ENEE 769R Advanced Topics in Control - Principles and Algorithms for Collectives: from Biology to Robotics (3 credits) Grade Method: REG/AUD (fall 2012 - MW 12:30-1:45pm, in room CSI 1122; Instr: P. S. Krishnaprasad. Prerequisite: MATH410 or equivalent, or permission of instructor.

Generalities: degrees of freedom problem; synergies; graphs and motifs; hierarchies. **Models of Individuals**: curves and frames; agent models on matrix Lie group **SE (n)**; manipulation and mobility; rigid body. **Models of Collectives**: agents and linkages (physical and informational); configuration space, symmetry and shape space; graphs and interconnection. **Goals and Tasks**: reach and grasp; product of exponentials formula; jacobians; Lie brackets and controllability; coverage; dynamics in shape space, relative equilibria. **Structure and Algorithms:** invariant manifolds; strategies and feedback laws; graphs and convergence; optimality; data from biological collectives; sampling and reconstruction.

A central theme of modern system science and engineering is the design, creation, and effective operation of multiple technological subsystems to achieve a coherent whole with autonomous and purposeful behavior. The multiple degrees of freedom present in such a system are to be harnessed towards accomplishing a diverse set of goals based on tasks assigned or discovered over time. The problem of organization and deployment of the degrees of freedom, to enhance versatility of the collective and optimize performance measures associated with specific tasks, is a central subject of this course. We shall refer to this as the *degrees of freedom problem*. This problem takes different forms in different contexts. For instance, how many fingers (with what types of contacts and mechanical configurations) suffice to make a mechanical hand? What types of manipulation primitives (in symbolic and signal form) are needed to achieve a rich variety of motions in the workspace of a robotic manipulator? What interaction strategies (mediated by vision or audition) should be executed by a group of autonomous robots engaged in a disaster mitigation context? How should such a collective manage its resources in a setting of competing individuals and conflict (with other collectives)? Many of these questions and challenges have parallels in the natural world (e.g. insect and mammalian locomotion, tool usage for manipulation by primates, colony formation and foraging in honey bees, flocking for predator avoidance in starlings, cooperative herding of prey by foraging dolphins). Sustained study of natural settings has yielded data and insights that provide clues as to the *natural algorithms* at work. Using a wide variety of theoretical and experimental approaches, robotics engineers have explored parallel concerns arising in the design of individual robotic systems and the coordinated operation of collectives of robots.

In this course, we will provide a systematic exposition of the modeling, analysis, and control methods that are useful in (a) understanding natural algorithms for collectives; (b) exploration of links between natural behavior and synthetic algorithms; (c) exploitation of game theoretic concepts applicable to robust and competitive strategies of collective behavior.

It is expected that participants in this course will bring, mathematical maturity (in the subjects of differential equations, probability, and related topics), a willingness to investigate novel formulations of problems, and an interest in bridging the disciplines of biology and engineering. Preparation at the level of a first year graduate student and readiness for independent work in reading and discussing a multi-disciplinary literature is required. Lecture Notes will be distributed.

The course will have four components: (i) models of individuals (e.g. degrees of freedom in a manipulator, mobile agents); (ii) models for grouping of individuals in collectives (e.g. mechanical linkages, sensory-guided networks); (iii) models of goals and tasks for collectives (e.g. grasping an object, swarming over a disaster area for information gathering; (iv) organizational structures, algorithms and performance measures (e.g. hierarchies and division of labor in foraging, variational principles in swarming, equilibrium strategies for dynamic and evolutionary games) based on (i), (ii), and (iii).

Students will be asked to turn in solutions to a Take Home Examination, and at least one Term Project. They will also be asked to make in-class presentations.