Cognitive Control in Collective Behavior

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MOTIVATION

Adversarial Learning

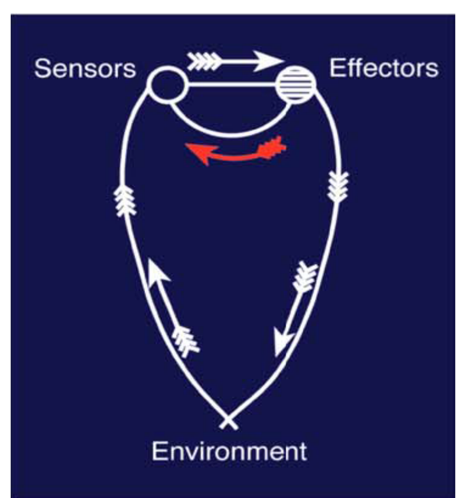


Figure 1 [1]

Hierarchy for active sensor control for perceptual advantage (e.g. cognitive radar) is an optimal control problem with special aspects:
(a) role of selective attention in scene analyses;
(b) adversarial learning.

The biologist Uexkuell has proposed an abstraction of the general dynamics of the perception-action cycle in sequential behavior toward a goal. The figure in this block is an abstraction of his schema.

Cognitive Processing

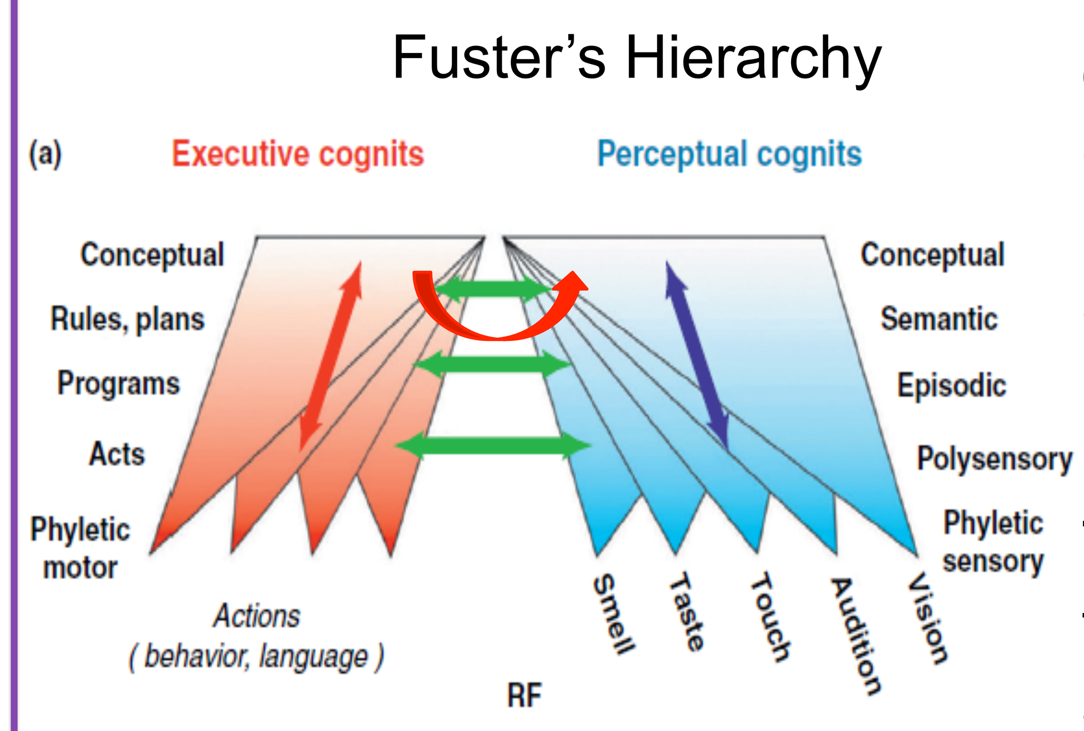
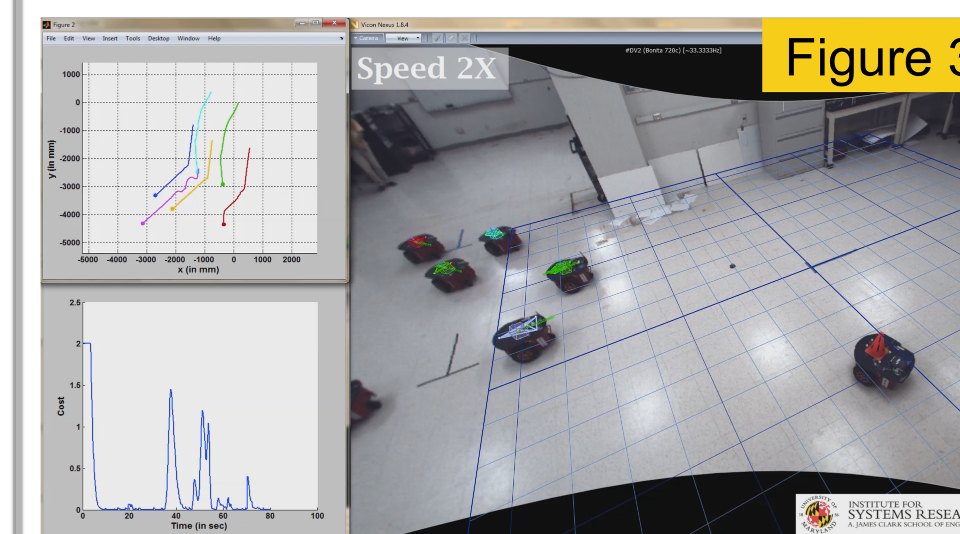


Figure 2 [1]

Schematic hierarchical order of perceptual and executive cognits. Bidirectional arrows indicate cortico-cortical connectivity: perceptual (dark blue), executive (red), and perceptual-executive (green). The inverted triangles symbolize the divergence of connections and increased size of cognits with ascending hierarchical order.

Implementations on a Testbed



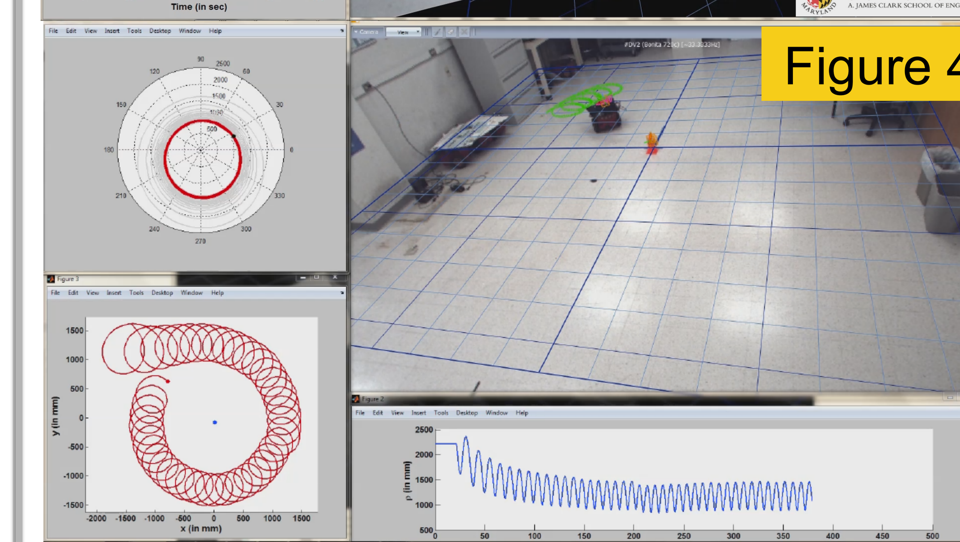


Figure 3 shows Topological Velocity Alignment (TVA) in which agents use an average of neighbors' control law [2].
Figure 4 shows an implementation of the periodic beacon-viewing under field of view constraints [3].

Bio-inspiration

Echolocating bats use acoustic pulses adaptively in complex dynamic environments to locate and track elusive prey, avoid obstacles, discern targets from clutter (e.g. vegetation), and reach targets via agile, sensori-motor feedback control. Cognitive capabilities evolved from a long arms-race between predator and prey – a case of adversarial learning. Bats **select** strategies according to context. Starlings use **action** to propagate information over a flock.

Collective Perception

Cooperating sensor platforms can make discrete selection from a pool of control strategies learned from field data (as in target search in different contexts). Candidate strategies for distributed UAV platforms include constant bearing beacon pursuit (attention is divided between units and target). One selection approach is based on evolutionary games – using simulations of encounters to compute initial payoff structures. See Figure 3 for example.

APPLICATIONS

1. Modeling Speed-Accuracy Tradeoffs

$$u_p(t) = \mu(w(t-\tau)+n(t)), n(t) \sim \mathcal{N}(0, \frac{k}{\tau})$$

In dyadic pursuit, as in [4]: (a) Pursuer uses *delayed* sensor information, (b) subject to *noise*, of strength inversely proportional to a *cognitive processing delay.* The feedback law above is shown to achieve motion camouflage in finite time with constraints on the gain μ.

2.Tracking a Moving Beacon

$$u_2 = \tilde{\mu}\sin(\kappa_2-\alpha) + \frac{1}{\nu_2\rho}(\nu_1\sin\kappa_1+\nu_2\sin\kappa_2)$$

Agent 2 (speed ν_2) tracks a moving beacon (agent 1, speed ν_1) using the constant-bearing pursuit law shown above, assuming $0<\nu_1<\nu_2$. Under this law, the manifold:

$$\mathcal{M}^{\alpha}_{CB} = \{(\rho,\kappa_1,\kappa_2)\in\mathbb{R}^+\times S^1\times S^1 \ : \ \kappa_2=\alpha\}$$

is attractive and invariant.

3. Addressing Limited Field of View

$$u_2^{FOV} = u_0 - \frac{\mu}{\rho\nu_2}, \quad u_0 \le 0, \ \mu > \nu_2,$$

Limited field of view constraints arise when a mobile agent tries to circle around a stationary beacon. The closed loop dynamics in this case substituting the above feedback law can be solved using knowledge of the solution to problem 2 and results in the agent periodically observing the beacon (Fig. 4, [3]).

References: **1.** J. M. Fuster, "The Prefrontal Cortex Makes the Brain a Pre-adaptive System," in *Proceedings of the IEEE*, vol. 102, no. 4, pp. 417-426, April 2014. **2.** U. Halder and B. Dey, "Biomimetic Algorithms for Coordinated Motion: Theory and Implementation," *2015 IEEE International Conference on Robotics and Automation (ICRA)*, pp. 5426-5432. **3.** U. Halder, B. Schlotfeldt and P. S. Krishnaprasad, "Steering for beacon pursuit under limited sensing," *2016 IEEE Conference on Decision and Control (CDC)*, pp. 3848-3855. **4.** V. Raju and P. S. Krishnaprasad, "Motion camouflage in the presence of sensory noise and delay," *2016 IEEE Conference on Decision and Control (CDC)*, pp. 2846-2852. (support: ONR, AFOSR, ARO, Northrop Grumman)