Delegation Management Versus the Swarm: A Matchup with Two Winners

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Swarms: Pros and Cons

Swarms, whether in nature or in robotics, have some distinct advantages. They are resilient, self-contained, largely self-reliant and comparatively cheap and easy to produce (whether by humans or nature) and reproduce. They are also, partly for these reasons, cheap and easy to “control.” In essence, a swarm “does what it does” and the swarm operator can, at best, localize when and where it does it. Even incentives and disincentives in economic or tax policy can be viewed as examples of exerting “environmental control” to manage the otherwise autonomous behaviors of (in this case, complex) agents who will “do what they do” with regards to the environment they experience.

On the other hand, many prior human experiments with swarm control have not turned out too well. The history of biological “swarm” usage is littered with examples of failure. By one estimate, less than 20% of biological control projects (introduction of a “swarm” of one type of biological agent to exert control on other agents) show evidence of “significant control” effects (Louda, et al., 1997). True, long history has taught us how to place bee hives so as to get approximately the pollination patterns we expect, but bees gladly pollinate noxious and competing weeds at the same time as they pollinate our crops. Other attempts to use swarms to our advantages have worked out even less well. The introduction of rabbits into Australia is a well-known example. In 1859, 24 rabbits were released on a farm near Victoria to provide a hunting stock. Within 10 years, they had multiplied to the point where 2 million could be trapped annually without a noticeable effect on the population. They are cited as the single largest factor in species loss and erosion in Australia over the past 150 years.

Alternative for Many-Agent Control: Delegation

The alternative to swarms in controlling large numbers of agents are various forms of delegation. Delegation approaches have a long history in human experience—beginning probably with tribal hunting and leading to the modern nation state and mega-corporation. Delegation presumes that agents are pre-disposed to be cooperative for one reason or another (which may itself be achieved through environmental control). Otherwise, there are two chief differences between a delegation system and a swarm:

1. The agent(s) in the delegation system are capable of performing more than one function or behavior. While it is not impossible to talk about delegation to a “primitive” agent who can do only one thing, this is a degenerate case and (as we have found in past development efforts), offers no advantages and some potential disadvantages over swarm behavior.

2. There is an indirect, and usually symbolic, means to enable the supervisor to efficiently interact with and directly affect, at least in part, which behaviors the subordinate agent(s) exhibit.

These two features combine to imply that in a delegation system, a supervisor tells the agent(s) what to do, retaining at least some of the planning and decision making processes, rather than relying on them to “do what they do” and attempting to find or create conditions in which doing that will be productive.
Delegation: Pros and Cons

The fact that agents in a delegation system must be capable of exhibiting multiple behaviors for the system to be effective, coupled with the fact that they must be capable of receiving and processing a symbolic communication medium, means that they must generally be more complex than swarm agents. The degree of intelligence possessed by the delegation agent makes it possible to delegate at higher, more abstract and aggregated levels of tasking or functionality, through posing abstract goals or constraints and priorities. This can make the delegation act more efficient and effective—which imposes a motivation for ever more complex agents. Finally, the fact that the communication medium between supervisor and subordinate must be, and ideally remain, open means that the act of delegation and ongoing supervision can be more complex and time- and workload consuming than the act of “setting loose” a swarm. Together, these factors give rise to many of the known weaknesses of non-swarm systems:

A. They are more expensive to build and operate and may require extensive training or development time
B. They are generally less resilient to failures of individual agents
C. They are generally less resilient to failures of communication
D. They can require more time and attention from an operator/supervisor

On the other hand, the greater level of capability and intelligence coupled with the ability to more precisely command behaviors can combine to enable a much more capable system with a much greater range of productive behaviors, all under more precise control (with less unintended consequences), than a swarm.

A TradeOff Space of Alternatives

In practice, of course, the alternatives exist along a spectrum. As the individual agents in a swarm get even slightly smarter and/or are able to exhibit multiple behaviors, the need to communicate with them and select and activate those different behaviors increases (with corresponding reductions in speed of use, resiliency to communications loss, etc.). And even the intelligent and highly complex agents can be interacted with in a swarm-like fashion (such as the manager who tells his crew to “just get busy and do something!”).

In (Miller and Parasuraman, 2007), I suggested the model in Figure 1 for characterizing different types of human interaction with subordinate agents (whether human, machine or any other type). The notion was that any such systemic relationship existed within a tradeoff space composed of three parameters, and that manipulating one of the parameters imposed consequences on the others:

- The competency of the human-machine system, that is, its ability to exhibit correct behavior across a range of contexts,
- The workload required from the supervisor achieve that competency, and
- The unpredictability of the system to the operator. Unpredictability refers to the inability of the operator to know exactly what the system will do when. It can be mitigated to a degree through good design, user interfaces and training, but it is a consequences of offloading tasks and, especially, decision making to subordinates or automation.

The goal of a flexible delegation system, such as the Playbook® approach we have been developing (Miller and Parasuraman, 2007; Miller, et al., 2011; Miller et al., 2012), is to provide the operator the ability to dynamically choose a configuration of these three parameters during system use, as illustrated in Figure 2. That is, the operator is able to decide whether to incur greater workload by issuing more detailed commands and monitoring more closely to reduce uncertainty and, presumably, achieve greater competency, or to tolerate potential increases in uncertainty and decreases in competency along with reduced workload by issuing high level, abstract delegation instructions.
rarely. Of course, this flexibility is feasible only when the prerequisites of intelligent agents with diverse capabilities and a communication mechanism for “discussing” activities are met.

I suspect that the human-agent relationship in a “pure” swarm system (one which exhibits only one behavior and which operates fully autonomously once released) should occupy a unique niche in my tradeoff space, as illustrated in Figure 3—extremely low workload to achieve extremely narrow competency with extremely large unpredictability.

![Workload Unpredictability Competency](Figure 3. Hypothesized relationship for a "pure" swarm system.)

This points to a flaw in the representation scheme in these figures. There is a discrepancy between workload required during “system operation”—that is, required to task, monitor and retask the agents—and that required to create the conditions of use for the system (through design, training, or particularly in the case of swarms, environment selection and preparation) before hand. How to treat such “outside the usage instance” work has been wrestled with, without a universally accepted solution, in the work of (Goodrich and Olsen, 2003) and (Crandall and Cummings, 2007).

Part of what makes swarms effective (and what makes their unpredictability potentially dangerous) is that their limited functionality requires careful selection of the conditions under which they are loosed to “do what they do”. If they are released in inappropriate circumstances, their performance will be suboptimal in some fashion, and, while that decrement can reasonably be laid at the feet of the human operator who failed to activate them appropriately, that may be small compensation for failures and missed opportunities. Nevertheless, that means that effort (loosely, “workload” in the above figures) must be expended before hand to evaluate whether conditions are right for the behavior the swarm exhibits, and this is not included in the workload dimension (nor, for that matter, is the workload required to select and train the more competent agents in a delegation system).

**Final Thoughts**

To claim that one approach to accomplishing desired goals is “better” than another is somewhat missing the point. Each has characteristics which make it desirable in some cases and less so in others. Each is also subject to breakdown cases and inappropriate usage. The trick, as in much design, is to understand these attributes and use them appropriately.

Of course, in the nature of alternatives existing on a spectrum, at some point they blend into each other. Extremely limited delegation systems, or delegation systems operating in conditions where interaction and the presumption of cooperation break down can and will behave like swarms. Similarly, sophisticated swarms—which are capable of exhibiting alternate behaviors which can be selected, commanded, or “influenced” by a human operator and, especially, those which include a presumption of cooperation in their motivation—will start to take on attributes of delegation system including the need for greater complexity and communication maintenance, as well as the ability to effect more precise and targeted behaviors.

**References**


