-326.
6. Parsegov, S.E., et al., *Novel Multidimensional Models of Opinion Dynamics in Social Networks.* Ieee Transactions on Automatic Control, 2017. **62**(5): p. 2270-2285.
7. Bay-Cheng, L.Y., et al., *Tracking homo oeconomicus: Development of the neoliberal beliefs inventory.* Journal of Social and Political Psychology, 2015. **3**(1): p. 71-88.
8. Beattie, P., *The road to psychopathology: Neoliberalism and the human mind.* Journal of Social Issues, 2019. **75**(1): p. 89-112.
9. Fukuyama, F., *The end of history and the last man*. 1992, New York, NY: Penguin.
10. Lorenz, J., M. Neumann, and T. Schröder, *Individual attitude change and societal dynamics: Computational experiments with psychological theories*.