

WAYNE HAYES: CURRICULUM VITÆ

Assistant Professor, Dept. of Computer Science, University of California, Irvine CA 92697-3435

Phone: (B)949-824-1753, (C)949-981-2222. FAX: 949-824-4056

Web Page: <http://www.ics.uci.edu/~wayne/>

E-mail: wayne@ics.uci.edu

Citizenship: Canadian

RESEARCH INTERESTS

- complex systems: dynamical systems, scientific computing, numerical analysis; optimization
- systems: parallel, distributed, grid computing; operating systems; compilers; software engineering
- computational biology: genome assembly, protein folding, network alignment

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, 1993.

PUBLICATIONS (All available on the above web page)

INVITED, REFEREED JOURNAL PUBLICATIONS

- IJ1.. **Wayne Hayes.** “Computer simulation, exact trajectories, and the gravitational N -body problem.” *American Journal of Physics* **72:9**, pp. 1251-1257 (September 2004).

REFEREED JOURNAL PUBLICATIONS

- 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 Hayes** and Wayne Enright. “Robust and Reliable Defect Control for Runge Kutta Methods.” *ACM Transactions on Mathematical Software* **33:1** 19 pages, 2007.
- 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.” *Physics 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).
- J9. **Wayne Hayes**, Brian Hunt, Michael Roberts, Cevat Ustun, James Yorke, Paul Havlak. “Assembling the rat with extended and error corrected reads.” Submitted (9 pages).
- J13. **Wayne Hayes**. “Surfing the Edge: Chaos *vs.* Near-Integrability in the Outer Solar System”. Submitted (31 pages).

CONFERENCES: REFEREED PUBLICATIONS

- CR4. Alexandre Goldsztejn and **Wayne Hayes**. “Rigorous Inner Approximation of the Range of Functions”. 12th GAMM - IMACS International Symposium 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 gravitational 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 Ethernet 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: INVITED TALKS

- 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. By invitation only.
- 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

- 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 Goldsztejn 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 Symposium 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 Symposium 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 and 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

- 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)*. Brisbane, Australia. June/July, 2003.

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.

INVITED SEMINAR & COLLOQUIUM TALKS

- I27. **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.
- I26. **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.
- I25. **Wayne Hayes.** “Solar System Surfing the Edge of Chaos.” Talk at US Naval Observatory, Washington, D.C. Invited by Michael Efroimsky. March 20, 2007.
- I24. **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.
- I23. **Wayne Hayes.** “Outer Solar System on the Edge of Chaos.” Seminar, Harvard Center for Astrophysics. 19 Oct, 2006.
- I22. **Wayne Hayes.** “Outer Solar System Surfing the Edgo of Chaos.” Colloquium, Institute of Physics, University of Belgrade. Invited by Alexandar Bogojevic. Aug 28, 2006.
- I21. **Wayne Hayes.** “Outer Solar System on the Edge of Chaos.” Invited talk at UCI Center for Cosmology Symposium, Monday 17 April 2006.
- I20. **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.
- I19. **Wayne Hayes.** “Rigorous Shadowing of Numerical Solutions of Ordinary Differential Equations by Containment.” Applied Mathematics Seminar, UCI. 2006-Jan-30.
- I18. **Wayne Hayes.** “From Butterflies to Galaxies: Validating Simulations of Large Chaotic Systems”. Mathematics Department Seminar, University of Victoria, Canada, 8 Dec. 2005.
- I17. **Wayne Hayes.** “From Butterflies to Galaxies: Validating Simulations of Large Chaotic Systems”. Computer Science Department Seminar, Simon Fraser University, Canada, 7 Dec. 2005.
- I16. **Wayne Hayes.** “From Butterflies to Galaxies: Validating Simulations of Large Chaotic Systems”. Computer Science Department Seminar, University of British Columbia, Canada, 6 Dec 2005.
- I15. **Wayne Hayes.** “Reliable N-body Simulation.” Joint Physics, Applied Mathematics, and Computer Science Colloquium, University of Belgrade, Serbia. Wednesday 14 Sept. 2005.
- I14. **Wayne Hayes.** “From Butterflies to Galaxies: reliable simulation of chaotic systems”. Colloquium, Dept. of Physics, UCI. 2 June 2005.
- I13. **Wayne Hayes.** “Rigorous Shadowing of Numerical Solutions of Ordinary Differential Equations by Containment”. Applied Mathematics Colloquium, UCLA. 12 May 2005.
- I12. **Wayne Hayes.** “From Butterflies to Galaxies: reliable simulation of chaotic systems.” Colloquium, Center for Applied Mathematical Sciences, University of Southern California. 25 April 2005.
- I11. **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.
- I10. **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.
- I9. **Wayne Hayes** “From Butterflies to Galaxies: reliable simulation of chaotic systems”. Numerical Analysis Seminar, Dept. of Computer Science, University of Toronto. 15 Oct. 2004.
- I8. **Wayne Hayes.** “A shadowing-based timestep criterion for softened gravitational n-body simulations”. Dept. of Computer Science, University of California, Irvine. 2004-Mar-12.
- I7. **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.

- I6. **Wayne Hayes**, “A shadowing-based timestep criterion for softened gravitational n-body simulations”. Dept. of Computer Science, University of Guelph. 2002-May-2.
- I5. **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.
- I4. **Wayne Hayes**. “Shadowing the gravitational N-body problem.” Seminar. Ontario Research Centre for Computer Algebra, University of Western Ontario. April, 2000.
- I3. **Wayne Hayes**. “Rigorous shadowing of numerical solutions of ODEs.” Seminar. Argonne National Labs. Chicago, Illinois. February, 2000.
- I2. **Wayne Hayes**. “A Fast Shadowing Algorithm for High Dimensional ODE Systems.” Seminar. Department of Computer Science, University of Toronto. March, 1996.
- I1. **Wayne Hayes**. “Shadowing the Large Gravitational N-body Problem.” G2000 Seminar. Department of Astronomy, University of Toronto. January, 1996.

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 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

EXPERIENCE

July 2004–present: Assistant Professor, Dept. of Computer Science, University of California, Irvine. At U.C. Irvine, I am collaborating 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 Institute 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 Institute, 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 average: 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 ACTIVITIES

1. **Referee** for papers in the following journals:

- (a) *Physics Letters A*
- (b) *Earth, Moon, and Planets*

- (c) *Monthly Notices of the Royal Astronomical Society*
 - (d) *Journal of the Royal Astronomical Society of Canada*
 - (e) 20th Annual Conference on Local Computer Networks
2. **Member** of ACM, SIAM, AMS, AAS, CAS.
 3. Spring 1999: **Expert Witness**, software source code theft.
 4. 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.
 5. 1993-1999: **Member of U. of T. 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.

REFERENCES

Available on request.