Wayne Hayes: Curriculum Vitæ

Associate Professor, Dept. of Computer Science, University of California, Irvine CA 92697-3435
Associate Director, UCI Center for Computational Morphodynamics
Web Page: `http://www.ics.uci.edu/~wayne/`
E-mail: `wayne@ics.uci.edu`
Citizenship: Canadian

Research Interests

- complex systems: dynamical systems, chaos, scientific computing, numerical analysis; optimization
- computational biology: network alignment, protein folding, genome analysis, morphogen transport
- machine learning: automated classification of scientific images (eg., galaxies)
- algorithms: approximate graph alignment, combinatorial graph theory, Ramsey theory, combinatorics
- computer systems: parallel, distributed, grid computing; operating systems; compilers; software engineering

Education

Ph.D. Computer Science, University of Toronto, 2001. *Rigorous Shadowing of Numerical Solutions of Ordinary Differential Equations by Containment.*
Advisory Committee: Kenneth R. Jackson (Advisor, CS), Wayne Enright (CS), Tom Fairgrieve (CS), Ted Shepherd (Physics), Scott Tremaine (Astronomy).

M.Sc. Computer Science, University of Toronto, 1995. *Efficient Shadowing of High Dimensional Chaotic Systems with the Large Astrophysical N-body Problem as an Example.* Supervisor: Kenneth R. Jackson (CS).

Honours B.Sc. Comp. Sci., Physics & Astronomy. University of Toronto, 1994.

Professional Positions **(Details in Experience section)**

Visiting Scientist, NASA Jet Propulsion Laboratory, Cryogenics group (April 2013–present)
Visiting Researcher, Dept. of Computer Science, University College London (Summer 2012)
Visiting Fellow, Oxford Centre for Collaborative Applied Mathematics (April–Sept. 2011)
Associate Professor, Computer Science, UC Irvine (July 2010–present)
Lecturer, Department of Mathematics, Imperial College London (1 yr fellowship, Oct. 2009–2010)
Associate Director, UC Irvine Center for Computational Morphodynamics (July 2009–present)
Assistant Professor, Computer Science, UC Irvine (July 2004–June 2010)
Visiting Scientist, *Centre Nationale Reserches Scientifique (CNRS)*, Nantes, France (summer 2008)
Research Associate, Inst. Phys. Sci. & Tech., U. Maryland College Park (Nov. 2002–June 2004)
Research Associate, Fields Inst. for Research in Math. Sci., Toronto (Sept. 2001–Oct. 2002)
Research Associate, Samuel Lunenfeld Research Inst., Toronto (part time, 2001–2002)
Software Engineer, Member of Tech. Staff, Altera Toronto Technology Center (Sep. 2000–Aug 2001)
Research Graduate Student, Computer Science Dept., Univ. Toronto, (1993–2000)
Software Engineer, Algorithmics. Inc., Toronto (1995)
Software Engineer, IBM Optimizing Compiler Group (1994)
Star Theatre Lecturer, McLaughlin Planetarium, Toronto (1991-1995)

Publications (All available on the above web page)

Refereed Journal Publications

J24. Darren Davis and **Wayne Hayes** "SpArcFiRe: Scalable Automated Detection of Spiral Galaxy Arm Segments" *The Astrophysical Journal* **790**:87, 14pp (2014).

J23. Srinivasan S, Hu JS, Currle DS, Fung ES, **Hayes WB**, Lander AD, Monuki ES. (2014) "A BMP-FGF Morphogen Toggle Switch Drives the Ultrasensitive Expression of Multiple Genes in the Developing Forebrain." *PLoS Comput Biol* **10(2)**: e1003463. doi:10.1371/journal.pcbi.1003463.

J22. **Wayne Hayes**, Kai Sun, Nataša Pržulj. "Graphlet-based measures are suitable for biological network comparison" *Bioinformatics* doi:10.1093/bioinformatics/bts729 (2013).

J21. Oleksii Kuchaiev, Aleksandar Stevanovic, **Wayne Hayes** and Nataša Pržulj. "GraphCrunch 2: Software tool for network modeling, alignment and clustering." *BMC Bioinformatics* 2011, **12**:24 doi:10.1186/1471-2105-12-24.

J20. Alexandre Goldsztejn, **Wayne Hayes**, Pieter Collins. "Tinkerbell is Chaotic". *SIAM Journal on Applied Dynamical Systems* **10(4)**, pp. 1480–1501 (2011).

J19. **Wayne Hayes**. "Computer simulation, exact trajectories, and the gravitational N-body problem." *American Journal of Physics* **72:9**, pp. 1251-1257 (September 2004). (Previously item IJ1 in my old C.V.)

J18. **Wayne Hayes**, Anton Malykh, and Christopher Danforth. "The interplay of chaos between the Terrestrial and Giant Planets" *Monthly Notices of the Royal Astronomical Society* 2010. doi:10.1111/j.1365-2966.2010.17027.x. 7 pages.

J17. Yong-Kang Zhu and **Wayne Hayes**. "Algorithm 908: Online exact summation of floating-point streams". *ACM Transactions on Mathematical Software* Vol. **37**:3 (2010). 12 pages.

J16. Tijana Milenković, Weng Leong Ng, **Wayne Hayes**, Nataša Pržulj. "Optimal Network Alignment with Graphlet Degree Vectors". *Cancer Informatics* 2010:**9** 121-137.

J15. Oleksii Kuchaiev, Tijana Milenković, Vesna Memišević, **Wayne Hayes**, Nataša Pržulj. "Topological network alignment uncovers biological function and phylogeny". *Journal of the Royal Society Interface* 2010 **7**, 1341-1354 doi:10.1098/rsif.2010.0063.

J14. Yong-Kang Zhu and **Wayne Hayes**. "Correct Rounding and a Hybrid Approach to Exact Floating-Point Summation." *SIAM J. Sci. Comput.* **31:4**, pp. 2981–3001 (2009).

J13. **Wayne Hayes**. "Surfing on the edge: chaos versus near-integrability in the system of Jovian planets". *Monthly Notices of the Royal Astronomical Society* **386**, pp. 295–306 (2008).

J12. **Wayne Hayes**. "Is the outer Solar System Chaotic?" *Nature Physics* **3**, pp. 689-691 (2007).

J11. **Wayne Hayes** and Kenneth R. Jackson. "A Fast Shadowing Algorithm for High Dimensional ODE Systems". *SIAM Journal on Scientific Computing* **29:4**, 1738–1758 (2007)

J10. Wayne Enright and **Wayne Hayes**. "Robust and Reliable Defect Control for Runge Kutta Methods." *ACM Transactions on Mathematical Software* **33:1** 19 pages, 2007.

J9. Michael Roberts, Aleksey V. Zimin, **Wayne Hayes**, Brian R. Hunt, Cevat Ustun, James R. White, Paul Havlak, James Yorke. "Improving Phrap-based assembly of the Rat Using Reliable Overlaps." *PLoS ONE* **3(3): e1836** (2008). Published online 2008 March 19. doi: 10.1371/journal.pone.0001836.

J8. Carmen Young, **Wayne Hayes**, Ken Jackson. "Rigorous High-dimensional Shadowing Using Containment: the General Case." *Discrete and Continuous Dynamical Systems* **14:2**, February 2006 pp. 329-342.

J7. **Wayne Hayes** and Kenneth R. Jackson. "A Survey of Shadowing Methods for Numerical Solutions of Ordinary Differential Equations." *Applied Numerical Mathematics* **53**, pp. 299-321 (2005). (doi:10.1016/j.apnum.2004.08.011)

J6. Michael Roberts, **Wayne Hayes**, Brian R. Hunt, Stephen M. Mount, James A. Yorke. "Reducing storage requirements for biological sequence comparison." *Bioinformatics* **20**:3363–3369 (Dec 2004).

J5. **Wayne Hayes** and Ken Jackson. "Rigorous Shadowing of Numerical Solutions of Ordinary Differential Equations by Containment." *SIAM J. of Numerical Analysis* 41:5 pp. 1948-1973 (2003).

J4. **Wayne Hayes**. "Shadowing-based reliability decay in collisionless n-body simulations." *Astrophysical Journal Letters* 587:L59-L62 (2003).

J3. **Wayne Hayes**. "Shadowing high-dimensional Hamiltonian systems: the gravitational N-body problem." *Physical Review Letters* **90**:5 (2003).

J2. **Wayne Hayes** and Scott Tremaine. "Fitting Selected Random Solar Systems to Titius-Bode Laws." *Icarus* 135 pp. 549–557 (1998).

J1. Bill Katz, Dan Driscoll, Kai Millyard, Bruce Waters, Mark Zalcik, Joe Adair, Andreas Gada, **Wayne Hayes**, Richard Kelsch, Richard McWaters, Richard Rokosz, John Zehethofer, Alex Fullerton, Ron Lyons, Marshall McCall. "Optical flashes in Perseus." *Astrophysical Journal Letters* 307:L33-L37 (1986).

Conferences: Refereed Publications

CR6. Darren R. Davis and **Wayne Hayes**. "Automated Quantitative Description of Spiral Galaxy Arm-Segment Structure." *Computer Vision and Pattern Recognition (CVPR) 2012*. Providence, Rhode Island, June 16–21, 2012.

CR5. Nataša Pržulj, Oleksii Kuchaiev, Aleksandar Stevanović, and **Wayne Hayes**. "Geometric Evolutionary Dynamics of Protein Interaction Networks". *Pacific Symposium in Biocomputing (PSB) 2010*, Hawaii, 4–8 January 2010.

CR4. Alexandre Goldsztejn and **Wayne Hayes**. "Rigorous Inner Approximation of the Range of Functions". 12th GAMM - IMACS International Symposion on Scientific Computing, Computer Arithmetic and Validated Numerics, Duisburg, Germany, 26–29 September, 2006 (9 pages).

CR3. Yong-Kang Zhu and **Wayne Hayes**. "Fast, Guaranteed-accurate Sums of Many Floating-Point Numbers". Proceedings of RNC7, the 7th Conference on Real Numbers and Computers, Loria, France. G. Hanrot, P. Zimmermann (Eds.), pp. 11-22 (2006).

CR2. **Wayne Hayes** and Kenneth R. Jackson. "Global error measures for the large gravitatonal N-body problem." *Proceedings of the 12th "Kingston" Meeting on Theoretical Astrophysics: Computational Astrophysics. ASP Conference Series Vol. 123 (1997)*, pp. 237-239. D. A. Clarke and M. J. West, Eds. Halifax, Nova Scotia. October, 1996.

CR1. **Wayne Hayes** and Mart L. Molle. "Solving Capture in Switched Two-Node Ethernets by Changing Only One Node." *Proceedings of the 20th Annual Conference on Local Computer Networks*, LCN '95, pp. 387-396. Minneapolis, Minnesota. October, 1995.

Conferences: Plenary/Invited Talks

PT2. **Wayne Hayes**. "Shadowing as a measure of backward error in numerical simulations." *Hybrid Methodologies for Symbolic-Numeric Computation.* Workshop at the Fields Institute, University of Waterloo, Friday 18 November 2011.

PT1. **Wayne Hayes**. "Reliability measures in the integration of ODEs." School and Conference on Computational Methods in Dynamics. Institute for Theoretical Physics, Trieste, Italy, 4-8 July 2011.

Conferences: Invited Talks

CI7. **Wayne Hayes**, Anton Malykh, Chris Danforth. "The interplay of chaos between the inner + outer planets in our Solar System" SciCADE 2011, Toronto, July 2011. Invited by Anita Tam.

CI6. **Wayne Hayes**. "Solar System: Surfing the Edge of Chaos". Invited by Roberto Barrio in the "High Precision Numerics" Minisymposium at DSPDEs, 31 May 2010, Barcelona, Spain.

CI5. **Wayne Hayes**. "From Butterflies to Galaxies: reliable simulation of chaotic systems". Invited talk, 2005 International Conference on Scientific Computation and FDifferential Equations (SciCADE). Nagoya, Japan, May 2005.

CI4. **Wayne Hayes**. "On simulation reliability: shadowing the gravitational and molecular dynamics n-body problems." Workshop on Chaos and Ergodicity in Realistic Hamiltonian Systems. *Centre de Récherches Mathematiques, Université de Montreal*, Canada, Dec. 11-14, 2007.

CI3. **Wayne Hayes**, "From Butterflies to Galaxies: reliable simulation of Chaotic Systems." BIRS Workshop on Mathematical Issues in Molecular Dynamics. Banff, Canada, June 4-9, 2005.

CI2. **Wayne Hayes** and Ken Jackson. "Rigorous Shadowing of Numerical Solutions of Ordinary Differential Equations by Containment." 50 minute talk presented at *NUMDIFF 10*, a tri-annual conference on the numerical solution of differential and differential-algebraic equations. Halle, Germany. September, 2003.

CI1. **Wayne Hayes** and Ken Jackson. "Rigorous shadowing of numerical trajectories of dynamical systems." *Minisymposium on validated numerics, SciCADE 2001.* Vancouver, B.C. July, 2001.

Conferences: Contributed Talks

CC28. **Wayne Hayes** and Darren Davis. "Quantifying galaxy morphology using automatic extraction of structure from images". *2012 American Astronomical Society's Division of Dynamical Astronomy (AAS/DDA) meeting*. Mount Hood, Oregon, May 2012.

CC27. Shyam Srinivasan, Spencer D. Currle, Jia Sheng Hu, **Wayne B. Hayes**, Arthur D. Lander, Edwin S. Monuki. "A dual morphogen toggle switch creates sharp and robust borders in the developing forebrain". *International Conference for Systems Biology (ICSB)*, Heidelberg, Germany, 2011.

CC26. **Wayne Hayes** and Darren Davis. "Extracting structure from galaxy images". *Neural Information Processing Systems (NIPS) 2011 Workshop on Cosmology Meets Machine Learning*, Granada, Spain, December 2011.

CC25. **Wayne Hayes** and Darren Davis. "Extracting structure from galaxy images". CITA25/BOND60 Conference, Toronto, 12–16 May, 2010.

CC24. **Wayne Hayes** and Darren Davis. "Extracting structure from galaxy images". AAS/DDA meeting, Boston, 26–29 April 2010.

CC23. Shyam Srinivasan, Spencer D. Currle, **Wayne B. Hayes**, Arthur D. Lander, Edwin S. Monuki. "A cross inhibitory positive feedback mechanism establishes a robust sharp border in the forebrain", *International Society for Developmental Biology*, Edinburgh, UK, 2009.

CC22. **Wayne Hayes** and Chris Danforth. "Outer Solar System Surfing the Edge of Chaos II: Slices Through the Observational Error Volume". Numerical Analysis Conference, Strathclyde University, Glasgow, Scotland, United Kingdom, June 2009.

CC21. Yong-Kang Zhu and **Wayne Hayes**. "Fixed-motion shadowing on gravitational n-body systems". SCAN 2008—14th GAMM-IMACS International Symposion on Scientific Computing, Computer Arithmetic and Validated Numerics. El Paso, Texas, 26–29 September 2008.

CC20. **Wayne Hayes** and Chris Danforth. "Outer Solar System Surfing the Edge of Chaos II: Slices Through the Observational Error Volume". 12th Serbian Mathematical Congress, Aug. 31–Sep. 3, 2008. Novi Sad, Serbia.

CC19. **Wayne Hayes** and Chris Danforth. "Outer Solar System Surfing the Edge of Chaos II: Slices Through the Observational Error Volume". Meeting of the American Astronomical Society (AAS) Division of Dynamical Astronomy (DDA). University of Colorado at Boulder. Apr 28-May 1, 2008.

CC18. Alexandre Goldsztejn and **Wayne Hayes**. "A New Containment Algorithm for Rigorous Shadowing." SciCADE 2007, International Conference on SCIentific Computation And Differential Equations. Le Palais du Grand Large, Saint-Malo, France, July 9–13, 2007.

CC17. **Wayne Hayes**. "Reliability of Galaxy Simulations." SciCADE 2007, International Conference on SCIentific Computation And Differential Equations. Le Palais du Grand Large, Saint-Malo, France, July 9–13, 2007.

CC16. **Wayne Hayes**. "Shadowing Reliability of Million-Particle Galaxy Simulations." Meeting of the American Astronomical Society (AAS) Division of Dynamical Astronomy (DDA). University of Michigan, Ann Arbor, May 6-10, 2007.

CC15. Alexandre Goldszstejn and **Wayne Hayes** (40% co-author). "Reliable inner approximation of the solution set to initial value problems with uncertain initial value." SCAN 2006—12th GAMM-IMACS International Symposion on Scientific Computing, Computer Arithmetic and Validated Numerics. Duisburg, Germany, 26–29 September 2006.

CC14. **Wayne Hayes**. "Outer Solar System on the Edge of Chaos." SCAN 2006—12th GAMM-IMACS International Symposion on Scientific Computing, Computer Arithmetic and Validated Numerics. Duisburg, Germany, 26–29 September 2006.

CC13. **Wayne Hayes**. "Rigorous Shadowing of Numerical Solutions of Ordinary Differential Equations by Containment." International Conference on Numerical Analysis and Applied Mathematics (ICNAAM 2006). Crete, Greece, 15-19 September, 2006.

CC12. **Wayne Hayes**. "Outer Solar System Surfing the Edge of Chaos." *Topics in Mathematical Analysis and Graph Theory* (MAGT 2006), Belgrade, Serbia, Sept. 1-4, 2006.

CC11. **Wayne Hayes**. "Outer Solar System on the Edge of Chaos." Meeting of the American Astronomical Society (AAS) Division of Dynamical Astronomy (DDA). Saint Mary's University, Halifax, Nova Scotia, Canada, June 25-29, 2006.

CC10. **Wayne Hayes**. "Shadowing-based timestep criterion for collisionless N-body simulations." 2005 IPAM N-body systems an astrophysics. UCLA, Apr 19 2005.

CC9. "Shadowing-based timestep criterion for collisionless N-body simulations." 2005 meeting of the Division of Dynamical Astronomy, American Astronomical Association. Santa Barbara, April 10-14, 2005.

CC8. **Wayne Hayes** and Kenneth Jackson. "Rigorous Shadowing of numerical solutions to ordinary differential equations by containment." *Joint Sherbrooke-Bishop's-CRM Colloquium Series in Analysis and Related Topics*. Sherbrooke, Quebec, Canada, Feb 16–17, 2005.

CC7. **Wayne Hayes**. "A shadowing-based timestep criterion for softened gravitational n-body simulations". AIMS Fifth International Conference on Dynamical Systems and Differential Equations, June 16-19, 2004. California State Polytechnic University, Pomona, California.

CC6. Michael Roberts, James Yorke, Brian Hunt, **Wayne Hayes**, Aleksey Zimin, Cevat Ustun. "Improving Sequence Assemblies Using High-quality Overlaps." *Third Annual RECOMB Satellite Meeting on DNA Sequencing Technologies and Computation*. Stanford University. May, 2003.

CC5. **Wayne Hayes** and Ken Jackson. "Rigorous shadowing of Numerical Solutions to Ordinary Differential Equations by Containment." *Southern Ontario and Western New York Numerical Analysis Day*. McMaster University, Hamilton, Ontario. April, 1999.

CC4. **Wayne Hayes**. "Can we trust numerical simulations of galaxy dynamics?" *Galaxy Dynamics Conference*. Rutgers University. August, 1998.

CC3. **Wayne Hayes** and Ken Jackson. "Rigorous Containment of Shadows of High-Dimensional Dynamical Systems." *SIAM 1998 Annual Meeting*. Toronto, Canada. July, 1998.

CC2. **Wayne Hayes** and Kenneth R. Jackson. "A Fast Shadowing Algorithm for High Dimensional ODE Systems." *Dynamical Numerical Analysis Conference*. Georgia Tech, Atlanta. December, 1995.

CC1. **Wayne Hayes** and Ken Jackson. "High-dimensional shadowing and the large gravitational N-body problem." *Ontario Numerical Analysis Day*. University of Waterloo. 1995.

Conferences: Posters

CP7. **Wayne Hayes**, Kai Sun, Nataša Pržulj. "On the Suitability of Graphlet-based Measures for Biological Network Comparison." *European Conference on Computationtal Biology (ECCB) 2012*, Basel, Switzerland, September 2012.

CP6. Shyam Srinivasan, Spencer D. Currle, Jia Sheng Hu, **Wayne B. Hayes**, Arthur D. Lander, Edwin S. Monuki. "A BMP-FGF cross inhibitory positive feedback mechanism as a basis for cell intrinsic ultrasensitivity and developmental border formation". *Society for Neuroscience*, San Diego, CA, 2010.

CP5. Shyam Srinivasan, Jia Sheng Hu, Spencer D. Currle, **Wayne B. Hayes**, Arthur D. Lander, Edwin S. Monuki. "Intracellular positive feedback driven by antagonistic extracellular signals as a basis for cell intrinsic ultrasensitivity and developmental border formation". *National symposium on Systems Biology of Stem Cells*, CA, 2010.

CP4. Shyam Srinivasan, Spencer D. Currle, Jia Sheng Hu, **Wayne B. Hayes**, Arthur D. Lander, Edwin S. Monuki. "A cross inhibitory positive feedback mechanism establishes a robust sharp border in the forebrain". *Society for Neuroscience*, Chicago, IL, 2009.

CP3. Oleksii Kuchaiev, Tijana Milenkovic, Vesna Memisevic, **Wayne Hayes**, and N. Pržulj. "Topological Network Alignment Uncovers Biological Function and Phylogeny" The 10th International Conference on Systems Biology (ICSB 2009), Stanford, CA, August 30–September 4, 2009.

CP2. **Wayne Hayes**, Yong-Kang Zhu. "Studying Reliability of Galaxy Simulations Using Shadowing" Meeting of the American Astronomical Society (AAS) Division of Dynamical Astronomy (DDA). University of Colorado at Boulder. Apr 28-May 1, 2008.

CP1. Michael Roberts, James Yorke, Brian Hunt, **Wayne Hayes**, Aleksey Zimin, Cevat Ustun. "Improving Sequence Assemblies Using High-quality Overlaps" *Intelligent Systems for Molecular Biology (ISMB).* Brisbase, Australia. June/July, 2003.

INVITED SEMINAR & COLLOQUIUM TALKS

ISC65. Ibid. to ISC60. Seminar given at

ISC64. Ibid. to ISC60. Seminar given at ASU Phoenix, 27 June 2014.

ISC63. Ibid. to ISC60. Seminar given at Lowell Observatory, Flagstaff AZ, 26 June 2014.

ISC62. Ibid. to ISC60. Seminar given at UNM Albuquerque, 24 June 2014.

ISC61. Ibid. to ISC60. Seminar given at CU Boulder, 19 June 2014.

ISC60. Darren Davis and **Wayne Hayes**. "SpArcFiRe: Scalable Automated Detection of Spiral Galaxy Arm Segments", Seminar at Canadian Institute for Theoretical Astrophysics, U. of Toronto, 2 May 2014.

ISC59. **Wayne Hayes**. "Modeling the Apocalypse at NASA's Jet Propulsion Laboratory", Friday, 2 May 2014, Bahen Centre for Information Technology, University of Toronto.

ISC58. **Wayne Hayes**. "Climate change: warming up to a heated topic". Public seminar to the Harvard Alumni Club of Southern California, 13 April 2014.

ISC57. "Measuring Structure from Spiral Galaxy Images". November 7, 2013, University of San Diego. Presented by Darren Davis.

ISC56. Darren Davis and **Wayne Hayes**. "Extracting Structure from Images of Spiral Galaxies", Seminar at McMaster University, Hamilton, Ontario, 13 Aug. 2013

ISC55. Darren Davis and **Wayne Hayes**. "Extracting Structure from Images of Spiral Galaxies", Computational Science Seminar at SDSU, 8 March 2013.

ISC54. Darren Davis and **Wayne Hayes**. "Extracting Structure from Images of Spiral Galaxies", Seminar at University of Toronto, 14th September 2012.

ISC53. **Wayne Hayes** and Darren Davis. "Shape Inference in Galaxy Images". Seminar, Department of Astronomy, University College London, 25 April 2012.

ISC52. **Wayne Hayes**, Alexandre Goldsztejn, Pieter Collins. "Tinkerbell is Chaotic". Numerical Analysis Seminar, Dept. of Computer Science, University of Toronto, 21 October 2011.

ISC51. **Wayne Hayes** and Darren Davis. "Shape Inference in Galaxy Images". Seminar at the Petnica Science Center, Serbia, 1 May 2011.

ISC50. **Wayne Hayes** and Darren Davis. "Shape Inference in Galaxy Images". Department Seminar, Astronomy Department, University of Arkansas, 24 Jan. 2011.

ISC49. **Wayne Hayes** and Darren Davis. "Shape Inference in Galaxy Images". Department Seminar, Astronomy Department, Oxford University, 9 Sept. 2010.

ISC48. **Wayne Hayes**, Anton Malykh, Chris Danforth. "Solar System Surfing the Edge of Chaos". Seminar, Pulkova Observatory, St. Petersburg, Russia, 20 Aug. 2010.

ISC47. **Wayne Hayes**, Anton Malykh, Chris Danforth. "Solar System Surfing the Edge of Chaos". Seminar, Keldysh Institute of Mathematics, Moscow, Russia, 16 Aug 2010.

ISC46. **Wayne Hayes** and Darren Davis. "Shape Inference in Galaxy Images". Department Seminar, Institute of Astronomy, Cambridge University, 14 July 2010.

ISC45. **Wayne Hayes** and Darren Davis. "Shape Inference in Galaxy Images". Department Colloquium, Computer Science, Cambridge University, 26 May 2010.

ISC44. **Wayne Hayes**, Anton Malykh, Chris Danforth. "Solar System Surfing the Edge of Chaos". Department Seminar, DAMPT, Cambridge University, 25 May 2010.

ISC43. **Wayne Hayes** and Darren Davis. "Shape Inference in Galaxy Images". Department Seminar, Computer Science, Queen Mary University of London, 24 May 2010.

ISC42. **Wayne Hayes** and Darren Davis. "Shape Inference in Galaxy Images". Department Seminar, Computer Science, University of East Anglia, 21 May 2010.

ISC41. **Wayne Hayes** and Darren Davis. "Shape Inference in Galaxy Images". Department Seminar, Computer Science, University of Toronto, 3 May 2010.

ISC40. **Wayne Hayes**, Anton Malykh, and Chris Danforth. "Outer Solar System Surfing the Edge of Chaos, Part II". Seminar at Department of Computer Science, University of Toronto, 30 April 2010.

ISC39. **Wayne Hayes** and Darren Davis. "Shape Inference in Galaxy Images". Department Seminar, Computer Science, University of Bristol, 11 March 2010.

ISC38. **Wayne Hayes**. "Recent developments in Complex Dynamical Systems." Seminar at Math Department, University of Reading, United Kingdom, 18 January 2010.

ISC37. **Wayne Hayes**, Anton Malykh, and Chris Danforth. "Outer Solar System Surfing the Edge of Chaos, Part II". Seminar at Math Department, Imperial College London, United Kingdom, June 30, 2009.

ISC36. **Wayne Hayes**, Anton Malykh, and Chris Danforth. "Outer Solar System Surfing the Edge of Chaos, Part II". Seminar at Math Department, Simon Fraser University, Vancouver, Canada, March 16, 2009.

ISC35. **Wayne Hayes** "Provable shadowing and advances in exact numerics." Talk at Centre Researches Mathematiques and Math Department, McGill University, Montreal, Quebec, Canada, 27 February 2009.

ISC34. **Wayne Hayes** and Yong-Kang Zhu. "Floating-Point Summation." Numerical Analysis Seminar, Department of Computer Science, University of Toronto, 18 December 2008.

ISC33. **Wayne Hayes**, Anton Malykh, and Chris Danforth. "Outer Solar System Surfing the Edge of Chaos, Part II". Seminar at Instituto de Astronomia Sede Ensenda, Mexico 24 November 2008.

ISC32. **Wayne Hayes** and Chris Danforth. "Outer Solar System Surfing the Edge of Chaos, Part II". Seminar at Astronomical Observatory of Paris, 30 October 2008.

ISC31. **Wayne Hayes** and Chris Danforth. "Outer Solar System Surfing the Edge of Chaos, Part II". Seminar at Department of Computer Science, University of Barcelona, 28 October 2008.

ISC30. **Wayne Hayes** and Chris Danforth. "Outer Solar System Surfing the Edge of Chaos, Part II". Seminar at Department of Computer Science, K. U. Leuven, 24 October 2008.

ISC29. **Wayne Hayes**. "Recent advances in Solar System and Planet Formation" Seminar at the Petnica Science Center, Serbia, 18 October 2008.

ISC28. **Wayne Hayes** and Chris Danforth. "Outer Solar System Surfing the Edge of Chaos, Part II". Seminar at Department of Computer Science, University of Toronto, March 28, 2008.

ISC27. **Wayne Hayes**. "Solar System Surfing the Edge of Chaos." Talk at Applied Mathematics Seminar and Lunar and Planetary Institute, University of Arizona. Invited by Renu Malhotra and Jocelyn Lega. April 6, 2007.

ISC26. **Wayne Hayes**. "From Butterflies to Galaxies: reliable simulation of chaotic systems." Talk at Dynamical Systems Group, Arizona State University. Invited by Ying-Cheng Lai. April 3, 2007.

ISC25. **Wayne Hayes**. "Solar System Surfing the Edge of Chaos." Talk at US Naval Observatory, Washington, D.C. Invited by Michael Efroimsky. March 20, 2007.

ISC24. **Wayne Hayes** and Ken Jackson. "Rigorous Shadowing of Numerical Solutions of Ordinary Differential Equations by Containment." Presented by Ken Jackson (a collaborator) at Laurier Seminar Series, 23 November, 2006.

ISC23. **Wayne Hayes**. "Outer Solar System on the Edge of Chaos." Seminar, Harvard Center for Astrophysics. 19 Oct, 2006.

ISC22. **Wayne Hayes**. "Outer Solar System Surfing the Edgo of Chaos." Colloquium, Institute of Physics, University of Belgrade. Invited by Alexandar Bogojevic. Aug 28, 2006.

ISC21. **Wayne Hayes**. "Outer Solar System on the Edge of Chaos." Invited talk at UCI Center for Cosmology Symposium, Monday 17 April 2006.

ISC20. **Wayne Hayes**. "Surfing the Edge: Chaos *vs.* Near-Integrability in the Outer Solar System". Invited talk to James Yorke's Chaos group at the Institute for Physical Sciences and Technology, University of Maryland, College Park, Feb 28, 2006.

ISC19. **Wayne Hayes**. "Rigorous Shadowing of Numerical Solutions of Ordinary Differential Equations by Containment." Applied Mathematics Seminar, UCI. 2006-Jan-30.

ISC18. **Wayne Hayes**. "From Butterflies to Galaxies: Validating Simulations of Large Chaotic Systems". Mathematics Department Seminar, University of Victoria, Canada, 8 Dec. 2005.

ISC17. **Wayne Hayes**. "From Butterflies to Galaxies: Validating Simulations of Large Chaotic Systems". Computer Science Department Seminar, Simon Fraser University, Canada, 7 Dec. 2005.

ISC16. **Wayne Hayes**. "From Butterflies to Galaxies: Validating Simulations of Large Chaotic Systems". Computer Science Department Seminar, University of British Columbia, Canada, 6 Dec 2005.

ISC15. **Wayne Hayes**. "Reliable N-body Simulation." Joint Physics, Applied Mathematics, and Computer Science Colloquium, University of Belgrade, Serbia. Wednesday 14 Sept. 2005.

ISC14. **Wayne Hayes**. "From Butterflies to Galaxies: reliable simulation of chaotic systems". Colloquium, Dept. of Physics, UCI. 2 June 2005.

ISC13. **Wayne Hayes**. "Rigorous Shadowing of Numerical Solutions of Ordinary Differential Equations by Containment". Applied Mathematics Colloquium, UCLA. 12 May 2005.

ISC12. **Wayne Hayes**. "From Butterflies to Galaxies: reliable simulation of chaotic systems." Colloquium, Center for Applied Mathematical Sciences, University of Southern California. 25 April 2005.

ISC11. **Wayne Hayes**. "From Butterflies to Galaxies: Validating Simulations of Large Chaotic Systems". Dept. of Electrical and Computer Engineering, University of California, Santa Barbara. 2005-Mar-4.

ISC10. **Wayne Hayes**. "From Butterflies to Galaxies: Validating Simulations of Large Chaotic Systems". San Diego Supercomputer Centre and Department of Computer Science, UCSD. 2005-Feb-11.

ISC9. **Wayne Hayes** "From Butterflies to Galaxies: reliable simulation of chaotic systems". Numerical Analysis Seminar, Dept. of Computer Science, University of Toronto. 15 Oct. 2004.

ISC8. **Wayne Hayes**. "A shadowing-based timestep criterion for softened gravitational n-body simulations". Dept. of Computer Science, University of California, Irvine. 2004-Mar-12.

ISC7. **Wayne Hayes**, "A shadowing-based timestep criterion for softened gravitational n-body simulations". School of Science, University of Ontario Institute of Technology. 2004-Feb-16.

ISC6. **Wayne Hayes**, "A shadowing-based timestep criterion for softened gravitational n-body simulations". Dept. of Computer Science, University of Guelph. 2002-May-2.

ISC5. **Wayne Hayes**. "Rigorous Shadowing of Numerical Trajectories of Dynamical Systems." *Informal Working Group on Validated Methods for ODEs and DAEs.* Fields Institute, Toronto. September, 2001.

ISC4. **Wayne Hayes**. "Shadowing the gravitational N-body problem." Seminar. Ontario Research Centre for Computer Algebra, University of Western Ontario. April, 2000.

ISC3. **Wayne Hayes**. "Rigorous shadowing of numerical solutions of ODEs." Seminar. Argonne National Labs. Chicago, Illinois. February, 2000.

ISC2. **Wayne Hayes**. "A Fast Shadowing Algorithm for High Dimensional ODE Systems." Seminar. Department of Computer Science, University of Toronto. March, 1996.

ISC1. **Wayne Hayes**. "Shadowing the Large Gravitational N-body Problem." G2000 Seminar. Department of Astronomy, University of Toronto. January, 1996.

Technical Reports

TR1. **Wayne Hayes** and Kenneth R. Jackson. "A Fast Shadowing Algorithm for High Dimensional ODE Systems." University of Toronto Department of Computer Science. March 1996.

Grants

- G6 \$1.8 million: NIH R01. Co-PI with PI Edwin Monuki, UCI. 2008-2013. Mathematical modelling of morphogen transport in organ development from stem cells.
- G5 \$17000: ICS Fund for Excellence, Summer 2008.
- G4 \$5000: UCI Teaching Release, July 2008.
- G3 \$1500: UCI CORCLR Research/Travel, June 2006.
- G2 \$2700: UCI CORCLR Research/Travel, March 2005.
- G1 \$2800: UCI FDCI Computing, February 2005.

Software

S1. "*libwayne*: A portable, re-usable code library of data structures and algorithms for discrete and continuous systems." Available at `http://www.cs.toronto.edu/~wayne/libwayne/`.

Academic Honours

Popular article about my work in *Physics World*, `http://physicsworld.com/cws/article/news/31230`, 2007-Sep-24.

Popular article about my work in *Physics Focus*, `http://focus.aps.org/story/v11/st8`, 2003-Feb-27

Ontario Graduate Scholarship (\$12,000) 1997-98 academic year

University of Toronto Open Fellowship (\$11,000) 1996-97 academic year

Students Supervised

Graduate Students

As advisor

Sridevi Maharaj (Ph.D., 2013–present): network analysis

Edwin Vargas (Ph.D., 2013–present): network analysis

Darren Davis (Ph.D., 2008–2014): automated galaxy image recognition and parsing.

Anton Malykh (M.Sc., 2008-2009): Granted M.Sc. degree, August 2009. Thesis: "A computational approach to chaos in the Solar System". Original work published as J18 above.

Yong-Kang Zhu (Ph.D., 2005-2009): Defended on 4 Dec., 2009. Thesis title: "Exact Floating-Point Summation and its Application in Shadowing." Original work published in papers CR3, J14, and J17.

Shyam Srinivasan (Ph.D., 2004-2011): Defended Summer 2011. Thesis title: "A cross-inhibitory positive feedback mechanism forms a robust sharp border in the forebrain".

Weng-Leong Ng (Ph.D., 2007-2011): Defended Summer 2011. Thesis title: "Partial Solutions for the Firing Squad Synchronization Problem on Rings"

Juan Leon (Ph.D., 2008-2011): Worked on shadowing of symmetric variable-timestep integrators before transferring to another advisor.

Edwin Vargas (2012-present): currently working on biological network analysis.

As committee member

Joel Berrier (Advancement to Candidacy, Astronomy, Summer 2006).

Heather Guenther (Advancement to Candidacy, Astronomy, Spring 2007).

Tijana Milenkovic (Computer Science: Advancement to Candidacy Winter 2007; Defense Dec. 2009).

Benjamin P. Ziemer (Advancement to Candidacy, Physics, Winter 2007).

Kyle Stewart (Advancement to Candidacy, Astronomy, Fall 2007).

Jonelle Walsh (Advancement to Candidacy, Astronomy, Winter 2009).

Oleksii Kuchaiev (Computer Science: Advancement to Candidacy Spring 2009, Defense Spring 2010).

Vesna Memisevic (Computer Science: Advancement to Candidacy Spring 2009, Defense Spring 2010).

Undergraduate Students

Astronomy Department (undergrads)

Joshua Cabrera, Spring 2014 quarter: galaxy analysis

Matthew Kelley, Spring 2013 quarter: galaxy analysis

Computer Science Department (undergrads), Spring 2014 CS199

Galaxy analysis projects: SpArcFiRe front ends: Leon Cao (Java front-end GUI); Mark Fernandez, Yu Jiang Albert (Python front-end GUI); Wilmer Domingo (Web front-end)

Galaxy analysis projects: Developing spiral galaxy queries: Wayne Lu, Xen Eldridge, Rachel Jang, Emily Nguyen, Nathaniel Valerio, Vinson Gotingco, Andy Feng, Mrunmayi, William Lee.

Tracking bacteria in a video: Huy Pham

Load balancing for graphlet counting: Michael Ragheb

Ice Sheet System Modeling projects: Contour tracking: Colin Ma, Efren Aguilar, Neeraj Shah

Ice Sheet System Modeling projects: Cover Tree (nearest neighbor) implementation: Lanna Keulanna Gandasetiawan

Ice Sheet System Modeling projects: Visualization projects in Python: Lewis Yuxuan Liu, German Krikorian, Moniroth, Patrice Mardo, Wesley Wu, Tina Li, Edward Kim.

Experience

April 2013–present: Visiting Scientist (sabbatical, part-time): NASA Jet Propulsion Laboratory, Pasadena, CA: working on the Ice Sheet System Model, used to predict sea level rise through the year 2100 by detailed modelling of the melting of the Greenland and Antarctic ice sheets.

July 2010–present: Associate Professor, Dept. of Computer Science, University of California, Irvine. I was promoted to Associate Professor with Tenure at UCI effective July 2010. My current research is described in my "Current Research" document, available separately.

Oct. 2009–Sept. 2010 Lecturer, Dept. of Mathematics, Imperial College London. I won a 1-year fellowship to pursue new reseach directions while on leave from UC Irvine.

July 15–August 14, 2008: Visiting Scientist, *Centre Nationale Reserches Scientifique (CNRS)*, Université de Nantes, France. I visited Alexandre Goldsztejn for a month, collaborating on rigorous shadowing, resulting in a paper on shadowing the "Gingerbread Man" and "Tinkerbell" maps.

July 2004–June 2010: Assistant Professor, Dept. of Computer Science, University of California, Irvine. During my time as an Assistant Professor at U.C. Irvine, I collaborated with astronomers such as James Bullock at UCI and John Dubinski at the University of Toronto to test whether their gravitational n-body simulations of galaxies and cosmological structure are shadowable. With my students and collaborators at UCI, I'm also working on modelling morphogen gradients in the developing brain; rigorously correct floating-point addition algorithms; improving lower bounds on Ramsey numbers; and the Quadratic Assignment Problem.

Nov. 2002–June 2004: Research Associate, Institute for Physical Sciences and Technology, University of Maryland. Genome assembly is the computational problem of re-assembling millions of pieces of a genome which has been chemically shattered for the purpose of sequencing. Although sequencing is extremely expensive (US$100M for the mouse, $60M for the rat), existing algorithms to assemble the sequences are computationally very crude. I was a member of the genome sequence assembly group under James Yorke at the University of Maryland, working in collaboration with Celera Genomics, Inc., The Institude for Genomic Research (TIGR), and the Baylor College of Medicine to improve the most CPU-intensive step in sequence assembly. Compared to existing algorithms, ours produced a 100-fold decrease in runtime, while simultaneously achieving a 10-fold decrease in the error rate, resulting in a better, more-quickly produced draft genome. Further dramatic improvements are likely to occur, and this is clearly an area where Computer Science can significantly contribute to the broader advancement of human knowledge. Our algorithms are based on ideas inspired by dynamical systems and point-set topology.

Nov. 2002–Jul. 2003: Research Associate, Samuel Lunenfeld Research Insitute, Mount Sinai Hospital, Toronto. I finished a small protein folding project under Christopher Hogue utilizing a large-scale distributed computing platform called TraDES (`http://bioinfo.mshri.on.ca/trades/index.html`).

Aug. 2001–2002: Post-Doctoral Fellow, Fields Institute for Research in Mathematical Sciences, Toronto. During the *Thematic Year on Numerical and Computational Challenges in Science and Engineering*, I collaborated with W. Enright to produce several new robust high-order Runge-Kutta integrators with an asymptotically correct defect estimate, resulting in a publication in *ACM TOMS*. I also visited James Yorke at the U. of Maryland to investigate computational challenges in gene sequencing, which led to my Research Associate position there; and I discussed distributed environmental modelling with Z. Zlatev of the University of Denmark. As well, I continued to pursue extensions of both of my theses, resulting in 3 publications.

Aug. 2000–July 2001: Software Engineer, Member of the Technical Staff, Altera Corporation. In the research and development group, I aided in the development of Altera's next-generation of programmable microchips. I worked with a group of about 10 highly motivated M.Sc.- and Ph.D.-educated co-workers to continue development of complex heuristics to approximately solve several NP-complete optimization problems arising from fitting arbitrary circuits onto programmable logic devices. I observed first-hand how productive a well-managed software engineering group can be.

1996-2000: Lecturer (Part Time), Dept. of Comp. Sci., University of Toronto. During my Ph.D. studies I prepared and taught the following courses.

> **CSC209H**, *Software Tools and Systems Programming in Unix and C* (Spring 1998 & Fall 1996). Topics: Advanced Unix shell programming, Unix System Programming in C. In the final assignment, students wrote a Unix shell from scratch, complete with piping and I/O redirection.
>
> **CSC270H**, *Fundamental Data Structures and Techniques* (Summer & Spring 2000, Summer 1999). Topics: Graph Theory, Dynamic Programming, Simulation, Numerical Methods, C, C++.

I have also been a teaching assistant for at least 19 courses, including courses on symbolic and scientific computing, numerical analysis, introductory programming, computer organization, databases, operating systems, systems programming, data structures and algorithms, dynamic programming, programming languages, and computer networks. My teaching evaluations are typically above averge: 6 out of 7 when the departmental average is 5, and many of my students tend to write rave comments on the evaluations.

1999-2000: Qualifier, CollegeHire.com, Austin, Texas. I interviewed and evaluated the technical knowledge of undergraduate candidates from Princeton University and the University of Toronto.

Jan–Aug 1995: Software Engineer, Algorithmics, Inc., Toronto. As a programmer who was also mathematically fluent, I facilitated communication between the financial engineers, who built customized risk models for financial derivatives, and the programmers responsible for implementing them.

1989–1993: Undergraduate Summer Research Assistant, Dept. of Comp. Sci., University of Toronto. Under Prof. Mart Molle, I devised and wrote communications networks simulations and analyzed protocols. A resulting publication is listed in the publications section.

1990-1991: Software Engineering Intern, IBM Canada Toronto Lab. For 16 months, I coded a Smalltalk library for an OS/2 database project, ported the build environment for the RISC/6000 optimizing compiler from CMS to Unix, and studied optimizing compiler technology.

1989-1995: Public Lecturer and Show Operator, McLaughlin Planetarium, Toronto. I lectured to the public about astronomy and ran and maintained automated shows in the main theatre; I wrote hypertext explaining hundreds of images in a computerized question-and-answer display.

Professional Service / Activities

1. Session Chair: "Results in the Restricted Three-Body Problem" School and Conference on Computational Methods in Dynamics. Institute for Theoretical Physics, Trieste, Italy, 4-8 July 2011.
2. Session Chair: Session 12, "Capture and Impact". Meeting of the American Astronomical Society (AAS) Division of Dynamical Astronomy (DDA). University of Colorado at Boulder. Apr 28-May 1, 2008.
3. Organizer, minisymposium on "Shadowing of Numerical Solutions". SciCADE 2007, International Conference on SCIentific Computation And Differential Equations. Le Palais du Grand Large, Saint-Malo, France, July 9–13, 2007.
4. **Referee** for papers in the following journals:
   (a) *Nature*
   (b) *Physica D: Nonlinear Phenomena*
   (c) *Applied Mathematics and Computation*
   (d) *Astronomical Journal*
   (e) *SIAM Journal on Scientific Computing*
   (f) *Physics Letters A*
   (g) *Earth, Moon, and Planets*
   (h) *Monthly Notices of the Royal Astronomical Society*
   (i) *Journal of the Royal Astronomical Society of Canada*
   (j) 20th Annual Conference on Local Computer Networks
5. **Member** of ACM, SIAM, AMS, AAS, CAS.
6. Spring 1999: **Expert Witness**, software source code theft.

7. 1993-2000 **Computing Insights Guest Lecturer**: I lectured to gifted high-school students about chaos and fractals, describing algorithms for creating images such as fractal landscapes.

8. 1993–1999: **Member of U. of Toronto Department of Computer Science Graduate Committee**. In addition, I have been a member of the Computer Science Graduate Student Society, which organizes social activities for graduate students.

Volunteer Activities

1995-2000: Organizer, Numerical Analysis Area Meetings, Dept. of Comp. Sci., University of Toronto.

1999-2000: Director, University of Toronto Outing Club.

1995-2000: Mentor for new Computer Science graduate students, University of Toronto.

References

Available on request.