FORMATION COHERENCE IN LARGE-SCALE NETWORKS:
FUNDAMENTAL LIMITATIONS OF LOCAL FEEDBACK

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Abstract

Problems of coordinated motion of vehicular formations have received much attention lately, especially in the areas of formation flight and so-called vehicular platoons. We investigate fundamental limitations that the use of only local feedback control has on the coherence of large formations that are subjected to stochastic disturbances.

The notion of coherence translates roughly into how closely can such formations resemble a solid object, and is unrelated to the notion of string instability. This question is also of interest in the context of naturally occurring swarms, such as birds in flying formations and schools of fish. Similar dynamical phenomena occur in distributed load balancing in parallel processing and consensus-type algorithms.

We examine these dynamical effects using the network topology of regular lattices, and investigate the role of topological dimension. A common phenomenon appears where a higher spatial dimension implies a more favourable scaling of coherence measures, with dimensions of 3 and 5 being necessary to achieve coherence in consensus and vehicular formations respectively with only local feedback. We show that microscopic error measures that involve only neighbouring vehicles scale much more favourably, and in some cases do not suffer from this effect. This phenomenon reflects a fact that in lower spatial dimensions, local stabilizing feedbacks are relatively unable to regulate against spatially large-scale disturbances, resulting in an unregulated, "undulating" type of motion for the entire formation. We point out connections between this analysis and the statistical mechanics of harmonic solids where such phenomena have long been observed, as well as connections with the theory of resistive lattices as has been observed by others.