



## Patrick Hayden

Stanford Professor of Quantum Physics and Professor, by courtesy, of Computer Science

 Curriculum Vitae available Online

### CONTACT INFORMATION

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### Bio

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#### BIO

Professor Hayden is a leader in the exciting new field of quantum information science. He has contributed greatly to our understanding of the absolute limits that quantum mechanics places on information processing, and how to exploit quantum effects for computing and other aspects of communication. He has also made some key insights on the relationship between black holes and information theory.

#### ACADEMIC APPOINTMENTS

- Professor, Physics

#### ADMINISTRATIVE APPOINTMENTS

- Director, It from Qubit: Simons Collaboration on Quantum Fields, Gravity, and Information, (2015- present)
- Professor of Physics, Stanford University, (2013- present)
- Associate Professor of Computer Science, McGill University, (2008-2013)
- Canada Research Chair in the Physics of Information, McGill University, (2005-2013)
- Assistant Professor of Computer Science, McGill University, (2004-2008)
- Sherman Fairchild Prize Doctoral Fellow, California Institute of Technology, (2001-2004)

#### HONORS AND AWARDS

- Simons Investigator, Simons Foundation (2014-)
- Outstanding Young Computer Science Researcher Prize, Canadian Association of Computer Science (2011)
- Distinguished Research Chair, Perimeter Institute for Theoretical Physics (2010-)
- Fellow, Canadian Institute for Advanced Research (2010-)
- Sloan Research Fellowship in Computer Science, Alfred P. Sloan Foundation (2007-2009)
- General Dynamics Distinguished Lecturer, University of Michigan Department of Electrical Engineering and Computer Science (2006)
- Scholar, Canadian Institute for Advanced Research (2004-2009)
- Rhodes Scholarship, University of Oxford (1998-2001)

## PROFESSIONAL EDUCATION

- D.Phil., University of Oxford , Physics (2001)
- B.Sc., McGill University , Mathematics and physics (1998)

## PATENTS

- Patrick Hayden, Robin Burgener. "United States Patent 5,745,759 Window Kernel", Apr 28, 1998

## LINKS

- Publications on arXiv: [http://arxiv.org/find/grp\\_cs,grp\\_math,grp\\_physics/1/au:+hayden\\_p/0/1/0/all/0/1](http://arxiv.org/find/grp_cs,grp_math,grp_physics/1/au:+hayden_p/0/1/0/all/0/1)
- Publications on Google Scholar: <https://scholar.google.com/citations?user=xbjTAm4AAAAJ>

## Teaching

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### COURSES

#### 2022-23

- Light and Heat: PHYSICS 45 (Aut)

#### 2021-22

- Advanced Mechanics: PHYSICS 110, PHYSICS 210 (Aut)

#### 2020-21

- Advanced Mechanics: PHYSICS 110, PHYSICS 210 (Aut)
- Graduate Quantum Mechanics I: PHYSICS 230 (Win)

#### 2019-20

- Advanced Mechanics: PHYSICS 110, PHYSICS 210 (Aut)
- Graduate Quantum Mechanics I: PHYSICS 230 (Win)

### STANFORD ADVISEES

#### Doctoral Dissertation Reader (AC)

Shangnan Aaland Zhou, Ronen Kroeze, Olivier Simon, Ryotatsu Yanagimoto

#### Postdoctoral Faculty Sponsor

Alex May, Jinzhao Wang

#### Doctoral Dissertation Advisor (AC)

Sam Cree, Dan Stefan Eniceicu, Jiani Fei, Sydney Timmerman, Kianna Wan, Michelle Xu

#### Doctoral Dissertation Co-Advisor (AC)

Kfir Dolev

## Publications

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### PUBLICATIONS

- **Perturbative Quantum Simulation.** *Physical review letters*  
Sun, J., Endo, S., Lin, H., Hayden, P., Vedral, V., Yuan, X.  
2022; 129 (12): 120505
- **A canonical Hamiltonian for open quantum systems** *JOURNAL OF PHYSICS A-MATHEMATICAL AND THEORETICAL*

- 
- Hayden, P., Sorce, J.  
2022; 55 (22)
- **Fault-Tolerant Qubit from a Constant Number of Components** *PRX QUANTUM*  
Wan, K., Choi, S., Kim, I. H., Shutter, N., Hayden, P.  
2021; 2 (4)
  - **The Markov gap for geometric reflected entropy** *JOURNAL OF HIGH ENERGY PHYSICS*  
Hayden, P., Parrikar, O., Sorce, J.  
2021
  - **Recycling qubits in near-term quantum computers** *PHYSICAL REVIEW A*  
Anikeeva, G., Kim, I. H., Hayden, P.  
2021; 103 (4)
  - **Error Correction of Quantum Reference Frame Information** *PRX QUANTUM*  
Hayden, P., Nezami, S., Popescu, S., Salton, G.  
2021; 2 (1)
  - **Continuous Symmetries and Approximate Quantum Error Correction** *PHYSICAL REVIEW X*  
Faist, P., Nezami, S., Albert, V. V., Salton, G., Pastawski, F., Hayden, P., Preskill, J.  
2020; 10 (4)
  - **A Quantum Multiparty Packing Lemma and the Relay Channel** *IEEE TRANSACTIONS ON INFORMATION THEORY*  
Ding, D., Gharibyan, H., Hayden, P., Walter, M.  
2020; 66 (6): 3500–3519
  - **Bit Threads and Holographic Monogamy** *COMMUNICATIONS IN MATHEMATICAL PHYSICS*  
Cui, S. X., Hayden, P., He, T., Headrick, M., Stoica, B., Walter, M.  
2020; 376 (1): 609–48
  - **Approximate Quantum Error Correction Revisited: Introducing the Alpha-Bit** *COMMUNICATIONS IN MATHEMATICAL PHYSICS*  
Hayden, P., Penington, G.  
2020
  - **Tight Limits on Nonlocality from Nontrivial Communication Complexity; a.k.a. Reliable Computation with Asymmetric Gate Noise**  
Shutter, N., Wootters, M., Hayden, P., IEEE  
IEEE.2020: 206-217
  - **Localizing and excluding quantum Information; or, how to share a quantum secret in spacetime** *QUANTUM*  
Hayden, P., May, A.  
2019; 3
  - **Quantum Virtual Cooling** *PHYSICAL REVIEW X*  
Cotler, J., Choi, S., Lukin, A., Gharibyan, H., Grover, T., Tai, M., Rispoli, M., Schittko, R., Preiss, P. M., Kaufman, A. M., Greiner, M., Pichler, H., Hayden, et al  
2019; 9 (3)
  - **Entanglement Wedge Reconstruction via Universal Recovery Channels** *PHYSICAL REVIEW X*  
Cotler, J., Hayden, P., Penington, G., Salton, G., Swingle, B., Walter, M.  
2019; 9 (3)
  - **Conditional mutual information of bipartite unitaries and scrambling** *JOURNAL OF HIGH ENERGY PHYSICS*  
Ding, D., Hayden, P., Walter, M.  
2016
  - **Holographic duality from random tensor networks** *JOURNAL OF HIGH ENERGY PHYSICS*  
Hayden, P., Nezami, S., Qi, X., Thomas, N., Walter, M., Yang, Z.  
2016
  - **Measuring the scrambling of quantum information** *PHYSICAL REVIEW A*  
Swingle, B., Bentsen, G., Schleier-Smith, M., Hayden, P.
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2016; 94 (4)

- **Spacetime replication of continuous variable quantum information** *NEW JOURNAL OF PHYSICS*  
Hayden, P., Nezami, S., Salton, G., Sanders, B. C.  
2016; 18
- **Summoning information in spacetime, or where and when can a qubit be?** *JOURNAL OF PHYSICS A-MATHEMATICAL AND THEORETICAL*  
Hayden, P., May, A.  
2016; 49 (17)
- **Bidirectional holographic codes and sub-AdS locality** *JOURNAL OF HIGH ENERGY PHYSICS*  
Yang, Z., Hayden, P., Qi, X.  
2016
- **Universal quantum computation by scattering in the Fermi-Hubbard model** *NEW JOURNAL OF PHYSICS*  
Bao, N., Hayden, P., Salton, G., Thomas, N.  
2015; 17
- **The information theoretic interpretation of the length of a curve** *JOURNAL OF HIGH ENERGY PHYSICS*  
Czech, B., Hayden, P., Lashkari, N., Swingle, B.  
2015
- **Multiboundary wormholes and holographic entanglement** *CLASSICAL AND QUANTUM GRAVITY*  
Balasubramanian, V., Hayden, P., Maloney, A., Marolf, D., Ross, S. F.  
2014; 31 (18)
- **TWO-MESSAGE QUANTUM INTERACTIVE PROOFS AND THE QUANTUM SEPARABILITY PROBLEM** *QUANTUM INFORMATION & COMPUTATION*  
Hayden, P., Milner, K., Wilde, M. M.  
2014; 14 (5-6): 384-416
- **Quantum Enigma Machines and the Locking Capacity of a Quantum Channel** *PHYSICAL REVIEW X*  
Guha, S., Hayden, P., Krovi, H., Lloyd, S., Lupo, C., Shapiro, J. H., Takeoka, M., Wilde, M. M.  
2014; 4 (1)
- **The locking-decoding frontier for generic dynamics** *PROCEEDINGS OF THE ROYAL SOCIETY A-MATHEMATICAL PHYSICAL AND ENGINEERING SCIENCES*  
Dupuis, F., Florjanczyk, J., Hayden, P., Leung, D.  
2013; 469 (2159)
- **From Low-Distortion Norm Embeddings to Explicit Uncertainty Relations and Efficient Information Locking** *JOURNAL OF THE ACM*  
Fawzi, O., Hayden, P., Sen, P.  
2013; 60 (6)
- **Towards the fast scrambling conjecture** *JOURNAL OF HIGH ENERGY PHYSICS*  
Lashkari, N., Stanford, D., Hastings, M., Osborne, T., Hayden, P.  
2013
- **Holographic mutual information is monogamous** *PHYSICAL REVIEW D*  
Hayden, P., Headrick, M., Maloney, A.  
2013; 87 (4)
- **Two-message quantum interactive proofs and the quantum separability problem** *28th Annual IEEE Conference on Computational Complexity (CCC)*  
Hayden, P., Milner, K., Wilde, M. M.  
IEEE.2013: 156-167
- **Quantum computation versus firewalls** *Journal of High Energy Physics*  
Harlow, D., Hayden, P.  
2013; 85
- **Quantum trade-off coding for bosonic communication** *PHYSICAL REVIEW A*

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- Wilde, M. M., Hayden, P., Guha, S.  
2012; 86 (6)
- **The information-theoretic costs of simulating quantum measurements** *JOURNAL OF PHYSICS A-MATHEMATICAL AND THEORETICAL*  
Wilde, M. M., Hayden, P., Buscemi, F., Hsieh, M.  
2012; 45 (45)
  - **Weak Decoupling Duality and Quantum Identification** *IEEE TRANSACTIONS ON INFORMATION THEORY*  
Hayden, P., Winter, A.  
2012; 58 (7): 4914-4929
  - **Classical Communication Over a Quantum Interference Channel** *IEEE TRANSACTIONS ON INFORMATION THEORY*  
Fawzi, O., Hayden, P., Savov, I., Sen, P., Wilde, M. M.  
2012; 58 (6): 3670-3691
  - **Quantum Communication in Rindler Spacetime** *COMMUNICATIONS IN MATHEMATICAL PHYSICS*  
Bradler, K., Hayden, P., Panangaden, P.  
2012; 312 (2): 361-398
  - **Information Trade-Offs for Optical Quantum Communication** *PHYSICAL REVIEW LETTERS*  
Wilde, M. M., Hayden, P., Guha, S.  
2012; 108 (14)
  - **Orbits of the Centralizer of a Linear Operator** *JOURNAL OF LIE THEORY*  
Best, P., Gualtieri, M., Hayden, P.  
2012; 22 (4): 1039-1048
  - **Quantum Broadcast Channels** *IEEE TRANSACTIONS ON INFORMATION THEORY*  
Yard, J., Hayden, P., Devetak, I.  
2011; 57 (10): 7147-7162
  - **QUANTUM INFORMATION Entanglement as elbow grease** *NATURE*  
Hayden, P.  
2011; 474 (7349): 41-43
  - **ASSISTED ENTANGLEMENT DISTILLATION** *QUANTUM INFORMATION & COMPUTATION*  
Dutil, N., Hayden, P.  
2011; 11 (5-6): 496-520
  - **From Low-Distortion Norm Embeddings to Explicit Uncertainty Relations and Efficient Information Locking** *43rd ACM Symposium on Theory of Computing*  
Fawzi, O., Hayden, P., Sen, P.  
ASSOC COMPUTING MACHINERY.2011: 773-782
  - **Quantum interference channels** *Proceedings of the 49th Allerton Conference on Communication, Control, and Computing*  
Fawzi, O., Hayden, P., Savov, I., Sen, P., Wilde, M.  
2011: 609-616
  - **Leggett-Garg inequalities and the geometry of the cut polytope** *PHYSICAL REVIEW A*  
Avis, D., Hayden, P., Wilde, M. M.  
2010; 82 (3)
  - **Conjugate degradability and the quantum capacity of cloning channels** *JOURNAL OF MATHEMATICAL PHYSICS*  
Bradler, K., Dutil, N., Hayden, P., Muhammad, A.  
2010; 51 (7)
  - **Trade-off capacities of the quantum Hadamard channels** *PHYSICAL REVIEW A*  
Bradler, K., Hayden, P., Touchette, D., Wilde, M. M.  
2010; 81 (6)

- **A Father Protocol for Quantum Broadcast Channels** *IEEE TRANSACTIONS ON INFORMATION THEORY*  
Dupuis, F., Hayden, P., Li, K.  
2010; 56 (6): 2946-2956
- **Concentration of Measure Effects in Quantum Information** *American-Mathematical-Society Short Course on Quantum Information Science/Annual Meeting of the American-Mathematical-Society*  
Hayden, P.  
AMER MATHEMATICAL SOC.2010: 3–12
- **The mother of all protocols: restructuring quantum information's family tree** *PROCEEDINGS OF THE ROYAL SOCIETY A-MATHEMATICAL PHYSICAL AND ENGINEERING SCIENCES*  
Abeyesinghe, A., Devetak, I., Hayden, P., Winter, A.  
2009; 465 (2108): 2537-2563
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Bradler, K., Hayden, P., Panangaden, P.  
2009
- **Counterexamples to the Maximal p-Norm Multiplicativity Conjecture for all  $p > 1$**  *COMMUNICATIONS IN MATHEMATICAL PHYSICS*  
Hayden, P., Winter, A.  
2008; 284 (1): 263-280
- **Contrasting Behavior of the 5/2 and 7/3 Fractional Quantum Hall Effect in a Tilted Field** *PHYSICAL REVIEW LETTERS*  
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2008; 101 (18)
- **Possibility, impossibility, and cheat sensitivity of quantum-bit string commitment** *PHYSICAL REVIEW A*  
Buhrman, H., Christandl, M., Hayden, P., Lo, H., Wehner, S.  
2008; 78 (2)
- **Capacity theorems for quantum multiple-access channels: Classical-quantum and quantum-quantum capacity regions** *IEEE TRANSACTIONS ON INFORMATION THEORY*  
Yard, J., Hayden, P., Devetak, I.  
2008; 54 (7): 3091-3113
- **Intrinsic gap of the  $\nu=5/2$  fractional quantum Hall state** *PHYSICAL REVIEW LETTERS*  
Dean, C. R., Piot, B. A., Hayden, P., Das Sarma, S., Gervais, G., Pfeiffer, L. N., West, K. W.  
2008; 100 (14)
- **Distributed compression and multiparty squashed entanglement** *JOURNAL OF PHYSICS A-MATHEMATICAL AND THEORETICAL*  
Avis, D., Hayden, P., Savov, I.  
2008; 41 (11)
- **A Decoupling Approach to the Quantum Capacity** *OPEN SYSTEMS & INFORMATION DYNAMICS*  
Hayden, P., Horodecki, M., Winter, A., Yard, J.  
2008; 15 (1): 7-19
- **Random Quantum Codes from Gaussian Ensembles and an Uncertainty Relation** *OPEN SYSTEMS & INFORMATION DYNAMICS*  
Hayden, P., Shor, P. W., Winter, A.  
2008; 15 (1): 71-89
- **Multiparty distributed compression of quantum information** *2nd International Conference on Quantum, Nano and Micro Technologies*  
Avis, D., Hayden, P., Savov, I.  
IEEE COMPUTER SOC.2008: 90–97
- **Black holes as mirrors: quantum information in random subsystems** *JOURNAL OF HIGH ENERGY PHYSICS*  
Hayden, P., Preskill, J.  
2007
- **Security of quantum bit string commitment depends on the information measure** *PHYSICAL REVIEW LETTERS*

- Buhrman, H., Christandl, M., Hayden, P., Lo, H., Wehner, S.  
2006; 97 (25)
- **On the distributed compression of quantum information** *IEEE TRANSACTIONS ON INFORMATION THEORY*  
Ahn, C., Doherty, A. C., Hayden, P., Winter, A. J.  
2006; 52 (10): 4349-4357
  - **Optimal superdense coding of entangled states** *IEEE TRANSACTIONS ON INFORMATION THEORY*  
Abeyesinghe, A., Hayden, P., Smith, G., Winter, A. J.  
2006; 52 (8): 3635-3641
  - **Aspects of generic entanglement** *COMMUNICATIONS IN MATHEMATICAL PHYSICS*  
Hayden, P., Leung, D. W., Winter, A.  
2006; 265 (1): 95-117
  - **Capacities enhanced by entanglement** *Encyclopedia of Mathematical Physics*  
Hayden, P.  
edited by Francoise, J. P., Naber, G. L., Tsou, S. T.  
Elsevier.2006: 418–424
  - **Random subspaces for encryption based on a private shared Cartesian frame** *PHYSICAL REVIEW A*  
Bartlett, S. D., Hayden, P., Spekkens, R. W.  
2005; 72 (5)
  - **Quantum information - Putting certainty in the bank** *NATURE*  
Hayden, P.  
2005; 436 (7051): 633-635
  - **Multiparty data hiding of quantum information** *PHYSICAL REVIEW A*  
Hayden, P., Leung, D., Smith, G.  
2005; 71 (6)
  - **Correcting quantum channels by measuring the environment** *QUANTUM INFORMATION & COMPUTATION*  
Hayden, P., King, C.  
2005; 5 (2): 156-160
  - **Capacity theorems for quantum multiple access channels** *IEEE International Symposium on Information Theory and Its Applications*  
Yard, J., Devetak, I., Hayden, P.  
IEEE.2005: 884–888
  - **Remote preparation of quantum states** *IEEE TRANSACTIONS ON INFORMATION THEORY*  
Bennett, C. H., Hayden, P., Leung, D. W., Shor, P. W., Winter, A.  
2005; 51 (1): 56-74
  - **Quantum broadcast channels** *Proceedings of the ERATO Conference on Quantum Information Science*  
Yard, J., Hayden, P., Savov, I.  
2005
  - **Sending classical and quantum information over quantum multiple access channels** *Proceedings of the ninth Canadian Workshop on Information Theory*  
Yard, J., Devetak, I., Hayden, P.  
2005: 387–390
  - **Quantum state transformations and the Schubert calculus** *ANNALS OF PHYSICS*  
Daftuar, S., Hayden, P.  
2005; 315 (1): 80-122
  - **Randomizing quantum states: Constructions and applications** *COMMUNICATIONS IN MATHEMATICAL PHYSICS*  
Hayden, P., Leung, D., Shor, P. W., Winter, A.  
2004; 250 (2): 371-391

- **Superdense coding of quantum states** *PHYSICAL REVIEW LETTERS*  
Harrow, A., Hayden, P., Leung, D.  
2004; 92 (18)
- **Structure of states which satisfy strong subadditivity of quantum entropy with equality** *COMMUNICATIONS IN MATHEMATICAL PHYSICS*  
Hayden, P., Jozsa, R., Petz, D., Winter, A.  
2004; 246 (2): 359-374
- **Entanglement in random subspaces** *7th International Conference on Quantum Communication, Measurement and Computing*  
Hayden, P.  
AMER INST PHYSICS.2004: 226-229
- **Conditions for equality in the strong subadditivity inequality for quantum entropy** *Communications of Mathematical Physics*  
Hayden, P., Jozsa, R., Petz, D., Winter, A.  
2004; 246 (2): 359-374
- **Generalized remote state preparation: Trading cbits, qubits, and ebits in quantum communication** *PHYSICAL REVIEW A*  
Abeyesinghe, A., Hayden, P.  
2003; 68 (6)
- **Hiding quantum data** *FOUNDATIONS OF PHYSICS*  
DiVincenzo, D. P., Hayden, P., Terhal, B. M.  
2003; 33 (11): 1629-1647
- **Universal entanglement transformations without communication** *PHYSICAL REVIEW A*  
van Dam, W., Hayden, P.  
2003; 67 (6)
- **Communication cost of entanglement transformations** *PHYSICAL REVIEW A*  
Hayden, P., Winter, A.  
2003; 67 (1)
- **Trading quantum for classical resources in quantum data compression** *JOURNAL OF MATHEMATICAL PHYSICS*  
Hayden, P., Jozsa, R., Winter, A.  
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- **The asymptotic entanglement cost of preparing a quantum state** *JOURNAL OF PHYSICS A-MATHEMATICAL AND GENERAL*  
Hayden, P. M., Horodecki, M., Terhal, B. M.  
2001; 34 (35): 6891-6898
- **Multiplayer quantum games** *PHYSICAL REVIEW A*  
Benjamin, S. C., Hayden, P. M.  
2001; 64 (3)
- **What is quantum computation?** *International Conference on Fundamental Sciences, Mathematics and Theoretical Physics*  
Ekert, A., Hayden, P., Inamori, H., Oi, D. K.  
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- **On the reversible extraction of classical information from a quantum source** *PROCEEDINGS OF THE ROYAL SOCIETY A-MATHEMATICAL PHYSICAL AND ENGINEERING SCIENCES*  
Barnum, H., Hayden, P., Jozsa, R., Winter, A.  
2001; 457 (2012): 2019-2039
- **Comment on "Quantum games and quantum strategies"** *PHYSICAL REVIEW LETTERS*  
Benjamin, S. C., Hayden, P. M.  
2001; 87 (6)
- **What is quantum computation?** *International Journal of Modern Physics A*  
Ekert, A., Hayden, P., Inamori, H., Oi, D.  
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- **Basic concepts in quantum computation** *Les Houches Session LXXII on Coherent Atomic Matter Waves*  
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SPRINGER-VERLAG BERLIN.2001: 663–701
- **Geometric quantum computation** *7th Meeting on Laser Phenomena*  
Ekert, A., Ericsson, M., Hayden, P., Inamori, H., Jones, J. A., Oi, D. K., Vedral, V.  
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- **Information flow in entangled quantum systems** *PROCEEDINGS OF THE ROYAL SOCIETY A-MATHEMATICAL PHYSICAL AND ENGINEERING SCIENCES*  
Deutsch, D., Hayden, P.  
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- **What is quantum computation?** *International Conference on Fundamental Sciences: Mathematics and Theoretical Physics*  
Ekert, A., Hayden, P., Inamori, H., Oi, D. K.  
WORLD SCIENTIFIC PUBL CO PTE LTD.2000: 351–383

## PRESENTATIONS

- It from Qubit (Part 1): Geometry as Compression