

# CURRICULUM VITAE

WOTAO YIN

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## ADDRESS

Department of Computational and Applied Mathematics  
Rice University  
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## EDUCATION

2001–2006      *Columbia University*, New York, NY, USA  
Ph.D. in Operations Research, 2006  
    Dissertation: The TV-L1 Model: Theory, Computation, and Applications.  
M.Phil. in Operations Research, 2006  
M.S in Operations Research, 2003  
  
1997–2001      *Nanjing University*, Nanjing, Jiangsu, China  
B.S. in Mathematics, 2001

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## RESEARCH INTERESTS

Numerical optimization and its applications in inverse problems such as compressed sensing, image processing, computer vision, and machine learning; variational imaging processing; combinatorial optimization, especially network flow problems, arising in scientific computing and industrial applications.

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## WORKING EXPERIENCE

07/2006–present    *Rice University*, Houston, TX, USA  
    Assistant Professor, Department of Computational and Applied Mathematics  
  
06/2004–06/2006    *Siemens Corporate Research*, Princeton, NJ, USA  
    Part-time Technical Employee, Department of Integrated Data Systems.

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## VISITING EXPERIENCE

09/2010–12/2010    *Institute for Pure and Applied Mathematics*, Los Angeles, CA, USA

**(A) Published in Refereed Journals**

1. Z. Wen, D. Goldfarb, and W. Yin. Alternating direction augmented Lagrangian methods for semidefinite programming. *Mathematical Programming Computation*, 2(3-4):203–230, 2010. [[pdf](#)]. [[code](#)]. [[data](#)].
2. Y. Wang and W. Yin. Sparse signal reconstruction via iterative support detection. *SIAM Journal on Imaging Sciences*, 3(3):462–491, 2010. [[pdf](#)]. [[website/code](#)].
3. W. Yin. Analysis and generalizations of the linearized Bregman method. *SIAM Journal on Imaging Sciences*, 3(4):856–877, 2010. [[pdf](#)].
4. F. Huang, Y. Chen, W. Yin, W. Lin, X. Ye, W. Guo, and A. Reykowski. A rapid and robust numerical algorithm for sensitivity encoding with sparsity constraints: Self-feeding sparse SENSE. *Magnetic Resonance in Medicine*, 64(4):1078–1088, 2010. [[pdf](#)].
5. J. Yang, Y. Zhang, and W. Yin. A fast alternating direction method for TVL1-L2 signal reconstruction from partial fourier data. *IEEE Journal of Selected Topics in Signal Processing, Special Issue on Compressed Sensing*, 4(2):288–297, 2010. [[pdf](#)]. [[website/code](#)].
6. S. Osher, Y. Mao, B. Dong, and W. Yin. Fast linearized Bregman iteration for compressive sensing and sparse denoising. *Communications in Mathematical Sciences*, 8(1):93–111, 2010. [[pdf](#)].
7. Q. Li, W. Yin, and Z. Deng. Image-based face illumination transferring using the logarithmic total variation model. *The Visual Computer*, 26(1):41–49, 2010. [[pdf](#)].
8. E. T. Hale, W. Yin, and Y. Zhang. A numerical study of fixed-point continuation applied to compressed sensing. *Journal of Computational Mathematics*, 28(2):170–194, 2010. [[pdf](#)]. [[website/code](#)].
9. D. Goldfarb and W. Yin. Parametric maximum flow algorithms for fast total variation minimization. *SIAM Journal on Scientific Computing*, 31(5):3712–3743, 2009. [[pdf](#)]. [[website/code](#)].
10. J. Yang, Y. Zhang, and W. Yin. An efficient TVL1 algorithm for deblurring multichannel images corrupted by impulsive noise. *SIAM Journal on Scientific Computing*, 31(4):2842–2865, 2009. [[pdf](#)]. [[website/code](#)].
11. J. Yang, W. Yin, Y. Zhang, and Y. Wang. A fast algorithm for edge-preserving variational multichannel image restoration. *SIAM Journal on Imaging Sciences*, 2(2):569–592, 2009. [[pdf](#)]. [[website/code](#)].
12. Z. Wen, W. Yin, D. Goldfarb, and Y. Zhang. A fast algorithm for sparse reconstruction based on shrinkage, subspace optimization and continuation. *SIAM Journal on Scientific Computing*, 32(4):1832–1857, 2009. [[pdf](#)]. [[website/code](#)].
13. J. Shi, W. Yin, S. Osher, and P. Sajda. A fast hybrid algorithm for large scale L1-regularized logistic regression. *Journal of Machine Learning Research*, 11:713–741, 2008. [[pdf](#)].
14. Y. Wang, J. Yang, W. Yin, and Y. Zhang. A new alternating minimization algorithm for total variation image reconstruction. *SIAM Journal on Imaging Sciences*, 1(3):248–272, 2008. [[pdf](#)]. [[website/code](#)].
15. D. Goldfarb, Z. Wen, and W. Yin. A curvilinear search method for  $p$ -harmonic flows on spheres. *SIAM Journal on Imaging Sciences*, 2(1):84–109, 2008. [[pdf](#)]. [[code](#)].
16. W. Yin, S. Osher, D. Goldfarb, and J. Darbon. Bregman iterative algorithms for l1-minimization with applications to compressed sensing. *SIAM Journal on Imaging Sciences*, 1(1):143–168, 2008. [[pdf](#)]. [[website/code](#)].

17. E. T. Hale, W. Yin, and Y. Zhang. Fixed-point continuation for l1-minimization: Methodology and convergence. *SIAM Journal on Optimization*, 19(3):1107–1130, 2008. [\[pdf\]](#). [\[website/code\]](#).
18. W. Yin, D. Goldfarb, and S. Osher. A comparison of three total variation based texture extraction models. *Journal of Visual Communication and Image Representation*, 18(3):240–252, 2007. [\[pdf\]](#).
19. W. Yin, D. Goldfarb, and S. Osher. The total variation regularized L1 model for multiscale decomposition. *SIAM Journal on Multiscale Modeling and Simulation*, 6(1):190–211, 2006. [\[pdf\]](#).
20. T. Chen, W. Yin, X. S. Zhou, D. Comaniciu, and T. Huang. Total variation models for variable lighting face recognition. *IEEE Transactions on Pattern Analysis and Machine Intelligence (PAMI)*, 28(9):1519–1524, 2006. [\[pdf\]](#).
21. D. Goldfarb and W. Yin. Second-order cone programming methods for total variation based image restoration. *SIAM Journal on Scientific Computing*, 27(2):622–645, 2005. [\[pdf\]](#).
22. O. Scherzer, W. Yin, and S. Osher. Slope and  $G$ -set characterization of set-valued functions and applications to non-differentiable optimization problems. *Communications in Mathematical Sciences*, 3(4):479–492, 2005. [\[pdf\]](#).
23. W. Yin, D. Goldfarb, and S. Osher. Image cartoon-texture decomposition and feature selection using the total variation regularized L1 functional. *Variational, Geometric, and Level Set Methods in Computer Vision*, 3752:73–84, 2005. [\[pdf\]](#).
24. S. Osher, M. Burger, D. Goldfarb, J. Xu, and W. Yin. An iterative regularization method for total variation-based image restoration. *SIAM Journal on Multiscale Modeling and Simulation*, 4(2):460–489, 2005. [\[pdf\]](#).
25. W. Yin, T. Chen, X. S. Zhou, and A. Chakraborty. Background correction for cDNA microarray image using the TV+L1 model. *Bioinformatics*, 21(10):2410–2416, 2005. [\[pdf\]](#).
26. T. Chen, T. Huang, W. Yin, and X. S. Zhou. A new coarse-to-fine framework for 3D brain MR image registration. *Computer Vision for Biomedical Image*, 3765:114–124, 2005. [\[pdf\]](#).

## **(B) Accepted for Publication in Refereed Journals**

27. J. Meng, W. Yin, H. Li, E. Houssain, and Z. Han. Collaborative spectrum sensing from sparse observations for cognitive radio networks. *IEEE JSAC Special Issue on Advances in Cognitive Radio Networking and Communications*, to appear, 2011. [\[pdf\]](#).

## **(C) Published in Refereed Conference Proceedings**

28. J. Meng, Y. Li, N. Nguyen, W. Yin, and Z. Han. High resolution OFDM channel estimation with low speed ADC using compressive sensing. *IEEE ICC 2011 Signal Processing for Communications Symposium*, to appear, 2011. [\[pdf\]](#).
29. Y. Li, W.-C. Shih, Z. Han, and W. Yin. Oil spill sensor using multispectral infrared imaging via l1 minimization. *International Conference on Acoustics, Speech, and Signal Processing (ICASSP'11)*, to appear, 2011. [\[pdf\]](#).
30. W. Yin, S. P. Morgan, J. Yang, and Y. Zhang. Practical compressive sensing with Toeplitz and circulant matrices. *In proceedings of Visual Communications and Image Processing (VCIP)*, 2010. [\[pdf\]](#). [\[website/code\]](#).
31. W. Guo and W. Yin. EdgeCS: an edge guided compressive sensing reconstruction. *In proceedings of Visual Communications and Image Processing (VCIP)*, 2010. [\[pdf\]](#).
32. J. Meng, W. Yin, H. Li, E. Houssain, and Z. Han. Collaborative spectrum sensing from sparse observations using matrix completion for cognitive radio networks. *International Conference on Acoustics, Speech, and Signal Processing (ICASSP'10)*, pages 3114–3117, 2010. [\[pdf\]](#).

33. S. Ma, W. Yin, Y. Zhang, and A. Chakraborty. An efficient algorithm for compressed MR imaging using total variation and wavelets. *IEEE International Conference on Computer Vision and Pattern Recognition (CVPR'08)*, pages 1–8, 2008. [pdf]. [code].
34. R. Chartrand and W. Yin. Iteratively reweighted algorithms for compressive sensing. *International Conference on Acoustics, Speech, and Signal Processing (ICASSP'08)*, pages 3869–3872, 2008. [pdf]. [code].
35. T. Chen, W. Yin, X. S. Zhou, D. Domaniciu, and T. Huang. Illumination normalization for face recognition and uneven background correction using total variation based image models. *IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'05)*, 2:532–539, 2005. [pdf].

#### (D) Submitted / Under Review

36. Y. Xu, W. Yin, Z. Wen, and Y. Zhang. An alternating direction algorithm for matrix completion with nonnegative factors. *Rice University CAAM Technical Report TR11-03*, 2011. [pdf].
37. W. Yin, Z. Wen, S. Li, J. Meng, and Z. Han. Dynamic compressive spectrum sensing for cognitive radio networks. *Rice University CAAM Technical Report TR11-04*, 2011. [pdf].
38. Z. Wen and W. Yin. A feasible method for optimization with orthogonality constraints. *Rice University CAAM Technical Report TR10-26*, 2010. [pdf]. [website/code].
39. Z. Wen, W. Yin, and Y. Zhang. Solving a low-rank factorization model for matrix completion by a non-linear successive over-relaxation algorithm. *Rice University CAAM Technical Report TR10-07*, 2010. [pdf]. [website/code].
40. J. Laska, Z. Wen, W. Yin, and R. Baraniuk. Trust, but verify: Fast and accurate signal recovery from 1-bit compressive measurements. *Rice University CAAM Technical Report TR10-30*, 2010. [pdf].
41. Z. Wen, W. Yin, H. Zhang, and D. Goldfarb. On the convergence of an active set method for l1-minimization. *Rice University CAAM Technical Report TR10-22*, 2010. [website/code].
42. L. Qu and W. Yin. Copula density estimation by total variation penalized likelihood with linear equality. *Rice University CAAM Technical Report TR09-40*, 2009.

#### (E) Technical Reports and Other Publications

43. S. Valiollahzadeh and W. Yin. Hyperspectral data reconstruction combining spatial and spectral sparsity. *Rice University CAAM Technical Report TR10-29*, 2010. [pdf].
44. W. Yin. Gurobi Mex: a MATLAB interface for Gurobi, user guide. *Online at [http://www.caam.rice.edu/~wy1/gurobi\\_mex/](http://www.caam.rice.edu/~wy1/gurobi_mex/)*, 2009-2011.
45. S. P. Morgan, W. Yin, and K. R. Vixie. A MATLAB implementation of a flat norm motivated polygonal edge matching method using a decomposition of boundary into four 1-dimensional currents. *arXiv:0812.0340v1*. *Rice University CAAM Technical Report TR09-35*, 2009. [pdf].
46. W. Yin and Y. Zhang. Extracting salient features from less data via l1-minimization. *SIAG/Optimization Views and News*, 19(1), 2008. [pdf].

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#### SOFTWARE PUBLICATIONS

1. Y. Zhang, Z. Wen, and W. Yin. LMafit: Low-Rank Matrix Fitting. <http://lmafit.blogs.rice.edu/>, 2010.
2. Y. Zhang, J. Yang, and W. Yin. YALL1: Your ALgorithms for L1, v1.0. <http://yall1.blogs.rice.edu/>, 2010.

3. W. Yin, S. Morgan, J. Yang, and Y. Zhang. RecPC: a code for practical compressive sensing with toeplitz and circulant matrices. <http://www.caam.rice.edu/~optimization/L1/RecPC>, 2010.
4. W. Yin. Gurobi Mex: a MATLAB interface for Gurobi, for solving linear, mixed-integer, and quadratic programs. [http://www.caam.rice.edu/~wy1/gurobi\\_mex/](http://www.caam.rice.edu/~wy1/gurobi_mex/), 2009-2011.
5. Y. Wang and W. Yin. Threshold ISD: A new compressed sensing algorithm via iterative support detection. <http://www.caam.rice.edu/~optimization/L1/ISD>, 2009.
6. J. Yang, Y. Zhang, and W. Yin. RecPF: Reconstruction from partial fourier data. <http://www.caam.rice.edu/~optimization/L1/RecPF>, 2008-2010.
7. Z. Wen and W. Yin. FPC-AS: An active-set continuation solver for the basis pursuit problem. [http://www.caam.rice.edu/~optimization/L1/FPC\\_AS](http://www.caam.rice.edu/~optimization/L1/FPC_AS), 2008-2009.
8. W. Yin. PGC: A preflow-push based graph-cut solver. <http://www.caam.rice.edu/~optimization/L1/pgc>, 2008.
9. Y. Wang, J. Yang, W. Yin, and Y. Zhang. FTVd: A fast algorithm for image deblurring and denoising with total variation regularization. <http://www.caam.rice.edu/~optimization/L1/ftvd/v4.1>, 2008-2010.
10. E. T. Hale, W. Yin, and Y. Zhang. FPC: A MATLAB solver for the basis pursuit problem. <http://www.caam.rice.edu/~optimization/L1/fpc>, 2007.
11. W. Yin. A MATLAB second-order cone programming based solver for total variation minimization. <http://www.caam.rice.edu/~wy1>, 2006.

## PENDING PATENTS

1. A. Chakraborty, W. Yin, and S. Ma. US 2009/0141995 A1. System and Method for Fixed Point Continuation for Total Variation Based Compressed Sensing Imaging.
2. W. Yin and A. Chakraborty. US 2006/0253311: Maintenance event planning and scheduling for gas turbines.

## AWARDS

2009	Alfred P. Sloan Fellow
2008	NSF CAREER Award

## GRANTS AND EXTERNAL SUPPORT

2010-2012	PI, NSF ECCS-1028790
2009-2012	Co-PI, ARL/ARO W911NF-09-1-0383 (PI: Richard Baraniuk)
09/2009-09/2011	Sloan Fellowship
2009-2012	PI, DOD/AFOSR, STTR 08 AF08-BT24 / #FA9550-10-C-0108, Phases I and II (Co-PI: Kevin Kelly)
2008-2013	PI, NSF CAREER Award DMS-0748839
2008-2012	PI, ONR Grant N00014-08-1-1101 (Co-PI: Yin Zhang)

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## RECENT PRESENTATIONS AND SHORT COURSES

- 01/03/2011 A Feasible Algorithm for Optimization with Constraints  $\|x\|_2 = 1$  or  $X^\top X = I$ , US-Mexico Workshop on Optimization and its Applications'11, Oaxaca, Oaxaca, Mexico.
- 12/21/2011 A Feasible Algorithm for Optimization with Constraints  $\|x\|_2 = 1$  or  $X^\top X = I$ , Chinese Academy of Sciences, Beijing, China.
- 12/20/2010 Optimization with Constraints  $\|x\|_2 = 1$  or  $X^\top X = I$ : Fast Curvilinear Search Algorithms, International Congress of Chinese Mathematicians, Beijing, China
- 12/12/2010 Optimization with Constraints  $\|x\|_2 = 1$  or  $X^\top X = I$ : A Fast Constraint-Preserving Method, the 8th International Conference on Optimization: Techniques and Applications, Shanghai, China
- 10/13/2010 Optimization with Orthogonality Constraints, IPAM Program on Modern Trends in Optimization and Its Application, Workshop II: Numerical Methods for Continuous Optimization, Los Angeles, CA
- 08/05/2010 Sparse Signal Reconstruction via Iterative Support Detection, International Conference on Mathematical Methods for Images, Guangzhou, China
- 08/01/2010 Sparse Signal Reconstruction via Iterative Support Detection, the Chinese Academy of Sciences, Beijing China
- 07/19-30/2010 Summer Course on Sparse Optimization, the Chinese Academy of Sciences, Beijing China
- 07/09/2010 Fast Algorithms for Compressive Sensing/Imaging based on Splitting, SFB Workshop on Imaging with Modulated/Incomplete Data, Graz, Austria
- 07/13/2010 Practical compressive sensing with Toeplitz and circulant matrices, International Conference on Visual Communications and Image Processing, Huangshan, China
- 05/25/2010 The Unreasonable Effectiveness of Bregman Iteration for L1-Related Minimization, International Conference on Computational and Mathematical Methods in Science and Engineering, Madison, WI
- 02/08/2010 Some Compressive Sensing Algorithms for Fast and Accurate Imaging, IPAM Workshop on Mathematical Problems, Models and Methods in Biomedical Imaging, Los Angeles, CA
- 02/06/2010 Compressive Sensing Algorithms for Fast and Accurate Imaging, Southwest Conference on Integrated Mathematical Methods in Medical Imaging, Arizona State University, Tempe, AZ
- 01/22/2010 Compressive Sensing Computation and Applications, Wireless Networking Group, University of Houston, Houston, TX
- 01/14/2010 Compressive Sensing and GPU Computation, Rice DSP Group, Houston, TX

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## COURSES AND SEMINARS

- Spring 2011 CAAM 210: Introduction to Engineering Computation  
CAAM 499/699 004: VIGRE: Sparse and Matrix Optimization and its Applications
- Spring 2010 CAAM 564: Numerical Optimization  
CAAM 499/699 004: VIGRE: Sparse Optimization Algorithms

Fall 2009 CAAM 565: Convex Optimization  
CAAM 499/699 004: VIGRE: Sparse Optimization Algorithms

Spring 2009 CAAM 210: Introduction to Engineering Computation  
CAAM 471: Introduction to Linear and Integer Programming

Fall 2008 CAAM 554: Convex Optimization  
CAAM 499/699 004: VIGRE: Image Processing, Compressed Sensing and Optimization

Spring 2008 CAAM/ECON 475: Integer Programming  
CAAM 499/699 004: VIGRE: Computational Image Processing

Fall 2007 CAAM 554: Convex Optimization

Spring 2007 CAAM/ECON 475: Integer and Combinatorial Optimization

Fall 2006 CAAM 554: Convex Optimization  
CAAM 499/699 004: VIGRE: Variational Image Processing

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#### POSTDOCS AND VISITORS

07/2010-present Yingying Li (co-host: Zhu Han)

10/2009-present Wolfgang Stefan

10/2009-09/2010 Zaiwen Wen (NSF Math Institutes' postdoc)

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#### VISITING SCHOLARS

09/2010-08/2011 Xin Liu (from the Chinese Academy of Sciences)

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#### DOCTORAL STUDENTS

08/2010-present Yangyang Xu (CAAM)

08/2009-present Wei Deng (CAAM, co-advisor: Wotao Yin)

08/2008-present Nabor Reyna Jr. (CAAM)

09/2008-12/2010 Jia Meng, PhD (University of Houston, main advisor: Zhu Han)

07/2006-06/2009 Yilun Wang (CAAM, co-advisor: Yin Zhang)

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#### OTHER STUDENTS

06/2010-present Shuyi Li (Rice Undergrad)

Summer 2009 Gerardo Garza (Rice AGEP)

Summer 2009 Yue Hu (Rice Undergrad)

Summer 2008 Noel Cavazos Jr. (Rice AGEP)

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## THESIS COMMITTEES

### Doctoral Theses, Directed/Co-Directed:

Yilun Wang, PhD 2009 (co-directed with Yin Zhang)

Thesis topic: Enhanced Compressed Sensing using Iterative Support Detection

Jia Meng, PhD 2010 (co-directed with Zhu Han, University of Houston)

Thesis topic: Compressive Sensing Applications in Wireless Networking

### Doctoral Thesis Committees:

Gang Hua (ECE), PhD 2010

Thesis topic: Spatial and Temporal Image Prediction with Magnitude and Phase Representations

Nan (Jenny) Zhang (STAT), PhD 2009

Thesis topic: Regression Survival Analysis With Dependent Censoring and a Change Point for the Hazard Rate: With Application to the Impact of the Gramm-Leach-Bliley Act to Insurance Companies' Survival

Marco F. Duarte (ECE), PhD 2009

Thesis topic: Compressive Sensing for Signal Ensembles

Joanna Papanikolaou, PhD 2009

Thesis topic: Historical Development of the BFGS Secant Method and Its Characterization Properties

Ryan Dunning (MATH), PhD 2009

Thesis topic: Asymptotics under Self-Intersection for Minimizers of Self-Avoiding Energies

Hongxiao Zhu (STAT), PhD 2008

Thesis topic: Functional Data Classification and Predictor Selection

Benjamin McClosky, PhD 2008

Thesis topic: Independence Systems and Stable Set Relaxations

Dharmpal Takhar (ECE), PhD 2008

Thesis topic: Compressed Sensing for Imaging Applications

Wei Zhu (MATH), PhD 2007

Thesis topic: Minimizing and Flow Problems for Multiple-Valued Functions and Maps

### Doctoral Thesis Proposal Committees:

Jason Laska (ECE), 2011

Ting Sun (ECE), 2010

Yilun Wang, 2009

Marco F. Duarte (ECE), 2009

Dharmpal Takhar (ECE), 2008

Benjamin McClosky, 2007

Hongxiao Zhu (STAT), 2007

Masters Theses, Directed/Co-Directed:

Yilun Wang, MA 2008 (co-directed with Yin Zhang)

Thesis topic: Fast Algorithms for Total Variation Minimization with Applications to Image Deconvolution and Compressed Sensing

Chengbo, Li, MA 2009 (co-directed with Yin Zhang)

Thesis topic: An Efficient Algorithm for Total Variation Regularization with Applications to the Single Pixel Camera and Compressive Sensing

Master Theses Committees:

Jing Ma, MA 2009

Thesis topic: Branch-decomposition Heuristics for Linear Matroids

Wei Lam Chang (ECE), MA 2008

Joanna Papakonstantinou, MA 2007

Nan (Jenny) Zhang (STAT), MA 2007

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## DEPARTMENTAL AND UNIVERSITY SERVICE

2008,2009,2010 CAAM Representative, Academic Fair for O-Week, Engineering Major Day  
09/24/2009 Meeting with NSF ADVANCE site visit reviewers  
07/29/2009 Summer Math Days, Lecture "Powerful Digital Image Processing"  
01/2007-present Member, CAAM Graduate Committee  
08/2008-06/2010 Chair, CAAM Colloquium  
10/2007-present Associate, Martel College  
11/2007 Co-host, the visit of the Los Alamos National Lab's DDMA Group to the Engineering School

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## PROFESSIONAL SERVICE

07/13/2010 Panelist, International Conference on Visual Communications and Image Processing  
10/29/2007 Panelist, NSF CDI Workshop at IPAM  
2005-present Reviewer, Applied Mathematics and Computation, Communications on Pure and Applied Mathematics, Computational Optimization and Applications, Digital Signal Processing, Mathematical Programming, IEEE Signal Processing Letter, IEEE Transactions on Image Processing, IEEE Transactions on Information Theory, IEEE Transactions on Signal Processing, Networks, Inverse Problems, Inverse Problems, Inverse Problems and Imaging, SIAM Journal on Imaging Sciences, SIAM Journal of Multiscale Modeling and Simulation, SIAM Journal on Optimization, Journal of Scientific Computing,  
2009 Co-organizer, the 20th International Symposium of Mathematical Programming in Chicago, 2009  
05/2008 Chair, SIAM Conference on Imaging Sciences 08, Session on Variational Color Image Processing

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## MEMBERSHIPS

- AMS
- SIAM (Activity groups: Imaging, Optimization)
- MPS
- INFORMS