The Effect of Anticipation on Control and Survival Strategies in a Multi-Agent, Resource-Centric Environment

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1 Motivation

Being able to control its environment is an essential element in the interaction of any lifeform, ranging from microorganisms to entire societies. It is particularly apparent in situations when multiple agents compete for a scarce resource. Such situations constrain the options of organisms in specific ways and are ubiquitous in biology, but also economy and everyday life.

We quantify control by means of *empowerment*, an information-theoretic measure for the combined controllability/observability of an environment. Empowerment interprets the perception-action loop of an agent as a communication channel and measures its capacity. It thus quantifies the amount of information that an agent can inject into its (future) sensoric observation by means of its actuator at an earlier time. This in turn represents the amount of control the agent has over its environment. Maximizing it has been hypothesized to be a candidate principle driving the behavior of organisms [2]. To our knowledge, very few studies examine control in a multi-agent environment by means of information theory [1].

Estimating potential sensor states in the perception-action loop requires to anticipate the behavior of the other agents. In the present work, we examine the impact of anticipation on local control. Furthermore, we evaluate whether empowerment triggers "savvy" behavior in a multi-agent environment where agents share a scarce resource. We consider "savvy" behavior if an agent primarily focusses its actions on survival, followed by consumption. In contrary, an example of "unsavvy" behavior is to consume greedily in life-threatening situations.

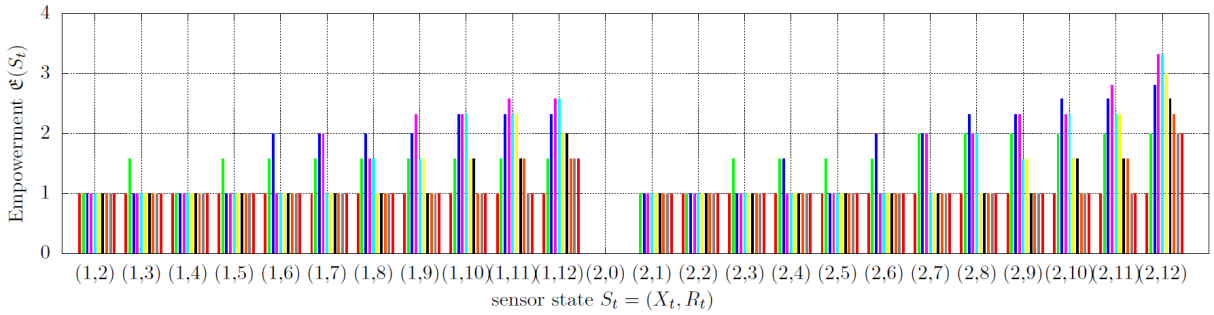

Figure 1: Empowerment over sensor states(idling/satisfied, resource level). We assume scarcity $\mathfrak{S}(|\phi|) = 0.25$ and a greedy behavioral model. Colors indicate different mental horizons.

2 Experiments

We assume discrete time, sensor- and actuator states. In our studies, we define three minimal agents which typically only survive if they consume the shared resource frequently. In some situations, however, the agents are able to step back for some time and idle. We furthermore consider the *mental horizon* of an agent which represents the amount of interaction cycles an agent can embrace when anticipating future sensor states. We consider a resource which is bounded from above and regenerates linearly in time. By varying the resource parameters, we define different levels of scarcity, representing ecological niches that demand the agent population to adapt their behavior, which, in our experiments, will be driven by empowerment of the agents. Agents only perceive the shared resource. Thus, the resource acts as a proxy to indirectly anticipate the behavior of other agents. In each experiment, a *behavioral model* either representing greedy or saving behavior of the other agents is initially assumed. Agents are given the ability to adapt

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their behavioral model for better anticipation. In our experiments, we rigorously evaluate the agents' behavior determined by local control for different mental horizons (fig. 1), varying levels of scarcity and two diametrical forms of anticipation.

3 Results

We found that agents driven to maximize their local empowerment show complex, and more importantly, savvy behavior. Individual behavior is very sensitive to different behavioral models used in anticipation. The agents develop risk-seeking, risk-averse or mixed strategies. We discovered that the behavioral models capable to generate the maximum subjective control were the most "appropriate" for different magnitudes of scarcity. In contrast, originally ill-adapted models developed away from the original behavior. As expected, different mental horizons have a strong impact on local control and behavior. However, empowerment does not value intermediate states. At long horizons, there may be few controllably end states, causing "helplessness" [3] and resulting in indecisiveness as well as spontaneous suicide. Interestingly, different behavioral models did not impact the agents' *survival rate* at the end of an experiment, but they affected their *lifetime* significantly (fig. 2).

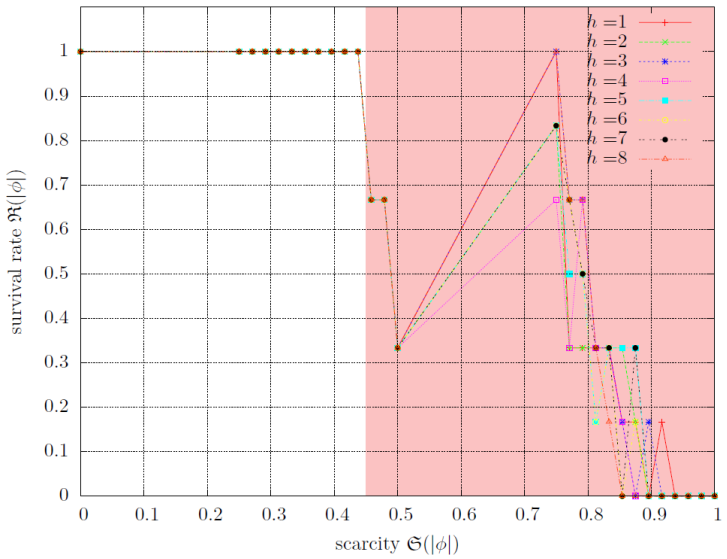

Figure 2: Survival rate $\mathfrak{R}(\phi)$ over scarcity $\mathfrak{S}(\phi)$ for mental horizons up to $h = 8$, $|\phi| = 4$, saving behavioral model.

4 Discussion

Under the assumptions above, we demonstrated inductively that multiple agents driven by empowerment can survive under scarcity in a flat hierachy without a need for authority. Furthermore, we found that a large mental horizon is not necessarily of benefit. Comparing experimental observations of suicidal behaviour with the behavior of humans and animals yields that "appraisal of the moment" is essential to life. In our experiments, agents seem to adapt best to a particular niche, if they assume their environment to act in a way that would be savvy locally.

5 References

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