Course Description:

This is a course on computational methods for real applications, based on a unique combination of group theory and statistical machine learning.

Symmetry is an essential and ubiquitous concept in nature, science and art. Numerous biological, natural or man-made structures exhibit symmetries as a fundamental design principle or as an essential aspect of their function. Whether by evolution or by design, symmetry implies potential structural efficiencies that make it universally appealing. Much of our understanding of the world is based on the perception and recognition of shared or repeated structures, and so is our sense of beauty. This course concentrates on
keen observations of symmetry patterns in various data forms in our daily life and our research. We develop effective computational treatments of symmetry.

**Group theory**, the ultimate mathematical theory for symmetry, will be well motivated by real world examples and be learned in an intuitive manner. The course abandons the classical definition-theorem-proof model and instead relies heavily on effective computational models with concrete applications in robotics, computer vision, computer graphics and medical image analysis. The emphasis is on hands-on computational experience and on producing state of the art, publishable research projects. From past experience in CMU and PSU, this course is particularly attractive to computer science and engineering graduate and undergraduate students. As a consequence, material with a fairly high level of sophistication can be absorbed and utilized with relative ease.

The key challenge of turning the concept of symmetry into a computationally useful tool is to figure out how to apply the concise symmetry group theory to the noisy albeit often near-regular real-world. So far, a robust, widely applicable general symmetry (all types of symmetries) detection algorithm for real world digital data (images or otherwise) remains to be elusive in spite of many years of effort. This challenge leads to the unique role this course will explore “computational symmetry” (Liu 2001). During the semester, we shall start with intuition, learn the basic mathematical concepts and develop state of the art computer algorithms for real-world problems. Our goal is to build “bridges” connecting, symmetry, symmetry group theory and real-world applications aiming at a general computational framework for robust symmetry discovery, analysis, synthesis and manipulation. Some exiting, new, specific data sets we will explore during this semester include but are not limited to:

-- Object Recognition image sets
-- Static and dynamic near-regular textures (all types of data with near-periodical patterns): applications in computer graphics and computer vision
-- Dancing with (a)symmetry (motion capture data from traditional and modern style dancers)
-- Human brain asymmetries (quantitative evaluation of age, gender and pathological differences)
-- The firing fields of rats grid cells (a hexagonal pattern! spatial navigation maps)
-- 4D Human faces (3D face with expression variations)
-- Arts: Papercutting, quilting and paintings
-- Your own research data sets!

**Course Plan**

The course will be based on a newly finished survey paper (120 pages) by Dr. Liu et al for the Journal of **Trend and Fundamentals of Computer Vision and Computer graphics**, a textbook written by Dr. Liu on “**Computational Symmetry**” and a set of state-of-the-art research papers. The focus of the course this round is on applying statistically learning theory (Bayesian theory, graph models, MCMC, sampling, manifold
learning, discriminative feature selection, mixture of Gaussian models …) to regularity discovery and novel applications in real computer vision, computer graphics problems, including image segmentation (both spatially and temporally, and depth-wise), image registration, tracking, image compression, object recognition, saliency maps, 3D reconstruction, texture analysis/synthesis/manipulation, categorization and classification … The course will be in the format of instructor/guest lectures, student presentations, homework, a semester-long research project and a term paper. Guest lectures are also included. The invited guest speakers in and out of the university will expose students to applications in very diverse domains, e.g. biology, medicine, architecture, material science, robotics, computer vision, and computer graphics.

Expected maximum number of students: 15.

Qualifications of Expected students: graduate and senior undergraduate with open-mindedness to do the impossible (develop algorithms by combining of group theory and statistical learning theory), curiosity for learning group theory in a practical way, hands-on attitude, and a desire to learn, experiment and publish.

**Grading Policy**

1. Written Homework (15%)
2. Oral Presentations (15%)
3. Class Participation (10%)
4. Term Project & Write-up (60%)
5. Extra Credit (10%)

-------

110% total

A weekly syllabus from previous course (Fall 2007) can be found here: [http://www.cse.psu.edu/~yanxi/CourseFall2007.htm](http://www.cse.psu.edu/~yanxi/CourseFall2007.htm)

An overview of the course: goals for this course --- yours and ours

Homework #1: demonstrate five instances of symmetry (e.g. images, photos, puzzles)

References:

*Near Regular Texture Analysis and Manipulation*  
<http://www.ri.cmu.edu/pubs/pub_4665.html>*


*Computational Symmetry* <http://www.ri.cmu.edu/pubs/pub_3958.html>*

/Y. Liu <http://www.ri.cmu.edu/people/liu_yanxi.html>/  

*Symmetries of Culture*: Theory and Practice of Plane Pattern Analysis*  
by Dorothy K. Washburn, Donald W. Crowe 1991
A similar course has been taught in CMU (Fall 2005) and PSU (Spring 2006, Fall 2006, Fall 2007). A total of ~50 students have taken this course taught by Dr. Liu. Several research papers by the students who took the course have submitted/published.

**Deformed Lattice Detection via Mean-Shift Belief Propagation**
Minwoo Park, Robert T. Collins, and Yanxi Liu
European Conference on Computer Vision (ECCV), Marseille, France, October 2008.

**Rotation Symmetry Group Detection Via Frequency Analysis of Frieze-Expansions**
Seungkyu Lee, Robert T. Collins and Yanxi Liu
Computer Vision and Pattern Recognition Conference (CVPR '08)

*Performance Evaluation of State-of-the-Art Discrete Symmetry Detection Algorithms.* Minwoo Park, Seungkyu Lee, Po-Chun Chen, Somesh Kashyap, Asad A. Butt and Yanxi Liu (CVPR '08)


*Quantified Symmetry for Entorhinal Spatial Maps*  
E. Chastain and Y. Liu  

*Shape Variation-based Frieze Pattern for Robust Gait Recognition*  
S. Lee, Y. Liu, and R. Collins  

*A Lattice-based MRF Model for Dynamic Near-regular Texture Tracking*  
W. Lin and Y. Liu  

*Discovering Texture Regularity as a Higher-Order Correspondence Problem*  
J.H. Hays, M. Leordeanu, A.A. Efros, and Y. Liu  

*Truly 3D Midsagittal Plane Extraction for Robust Neuroimage Registration*  
L. Teverovskiy and Y. Liu  

*Symmetries of Dance*  
X. Yang, M. Spivak, C. Bregler and Y. Liu,  
Submitted to CVPR 2009.