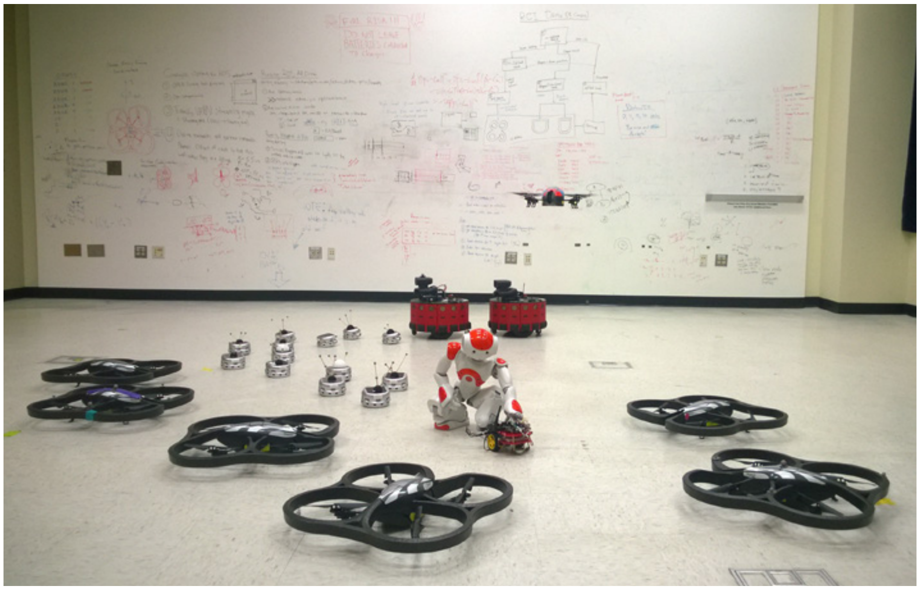
Human Interactions With Complex Networks

Human-Swarm Interactions

Imagine you are surrounded by a million robot mosquitoes and you have a single joystick you can use for interacting with the swarm. How should this interaction be structured?

Appropriate abstractions of the swarm/complex network of agents are needed that are controllable (Can the operator use the abstractions to achieve the desired performance?) and observable (Are the abstractions transparent, i.e., can they be inferred by and acted upon by the operator?).



Inverting the Many-to-One Relationship

As many facets of society move toward greater levels of automation, the current many-to-one relationship, wherein multiple operators are required to control a single dynamical agent (e.g., an autonomous vehicle), is not sustainable. Instead, a single operator needs to be able to influence and control large collections of agents over an interconnected network. At its core, the problem of devising effective control strategies for making human operators able to control complex networks aims at inverting the current many-to-one relationship.

Multi-Agent Robotics

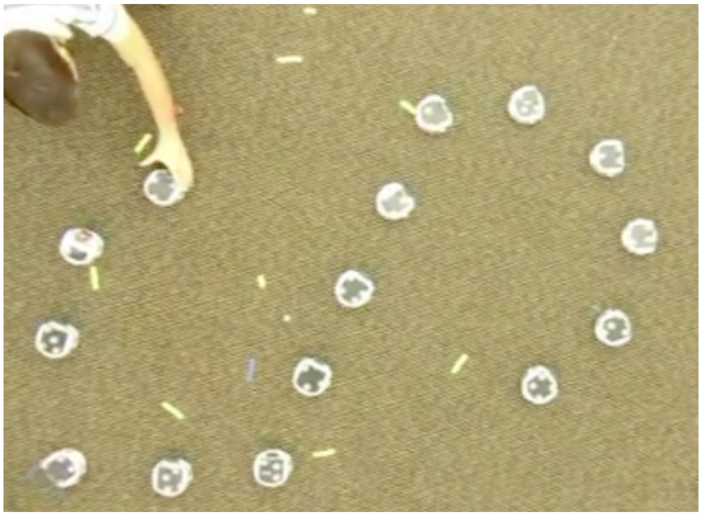
One particular application domain where human operators must control large collections of agents is multi-agent robotics. Key objectives that the interactions must support include

- Formation control (How can the robots be driven to particular shapes?);
- Coverage control (How can they be made to cover an area?);
- Swarming and flocking (How can coordinated behaviors be enforced?).

All of these objectives can be cast in terms of desired global geometries and shapes, and the human operator should be able to specify the shape and influence the multi-robot network to achieve the desired shape.

Leader-Follower Interactions

The image below shows an example of the leader-follower paradigm for controlling teams of robots wherein the user takes control of individual leader-agents in the network. By manipulating the leaders, the rest of the network can be controlled indirectly through interagent couplings effected by wireless communication. Alternatives to the leader-follower paradigm include boundary control (boundary agents are manipulated), fluid-based interactions (the operator "stirs" the team of robots), and behavioral interactions (behaviors rather than positions are manipulated by the operator).



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Operator Decision Support

One significant challenge facing the successful deployment of unmanned aerial vehicles (UAVs) in unstructured environments is the level of human involvement needed to carry out the mission. Control strategies are needed that will allow pilots to control and coordinate multiple UAVs.

Affordances and User Interfaces

An affordance is a relation between an object and a user wherein the object allows the user to perform a particular action. The affordances identified when controlling a swarm include stretching the swarm, molding it into a particular shape, splitting and merging sub-swarms, and mixing of different swarms. The image at right shows one possible "swarm interface" that allows the operator to interact with the swarm by manipulating the shape of a deformable medium (clay).

Influence vs. Control?

In a network of agents that are updating their states according to some interaction protocol, one can ask how easy or hard it is to influence such a network. The answer to this question depends on several factors, such as the form of the interaction dynamics, the structure and dynamics of the underlying information-exchange network, and the mechanism whereby the external influence is injected into the network. But key among these factors is what is meant by *influence* itself. This term can mean anything from very precise, global coordination of all agents to instantaneous (or short-term) notions of ensemble-level trends. Several interesting and important questions need to be answered, such as:

- What are appropriate system-theoretic notions for characterizing how easy or hard it is to influence complex networks?
- Can social influence be characterized in system-theoretic terms, thus bridging two different ways in which influence is understood?
- Some networks may be easy to control algorithmically but hard for human operators to control. How can this distinction be quantified in a precise manner?

For more information: J.P. de la Croix and M. Egerstedt, Controllability characterizations of leader-based swarm interactions, AAAI Symposium on Human Control of Bio-Inspired Swarms, Arlington, VA, 2012; Y.Y. Liu, J.J. Slotine, and A.L. Barabasi, Controllability of complex networks, Nature, 2011, pp. 167-173.