BOURNE, Chris Associate Professor (Institute of Liberal Arts and Sciences)

Office: Rm. 419 in Humanities Bldg.
Phone: +81 (0)52–789–5181 (ext. 5181)
Email: cbourne (at) nagoya-u.jp
Web-site: https://sites.google.com/site/khomologyzone/

Membership of Academic Societies:
International Association of Mathematical Physics (IAMP),
The Mathematical Society of Japan (MSJ),
Australian Mathematical Society (AustMS)

Research Interest:

- Operator algebras
- Index theory and noncommutative geometry
- Mathematical physics

Research Summary:

Much of my research is about the application of operator algebras, noncommutative geometry and index theory to systems in non-relativistic quantum physics.

Quantum mechanical observables are represented by operators on a complex Hilbert space. We can study algebras of observables/operators to rigorously define and study various properties of the underlying physical system. Noncommutative geometry and index theory can then potentially be used to determine a system's topological properties. In more detail, we can use ideas from index theory and K-theory of operator algebras to assign a topological index to a system that serves as a mathematical phase label. Topological phase labels are invariant under deformations or small perturbations and physical systems described by topological phases, such as the quantum Hall effect, posses many novel properties.

In previous research, I studied topological phases of a variety of systems such as symmetric free-fermions [4, 5] and many-body ground states in quantum statistical mechanics with a spectral gap condition [3].

The study of index theory in quantum mechanics, where anti-linear symmetries such as time-reversal symmetry may play an important role, has also motivated new research on K-theory and index theory on real Hilbert spaces. The paper [1] develops spectral flow and index theory on real Hilbert spaces with additional 'Clifford algebra symmetries', which can be connected to quantum mechanical symmetries.

Recently I have been exploring new applications of index theory techniques in physics and beyond. An example is the paper [2], which applies methods in coarse geometry, a framework used to study the index theory of non-compact manifolds, to the ground states of superconductor models. Currently I am studying the relevance of operator algebras, noncommutative geometry and index theory in quantum walks and quantum information theory. I am also working on further developments of operator algebras, noncommutative geometry and index theory regardless of potential applications.

Major Publications:

[1] C. Bourne, A. L. Carey, M. Lesch and A. Rennie. The KO–valued spectral flow for skew-adjoint Fredholm operators. *J. Topol. Anal.*, **14**(2):505–556, 2022.

[2] C. Bourne. Locally equivalent quasifree states and index theory. *J. Phys. A: Math. Theor.*, **55**(10):104004 (38 pages), 2022.
[3] C. Bourne and Y. Ogata. The classification of symmetry protected topological phases of one-dimensional fermion systems. *Forum Math. Sigma*, **9**, Article No. e25 (45 pages), 2021.
[4] C. Bourne and B. Mesland. Index theory and topological phases of aperiodic lattices. *Ann. Henri Poincaré*, **20**(6):1969–2038, 2019.
[5] C. Bourne and A. Rennie. Chern numbers, localisation and the bulk-edge correspondence for continuous models of topological phases. *Math. Phys. Anal. Geom.*, **21**(3):16 (62 pages), 2018.

Awards and Prizes:

- Journal of Physics A (Mathematical and Theoretical) Best Paper Prize 2020

Education and Appointments:

2015 PhD (Mathematics), The Australian National University
2016 Postdoc, Friedrich-Alexander Universität Erlangen-Nürnberg
2017 JSPS Postdoc, Tohoku Univerisity
2018 Assistant Professor, Tohoku University
2018 Visiting Scientist, RIKEN iTHEMS
2023 Associate Professor, Nagoya University

Message to Prospective Students:

My research is in the field of noncommutative geometry, operator algebras and their applications in physics. Noncommutative geometry and operator algebras bring together many ideas from different areas of mathematics. This combination of mathematical ideas makes the field interesting to work in, but it also means that one needs a basic knowledge of many different mathematical fields, which can be daunting for new students. I hope to be able to help you navigate this barrier of entry and assist you to find an area of study that you find interesting. Some reference books that we use in the small-group seminar are below:

[1] J. M. Gracia-Bondía, J. C. Várilly, H. Figueroa – Elements of Noncommutative Geometry
[2] K. Davidson – C*-Algebras by Example
[3] N. E. Wegge-Olsen – K-Theory and C*-Algebras: A Friendly Approach
[4] O. Bratteli, D. Robinson – Operator Algebras and Quantum Statistical Mechanics
[5] D. Bleecker, B. Booß-Bavnbek – Index Theory with Applications to Mathematics and Physics
[6] N. Higson, J. Roe – Analytic K-homology