# Modelling opinion dynamics of an adaptive robot swarm

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We model opinion dynamics on a time-varying network and we show that model predictions are improved by using Holling's type II functional response to modulate the interaction rate.

We study the opinion dynamics of a large group of agents that moves in a bidimensional environment and interact locally with each other. This kind of model can describe diffusion of opinions in living societies, as well as in artificial swarms. We aim to engineer the behaviour of an adaptive robot swarm able to agree on the best available option in a dynamic environment. Options refer to environmental aspects that robots can locally sense from the environment (*e.g.* locations of interest in the environment) and make noisy estimates of the option's quality. We analyse a minimal voting behaviour that allows the system to both reach consensus when environmental conditions are stable, and to adapt to changes when the options vary.

**Behaviour.** Robots diffuse in the environment (through random walk) to monitor the available options and to share with each other their opinion on the best location. The robots have a minimalistic behaviour and only store the location and quality of the preferred option. The robots do not know about the number of options or their quality; a robot knows about an option only when it discovers it or other robots vote for it. The voting model that the robot employs is the classical voter model in which, at every update step, robots select one random message among the ones received from the neighbours and set their opinion to the one of the selected message. Voting messages only contain the location of the preferred option thus a robot once informed goes to assess the received option's quality. The swarm converges towards the best option because each robot communicates with a frequency linearly proportional to the estimated quality.

**Adaptation to changing environment.** In several scenarios, the environment can be subject to changes in terms of appearance of new candidate locations, the disappearance of existing location, or change in their quality. A simple variation of the voter model that allows the system to adapt to these changes of options consists in constantly monitoring the environment. The monitoring is implemented by the robots which estimate the quality of every encountered option and switch to it when its quality is superior of the current option's quality.

**Modelling of the decentralised process.** A classical macroscopic description of the decision dynamics is to derive from the state transitions a mean-field model in the form of a system ODE system. Each equation of the model describes how subpopulations (group of robots with the same opinion) change over time. The model assumes a well-mixed system in which interactions are not constrained by the interaction network. This model's prediction is that the system would always adapt to the best existing option even when the initial state is consensus for another option. The predictions do not match the results of the multi-agent simulations. Most of the times, in multi-agent simulations, large swarms do not adapt to changes. To address this behavior, we modify the model by taking into account that in typical robotic systems the network dynamics (change in neighbourhood) are slower than the opinion dynamics (voting between neighbours). Therefore we model the interactions among robots via the Holling's type II functional response. Normally employed in ecology, in our model this functional response describes that new information can diffuse at a rate sublinear to the number of robots and constrained by the rate of interaction with new individuals. This means that the rate by which robots in subpopulation $x$ recruit robots of subpopulation $y$, when $y$ is much larger than $x$, is independent of the size of $y$. The modified model presents a fold bifurcation as a function of the robots' density (*i.e.* average number of robots in communication range) and option's quality. The system prior to bifurcation has a single stable point which corresponds to adaptation to the best option. After the bifurcation, the system has two stable points which may trap the system in the current consensus and not allow it to adapt to the new option. The new model predictions match the multi-agent simulations (see left figure) and the (preliminary) swarm robotics experiments (not shown). In addition, the model also gives insights on how to modify the system in order to improve adaptability in large swarms. A counterintuitive solution suggested by the model results is that adaptability of the group increases as the robot's communication range decreases (see central figure). That is, in our setup, speaking with fewer individuals at a time seems to improve the ability of the system to disseminate new localised information (see right figure).