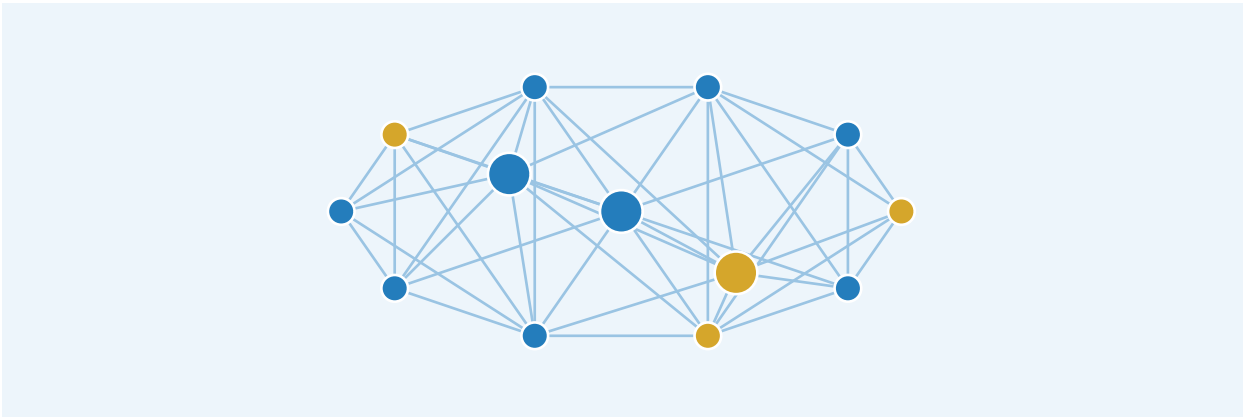
GUR ARYEH RESEARCH INSTITUTE
Complexity · Networks · Emergence · Adaptive Persistence

RESEARCH PROGRAM PAPERS / 001

Relational Foundations of Matter, Time and Space

Investigating the emergence of physical reality



Scientific foundations • Research questions • Methodological direction

November 2026 | Version 0.4 | Public-facing draft for review

www.guraryeh.org

Abstract

Modern physics describes physical phenomena with remarkable precision, yet the fundamental status of matter, time and space remains an open question. General relativity establishes a dynamical relationship between matter and spacetime geometry, while quantum theory challenges classical notions of independently defined physical properties. This research program explores whether a relational perspective can contribute to understanding the foundations of physical reality.

The program combines theoretical analysis, complex systems science, discrete mathematics and computational exploration. Its objectives are to identify conditions under which organized structures, temporal descriptions and effective spatial properties may arise in abstract systems, and to assess the relevance of such findings to established physics. The research is exploratory: no alternative physical theory or empirical result is claimed.

Keywords: relational ontology; emergent spacetime; foundations of physics; complex systems; scientific modeling.

1. Scientific motivation

Newtonian mechanics describes material bodies within an independently defined spatial and temporal framework. General relativity replaces the fixed geometric background of that description with dynamical spacetime. Quantum mechanics further challenges the classical conception of physical objects possessing independently defined properties. These developments motivate questions about the status of the entities and structures used in physical theories.

GARI investigates whether relations and collective organization offer a useful starting point for addressing these questions. The aim is not to replace successful physical theories by assertion, but to investigate possible explanatory foundations and the conditions under which established physical descriptions might be recovered.

2. Historical and theoretical antecedents

Relational thinking has a long history. Leibniz challenged the conception of space and time as independently existing containers; Mach explored the relational character of inertia. Einstein’s general relativity transformed the status of spacetime geometry [1]. These antecedents motivate, but do not establish, contemporary proposals for emergent physical structures.

Emergence and collective organization

Anderson emphasized the importance of collective organization and the emergence of regularities not apparent at the level of individual constituents [2]. This perspective provides a general motivation for studying how effective physical descriptions can arise from underlying systems.

Relational and temporal descriptions

Page and Wootters explored the description of dynamics through correlations in a stationary quantum framework [3]. Rovelli’s relational quantum mechanics treats the attribution of physical quantities in relational terms [5]. These approaches address distinct problems and should not be conflated with a general derivation of physical time.

Discrete and emergent geometry

Causal set theory investigates spacetime through discrete partially ordered structures [4,9]. Quantum Graphity explores models in which effective locality can emerge [6]. Van Raamsdonk examined connections between quantum entanglement and spacetime geometry in holographic settings [7], while Oriti investigated the conceptual and physical implications of spacetime emergence in quantum gravity [8].

These traditions provide important precedents for the program. They also establish a demanding standard: any new proposal must be compared with existing results and must identify what it adds beyond them.

3. Research orientation and questions

The intended distinctive direction of GARI is to examine matter, time and space within a shared research agenda informed by relational thinking and complex systems science. Rather than assuming that a single mechanism has already been identified, the program investigates whether common explanatory principles can be found across these domains. The originality of this orientation and of any subsequent formal theory remains subject to literature review.



Figure 1. The three physical domains investigated by the program. The illustration identifies research subjects rather than a proposed mechanism.

Central research question

Can a relational perspective provide a scientifically productive account of the foundational properties associated with matter, time and space?

Subsidiary questions

What organizational conditions are relevant to the identity and stability of physical structures? Under what conditions can meaningful temporal descriptions arise? What mathematical properties are necessary for an effective geometry and locality? How might such descriptions be related to experimentally established physical principles?

4. Research methodology

The program integrates conceptual analysis, mathematical modeling and computational experiments. Initial studies will examine simplified systems in which assumptions can be stated explicitly and their consequences assessed independently. Model selection will be guided by explanatory clarity, tractability and relevance to the research questions.

Theoretical and computational investigation

Theoretical work will clarify the distinction between foundational assumptions and derived properties. Mathematical investigations will assess consistency and explore the range of possible behaviors. Computational studies, where appropriate, will examine robustness, sensitivity to assumptions and the limits of candidate descriptions. AI-assisted exploration will support literature analysis, mathematical investigation and modeling, with scientific evaluation remaining essential.

5. Anticipated qualitative outcomes

The program seeks to identify conditions under which abstract systems exhibit organized structures, meaningful temporal descriptions or effective spatial properties. It also seeks to determine whether common explanatory principles are plausible and where distinct mechanisms may be necessary. These outcomes are research targets rather than established predictions.

Negative results are equally relevant: a model may fail to reproduce desired properties, depend on assumptions that undermine its explanatory purpose, or lack a credible connection with physical observations. Such findings would help constrain the theoretical possibilities.

6. Scientific validation and limitations

Mathematical emergence is not sufficient to establish physical emergence. A stable mathematical configuration does not by itself constitute matter, an ordering does not by itself establish physical time, and an abstract geometry need not correspond to physical space. The program must distinguish formal properties from physical interpretations and empirical evidence.

Candidate explanations will therefore be assessed for mathematical consistency, explicit assumptions, robustness and compatibility with established physics. A mature theory would need to address relevant quantum and relativistic principles, identify its domain of applicability and, where possible, yield independently testable consequences.

7. Current research status

The program is in its foundational theoretical phase, focusing on conceptual formulation and the development of preliminary mathematical model ideas. No validated physical model or original empirical discovery is reported in this paper. Subsequent work will focus on formal development, critical comparison with antecedents and systematic evaluation of candidate models.

8. Scientific significance

A successful investigation could clarify the relationship between fundamental assumptions and effective physical descriptions, and contribute to the dialogue between foundations of physics and complex systems science. Even if a unified explanation proves unattainable, identifying its limitations could help sharpen the questions guiding future theoretical research.

References

[1] Einstein, A. (1916/1952). The Foundation of the General Theory of Relativity. In The Principle of Relativity (pp. 109–164). New York: Dover Publications.

[2] Anderson, P. W. (1972). More Is Different. Science, 177, 393–396.

[3] Page, D. N., & Wootters, W. K. (1983). Evolution without evolution: Dynamics described by stationary observables. Physical Review D, 27, 2885.

[4] Bombelli, L., Lee, J., Meyer, D., & Sorkin, R. D. (1987). Space-Time as a Causal Set. Physical Review Letters, 59, 521.

[5] Rovelli, C. (1996). Relational Quantum Mechanics. International Journal of Theoretical Physics, 35, 1637–1678.

[6] Konopka, T., Markopoulou, F., & Severini, S. (2008). Quantum Graphity: A Model of Emergent Locality. Physical Review D, 77, 104029.

[7] Van Raamsdonk, M. (2010). Building up spacetime with quantum entanglement. General Relativity and Gravitation, 42, 2323–2329.

[8] Oriti, D. (2014). Disappearance and emergence of space and time in quantum gravity. Studies in History and Philosophy of Modern Physics, 46, 186–199.

[9] Surya, S. (2019). The causal set approach to quantum gravity. Living Reviews in Relativity, 22, 5.

Editorial note: Selected bibliography; metadata and literature coverage require final verification before public release.