

The Universal Arrow of Time

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Abstract. The Arrow of Time is an empirical feature of nature – time has a direction from the past to the future. However, the laws of Quantitative Science do not generally include the Arrow of Time. It is shown that this is because the Arrow of Time is a qualitative feature of nature that cannot be captured by Quantitative Science. To capture the Arrow of Time, a Qualitative Paradigm of Science is introduced that is a generalisation of the Mathematical Philosophy of Nature underpinning Quantitative Science. Within this paradigm, the Arrow of Time is captured in a new universal Law of Nature – the Universal Arrow of Time. Since Quantitative Science cannot capture the Arrow of Time, the special sciences cannot in general be reduced to Quantitative Science.

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1. Introduction. The source of the Arrow of Time is one of science's greatest mysteries (Coveney and Highfield 1990). Whilst the Arrow of Time appears to be part of empirical experience, our fundamental laws of nature are in general time-symmetric – they do not distinguish between forward and backward time (Greene 2004, 144-45). As a consequence, some researchers believe that the Arrow of Time is an illusion (Davies 2002) whilst others believe the Arrow of Time is a fundamental law of nature that they seek to discover (Prigogine 1997).

It was once thought that the second law of thermodynamics would provide the source for the Arrow of Time. The second law states that the entropy of an isolated system not in equilibrium will tend to increase over time, approaching a maximum value at equilibrium. However, since the classical mechanics on which entropy is based is time symmetric, entropy theoretically increases both towards the future and the past. Therefore, whatever the current state of a non-equilibrium system, its theoretical entropy most likely evolved from a more probable state in the past and will most likely evolve to a more probable state in the future. Since theoretical entropy is time symmetric, it is not the source of the Arrow of Time (Landau and Lifshitz 1958, 30).²

Given current knowledge, there are three broadly held views in relation to the Arrow of Time:

1. There is no Arrow of Time.
2. There is an Arrow of Time and it can be discovered by Quantitative Science.
3. There is an Arrow of Time but it is beyond the reach of Quantitative Science.

The first two views have been the focus of research into the Arrow of Time. In this paper it is shown that there is an Arrow of Time but it is beyond the reach of Quantitative Science. To do this, a distinction needs to be made between real time and mathematical time.

2. Real Time versus Mathematical Time. Real time is the qualitative time that is experienced. On the other hand, mathematical time is the quantitative representation of real time. The time variables in the equations of Quantitative Science represent mathematical time, not real time. Mathematical time covers real time as an infinite time-ordered collection of unique instants of time. When calculating using the equations of Quantitative Science, for the time variables are substituted instants of time from the collection of instants of time that is mathematical time. Quantitative Science uses mathematical time, but mathematical time is not the same as real time (Bergson 1911).

Mathematical time contains instants of time. Each instant of time is a point, which is time-symmetric. Since each instant of time is time-symmetric, each instant of time does not have a time-asymmetric Arrow of Time. Therefore, each instant of time could

² For similar arguments, see Poincaré (1893), Popper (1965), Weizsäcker (1980, 140), and Albert (2000, 77).

equally represent a sample of forward or backward time. Since mathematical time is a time-ordered collection of time-symmetric instants of time with no beginning or end, it is also time symmetric.

A time-ordered collection does not have within it a direction. Consider a time-ordered collection arranged horizontally. A part of the collection could be viewed from left to right and it asserted that a member of the collection to the left comes before a member to the right. But, equally, a part of the same collection could be viewed from right to left and it asserted that a member of the collection to the right comes before a member to the left. The time-ordered collection is ordered in both directions – from left to right and right to left. As a result, the time-ordered collection of time-symmetric instants of time could equally represent forward or backward time.

Mathematical time represents moving real time by a time-ordered collection of unmoving instants of time. Whilst real time is moving and has a direction, mathematical time is time-ordered but does not have a direction. The time-ordered instants of time can be given labels, such as the labels: 1 second, 2 seconds, 3 seconds, and so forth. But this does not give mathematical time its direction as the labels could represent the time since a point in time or the time before a point in time.

Real time is transformed to mathematical time during the act of measurement. Since measurements are *recorded* at time-symmetric instants of time, the time-asymmetric Arrow of Time is lost. As a consequence, mathematical time does not uniquely represent real time. Instead, mathematical time represents both forward *and* backward time in much the same way as the sequence $\{1,2,3,4,\dots\}$ can represent the absolute function of the sequence $\{1,2,3,4,\dots\}$ *and* the absolute function of the sequence $\{-1,-2,-3,-4,\dots\}$.

Given mathematical time represents both forward *and* backward time, it is simply a model of real time.

3. Quantitative Science. For time to be an area of study for Quantitative Science, it needs to be transformed from qualitative real time to quantitative mathematical time (Poincaré 1963, 18). Quantitative Science transforms physical problems from real time to mathematical time when taking measurements, which are *recorded* at instants of time. Quantitative Science then undertakes its analysis in mathematical time. However, science also interprets the solutions of Quantitative Science thereby implicitly transforming mathematical time back to real time. For example, since mathematical time represents both forward *and* backward time, the radiation field solutions of Quantitative Science have two solutions – the ‘advanced’ and ‘retarded’ solutions. The ‘retarded’ solution corresponds to forward time and the ‘advanced’ solution to backward time. When physicists choose the ‘retarded’ solution as the physically realisable solution, they are implicitly transforming mathematical time back to real time.

Since Quantitative Science uses mathematical time whose instants of time are time-symmetric, then so the theories of Quantitative Science are also time-symmetric. In particular, the theories of Quantitative Science provide mathematical relationships

between undefined pre-existing entities. For the temporal theories of Quantitative Science, one of those undefined pre-existing entities is the instant of time. The mathematical relationships between the undefined pre-existing entities cannot change the kind of the undefined pre-existing entities. For example, the mathematical relationships cannot change time-symmetric instants of time to time-asymmetric instants of time. As a result, the temporal theories of Quantitative Science cannot capture the Arrow of Time because one of their undefined pre-existing entities is the time-symmetric instant of time. Put another way, what comes out of theories is a function of what is put in. If time-symmetric instants of time are put into the theories, then what comes out is time-symmetric theories.

So, to briefly summarize, Quantitative Science uses mathematical time which is an approximation to real time. The fundamental metaphysical entity of mathematical time is the instant of time. Since an instant of time does not have an Arrow of Time, mathematical time (and therefore Quantitative Science) is unable to capture the Arrow of Time.

Now, if Quantitative Science cannot capture the Arrow of Time then the fact that Quantitative Science does not have an Arrow of Time cannot be used as a justification for their being no Arrow of Time in nature. Instead, since the empirical evidence suggests that nature has an Arrow of Time (Coveney and Highfield 1990), the prevailing paradigm that underpins Quantitative Science needs to be re-examined.

5. Prevailing Paradigm. There is no explicit prevailing paradigm as Quantitative Science does not recognise the philosophy of nature underpinning it. However, implicitly, the prevailing paradigm underpinning Quantitative Science is the Mathematical Philosophy of Nature.

Mathematical Philosophy of Nature. All of nature is fundamentally quantitative and can be explained using mathematics.

However, it has just been shown that not all of nature is fundamentally quantitative. In particular, real time is non-quantitative. Our quantitative representation of time, called mathematical time, is a model of non-quantitative real time – not real time itself. Since Quantitative Science uses mathematical time, not real time, its most fundamental theories, such as general relativity and quantum theory, are mathematical models of nature, not reality itself. The extraordinary accuracy of some of the predictions of general relativity and quantum theory have led to a belief that the theories are more than models of nature – they are reality. However, this is not the case. Since the Mathematical Philosophy of Nature cannot capture the Arrow of Time, if all of science including the Arrow of Time is to be unified then a new scientific paradigm is needed.

6. New Scientific Paradigm. A new scientific paradigm must explain all observations explained within the prevailing paradigm, together with present anomalies. Therefore, a new scientific paradigm is usually a generalisation of a prevailing paradigm. The prevailing paradigm of Quantitative Science is the Mathematical Philosophy of Nature. So, if a new paradigm that resolves the present anomaly is to be introduced, it will need to be a generalisation of the Mathematical Philosophy of Nature. This will enable the mathematical knowledge built up within the prevailing paradigm to be retained.

The Mathematical Philosophy of Nature makes quantity the basis of the universe. Quantity measures the *amount* of quality, it does not measure quality itself (Feibleman 1956a, 631). As a result, quantitative theories model the *amount* of quality, they do not model quality itself. As such, quantitative theories are a subset of qualitative theories (Feibleman 1956b, 215). In particular, quantitative theories can be represented qualitatively (for example, they can be described) but, in general, qualitative theories cannot be represented by quantitative theories. The benefit of quantitative theories is that they may lead to definite predictions. The benefit of qualitative theories is that they may be more general whilst still being explanatory. For example, the non-quantitative theories of evolution are explanatory whilst not making definite predictions.

The appropriate new scientific paradigm is the Qualitative Philosophy of Nature.

Qualitative Philosophy of Nature. All of nature is fundamentally qualitative and can be explained qualitatively and, sometimes, quantitatively using mathematics.

This paradigm is a generalisation of the Mathematical Philosophy of Nature since it recognises that sometimes nature can be explained quantitatively using mathematics. Since the new paradigm is a generalisation of the prevailing paradigm, it retains all the explanatory power of the Mathematical Philosophy of Nature whilst providing an opportunity to resolve the present anomaly – the basis of the non-quantitative Arrow of Time.

7. Universal Arrow of Time. Empirically there are a number of Arrows of Time (e.g. see Table A). These empirical Arrows of Time represent the effect of the Arrow of Time. They are not the cause or source of the Arrow of Time. For example, the cosmological arrow of time is not the source of the Arrow of Time. That is, time does not have an arrow because empirically the universe has always expanded to date. The expansion of the universe is a phenomena, not a universal Law of Nature.

Table A
Empirical Arrows of Time

Arrow of Time	Description
Cosmological arrow	Expansion of the universe
Causal arrow	Effects follow causes
Measurement arrow	Quantum collapse of the wave function
Uncertainty arrow	Whilst possible to know past exactly, not possible to know future exactly
Particle arrow	Kaon decay
Radioactive arrow	Radioactive decay
Electromagnetic arrow	Outward flow of electromagnetic radiation
Thermodynamic arrow	Increasing entropy
Biological arrow	Biological evolution
Ageing arrow	Death comes after conception
Record arrow	Records of past, not future (e.g. fossils)
Psychological arrow	Remember past, not future (e.g. memories)
Knowledge arrow	Know things in past, not future
Intervention arrow	Bring about things in future, not past
Symmetry breaking arrow	Increasing symmetry breaking (in general)
Complexification arrow	Increasing biological, ecological, sociological, and economic complexity (in general)

Empirically time is *universal* – it exists in all local regions of space and at all energies in the universe. Since the Arrow of Time is by definition a feature of time, it is universal like time. All the empirical Arrows of Time are then manifestations of the Universal Arrow of Time. Since the Arrow of Time is an empirical feature of nature and Quantitative Science cannot capture it, a new qualitative Law of Nature is required to represent the Arrow of Time. The Universal Arrow of Time is the new Law of Nature:

Universal Arrow of Time. Time has a one-way direction (from the beginning of time, if there was a beginning).

The Universal Arrow of Time is a new Law of Nature. It is generally agreed that Laws of Nature are universal, relational, and projectable (Clarke 1998, 22-23). The introduced Universal Arrow of Time is, by definition, universal, it represents a directional relation from before to after, and the Law is projectable into the future. Another feature of the fundamental Laws of Nature is that they are consistent with each other. Since the existing Laws of Nature are independent of whether there is a Universal Arrow of Time or not, the new Universal Arrow of Time is consistent with the existing Laws of Nature.

8. Conclusion. In general the special sciences, such as physics, chemistry, biology, psychology, sociology, and economics, empirically have an Arrow of Time. However, it has been shown that Quantitative Science cannot capture the Arrow of Time. If Quantitative Science cannot capture the Arrow of Time, then it cannot in general capture all the features of the special sciences. As a consequence, the special sciences cannot in general be reduced (in an epistemological and methodological sense) to Quantitative Science.

One of the goals of science is to unify our fundamental understanding of nature. The Arrow of Time is a fundamental part of nature. This feature of nature cannot be captured by Quantitative Science. As a consequence, a comprehensive unified theory of science that includes the Arrow of Time is not possible within the confines of Quantitative Science. However, by adopting a more general paradigm of science (i.e. the Qualitative Philosophy of Nature), it is possible to capture the Arrow of Time in a more general, Qualitative Science. Within this science it may be possible to develop a more comprehensive unified theory of nature that includes the Arrow of Time.

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