A Large-Scale 3D Simulation of Continuous Social Dynamics using Social Particle Swarm Model on Parallel Architecture

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Introduction

Cooperative relationships are important to maintain high adaptivity in our societies while their structures undergo constant change. The development of information technology made a great impact on our lives and the way we interact; Social Networking Services brought about high continuity in our social interactions in two senses: One is temporal continuity by keeping us constantly connected in time in a non-discrete way, as well as in parallel; through hand-held devices for example, numerous people interact within an extended time frame and mostly are connected at the same time. The second is continuity in the closeness of social relationships. We use various kinds of SNS with different topologies of interactions and communicate with others at different frequencies, which presents continuous variations in the degree of social closeness with others. In addition, the exponential expansion of these networks in the world and consequently, the scale of interactions is another indicator of the major effect of these networks on our social relationships, allowing for larger-scale communication by alleviating the physical boundaries and increasing the rate of interactions over the globe.

Based on the concept of self-driven particle models, Nishimoto et al. constructed a simple computational model for investigating such continuously changing social relationships termed social particle swarm (SPS) model (Nishimoto et al., 2013). They assumed that individuals were in a two-dimensional social or psychological space, and the proximity between two individuals reflects their social or psychological closeness. Interactions between individuals in the space is regarded as changes in social or psychological relationships based on game-theoretical relationship (e.g., prisoners dilemma) between strategies of individuals. Each particle has a strategy for the prisoners dilemma game, and gets closer to (away from) neighbors from which each particle obtains positive (negative) payoffs. They observed repeated occurrences of explosive dynamics that consisted of a formation of an altruistic cluster followed by its collapse with explosive dispersal of defective particles. The similar dynamics were observed both computationally and experimentally (see (Suzuki et al., 2018)). However, it is still not clear whether and how the significant increase in the scale of social networks, as discussed above, can bring about more diversity and demonstrate emerging patterns for higher-level interactions. Such hierarchical structures and interactions between communities are ubiquitous in real societies, and we expect that larger population sizes enable us to see novel emerging patterns both structural and behavioral.

Our purpose is to construct and analyze a large-scale 3D simulation of continuous social dynamics using an extended SPS model on parallel architecture. We use a 3D space as a minimal approximation of a complex of social relationships that have much larger dimensions and comprise many channels of interaction, keeping sufficient spatial locality even when there is a large number of agents. Due to the demanding computational power of large multi-agent systems' simulations, parallel architecture as a simulation platform best fits our goal. We devised an extension of the original SPS model to 3D space and implemented it using an open source framework for multi-agent simulation on GPGPU, called Flame GPU (Richmond and Chimeh, 2011). We conduct a preliminary analysis on the behavior of the population while varying the population size.

Model

We assume N agents represented as particles arranged in a cubic space (4^3) with a periodic boundary condition. The position of each agent represents her social relationship against the other agents, which approximates her physical, social and psychological properties that may affect its interest against its neighbors. The proximity between two agents reflects their social closeness.

At each time step, the game theoretical relationship of each agent is determined in the same manner as in the SPS model. Each agent (i) calculates the ratio of cooperators (rc) among her neighbors, which is defined as agents within the interaction range $(IR = 0.1)$ around her, in the previous step. The agent compares it with her own cooperation threshold (ct) the value of which is randomly pre-set. If $rc > ct$, she selects '*Cooperation*', otherwise, she selects

'*Defection*'. Moreover, an agent switches her current strategy with a small probability ($p = 0.00003$).

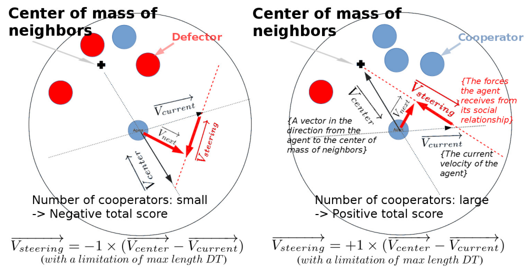

Figure 1: Movement selection.

Then, the type of movement (attraction/repulsion) of an agent (i) is decided upon the total score she receives from her neighbors, inversely weighted by the distance between the focal agent and her neighbors: $total\_score_i = \sum_{j \in Neigh_i} \frac{pay_{(i,j)}}{|\overrightarrow{d}_{i,j}|}$, where $pay_{(i,j)}$ is the payoff agent (i) obtains from a prisoner's dilemma game with an agent j (R=1, T= 1.4, S=-1.4, P=-1). $Neigh_i$ are the neighbors of agent i, and $d_{i,j}$ is the distance between i and her neighbor j. As indicated in Figure 1, if the total score is higher than 0, the agent moves towards the center of mass of her neighbors (attraction). Otherwise, it gets away from her neighbors (repulsion). This is a simplified version of the behavioral rule in the SPS model for a smoother integration within Flame GPU framework. We use Reynolds' steering formula (Reynolds, 1999) to get each agent's steering force vector (i.e., the force the agent receives from her social relationship) $\overrightarrow{V_{steering}}$ with a maximal velocity $DT (= 0.015)$.

Results and observations

We ran simulations with N=1,000; 10,000 and $100,000$[1]. Figure 2 shows (a) the speed-size distribution of clusters, classified with the DBSCAN algorithm, when $N = 1,000$ and $100,000$ (left), and a snapshot of (b) the whole population and (c) an explosion of a cooperative cluster when $N = 100,000$. Agents started randomly navigating the 3D space. Shortly, they began forming cooperative clusters, then moving as a whole unit, wandering about the center of the cluster (Figure 2 (b)). Some cooperative clusters started exploding as a result of overpopulation by defectors which was observed in the original SPS model (Figure 2 (c)). We also observed that some clusters got closer and merged or collapsed, and an explosion of a large cluster brought about multiple small clusters, which further affected the behavior of other clusters.

From Figure 2 (a), we see that there was a very large variation in the size when N was large. The speed of larger clusters tended to be around 0.01, which is due to the fact that a lot of agents went around the center of the cluster, keeping the whole cluster at a fixed location. We also see that there were relatively large variations in the speed among smaller clusters, this is also expected to be due to the fact that an explosion of a large cluster brought about such variations in clusters and their speed. As the simulation time elapsed, the whole population structure tended to converge to a scale-free like distribution of the clusters size, which we need to further investigate. The mutation rate also had an effect on clustering behavior; increased values ($p = 0.03$) introduced a lot of wandering agents in the population. With higher values ($p = 0.3$) there were hardly any clusters.

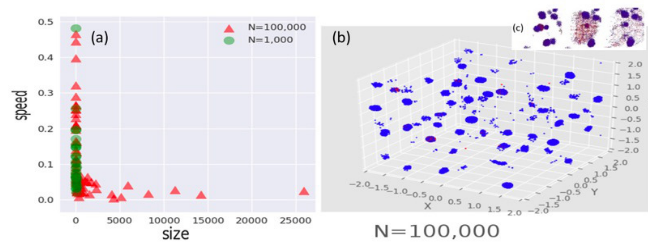

Figure 2: (a) Speed and size distribution of clusters for $N = 1,000$ and $100,000$. (b) Clusters positions in 3D space and (c) an explosion of a cluster for $N = 100,000$.

Conclusion

We constructed a large-scale 3D simulation of continuous social dynamics using a self-driven particle model. The large population size had an important effect on cooperative behavior, and it allowed for distinctive patterns to emerge that can hardly be seen in smaller populations, such as inter-cluster interactions and a scale-free like distribution of the clusters size.

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[1]Video demos on Youtube: `https://bit.ly/2IUWbY7`