Grand Challenge: Bio-inspired Monitoring and Warning Systems for Earthquakes and Natural Disasters

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A combination of *hypothesis-driven experiments* and *quantitative modeling and analysis* will (1) advance the understanding of *distributed sensing* in biological systems and (2) provide the foundation of knowledge for leveraging biological inspirations in the synthesis of *fast and accurate* monitoring and warning systems.

Distributed sensing is an effective threat-avoidance and/or resource-localization strategy for many organisms. For example, experimental studies show that *schooling* fish are more accurate than *individual* fish in the selection of the direction in which to flee an external threat. Schooling may also reduce the *latency* in responding to an external stimulus. An ant colony displaced from its nest uses distributed sensing *and* collective decision-making to optimally select a new nesting site out of multiple candidates. In social-foraging species, such as wolves and vultures, distributed sensing and motion coordination broaden the positive impact of *resource discovery* throughout a network of interacting animals.

By fusing information provided by individual sensors, a distributed sensor array has the capacity to *amplify* signals and *attenuate* noise. As a simple example, compare the error in a single *noisy* measurement of temperature with the error in the average of ten noisy measurements. In fact, measurements need not be collocated -- the spatial and temporal distribution of sensor platforms in a distributed sensor array can be designed to optimize sampling performance of a dynamic spatiotemporal process, such as an earthquake or tropical cyclone. For certain processes, the sampling performance of a set of mobile sensor platforms can be further enhanced by motion-coordination algorithms.

One can view distributed sensing from the perspective of *probabilistic* sensing, in which the operation of an individual sensor (or sensor array) trades off the probability of signal *detection* (PD) with the probability of a *false alarm* (PFA). Increasing PD by lowering the detection threshold typically results in an undesirable increase in PFA. The relationship between PD and PFA can be graphically depicted in a *receiver* *operating characteristic* (ROC curve), in which PD is a monotonically increasing function of PFA. Sensor performance can be characterized in terms of the position in the PD-PFA plane of the *knee* of the ROC curve, which signifies the threshold level above which minimal gains in PD are achieved at a large cost in PFA.

The challenge is to apply ROC analysis to quantitatively evaluate the performance of a biological network as distributed sensing array in order to construct a modeling framework for the design and optimization of synthetic sensor networks. Modeling questions range from how to represent *organism-level interactions* to how to characterize the *topological properties* of the interaction network. The ultimate goal is to analytically relate the underlying array configuration to sensing performance, and then to identify the configuration that optimizes performance in the application of an earlywarning system.