ROCHESTER INSTITUTE OF TECHNOLOGY
COURSE OUTLINE FORM

COLLEGE OF SCIENCE

Chester F. Carlson Center for Imaging Science

NEW COURSE: COS-IMGS-711 – Computational Methods for Imaging Science

1.0 Course Approvals

Required course approvals:	**Approval Requested Date:**	**Approval Granted Date:**
Academic Unit Curriculum Committee	10/11/12	10/12/12
College Curriculum Committee	10/15/2012	11/5/12

Optional designations:	**Is designation desired?**		***Approval request date:**	****Approval granted date:**
General Education:		No		
Writing Intensive:		No		
Honors		No		

2.0 Course information:

Course title:	Computational Methods for Imaging Science
Credit hours:	3
Prerequisite(s):	IMGS-616 or IMGS-682, or permission of instructor
Co-requisite(s):	None
Course proposed by:	Harvey Rhody
Effective date:	Fall 2013

	Contact hours	**Maximum students/section**
Classroom	3	30
Lab		
Studio		
Other (specify)		

2.1 Course Conversion Designation (Please check which applies to this course)

	Semester Equivalent (SE) Please indicate which quarter course it is equivalent to:
	Semester Replacement (SR) Please indicate the quarter course(s) this course is replacing:
X	New (Previously offered as a special topics course)

2.2 Semester(s) offered (check)

Fall X	Spring	Summer	Other

All courses must be offered at least once every 2 years. If course will be offered on a bi-annual basis, please indicate here:

2.3 Student Requirements

Students required to take this course: None.
Students who might elect to take the course: Graduate students in Imaging Science, Engineering, or computationally-inclined students in math, science, and computer science.

3.0 Goals of the course (including rationale for the course, when appropriate):

3.1 To develop fluency in computational modeling of phenomena.
3.2 To understand computational building blocks of common computing systems for image processing.
3.3 To develop techniques for project management for large algorithm implementation.

4.0 Course description

COS-IMGS-711 **Computational Methods for Imaging Science**

This course addresses computational topics that are important in a variety of applications in imaging science. Examples of topics that may be included are: vector space operations, including matrix factorizations and solutions of systems of equations (used in hyperspectral target detection and image compression, among many other applications); linear and nonlinear optimization (used for the design of detectors, camera calibration, bundle adjustment, etc.); iterative methods and dynamic systems (Kalman filtering, tracking, optical flow, etc.); random number generation and use (Monte Carlo methods, system performance evaluation, etc.); and energy minimization techniques applied to image processing (used for image enhancement, segmentation, etc.) (Prerequisites: IMGS-616 or IMGS-682, or permission of instructor) **Class 3, Credit 3 (Fall)**

5.0 Possible resources (texts, references, computer packages, etc.)

5.1 Reference material is available in the form of papers and online publications.

6.0 Topics (outline):

6.1 Vectors and vector spaces
- 6.1.1 Mathematical objects: points, lines, surfaces, functions, sequences
- 6.1.2 Images and signals
- 6.1.3 Linear vector spaces
- 6.1.4 Measuring similarities and differences: metric spaces
- 6.1.5 Dimensions and basis representations
- 6.1.6 Application examples and computational tools
- 6.1.7 Project: Construction of a vector-space basis for hyperspectral imagery with application to material classification. (Note: All projects will be implemented in a high-level programming language (Matlab, Python or C++) and tested using provided data and examples.)

6.2 Linear equations from a vector space perspective
- 6.2.1 Matrix representation of linear equations
- 6.2.2 Solutions by elementary row operations using elementary matrix products
- 6.2.3 Rank and dimensionality of solution space
- 6.2.4 Numerical methods issues; pivoting to reduce sensitivity
- 6.2.5 Matrix norms and application to error/sensitivity analysis
- 6.2.6 Householder transformations
- 6.2.7 QR decomposition and use in equation solving
- 6.2.8 Project: Given a set of point correspondences between two images, compute the fundamental matrix, camera projection matrices, and coordinate transformations between cameras.

6.3 Linear approximation
- 6.3.1 Subspace projection
- 6.3.2 Orthogonality principle
- 6.3.3 Inner product representation of projection error; weighted error measures
- 6.3.4 Linear regression
- 6.3.5 Pseudo-inverse and its representation as a projection
- 6.3.6 QR approach and norm equivalences between orthogonal matrix transformations
- 6.3.7 Linear curve fitting; polynomial approximation and related topics
- 6.3.8 Sensitivity issues understood from vector space geometry
- 6.3.9 Application examples and computational tools
- 6.3.10 Project: Given an over-determined set of noisy point correspondences between image planes, compute a planar homography by direct linear transform (DLT) minimization.

6.4 Matrix factorizations
- 6.4.1 LU decomposition and applications
- 6.4.2 Cholesky factorization
- 6.4.3 QR decomposition and relationship to LU and Cholesky
- 6.4.4 Six cases for Ax=b: Rank tests vector space models
- 6.4.5 Row and column spaces and their nulls
- 6.4.6 Geometric interpretation of the system
- 6.4.7 Pseudo-inverse revisited
- 6.4.8 Application examples and computational tools

- 6.4.9 Project: Characterization of the categories of over and under determined problem classes for Ax=b and determination of row and column space bases for a set of pattern matching problem data.

6.5 Eigenvector and eigenvalue analysis

- 6.5.1 System matrix A as a linear projector in y=Ax
- 6.5.2 Natural modes of A as eigenvectors: Au=cu
- 6.5.3 Caley-Hamilton Theorem and application to modeling of eigenvector space
- 6.5.4 Diagonalization and application to matrix powers
- 6.5.5 Computation of functions of a matrix
- 6.5.6 Hermitian matrices and related vector space topics
- 6.5.7 Properties of vector spaces based on eigenvector representations
- 6.5.8 Matrix expansions
- 6.5.9 Quadratic forms
- 6.5.10 Covariance matrix and generation of correlated random numbers
- 6.5.11 The maximum principle
- 6.5.12 Principal components
- 6.5.13 Karhunen-Loeve transformation
- 6.5.14 Application examples and computational tools
- 6.5.15 Project: Characterization of sensor data in terms of in-class covariances and between-class distance metrics based on Mahalinobis distance for provided training and testing data sets.

6.6 Singular value decomposition

- 6.6.1 Representation of A=USV’
- 6.6.2 Special properties of U, S and V
- 6.6.3 SVD and diagonalization of $A^H A$
- 6.6.4 Calculation of the pseudo-inverse using SVD
- 6.6.5 Vector space analysis: representation of row, column and null spaces of A
- 6.6.6 Expansion and approximation via SVD
- 6.6.7 Snapshot method and rogues gallery example
- 6.6.8 Application examples and computational tools
- 6.6.9 Project: Snapshot method and rogues gallery example for face recognition.

6.7 Constrained least-squares

- 6.7.1 Problem LSE: Least squares minimization with equality constraints
- 6.7.2 Review of projection operator solutions and projection operators
- 6.7.3 Representation of approximation error as a null-space vector
- 6.7.4 Problem LSI: Solutions under inequality constraints
- 6.7.5 Reduction of LSI to NNLS via Least Distance Programming (LDP)
- 6.7.6 Problem LSIE: Solutions under both equality and inequality constraints
- 6.7.7 Reduction of LSIE to LSI
- 6.7.8 Computing solutions via SVD and friends
- 6.7.9 Application examples and computational tools
- 6.7.10 Project: Unmixing of hyperspectral image material distributions by combination of hyperspectral and panchromatic imagery.

6.8 Nonlinear least-squares

- 6.8.1 Representing the nonlinear minimization problem
- 6.8.2 Description of solution search methods: Gradient descent, statistical,

geometric

6.8.3 Taylor series expansion of nonlinear function using gradient and Hessian

6.8.4 Conditions on solution to be a local minimizer

6.8.5 Positive-definite matrices and their properties

6.8.6 Quadratic functions

6.8.7 Implementation approaches for steepest descent, line search methods

6.8.8 Trust region methods

6.8.9 Levenberg-Marquardt algorithm

6.8.10 Geometric approaches: Nelder-Mead Simplex algorithm

6.8.11 Project: Estimation of the parameters of a planar homography for noisy point-match data using nonlinear least-squares.

7.0 Intended course learning outcomes and associated assessment methods of those outcomes

Course Learning Outcome	Homework Assignments	Computational Projects	Exams
7.1 Demonstrate the ability to model problems as systems of equations and to express them in vector space mathematics	X	X	X
7.2 Develop computational fluency with matrix and vector computations	X	X	X
7.3 Analyze the numerical sensitivity of algorithms	X	X	X
7.4 Formulate algorithm test and evaluation methods		X	
7.5 Demonstrate proficiency in the use of computing tools (e.g., Matlab)	X	X	X

8.0 Program outcomes and/or goals supported by this course

Prepares graduate students in science and engineering for careers in imaging science by preparing them to construct sophisticated mathematical models of realistic problems associated with imaging systems and to implement computations with practical programming tools for testing, evaluation, and refinement of designs.

9.0 N/A

10.0 Other relevant information (such as special classroom, studio, or lab needs, special scheduling, media requirements, etc.)

Smart classroom with Internet access; also offered online

11.0 Supplemental information for Optional Course Designations: If the course is to be considered as writing intensive or as a general education or honors course, include the sections of the course syllabus that would support this designation.

None