

# Event Symmetry

Subjects: Quantum Science & Technology

Contributor: HandWiki Xu

In physics, event symmetry includes invariance principles that have been used in some discrete approaches to quantum gravity where the diffeomorphism invariance of general relativity can be extended to a covariance under every permutation of spacetime events.

Keywords: general relativity ; quantum gravity ; diffeomorphism

---

## 1. The Principle of Event Symmetry

### 1.1. What it Means

Since general relativity was discovered by Albert Einstein in 1915, observation and experiment have demonstrated that it is an accurate gravitation theory up to cosmic scales. On small scales, the laws of quantum mechanics have likewise been found to describe nature in a way consistent with every experiment performed, so far. To describe the laws of the universe fully a synthesis of general relativity and quantum mechanics must be found. Only then can physicists hope to understand the realms where gravity and quantum come together. The Big Bang is one such place.

The task to find such a theory of quantum gravity is one of the major scientific endeavours of our time. Many physicists believe that string theory is the leading candidate, but string theory has so far failed to provide an adequate description of the Big Bang, and its success is just as incomplete in other ways. That could be because physicists do not really know what the correct underlying principles of string theory are, so they do not have the right formulation that would allow them to answer the important questions. In particular, string theory treats spacetime in quite an old fashioned way even though it indicates that spacetime must be very different at small scales from what we are familiar with.

General relativity by contrast, is a model theory based on a geometric symmetry principle from which its dynamics can be elegantly derived. The symmetry is called general covariance or diffeomorphism invariance. It says that the dynamical equations of the gravitational field and any matter must be unchanged in form under any smooth transformation of spacetime coordinates. To understand what that means you have to think of a region of spacetime as a set of *events*, each one labelled by unique values of four coordinate values  $x, y, z$ , and  $t$ . The first three tell us *where* in space the event happened, while the fourth is time and tells us *when* it happened. But the choice of coordinates that are used is arbitrary, so the laws of physics should not depend on what the choice is. It follows that if any smooth mathematical function is used to map one coordinate system to any other, the equations of dynamics must transform in such a way that they look the same as they did before. This symmetry principle is a strong constraint on the possible range of equations and can be used to derive the laws of gravity almost uniquely.

The principle of general covariance works on the assumption that spacetime is smooth and continuous. Although this fits in with our normal experience, there are reasons to suspect that it may not be a suitable assumption for quantum gravity. In quantum field theory, continuous fields are replaced with a more complex structure that has a dual particle-wave nature as if they can be both continuous and discrete depending on how you measure them. Research in string theory and several other approaches to quantum gravity suggest that spacetime must also have a dual continuous and discrete nature, but without the power to probe spacetime at sufficient energies it is difficult to measure its properties directly to find out how such a quantised spacetime should work.

This is where event symmetry comes in. In a discrete spacetime treated as a disordered set of events it is natural to extend the symmetry of general covariance to a discrete event symmetry in which any function mapping the set of events to itself replaces the smooth functions used in general relativity. Such a function is also called a permutation, so the principle of event symmetry states that the equations governing the laws of physics must be unchanged when transformed by any permutation of spacetime events.

## 1.2. How it Works

It is not immediately obvious how event symmetry could work. It seems to say that taking one part of space time and swapping it with another part a long distance away is a valid physical operation, and that the laws of physics must be written to support this. Clearly this symmetry can only be correct if it is hidden or broken. To get this in perspective consider what the symmetry of general relativity seems to say. A smooth coordinate transformation or diffeomorphism can stretch and twist spacetime in any way so long as it is not torn. The laws of general relativity are unchanged in form under such a transformation. Yet this does not mean that objects can be stretched or bent without being opposed by a physical force. Likewise, event symmetry does not mean that objects can be torn apart in the way the permutations of spacetime would make us believe. In the case of general relativity the gravitational force acts as a background field that controls the measurement properties of spacetime. In ordinary circumstances the geometry of space is flat and Euclidean and the diffeomorphism invariance of general relativity is hidden thanks to this background field. Only in the extreme proximity of a violent collision of black holes would the flexibility of spacetime become apparent. In a similar way, event symmetry could be hidden by a background field that determines not just the geometry of spacetime, but also its topology.

General relativity is often explained in terms of curved spacetime. We can picture the universe as the curved surface of a membrane like a soap film that changes dynamically in time. The same picture can help us understand how event symmetry would be broken. A soap bubble is made from molecules that interact via forces that depend on the orientations of the molecules and the distance between them. If you wrote down the equations of motion for all the molecules in terms of their positions, velocities and orientations, then those equations would be unchanged in form under any permutation of the molecules (which we will assume are all the same). This is mathematically analogous to the event symmetry of spacetime events. The equations may be different, and unlike the molecules on the surface of a bubble, the events of spacetime are not embedded in a higher-dimensional space, yet the mathematical principle is the same.

Physicists do not presently know if event symmetry is a correct symmetry of nature, but the example of a soap bubble shows that it is a logical possibility. If it can be used to explain real physical observations then it merits serious consideration.

## 1.3. Maximal Permutability

American philosopher of physics John Stachel has used permutability of spacetime events to generalize Einstein's hole argument.<sup>[1]</sup> Stachel uses the term quiddity to describe the universal qualities of an entity and haecceity to describe its individuality. He makes use of the analogy with quantum mechanical particles, that have quiddity but no haecceity. The permutation symmetry of systems of particles leaves the equations of motion and the description of the system invariant. This is generalised to a *principle of maximal permutability*<sup>[2]</sup> that should be applied to physical entities. In an approach to quantum gravity where spacetime events are discrete, the principle implies that physics must be symmetric under any permutations of events, so the principle of event symmetry is a special case of the principle of maximal permutability.

Stachel's view builds on the work of philosophers such as Gottfried Leibniz whose monadology proposed that the world should be viewed only in terms of relations between objects rather than their absolute positions. Ernst Mach used this to formulate his relational principle, which influenced Einstein in his formulation of general relativity. Some quantum gravity physicists believe that the true theory of quantum gravity will be a relational theory with no spacetime. The events of spacetime are then no longer a background in which physics happens. Instead they are just the set of events where an interaction between entities took place. Characteristics of spacetime that we are familiar with (such as distance, continuity and dimension) should be emergent in such a theory, rather than put in by hand.

## 2. Quantum Graphity and Other Random Graph Models

In a random graph model of spacetime, points in space or events in spacetime are represented by nodes of a graph. Each node may be connected to any other node by a link. In mathematical terms this structure is called a graph. The smallest number of links that it takes to go between two nodes of the graph can be interpreted as a measure of the distance between them in space. The dynamics can be represented either by using a Hamiltonian formalism if the nodes are points in space, or a Lagrangian formalism if the nodes are events in spacetime. Either way, the dynamics allow the links to connect or disconnect in a random way according to specified probability rule. The model is event-symmetric if the rules are invariant under any permutation of the graph nodes.

The mathematical discipline of random graph theory was founded in the 1950s by Paul Erdős and Alfréd Rényi.<sup>[3]</sup> They proved the existence of sudden changes in characteristics of a random graph as parameters of the model varied. These are similar to phase transitions in physical systems. The subject has been extensively studied since with applications in

many areas including computation and biology. A standard text is "Random Graphs" by Béla Bollobás.<sup>[4]</sup>

Application to quantum gravity came later. Early random graph models of space-time have been proposed by Frank Antonen (1993),<sup>[5]</sup> Manfred Requardt (1996)<sup>[6]</sup> and Thomas Filk (2000).<sup>[7]</sup> Tomasz Konopka, Fotini Markopoulou-Kalamara, Simone Severini, and Lee Smolin of the Canadian Perimeter Institute for Theoretical Physics introduced a graph model that they called **Quantum Graphity**.<sup>[8][9][10][11]</sup> An argument based on quantum graphity combined with the holographic principle can resolve the horizon problem and explain the observed scale invariance of cosmic background radiation fluctuations without the need for cosmic inflation.<sup>[11][12]</sup>

In the quantum graphity model, points in spacetime are represented by nodes on a graph connected by links that can be *on* or *off*. This indicates whether or not the two points are directly connected as if they are next to each other in spacetime. When they are *on* the links have additional state variables that define the random dynamics of the graph under the influence of quantum fluctuations and temperature. At high temperature, the graph is in *Phase I* where all the points are randomly connected to each other and no concept of spacetime as we know it exists. As the temperature drops and the graph cools, it is conjectured to undergo a phase transition to a *Phase II* where spacetime forms. It will then look like a spacetime manifold on large scales with only nearest-neighbour points being connected in the graph. The hypothesis of quantum graphity is that this *geometrogenesis* models the condensation of spacetime in the Big Bang, and in support of the quantum foam idea <sup>[13]</sup>.

### 3. Event Symmetry and String Theory

String theory is formulated on a background spacetime just as quantum field theory is. Such a background fixes spacetime curvature, which in general relativity is like saying that the gravitational field is fixed. However, analysis shows that the excitations of the string fields act as gravitons, which can perturb the gravitational field away from the fixed background. So, string theory actually includes dynamic quantised gravity. More detailed studies have shown that different string theories in different background spacetimes can be related by dualities. There is also good evidence that string theory supports changes in topology of spacetime. Relativists have therefore criticised string theory for not being formulated in a background independent way, so that changes of spacetime geometry and topology can be more directly expressed in terms of the fundamental degrees of freedom of the strings.

The difficulty in achieving a truly background independent formulation for string theory is demonstrated by a problem known as Witten's Puzzle.<sup>[14]</sup> Ed Witten asked the question "What could the full symmetry group of string theory be if it includes diffeomorphism invariance on a spacetime with changing topology?". This is hard to answer because the diffeomorphism group for each spacetime topology is different and there is no natural way to form a larger group containing them all such that the action of the group on continuous spacetime events makes sense. This puzzle is solved if the spacetime is regarded as a discrete set of events with different topologies formed dynamically as different string field configurations. Then the full symmetry need only contain the permutation group of spacetime events. Since any diffeomorphism for any topology is a special kind of permutation on the discrete events, the permutation group does contain all the different diffeomorphism groups for all possible topologies.

There is some evidence from Matrix Models that event-symmetry is included in string theory. A random matrix model can be formed from a random graph model by taking the variables on the links of the graph and arranging them in a  $N$  by  $N$  square matrix, where  $N$  is the number of nodes on the graph. The element of the matrix in the  $n^{\text{th}}$  column and  $m^{\text{th}}$  row gives the variable on the link joining the  $n^{\text{th}}$  nodes to the  $m^{\text{th}}$  node. The event-symmetry can then be extended to a larger  $N$  dimensional rotational symmetry.

In string theory, random matrix models were introduced to provide a non-perturbative formulation of M-Theory using noncommutative geometry. Coordinates of spacetime are normally commutative but in noncommutative geometry they are replaced by matrix operators that do not commute. In the original M(atric) Theory these matrices were interpreted as connections between instantons (also known as D0-branes), and the matrix rotations were a gauge symmetry. Later, Iso and Kawai reinterpreted this as a permutation symmetry of space-time events<sup>[15]</sup> and argued that diffeomorphism invariance was included in this symmetry. The two interpretations are equivalent if no distinction is made between instantons and events, which is what would be expected in a relational theory. This shows that Event Symmetry can already be regarded as part of string theory.

## 4. Trivia

### 4.1. Greg Egan's Dust Theory

The first known publication of the idea of event symmetry is in a work of science fiction rather than a journal of science. Greg Egan used the idea in a short story called "Dust" in 1992<sup>[16]</sup> and expanded it into the novel *Permutation City* in 1994. Egan used dust theory as a way of exploring the question of whether a perfect computer simulation of a person differs from the real thing. However, his description of the dust theory as an extension of general relativity is also a consistent statement of the principle of event symmetry as used in quantum gravity.

The essence of the argument can be found in chapter 12 of "*Permutation City*". Paul, the main character of the story set in the future, has created a copy of himself in a computer simulator. The simulation runs on a distributed network sufficiently powerful to emulate his thoughts and experiences. Paul argues that the events of his simulated world have been remapped to events in the real world by the computer in a way that resembles a coordinate transformation in relativity. General relativity only allows for covariance under continuous transformations whereas the computer network has formed a discontinuous mapping that permutes events like "a cosmic anagram". Yet Paul's copy in the simulator experiences physics as if it were unchanged. Paul realises that this is "Like [...] gravity and acceleration in General Relativity — it all depends on what you can't tell apart. This is a new Principle of Equivalence, a new symmetry between observers."

---

## References

1. J Stachel, "'The Relations Between Things' versus 'The Things Between Relations': The Deeper Meaning of the Hole Argument", in *Reading Natural Philosophy/ Essays in the History and Philosophy of Science and Mathematics*, ed. David Malament Chicago and LaSalle, IL, Open Court pp 231-266 (2002)
2. J. Stachel, "Structure, individuality and quantum gravity" in *Structural Foundations of Quantum Gravity*, edited by D.P. Rickles, S.R.D. French and J. Saatsi Oxford University Press (2005) arXiv:gr-qc/0507078 <http://arxiv.org/abs/gr-qc/0507078>
3. P. Erdős, A Rényi, "On Random Graphs I", *Publ. Math. Debrecen* 6, p. 290–297, (1959)
4. B. Bollobás, "Random Graphs", 2nd Edition, Cambridge University Press, (2001)
5. Antonsen, Frank (1994). "Random graphs as a model for pregeometry". *International Journal of Theoretical Physics* (Springer Science and Business Media LLC) 33 (6): 1189–1205. doi:10.1007/bf00670785. ISSN 0020-7748. <https://dx.doi.org/10.1007%2Fbf00670785>
6. M. Requardt, "Emergence of Space-Time on the Planck Scale within the Scheme of Dynamical Cellular Networks and Random Graphs", (1996), arXiv:hep-th/9612185 <http://arxiv.org/abs/hep-th/9612185>
7. Filk, Thomas (2000-11-16). "Random graph gauge theories as toy models for non-perturbative string theories". *Classical and Quantum Gravity* (IOP Publishing) 17 (23): 4841–4854. doi:10.1088/0264-9381/17/23/304. ISSN 0264-9381. <https://dx.doi.org/10.1088%2F0264-9381%2F17%2F23%2F304>
8. T Konopka, F Markopoulou, L Smolin, "Quantum Graphity", (2006), arXiv:hep-th/0611197 <http://arxiv.org/abs/hep-th/0611197>
9. Konopka, Tomasz; Markopoulou, Fotini; Severini, Simone (2008-05-27). "Quantum graphity: A model of emergent locality". *Physical Review D* (American Physical Society (APS)) 77 (10): 104029. doi:10.1103/physrevd.77.104029. ISSN 1550-7998. <https://dx.doi.org/10.1103%2Fphysrevd.77.104029>
10. Hamma, Alioscia; Markopoulou, Fotini; Lloyd, Seth; Caravelli, Francesco; Severini, Simone; Markström, Klas (2010-05-17). "Quantum Bose-Hubbard model with an evolving graph as a toy model for emergent spacetime". *Physical Review D* (American Physical Society (APS)) 81 (10): 104032. doi:10.1103/physrevd.81.104032. ISSN 1550-7998. <https://dx.doi.org/10.1103%2Fphysrevd.81.104032>
11. Caravelli, Francesco; Markopoulou, Fotini (2011-07-05). "Properties of quantum graphity at low temperature". *Physical Review D* (American Physical Society (APS)) 84 (2): 024002. doi:10.1103/physrevd.84.024002. ISSN 1550-7998. <https://dx.doi.org/10.1103%2Fphysrevd.84.024002>
12. Magueijo, João; Smolin, Lee; Contaldi, Carlo R (2007-07-04). "Holography and the scale invariance of density fluctuations". *Classical and Quantum Gravity* (IOP Publishing) 24 (14): 3691–3699. doi:10.1088/0264-9381/24/14/009. ISSN 0264-9381. <https://dx.doi.org/10.1088%2F0264-9381%2F24%2F14%2F009>
13. Caravelli, Francesco; Markopoulou, Fotini (2012-07-10). "Disordered locality and Lorentz dispersion relations: An explicit model of quantum foam". *Physical Review D* (American Physical Society (APS)) 86 (2): 024019.

14. E. Witten, "Space-time Transitions in String Theory", (1993)
15. Iso, Satoshi; Kawai, Hikaru (2000-02-20). "Space-time and matter in IIB matrix model: Gauge symmetry and diffeomorphism". *International Journal of Modern Physics A* (World Scientific Pub Co Pte Lt) 15 (05): 651–666. doi:10.1142/s0217751x0000032x. ISSN 0217-751X. <https://dx.doi.org/10.1142%2Fs0217751x0000032x>
16. G. Egan, "Dust", Isaac Asimov's Science Fiction Magazine, July 1992.

---

Retrieved from <https://encyclopedia.pub/entry/history/show/76682>