CURRICULUM VITAE: Dr Azhar Iqbal (ORCID: 0000-0002-5221-9384)

Personal details

NAME: **Azhar Iqbal**
CITIZENSHIP: Australian
ADDRESS: School of Electrical & Electronic Engineering, University of Adelaide, SA 5005, Australia.
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Tertiary education

2006 PhD, Applied Mathematics, University of Hull, UK
1995 BSc (Hons), Physics, University of Sheffield, UK

Fellowships and awards (selected)

2016- 2017 Faculty of Engineering, Computer & Mathematical Sciences (ECMS) Interdisciplinary Research Grant Scheme 2016 (jointly with Prof Derek Abbott & Dr Virginie Masson) at the University of Adelaide
2007- 2011 ARC Australian Postdoctoral Research (APD) Fellowship, Australia
2006- 2007 JSPS Postdoctoral Research Fellowship for Foreign Researchers, Japan
2002- 2005 Fully funded PhD Research Scholarship from the University of Hull, UK, for overseas research students
1992- 1995 Fully funded Merit Scholarship from the Government of Pakistan for studying overseas at the University of Sheffield, UK

Career history

2013–Present Adjunct Senior Lecturer, School of Electrical & Electronic Engineering, University of Adelaide
2019–Present Founder, INTERACTIVE DECISIONS, Consulting for Game Theory
2013–2014 Assistant Professor, Department of Mathematics and Statistics, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia
2012–2013 Senior Research Associate (ARC grant funded), University of Adelaide
2007–2013 ARC Australian Postdoctoral Fellow (APD), University of Adelaide
2006–2007 JSPS Postdoctoral Research Fellow, Kochi University of Technology, Japan
2006–2006 Assistant Professor, School of Natural Sciences, National University of Sciences and Technology (NUST), Islamabad, Pakistan

Esteem indicators

- My work on evolutionary stability in quantum regime was published as a Chapter in the book *Quantum Aspects of Life*, edited by Paul C. W. Davies et al and with the foreword by Sir Roger Penrose. This book was on Imperial College Press' best-seller list for four consecutive years.
- My first study of the game-theoretic concept of an Evolutionarily Stable Strategy (ESS) within the area of quantum games and its potential role the understanding of rise of complexity at molecular level was described in the book *A Beautiful Math: John Nash, Game Theory, and Modern Quest for Code of Nature*, by Tom Siegfried, Joseph Henry Press, Washington DC, 2006, page 195.
- A recently independent bibliometric article presented as a case study (Huang et al., Proc. 2018 4th Int. Conf. Inf. Manag., ICIM2018) has listed me as the leading author in the research area of quantum games.
- In an independent analysis developed in the bibliometric paper "The pagerank-index: Going beyond citation counts in quantifying scientific impact of researchers," PLOSONE, Vol. 10, No. 8, Art. No. e0134794 (2015), authors U. Senanayake, M. Piraveenan, and A. Zomaya at the Centre for Complex Systems Research, University of Sydney, ranked me as the very top author in the research area of quantum games, using a ranking scheme based on pagerank-index (p-index).

Professional activities

Professional memberships:

- 2017-present: *Australian Mathematical Society*
- 2017-present: *Game Theory Society*
- 2011-2014: *Australian Institute of Physics*
- 2006-present: *COSNet-Complex Open Systems Research Network*
- 2006-present: *Australian Nanotechnology Network*
- 2016-present: *JSPS Alumni Association of Australia*

Committee memberships:

- 2013-2014: Research Committee, Department of Mathematics & Statistics, King Fahd University of Petroleum & Minerals, Saudi Arabia

- 2006: Postgraduate Admission Committee, Centre for Natural Sciences, National University of Sciences and Technology, Pakistan

Consulting/Advisories:

- 2019-present: INTERACTIVE DECISIONS—Consulting for Game Theory
- 2017: Exam Office/Student Services Division, University of Wollongong, Australia
- 2017: National Science Centre (Narodowe Centrum Nauki - NCN), Poland
- 2015: Faculty of Engineering & IT, University of Sydney, Australia

Reviewing service

- *Scientific Reports* (Nature)
- *Quantum Information and Computation*
- *Physics Letters A*
- *Physica A: Statistical, Mechanics and its Applications*
- *Decision Support Systems*
- *Journal of Industrial and Management Optimization*
- *Journal of Physics A: Mathematical & Theoretical*
- *International Journal of Quantum Information,* and
- *Quantum Information Processing*

Ten career-best research outputs

Key Author IDs:

ISI Researcher ID	Google Scholar ID	ORCID	Loop ID
E-8749-2011	Kq1NmsUAAAAJ	0000-0002-5221-9384	255391

Key performance metrics:

h-index = 21	i10-index = 37	Citations > 1,450	Reads > 12,300	Views > 8,300
Google Scholar	Google Scholar	Google Scholar	ResearchGate	Loop

- **Impact:** *I obtained my PhD in 2006 and my ISI h-index = 17. An ISI h-index equal to the number of years since the PhD is regarded as internationally competitive. My h-index exceeds this criterion. My present ISI citation count is at > 820 in total. My Scholar Google h-index = 21, with > 1450 citations.*
- **Journal quality:** *Whilst no ranking scheme is perfect, most of the journals below were ranked ERA A* in the old ranking scheme—with exception of a new journal launched after the ranking scheme. In terms of ISI rankings, they are all in the top of their disciplines. Physical Review A, Physical Review E and Proceedings of IEEE are all within the top 0.2% of all journals on ISI ranked by Eigenfactor.*
- **Accession date:** *All rankings herein were measured on 18th July 2019.*

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1. A. Iqbal and A. H. Toor, Backwards-induction outcome in a quantum game, ***Physical Review A***, Vol. 65, Art. No. 052328 (2002).
   - **Significance:** This is the first study of a quantum version of a sequentially played dynamic form of the duopoly game describing strategic interaction between two competing agents.
   - **Journal ranking:** 2nd out of 90 journals on ISI in Optics by Eigenfactor.

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2. A. Iqbal and A. H. Toor, Quantum mechanics gives stability to a Nash equilibrium, ***Physical Review A***, Vol. 65, Art. No. 022306 (2002).
   - **Significance:** This paper shows that not only quantizing a game is of significance for the game-theoretic solution concept of Nash equilibrium but also for its refinement.
   - **Journal ranking:** 2nd out of 90 journals on ISI in Optics by Eigenfactor.

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3. A. Iqbal and T. Cheon, Constructing quantum games from non-factorizable joint probabilities, ***Physical Review E***, Vol. 76, Art. No. 061122 (2007).
   - **Significance:** This work presents a new approach in constructing quantum games directly from the non-factorizable property of a set of quantum mechanical joint probabilities. Probability sets that violate Bell's inequalities are non-factorizable but the converse in not necessarily true.
   - **Journal ranking:** Ranked 2nd out of 34 journals on ISI in Mathematical Physics by Impact Factor.

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4. Q. Li, M. Chen, M. Perc, A. Iqbal, and D. Abbott, Effects of adaptive degrees of trust on coevolution of quantum strategies on scale-free networks, ***Scientific Reports*** (Nature**)**, Vol. 3, Art. No. 2949 (2013).
   - **Significance:** This paper investigates the impact of adaptive degrees of trust on the evolution of cooperation in the Prisoners' Dilemma game on scale-free networks.
   - **Journal ranking:** 6th out of 63 journals on ISI in Multidisciplinary Sciences by Eigenfactor.

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5. Q. Li, A. Iqbal, M. Chen, and D. Abbott, Evolution of quantum and classical strategies on networks by group interactions, ***New Journal of Physics***, Vol. 14, Art. No. 103034 (2012).
- **Significance:** This work introduces quantum strategies within evolutionary games and investigates the evolution of quantum and classical strategies on networks in the public goods game.
- **Journal ranking:** 3rd out of 79 journals on ISI in Multidisciplinary Physics by Eigenfactor.

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6. J. M. Chappell, S. P. Drake, C. L. Seidel, L. J. Gunn, A. Iqbal, A. Allison, and D. Abbott, Geometric algebra for electrical and electronic engineers, ***Proceedings of IEEE***, Vol. 102, No. 9, pp 1340–1363 (2014).
- **Significance:** The benefits of using the formalism of Clifford's geometric algebra (GA) are explicated when applied to Electromagnetism.
- **Journal ranking:** 6th out of 257 journals on ISI in Electrical & Electronic Engineering by Impact Factor.

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7. T. Cheon and A. Iqbal, Bayesian Nash equilibria and Bell inequalities, ***Journal of the Physical Society of Japan***, Vol. 77, Art. No. 024801 (2008).
- **Significance:** This paper formulates Bayesian games in a multi-sector probability matrix formalism that can cope with quantum as well as the classical strategies, thus establishing a direct link between the true quantum gain of game's payoff and the violation of Bell's inequalities.
- **Journal ranking:** 13th out of 79 journals on ISI in Multidisciplinary Physics by Eigenfactor.

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8. A. Iqbal and A. H. Toor, Evolutionarily stable strategies in quantum games, ***Physics Letters A***, Vol. 280, No. 5-6, pp 249–256 (2001).
- **Significance:** This is the first study on the fate of an Evolutionarily Stable Strategy when a considered classical game is quantized. Such games have been anticipated to underpin the rise of complexity and self-organization at molecular level.
- **Journal ranking:** 12th out of 79 journals on ISI in Multidisciplinary Physics by Eigenfactor.

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9. A. Iqbal and S. Weigert, Quantum correlation games, ***Journal of Physics A: Mathematical & General***, Vol. 37, pp 5873–5885 (2004).
- **Significance:** This paper proposes an Einstein-Podolsky-Rosen (EPR) type setting for playing games quantum mechanically in which players' payoff relations are expressed as functions of correlations of quantum mechanical measurement outcomes.
- **Journal ranking:** 3rd out of 53 journals on ISI in Mathematical Physics by Eigenfactor.

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10. A. Iqbal, T. Cheon, and D. Abbott, Probabilistic analysis of three-player symmetric quantum games played using EPR setting, ***Physics Letters A***, Vol. 372, No. 44, pp 6564–6577 (2008).
- **Significance:** This work presents a probabilistic framework based on the concept of non-factorizable joint probabilities for multi-player quantum games.
- **Journal ranking:** 12th out of 79 journals on ISI in Multidisciplinary Physics by Eigenfactor.

Publications list

Book chapter

1. **A. Iqbal** and T. Cheon, Evolutionarily stability in quantum games, appeared as Chapter 13 in *Quantum Aspects of Life*, forward by Sir Roger Penrose, edited by D. Abbott, P.C.W. Davies and A. K. Pati, Imperial College Press, ISBN 978-1-84816-267-9 (2008).

Refereed journal articles

2. **A. Iqbal**, L. J. Gunn, M. Guo, M. A. Babar, and D. Abbott, Game theoretical modelling of network/cyber security, accepted for publication in IEEE Access on Oct 8, 2019. Preprint available for download at this link (2019).
3. **A. Iqbal** and D. Abbott, A game theoretical perspective on the quantum probabilities associated with a GHZ state, *Quantum Information Processing*, Vol. **17**, Art. No. 313 (2018).
4. **A. Iqbal**, J. M. Chappell, and D. Abbott, The equivalence of Bell's inequality and the Nash inequality in a quantum game-theoretic setting, *Physics Letters A*, Vol. **382**, Issue 40, pp 2908-2913 (2018).
5. **A. Iqbal**, V. Masson, and D. Abbott, Kidnapping model: an extension of Selten's game, *Royal Society Open Science*, Vol. **4**, Art. No. 171484 (2017).
6. J. M. Chappell, J. G. Hartnett, N. Iannella, **A. Iqbal**, and D. Abbott, Time as a geometric property of space, *Frontiers in Physics* **4**, Art. No. 44 (2016).
7. S. Zhou, D. G. Valchev, A. Dinovitser, J. M. Chappell, **A. Iqbal**, B. W.-H. Ng, T. W. Kee, and D. Abbott, Terahertz signal classification based on geometric algebra, *IEEE Transactions on Terahertz Science & Technology* **6**(6), pp. 793–802 (2016).
8. J. M. Chappell, **A. Iqbal**, J. G. Hartnett, and D. Abbott, The vector algebra war: a historical perspective, *IEEE Access* **4**, pp. 1997–2004 (2016).
9. **A. Iqbal**, J. M. Chappell, and D. Abbott, On the equivalence between non-factorizable mixed-strategy classical games and quantum games, *Royal Society OS* **3**, Art. No. 150477 (2016).

10. **A. Iqbal**, J. M. Chappell, and D. Abbott, Social optimality in quantum Bayesian games, *Physica A: Statistical Mechanics and its Applications* **436**, pp 798–805 (2015).
11. J. M. Chappell, **A. Iqbal**, L. J. Gunn, and D. Abbott, Functions of multivector variables, *PLOSONE* **10**(3), Art. No. e0116943 (2015).
12. **A. Iqbal**, J. M. Chappell, Q. Li, Charles E. M. Pearce, and D. Abbott, A probabilistic approach to the quantum Bayesian games of incomplete information, *Quantum Information Processing* **13**, pp 2783–2800 (2014).
13. J. M. Chappell, S. P. Drake, C. L. Seidel, L. J. Gunn, **A. Iqbal**, A. Allison, D. Abbott, Geometric algebra for electrical and electronic engineers, *Proceedings of IEEE* **102**(9), pp 1340–1363 (2014).
14. Q. Li, M. Chen, M. Perc, **A. Iqbal**, and D. Abbott, Effects of adaptive degrees of trust on coevolution of quantum strategies on scale-free networks, *Scientific Reports* **3**, Art. No. 2949 (2013).
15. Q. Li, **A. Iqbal**, M. Perc, M. Chen, and D. Abbott, Coevolution of quantum and classical strategies on evolving random networks, *PLOSONE* **8**(7), Art. No. e68423 (2013).
16. J. M. Chappell, **A. Iqbal**, M. A. Lohe, L. von Smekal, and D. Abbott, An improved formalism for quantum computation based on geometric algebra—case study: Grover's search algorithm, *Quantum Information Processing* **12**(4), pp 1719–1735 (2013).
17. J. M. Chappell, **A. Iqbal**, N. Iannella, and D. Abbott, Revisiting special relativity: A natural algebraic alternative to Minkowski spacetime, *PLOSONE* **7**(12), Art. No. e51756 (2012).
18. Q. Li, **A. Iqbal**, M. Chen, and D. Abbott, Evolution of quantum strategies on a small-world network, *European Physical Journal B* **85**, Art. No. 376 (2012).
19. Q. Li, **A. Iqbal**, M. Chen, and D. Abbott, Evolution of quantum and classical strategies on networks by group interactions, *New Journal of Physics* **14**, Art. No. 103034 (2012).
20. J. M. Chappell, **A. Iqbal** and D. Abbott, N-player quantum games in an EPR setting, *PLOSONE* **7**(5), Art. No. e36404 (2012).
21. K. Eshraghian, O. Kavehei, K. -R. Cho, J. M. Chappell, **A. Iqbal**, S. F. Al-Sarawi and D. Abbott, Memristive device fundamentals and modelling: Applications to circuits and systems simulation, invited paper, *Proceedings of IEEE* **100**(6), pp 1991–2007 (2012).
22. Q. Li, **A. Iqbal**, D. Abbott and M. Chen, Quantum strategies win in a defector-dominated population, *Physica A: Statistical Mechanics and its Applications* **391**(11), pp 3316–3322 (2012).
23. J. M. Chappell, **A. Iqbal** and D. Abbott, Analysis of two-player quantum games in an EPR setting using geometric algebra, *PLOSONE* **7**(1), Art. No. e29015 (2012).
24. J. M. Chappell, **A. Iqbal** and D. Abbott, Analyzing three-player quantum games in an EPR type setup using geometric algebra, *PLOSONE* **6**(7), Art. No. e21623 (2011).
25. J. M. Chappell, M. A. Lohe, L. von Smekal, **A. Iqbal**, D. Abbott, A precise error bound for quantum phase estimation, *PLOSONE* **6**(5), Art. No. e19663 (2011).
26. O. Kavehei, **A. Iqbal**, Y. S. Kim, K. Eshraghian, S. F. Al-Sarawi and D. Abbott, The fourth element: characteristics, modelling, and electromagnetic theory of the memristor, *Proceedings of the Royal Society A* **466**(2120), pp. 2175–2202 (2010).
27. **A. Iqbal** and D. Abbott, Constructing quantum games from a system of Bell's inequalities, *Physics Letters A* **374**(31–32), pp. 3155–3163 (2010).
28. J. M. Chappell, **A. Iqbal** and D. Abbott, Constructing quantum games from symmetric non-factorizable joint probabilities, *Physics Letters* A **374**(40), pp. 4104–4111 (2010).
29. **A. Iqbal** and D. Abbott, Quantum matching pennies game, *Journal of the Physical Society of Japan* **78**, Art. No. 014803 (2009).
30. **A. Iqbal** and D. Abbott, Non-factorizable joint probabilities and evolutionarily stable strategies in the quantum prisoner's dilemma game, *Physics Letters A* **373**(30), pp. 2537-2541 (2009).
31. J. M. Chappell, **A. Iqbal**, M. A. Lohe and L. von Smekal, An analysis of the quantum penny flip game using geometric algebra**,** *Journal of the Physical Society of Japan* **78**, Art. No. 054801 (2009).
32. **A. Iqbal**, T. Cheon and D. Abbott, Probabilistic analysis of three-player symmetric quantum games played using EPR setting, *Physics Letters A* **372**(44), pp. 6564–6577 (2008).
33. T. Cheon and **A. Iqbal**, Bayesian Nash equilibria and Bell inequalities, *Journal of the Physical Society of Japan* **77**, Art. No. 024801 (2008).
34. **A. Iqbal** and T. Cheon, Constructing quantum games from non-factorizable joint probabilities, *Physical Review E* **76**, Art. No. 061122 (2007). This article was selected to be reproduced in January 2008 issue of *Virtual Journal of Quantum Information*: http://www.vjquantuminfo.org.
35. **A. Iqbal**, Playing games with EPR-type experiments**,** *Journal of Physics A: Mathematical & Theoretical* **38**(43), pp. 9551–9564 (2005).

36. **A. Iqbal**, Quantum correlations and Nash equilibria of a bi-matrix game**,** *Journal of Physics A: Mathematical & Theoretical* **37**(29), pp. L353–L359 (2004).
37. **A. Iqbal** and S. Weigert, Quantum correlation games, *Journal of Physics A: Mathematical & General* **37**, pp. 5873–5885 (2004).
38. **A. Iqbal** and A. H. Toor, Stability of mixed Nash equilibria in a symmetric quantum game, *Communications in Theoretical Physics* **42**(3), pp. 335–338 (2004).
39. **A. Iqbal**, Quantum games with a multi-slit electron diffraction set-up, *Nuovo Cimento B* **118**(5), pp. 463–468 (2003).
40. **A. Iqbal** and A. H. Toor, Backwards-induction outcome in a quantum game, *Physical Review A* **65**, Art. No. 052328 (2002). [This article was selected to be reproduced in May 2002 issue of *Virtual Journal of Quantum Information*: http://www.vjquantuminfo.org.]
41. **A. Iqbal** and A. H. Toor, Quantum mechanics gives stability to a Nash equilibrium, *Physical Review A* **65**, Art. No. 022306 (2002). [This article was selected to be reproduced in February 2002 issue of *Virtual Journal of Biological Physics Research*: http://www.vjbio.org.]
42. **A. Iqbal** and A. H. Toor, Darwinism in quantum systems? *Physics Letters A* **294**(5–6), pp. 261–270 (2002).
43. **A. Iqbal** and A. H. Toor, Quantum repeated games*, Physics Letters A* **300**(6), pp. 537–542 (2002).
44. **A. Iqbal** and A. H. Toor, Quantum cooperative games, *Physics Letters A* **293**(3–4), pp. 103-108 (2002).
45. **A. Iqbal** and A. H. Toor, Entanglement and dynamic stability of Nash equilibria in a symmetric quantum game, *Physics Letters A* **286**(4), pp. 245–250 (2001).
46. **A. Iqbal** and A. H. Toor, Evolutionarily stable strategies in quantum games, *Physics Letters A* **280** (5–6), pp. 249–256 (2001).

Submitted/in progress/online articles

47. **A. Iqbal**, P. Hoodbhoy, and D. Abbott, Can quantum-mechanical description of physical reality be considered complete? (an Urdu translation) (2019). Available for download at this link.
48. **A. Iqbal** and D. Abbott, Quantum strategies and evolutionary stability (in Urdu) (2019). Available for download at this link.

Fully refereed conference proceedings

49. S. L. Zhou, D. G. Valchev, A. Dinovitser, J. M. Chappell, **A. Iqbal**, B. W. H. Ng, T. W. Kee, and D. Abbott, Dispersion-independent terahertz classification based on Geometric Algebra for substance detection, International Conference on Infrared, Millimeter, and Terahertz Waves, IRMMW-THz 2016, Copenhagen, Denmark, September 25-30 (2016).
50. P. Bruza, **A. Iqbal** and K. Kitto, The role of non-factorizability in determining "pseudo-classical" non-separability, *AAAI-Fall 2010 Symposium on Quantum Informatics for Cognitive, Social, and Semantic Processes, Washington DC*, November 11–13 (2010): http://sites.google.com/site/qiscience/home.
51. **A. Iqbal** and T. Cheon, Constructing multi-player quantum games from non-factorizable joint probabilities, *Proc. SPIE Microelectronics, MEMS, and Nanotechnology,* Australian National University, Canberra, **6802,** Art. No. 68020A (2008).
52. O. Kavehei, Y.-S. Kim, **A. Iqbal**, K. Eshraghian, S. F. Al-Sarawi, and D. Abbott, The fourth element: Insights into the Memristor, *Proceedings of the International Conference on Communications, Circuits and Systems*, California, USA, pp. 921–927 (2009).

Other publication outputs

53. **A. Iqbal**, A unifying framework for classical and quantum games, presentation in *Conference on Recent Advances in Mathematical Methods, Models and Applications*, Centre for Advanced Studies in Mathematics, Lahore University of Management Sciences, Lahore, Pakistan (2009).
54. **A. Iqbal** and D. Abbott, Quantum matching pennies game, poster presentation in *18th Biennial Australian Institute of Physics Congress*, the University of Adelaide (2008).
55. **A. Iqbal** and T. Cheon, Constructing quantum games from non-factorizable probabilities, poster presentation in *Asian Conference on Quantum Information Science*, Shiran Kaikan, Kyoto University, Japan (2007): http://aqis-conf.org/archives/aqis07/

Funding track record

- 2016-2017: Faculty of Engineering, Computer & Mathematical Sciences (ECMS) Interdisciplinary Research Grant Scheme 2016 (jointly with Prof Derek Abbott & Dr Virginie Masson) at the University of Adelaide. Awarded grant: AU$30,000
- 2007–2011: Australian Research Council (ARC) Discovery Grant DP0771453 (Principal Investigator) awarded by the Australian Research Council at the University of Adelaide for the research project “Study of Mathematical Models of Evolution using the Theory of Quantum Games.” Awarded grant: AU$247,092

- 2006–2007: Japan Society for Promotion of Science (JSPS) Research Grant P06330 (Principal Investigator) awarded by the Japan Society for the Promotion of Science at the Kochi University of Technology, Tosayamada, Kochi, Japan for a research project "Hilbert space formulation of quantum games." Awarded grant: ¥ 4,958,500
- 2002–2005: University's PhD Research Scholarship (fully-funded), University of Hull, UK

Supervision

At the University of Adelaide, I have closely assisted in mentoring two PhDs (O. Kavehei and J. Chappell) and supervising a number of Masters Project students.

- Dr O. Kavehei's thesis received the University's Alumni Medal. This thesis medal is significant as only one is awarded per year across the whole year and it signifies outstanding world-class performance.
- I hosted and closely mentored Dr Qiang Li, Chongqing University, China, as postdoctoral visiting scholar for one and half year. This resulted in significant joint publications in the area of quantum networks, including a publication in Nature's *Scientific Reports* (Vol. 3, Art. No. 2429, 2013).

Invited talks (selected)

2015 School of Engineering, University of South Australia, Mawson Lakes Campus, Adelaide
2014 King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia
2013 King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia
2012 School of Electrical & Electronic Engineering, University of Adelaide
2010 Quantum Interaction Group, Queensland University of Technology, Brisbane, Australia
2009 Mathematics & Statistics Colloquium Series, Portland State University, Oregon, USA
2009 Centre for Quantum Physics, COMSATS Institute of Information Technology, Islamabad, Pakistan
2008 Quantum Computing Group, School of Physical Sciences, University of Adelaide (series of four talks)
2007 Graduate School, Kochi University of Technology, Tosayamada, Kochi, Japan
2007 Theory Division, High Energy Accelerator Research Organization (KEK), Tsukuba, Japan

Research collaborations (past and present) leading to publications

a) Prof. Charles E. M. Pearce, University of Adelaide
b) Prof. Lorenz von Smekal, TU Darmstadt, Germany
c) Dr Stefan Weigert, University of York, UK
d) Prof. Peter Bruza, Queensland University of Technology, Australia
e) Dr Samuel Picton Drake, DST, Edinburgh, Australia
f) A/Prof Max A. Lohe, University of Adelaide
g) Prof. Derek Abbott, University of Adelaide
h) Dr James M. Chappell, University of Adelaide
i) Prof. Taksu Cheon, Kochi University of Technology, Japan
j) Dr Omid Kavehei, RMIT, Australia
k) Dr Said Al-Sarawi, University of Adelaide
l) Prof. Kamran Eshraghian, Chunbuk National University, South Korea
m) Dr Qiang Li, Chongqing University, China
n) Dr Nicolangelo Iannella, University of Nottingham, UK
o) Prof. Matjaž Perc, University of Maribor, Slovenia
p) Dr Lachlan J. Gunn, University of Adelaide (winner of Mazumdar math prize)
q) Dr Andrew Allison, University of Adelaide
r) Dr Kirsty Kitto, Queensland University of Technology, Australia
s) Prof. Minyou Chen, Chongqing University, China
t) A/Prof Tak W. Kee, University of Adelaide
u) Dr Alex Dinovitser, University of Adelaide
v) A/Prof. Abdul Hameed Toor, Quaid-i-Azam University, Pakistan
w) Dr Shengling Zhou, Southwest University, China

Research contributions

Introduction and focus: My core research expertise is in *quantum game theory* that extends the established branch of mathematics called game theory towards the quantum domain. This research area came into existence in 1999 building on the research field of quantum information/computation. It studies the strategic interaction among rational agents who share the two key resources of the field of quantum information/computation: **(i)** quantum superposition and **(ii)** entanglement. A quantum game is strategic manoeuvring of a quantum system by agents and involves unitary transformations and quantum measurement. Agents' utilities are functions of their strategic actions (strategies) and are obtained from the outcomes of measurements performed on the quantum system. In 1999 it was observed that quantum algorithm for an oracle problem can be understood as a 'quantum strategy' for a player in a two-player zero-sum game in which the other player is constrained to play the classical strategy. The list of known quantum algorithms is small and this observation led to exploring game theory in order to develop an improved understanding of the working of quantum algorithms. This area analyses strategic interaction in the presence of quantum entanglement and game theory is added to the set of existing mathematical tools in the continuing efforts to develop further quantum algorithms.

My research contributions are along the following three streams:

Quantum game theory: In the area of my core research expertise, I have made contributions in a number of directions: **a)** *Evolutionary stability in the quantum regime**:*** Introduced in the 1970s by mathematical biologists, the game theoretical notion of an Evolutionarily Stable Strategy (ESS) models an evolving population under evolutionary pressures. Being a refinement notion on the set of symmetric Nash equilibria, the ESS concept is the central stability solution concept of evolutionary game theory. My work determined how an ESS becomes susceptible when the interactions among agents (players) in a population, while engaged in pair-wise conflicts and under evolutionary pressures, become quantum-mechanical. The work showed that the quantum entanglement is relevant not only for Nash equilibrium but also for its refinements. A view of this work appeared in the book chapter in the book *Quantum Aspects of Life*, Imperial College Press, 2008 (pp. 251–288); **b)** *Entanglement determining the game-theoretic outcomes:* The area of quantum games was pioneered by work showing how sharing quantum entanglement results in the emergence of non-classical Nash equilibria. This motivated my work analysing the fate of other game-theoretic solution-concepts when players have access to quantum entanglement, including "Social Optimality" (*Physica A: Stat. Mech. Applic.* **436**:798–805, 2015), "Value of Coalition" (*Phys. Lett. A* **293**(3-4): 103-108, 2002), "Backwards-induction Outcome" (*Phys. Rev. A.* **65**(5): 052328, 2002) and "Sub-game Perfect Outcome" (*Phys. Lett. A,* **300**(6): 541–546, 2002); **c)** *Introducing Einstein-Podolsky-Rosen (EPR) setting for quantum games:* In order to identify the truly quantum content of quantum games, I developed an EPR setting for enacting quantum games (*J. Phys. A: Math. Theor.* **37**(22): 5873-5885, 2004) as part of my PhD thesis at the University of Hull, UK; **d)** *Quantum games from non-factorizable joint probabilities:* As part of my postdoctoral work during a prestigious research fellowship from Japan Society for the Promotion of Science, and while working under Prof Taksu Cheon at the Kochi University of Technology, Japan, I developed a new approach in constructing quantum games from the concept of non-factorizable joint probabilities (*Physical Review E* **76**(6): 061122, 2007). A follow up of this work appeared in a number of other publications, including the joint work with Dr J. Chappell (*Physics Letters A* **374**(40): 4104–4111, 2010); **e)** *Quantum games from Bell's inequalities:* During my Australian Postdoctoral Research Fellowship and working under Prof Derek Abbott, I developed a new approach to constructing quantum games directly from a system of Bell's inequalities (*Phys. Lett. A* **374** (31–32), 3155-3163 (2010); **f)** *Quantum games on networks:* In collaboration with Dr Qiang Li, Chongqing University, China, I presented investigations on quantum games played on networks (*Scientific Reports* (Nature) **3**, 1–7 (2013)); **g)** *Bayesian quantum games:* Bayesian games have more complex underlying probabilities structure and offer richer environment in studying the role of quantum probabilities in quantum games. Jointly with Prof Taksu Cheon, I developed the first investigation on quantum Bayesian games (*J. Phys. Soc. Japan* **77**(2):024801, 2008). Its follow up paper (Q. Inform. Process. **13**, 2783-2800 (2014)) appeared later with my colleagues at the University of Adelaide; **h)** *Concept combinations using quantum games:* In joint work with Prof Peter Bruza, Queensland University of Technology, I contributed to the first investigation of using quantum games in the understanding and description of concept combinations in human cognition (*AAAI-Fall 2010 Symp. Quant. Inform. Cogn., Soc., Sem. Processes*, Washington DC, November 11–13, 2010).

Geometric algebra (GA): GA combines the algebraic structure of Clifford's algebra with the explicit geometric meaning of its mathematical elements at its foundation. It is a coherent mathematical language that augments the powerful geometric intuition of the human mind with the precision of an algebraic system. In a number of joint works with Dr J. Chappell, Prof Derek Abbott and others, I contributed to the first studies of quantum games using GA. This includes the study of Meyer's quantum penny-flip game using GA (*J. Phys. Soc. Japa*n **78:**54801, 2009) building up on Meyer's pioneering work in the area of quantum game theory, a GA-based analysis of two-player (*PLOSONE* **7**(1): 29015, 2012) and three-player quantum games in an EPR type setup (*PLoS One* **6**(7):1–11, 2011), studies in special relativity using GA (*PLOSONE* **7**(12):1-10, 2012), investigation of N-player quantum games in an EPR setting (*PLOSONE* **7**(5), 1–9, 2012), developing an improved formalism for quantum computation based on GA and applying it to Grover's search algorithm (*Q. Inform. Process*. **12**(4):1719–1735, 2013), exploring the benefits of GA formalism for electrical and electronic engineers (*Proc. IEEE.* **102**(9):1340–1363, 2014), study of the functions of multivector variables in GA (*PLOSONE* **10**(3):0116943, 2015), and the study of time as a geometric property of GA-based conception of space (*Front. Phys.* **4**:44, 2016).

Mathematical modelling of memristors: Memristor a portmanteau of "memory" and "resistor" and is a type of passive circuit elements that maintain a relationship between the time integrals of current and voltage across a two terminal element. In collaboration with my colleagues at the University of Adelaide, I have developed mathematical modelling of memristive devices (*Proc. R. Soc. Lond. Ser. A-Math. Phys. Eng. Scien.* **466**(2120):2175–2202, 2010) and (*Proc. Int. Conf. Comm., Circuits and Systems*, ICCCAS, pp. 921-927, 2009) and its applications to circuits and systems simulation
(*Proc. IEEE* **100**(6): 1991–2007, 2012).

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