An Opinion-Driven Behavioral Dynamics Model for Addictive Behaviors

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Abstract:

We present a model of behavioral dynamics that combines a social network-based opinion dynamics model with generative agent behavior. The behavioral component utilizes an initiation threshold such that if an agent's opinion exceeds this threshold, the agent will initiate the behavior. We also introduce an "addiction factor" that reinforces behavior propensities to induce history-dependent agent behavior. This interplay between hysteresis in the behavior versus opinion-driven behaviors characterizes the tradeoffs involved in addiction. This component allows us to model situations in which an individual's behavior is driven less by opinion, and more by physiological or psychological conditions that serve to maintain the behavior.

Individuals are modeled as nodes on a social network where they are connected by directed edges capturing behavior and opinion influence factors. We demonstrate the application of this model to smoking behaviors and related public policies, showing that the effects of policies can interact in synergistic or antagonistic ways with population opinions and individual addiction. We find that interventions are most effective as cocktails addressing both opinion and physiological aspects. For example, public health messages can motivate people to quit by lowering opinions about smoking, but they will be most effective in enabling behavioral change if they are implemented in conjunction with interventions that mitigate the effects of addiction.

Model Specification:

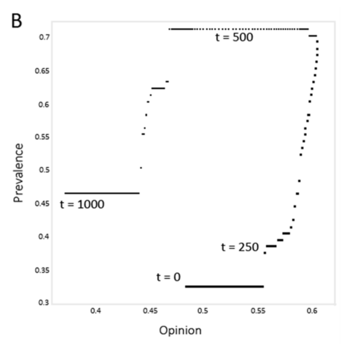
Initial parameters and setup:

- 250 agents/nodes connected using ER random directed network. Each of the possible N(N-1) directed edges exists with p=0.023, yielding ~1437 edges.
- Initial opinion distribution for each product is uniformly random on (0,1).
- The number of products ranges from 1 to 4, but can be expanded.
- The tolerance parameter ε specifies the maximum pairwise difference in opinion for which an agent includes that network neighbor in its opinion updating.

$$\left|x_i(t) - x_j(t)\right| \le \varepsilon$$

Opinion tolerance is homogenous, but its value is swept as a control parameter.

- Agents with an opinion level above their initiation threshold turn into smokers. The initiation threshold is homogenous, and also swept as a control parameter.
- Smoking agents will continue to smoke unless/until their opinion drops below their cessation threshold. However, tobacco product use contributes to addiction, which translates into a decreasing cessation threshold. Therefore an agent's cessation threshold is adaptive to its behavior, but it is initially homogenous, and also swept as a control parameter for sensitivity analysis.



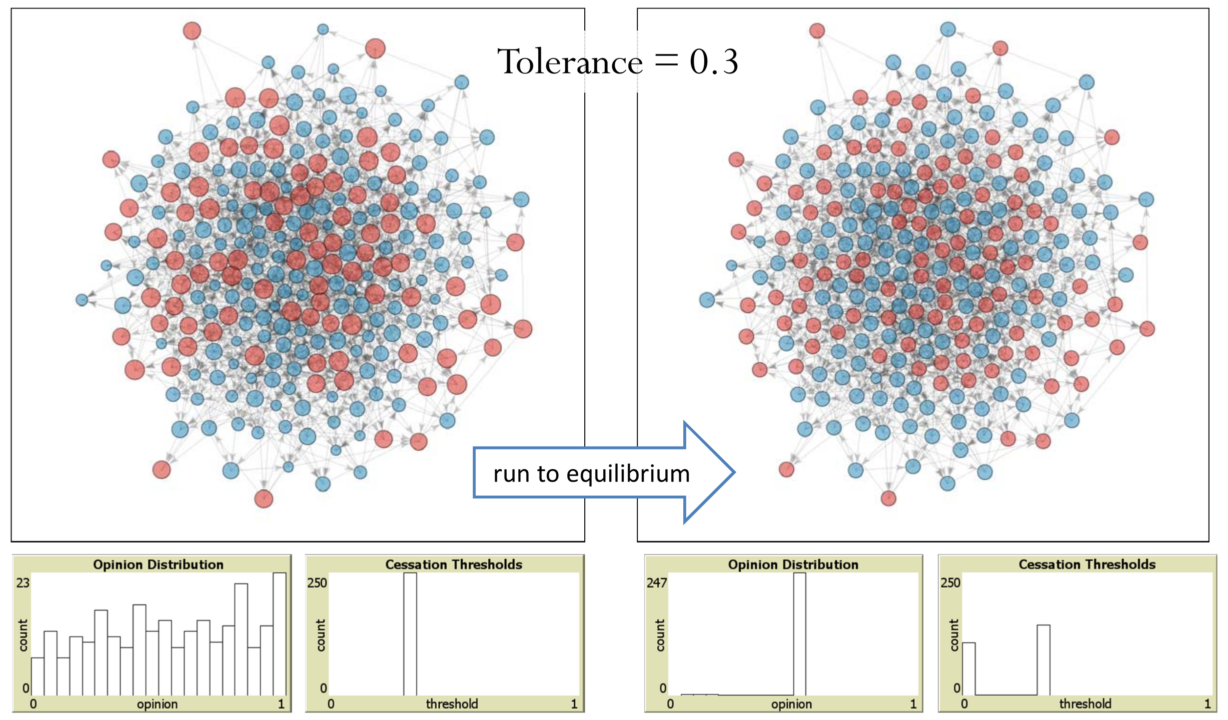
- Agents simultaneously update their opinion based on the permeability−weighted (μ_{ij}=0.1) average opinion across immediate network neighbors (within the tolerance level):

$$x_i(t+1) = x_i(t) + \frac{1}{|S_i|}\sum_{j \in S_i} \mu_{ij}\left[x_j(t) - x_i(t)\right]$$

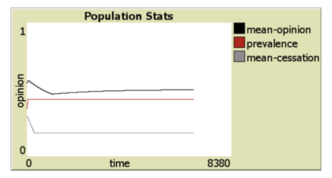
- When included, ad campaigns act as "media nodes" with a large influence (e.g. in-degree of 25), but that are not influenced by other agents (and hence have fixed opinions). The permeability (influence weight) of media nodes can differ from social links (media permeability of 0.05 used here).

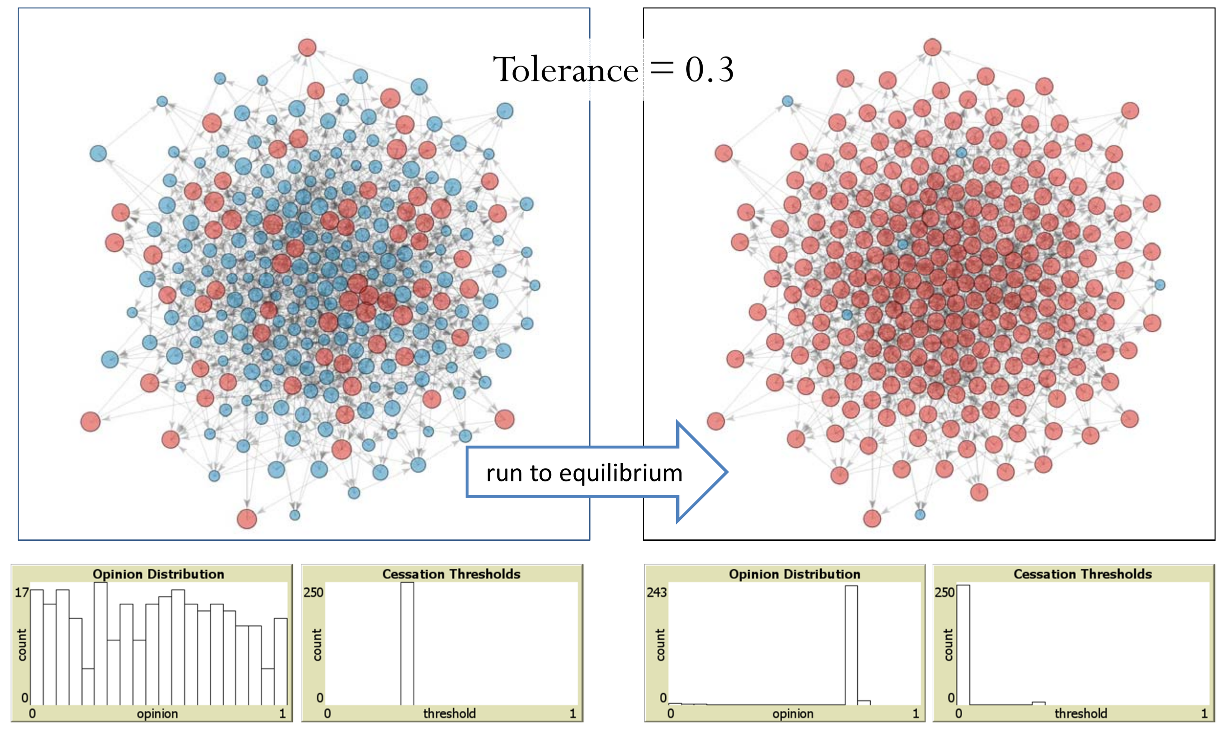
Model Dynamics:

Depending on the details of the hypothetical scenario under study, the system behaviors of this model can vary greatly – including phase transitions and polarized outcomes – through parameter changes and/or random variations in the setup. Some examples of such effects are demonstrated below through hypothetical scenarios in which blue nodes represent non-smokers, red nodes represent smokers, and directed edges represent opinion influence.

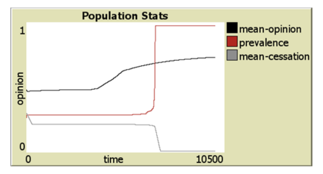


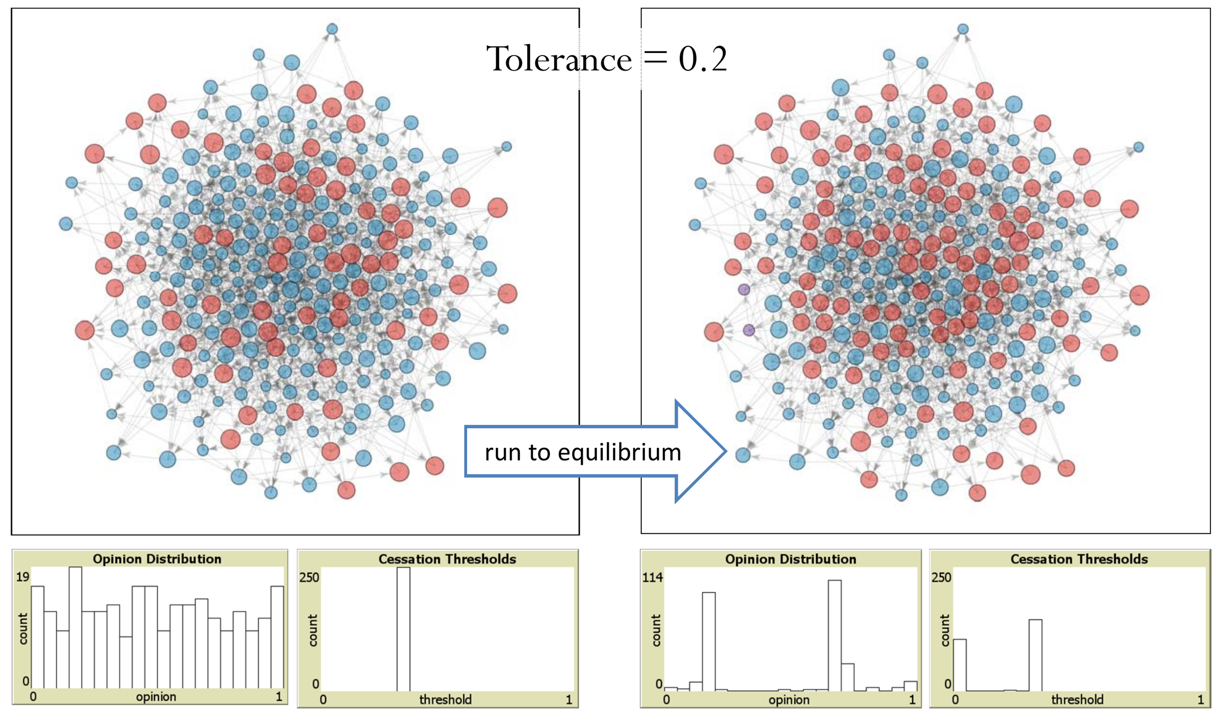
The initially uniform opinion distribution produces a population with a percentage of smokers roughly equal to the initiation threshold level (set here to 0.7). The longer people smoke, the lower their cessation threshold becomes (initially set at 0.3 here). As a result, initial smokers rarely quit, but come to an opinion such that they wouldn't have started smoking. The ending opinion distribution is nearly homogenous, while the smoking behaviors and cessation thresholds widely differ across agents.



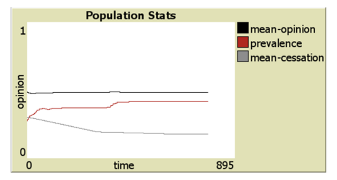


From certain initial configurations of edges and initial distributions of opinions, the system undergoes a sudden transition from a smoking minority to nearly 100% prevalence. However, the opinion change underlying the dramatic prevalence effect is a gradual increase beyond the initiation threshold over a population with similar opinions. The existence of "opinion pumps" (influence others, but not influenced) in the directed network can account for much of the long-term opinion dynamics and equilibrium system state.





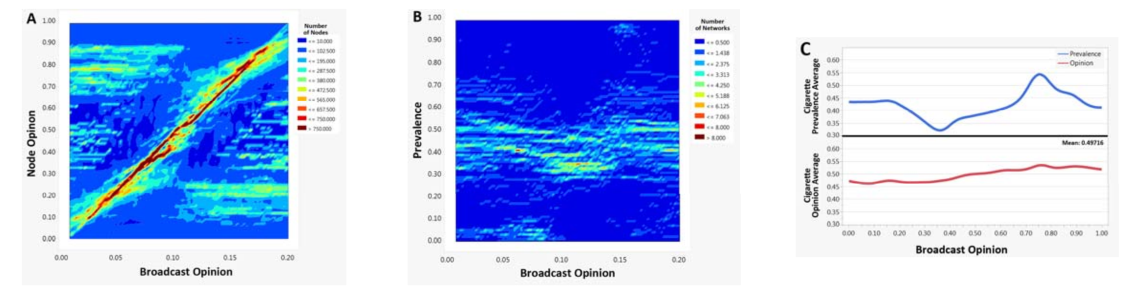
A reduction in the tolerance (the maximum difference in opinion at which agents are influenced by neighbors) below 0.27 generates outcomes with a major split and greater variety in opinions. In this case, many smokers do not wish to quit. Final prevalence levels are more variable, but less extreme, with lower tolerance because opinions are less able to spread. However, increasing the network density again produces more homogenous opinions, which tend to be higher with lower tolerance.



Other parameter sweeps performed include: (1) multiple products and separate risk perceptions for each product to capture gateways to initiation and cessation; (2) media influences by tobacco companies and anti-smoking groups, their trustworthiness, and their influence on opinion; (3) asymmetries in influence compared to reciprocal influence; (4) population size; and (5) edge density.

Model Results:

In order to capture the effects of cigarette advertising and anti-smoking campaigns we tested the resulting opinion and prevalence values for injecting opinions across the (0,1) spectrum via a media node.



We observe that, at any given broadcast opinion value, the media node is capable of influencing significant numbers of individuals, as shown in the individual opinion contour plot. The effect of the broadcast node on average network opinion is more modest, due to the large number of nodes unaffected by the broadcast due to being outside agents' tolerance constraint.

Among the variables we explored the effects of, sweeping the value of the initiation threshold produces system behavior with valuable practical insight. With a low tolerance value (i.e. < 0.27), agents' opinions consistently form multimodal distributions. The prevalence of smokers in diagram (a) below results from the case in which there is no addiction, and the cessation threshold is set to the initiation threshold. Variations in the network structure and influence generate regimes of outcomes for different value ranges, but they do not vary directly with the initiation threshold value.

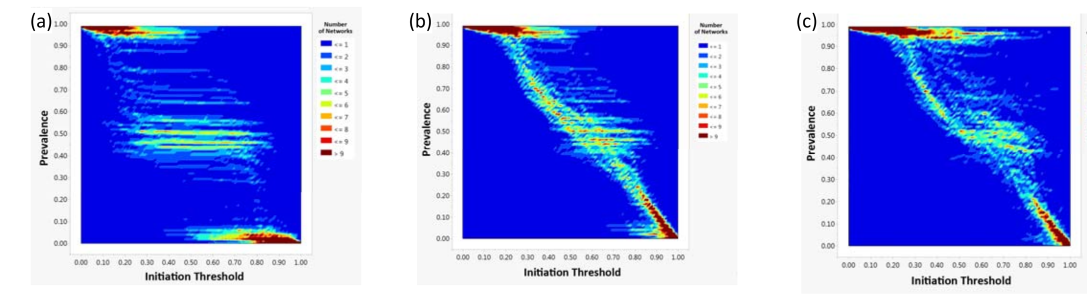


Diagram (b) adds an addiction factor such that cessation is 0.3 lower than initiation, and this generates a more linear relationship between the initiation threshold and prevalence. Diagram (c) includes the addiction factor as well as an advertising campaign with a broadcasted opinion set equal to the initiation threshold plus 0.025. The ability to influence nodes of low opinion when the initiation threshold is low causes saturation at a prevalence of 1.0 for a wider array of initiation threshold values than was shown in previous scenarios, and overall levels of prevalence are increased.

Next Steps:

Our next generation model includes features that facilitate verification, support more developed cognitive processes, and foster advanced social decision making:

- Real social networks – using longitudinal data from schools (and other sources) we are analyzing social and opinion influence characteristics, and their effects on behavior, across time to both inform and validate generated agent behaviors.
- Dynamic social networks – network connections, and thus influence, adapt to behaviors and opinions to reflect homophily and selective detachment.
- Variable consumption – rather than categorizing agents by smoker/nonsmoker, agents will have a variable consumption rate in order to better capture initiation, product transfer, and cessation behavior patterns as well as to more accurately assess health impacts and the effectiveness of specific intervention strategies.
- Richer agent characteristics – we will incorporate the behavior influences of geographic and demographic profiles as uncovered by independent research, tie them into the opinion and social dynamics engines, and use these enriched models to help inform region-specific risk factors and information deployment strategies.

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