ENEE 765 ADAPTIVE CONTROL (and Learning Theory), fall 2019, Tu Th, 5:00-6:15 pm in AJC 2132; Instructor: P. S. Krishnaprasad (krishna@umd.edu; 301-405-6843). Office is in A.V. Williams Building – room 2233. Office Hours: M 5:00 pm – 7:00 pm; and W 5:00 pm – 6:50 pm (class discussion session – CSI 3118); (old website: http://www.ece.umd.edu/class/enee765.F2017/ to be updated during summer 2019)

Feedback, adaptation and learning are essential elements in complex systems. Rigorous understanding of these processes is a subject of continuing study. This is a course on the *general principles of adaptive control and learning,* concentrating on continuous time deterministic aspects, while including *some discrete time stochastic models and methods*. Algorithms based on (*degenerate*) gradient descent will supply essential computational tools. Salient aspects of adaptive systems include: (a) automatic variation of gain parameters in feedback loops according to specific adaptation rules; (b) on-line identification (i.e. learning) of parameters of a system as a precursor to using knowledge of parameter estimates in control laws; (c) nonlinear dynamics and multiple time scales in the *combination* of system (plant) and adaptive controller; (d) data-driven learning of strategies of action through examination of payoffs. These are also salient aspects of a class of signal processing algorithms known as *adaptive filters* which play an important role in biology, communication technology and robotics.

In this course, we will (i) discuss system identification (i.e. learning a model from empirical data) to analyze the behavior of adaptive control schemes such as model reference adaptive control and self-tuning regulators; (ii) answer questions of convergence, stability, and robustness, using various analytical tools (e.g. Lyapunov stability theory, perturbation and averaging theory, design principles for informative input signals etc.); (iii) discuss methods from machine learning theory (e.g. approaches based on reproducing kernel Hilbert spaces (RKHS), etc.); (iv) provide an introduction to reinforcement learning and game-theoretic learning; (v) introduce modern developments in extremum seeking systems using Lie algebraic techniques.

Course Prerequisite: Background in ordinary differential equations, control theory and mathematical maturity (stability theory). Familiarity with the material in ENEE 660 (system theory), ENEE 661 (nonlinear control), and ENEE 620 (Probability and Stochastic Processes) desired. Contact instructor for further information.

References: Item (g) below – Astrom-Wittenmark (2008 edition) is the textbook

(a) P. S. Krishnaprasad, *Lecture Notes on Adaptive Control* – supplied through website.

(b) Papers on adaptive signal processing and machine learning (will be on-line, or provided by email), including F. Cucker and S. Smale, "On the mathematical foundations of learning," *Bull. Amer. Math. Soc*. **39** (2002), 1-49.

(c) F. Cucker and D. X. Zhou, *Learning Theory: an approximation theory viewpoint*, Cambridge University Press, 2007.

(d) H. K. Khalil, *Nonlinear Systems,* Prentice Hall, 3rd ed., Englewood Cliffs, 2002.

(e) S. Sastry and M. Bodson, *Adaptive Control: Stability, Convergence and Robustness*, Prentice Hall, 1989-1994 (available now as a free downloadable item from http://www.ece.utah.edu/~bodson/acscr/index.html), 2nd edition, Dover, NY, 2011.

(f) S. Sastry, *Nonlinear Systems: Analysis, Stability and Control*, Springer, NY, 1999.

(g) K. J. Astrom and B. Wittenmark, *Adaptive Control*, 2nd edition, Dover, NY, 2008.

(h) V. S. Borkar, *Stochastic Approximation: A Dynamical Systems Viewpoint*, Cambridge University Press, 2008.

Grading: Five to eight homework sets and a Semester Project will determine the grades. The entire set of homework assignments will include **reading assignments** as well, and grades in the homework sets will count towards 50% of your semester grade. Discussion of homework assignments among the students in class and the instructor is permitted. Consultation of library material is permitted. *Acknowledgement of such consultation is expected*. All submitted work however should reflect individual effort and understanding. The Semester Project will count towards 50% of the semester grade. Selection and start of work on a Semester Project will be expected to take place no later than October 15. Completion of the project (including submission of a report of about 10 pages) is required by the last day of exams in the announced fall semester schedule. Questions about format and content of the report of the Semester Project will be answered in class. **There will be no incomplete grades allowed except for health reasons or dire emergencies**.

Policy on Classroom Environment

It is of utmost importance to maintain a classroom environment conducive to focus on and attention to instruction. **Hence usage of electronic devices (music equipment, cell phones, text messaging devices and computers) is disallowed during regular class hours.**