The Formulation of Temporal Relationships within Physics Theories

Hans H. Diel
Diel Software Beratung und Entwicklung
Seestr. 102, 71067 Sindelfingen, Germany
Tel: 49-7031-803991 E-mail: diel@netic.de

Abstract

The endeavor to reduce or eliminate the special role of time, both with the theories of physics and the manner in which the theories are formulated, has a long tradition. Indeed, the effort had already begun with Newton's mechanics and has been exalted with Einsteins theories of special and general relativity. These theories were formulated in mathematical terms (e.g. differential equations, tensors, symmetries) that do not allow for a special role for temporal aspects. The resulting kind of descriptions, which the author calls "declarative descriptions", were so successful that they became the preferred and dominating type of description associated with physics theories. Although the author appreciates the power and beauty of declarative descriptions, he detected limitations in their applicability, especially with the specification of more complex temporal structures (i.e., processes). As will be shown in this paper, the insistence on "general purpose" description methods impedes progress in certain areas of physics dealing with processes.

Keywords: Causality, Declarative descriptions, Functional descriptions, Process specifications, Time arrow

1. Introduction

The principles underlying theories of physics often influence the way these theories are formulated, and vice versa, the chosen method of description may also influence the statements of a theory. As part of a long tradition, temporal relationships are expressed in physics theories as much as possible by description methods that do not distinguish between temporal and non-temporal relationships.

The dominating type of description used in physics theories is here called "declarative description". Declarative descriptions declare *static* conditions, equations, and axioms, that hold for the subject described. With classical theories (including special relativity and general relativity), the static equations and axioms are even sufficient to derive dynamical behavior (for example, the equations of motion). The success of classical theories and of the related description methods has (justifiably) resulted in a preference for declarative descriptions among physicists. However, as will be shown, it also resulted in some cases in a reluctance to consider solutions that are not suited for declarative descriptions. This situation impedes progress in certain areas of physics dealing with processes. The description of (complex) processes requires "functional descriptions".

After the definition of declarative and functional descriptions (Section 2), this paper will describe a number of areas in which process-oriented, i.e., functional descriptions offer a chance for new concepts and solutions (Section 3). Arguably, purely declarative descriptions may be insufficient in principle for some of these "problem areas".

2. Declarative versus Functional Descriptions

Physics theories are understood as descriptions or specifications of how nature behaves. The author distinguishes between two types of descriptions for the formulation of physics theories: declarative descriptions and functional descriptions. Declarative descriptions are preferred by physicists. The terms "declarative description" and "functional description" appear in the literature; however, these terms are mostly used in contexts outside of physics (see, for example, Maudlin (1989) on functional description). Because their usage does not always exactly match the meaning required for the discussion in the context of physics theories, the terms are explained in the following sections.

2.1 Declarative Descriptions

The term "declarative description" or "declarative specification" was probably first used in the context of computer science, in which it referred to the specification of a function's semantics without specifying, at the same time, an algorithm (see Spinellis (2003)). Declarative descriptions of a physics theory declare conditions and relationships that hold for the objects and state variables of the theory. The relationships specified using declarative descriptions contain axioms, principles, symmetries, formulas, and equations. Wherever possible, the descriptions are formulated in mathematical language.
The axioms and equations of declarative descriptions specify *static relationships*, i.e., relationships that hold independent of time. However, these static relationships often allow for the derivation of the dynamical behavior of a system. Descriptions expressed in terms of differential equations containing the time derivative are common examples of static declarative descriptions from which dynamic behavior can be derived.

The following are famous examples of declarative descriptions:

- Relationship mass - energy: $E = mc^2$
- Uncertainty relation - Relationship between Δx and Δp : $\Delta p * \Delta x \geq h/2$.
- Condition: c is the maximum speed
- Symmetry law: four-vectors obey the Lorentz-group symmetry
- Conservation law: energy is a conserved entity
- Differential equation - Schrödinger equation - Relationship ψ - change of ψ :
  $ih\ \delta\psi(x,t) / \delta t = H(x,t)\ \psi(x,t)$

As an example from outside of physics, the declarative specification of a Sort function would be
$Sort(\{ x_1, x_2,\ldots,x_n\})) \rightarrow \{ x_1', x_2',\ldots,x_n'\}$ with $x_1' \leq x_2 \leq \ldots \leq x_n'$.

2.2 Functional Descriptions

Functional descriptions describe the dynamical evolution of a system. As mentioned above, simple types of dynamical behavior can be described in the form of differential equations. More complex processes (for example, processes involving continued interaction with the environment) require more elaborate types of descriptions. Unfortunately, few languages and formalisms that are suitable for functional specifications exist. For less complex processes, natural language (possibly in addition to differential equations) may be satisfactory. For more complex processes, the formal description methods used in computer science may be applicable. A possible functional description of a given Sort function would describe an algorithm; for example:

Sort($\{x_1, x_2,\ldots,x_n\}$)) := { For i = 1 to n do the following {

as long as not $x_1 \le x_2 \le \ldots \le x_i$

{shift element x_i to position j such that in the resulting set

$\{x_1', \ldots, x_j', \ldots, x_n'\}$ $x_1' \le x_2' \le \ldots \le x_j'$;

} } }

This functional description of the Sort function describes, of course, just one of many alternative sort algorithms. For an abstract definition of the Sort function, it provides unnecessary, and possibly confusing, details. However, for concrete subjects, such as computer programs, most processes in chemistry, biology, sociology and medicine, and some areas of physics (see Section 3), this additional detail may be essential. Typical constituents of a functional description are process steps together with methods indicating how the process steps relate to each other (e.g., sequential, parallel, iterations, alternatives, conditional continuation).

2.3 Limitations of Purely Declarative Descriptions

The beauty of various declarative descriptions of physics derives primarily from their compactness. It is impressive not only to physicists how much physics can be expressed by short and compact equations. Therefore, there are good reasons for maintaining declarative descriptions as the preferred type of description in physics, even in specifying temporal relationships. However, there are three types of limitations that must be understood and that may be overcome by an extended use of functional descriptions:

1. More complex processes may not be specifiable with purely declarative descriptions such as differential equations. In areas of science that involve more complex processes (e.g., biology and computer science), it is clear that not all types of processes can be described in terms of differential equations. The principal type of processes that typically imply more complex relationships is interactions.
2. Declarative descriptions may not be sufficient for the specification of *how things function*. In (Feynman 1985) , R. Feynman writes "I have pointed out these things because the more you see how strangely Nature behaves, the harder it is to make a model that explains how even the simplest phenomena actually work. So theoretical physics has given up on that." Explaining "how phenomena actually work" is called "a functional description" in this paper.

3. The compactness of declarative specifications may entail that structures and relationships cannot be easily covered by a certain compact specification may be ignored. For example, the often claimed time symmetry of the laws of physics will disappear when the application of the laws of physics is considered from the point of view of a process (see Section 3.4).

Admitting that there are good reasons for a physicist's preference in (traditional) declarative descriptions, it is reasonable to try to formulate a theory first of all in terms of a declarative description. However, if a declarative description cannot be found at all (case 1), or if the declarative description does not enable one to derive how things function (case 2), functional descriptions should be considered as a possible solution. This does not mean that the development of functional descriptions in those cases will be a trivial task. However, the work towards a functional description may open the way for new solutions that are not possible with the insistence on (declarative) differential equations as the standard way to describe the evolution of a physical system.

3. Candidate Areas for Functional Descriptions in Physics

Below, five examples of physical processes are given where the author sees a chance for functional descriptions to provide the resolution of known problems. The list is not exhaustive. Whenever non-trivial temporal relationships exist or cannot be excluded, the insistence on purely declarative descriptions is considered by the author to be a mistake.

3.1 Quantum Theory – Transition from Probabilities to Facts

Quantum theory (QT) predicts probabilities rather than facts. Statements on (the point in time) when probabilities are turned into facts are not considered part of QT, except for the statement that the facts are observable at the time of measurement. The process that performs the transition to facts or results in the transition can hardly be described by declarative descriptions. Ideas on the transition from probabilities to facts are part of so-called interpretations of QT (Baumann and Sexl 1984). These interpretations of QT simultaneously offer theories on the measurement problem of QT (Maudlin 1995) and the (apparent) collapse of the wave function.

Most of these interpretations of QT continue to rely on declarative descriptions (mainly verbal descriptions). The collapse of the wave function (clearly a *process* step) is either negated (the many worlds interpretation, see (Everett 1957; Zeh 2012)), or modeled by a modification of the Schrödinger equation (see (Ghirardy Rimini Weber 1980), or associated in an unsatisfactory way with observation. Only one of those interpretations, the Transactional Interpretation (Cramer 1986) can be viewed as a functional (i.e., process-based) description. Based on the assumption that the transition from probabilities to facts, the measurement process, and the collapse of the wave function, are all consequences of specific circumstances involving interactions between particles and that an explanation of the interaction process requires a functional description of interactions in QT, in (Diel 2013a) such a Functional Interpretation of QT is proposed.

3.2 Quantum Theory – Destruction of Interference

The famous double-slit experiment of QT demonstrates an important feature of QT, the formation and destruction of interference. The rule for determining when interference occurs is one of the basic laws of QT. In Feynman, Leighton, and Sands (1971), it is phrased as follows:

"When an event can occur in several alternative ways, the probability amplitude for the event is the sum of the probability amplitudes for each way considered separately. There is interference:

$\Phi = \Phi_1 + \Phi_2$

$P = | \Phi_1 + \Phi_2 |^2$

If an experiment is performed which is capable of determining whether one or another alternative is taken, the probability of the event is the sum of the probabilities for each alternative. The interference is lost.

$P = P_1 + P_2$ "

Almost every textbook on QT contains a similar formulation. When the author attempted to incorporate this rule into a computer simulation of QT, it turned out that this is not possible (Diel 2013b). The problem is that a condition such as "an experiment is performed which is capable of determining whether one or another alternative is taken" cannot be understood as a trivial self-explanatory condition, nor can it be reasonably defined in terms of any other mathematical construct. It may be possible to find an alternative, somewhat more concrete phrasing of the above rule, such as, "The probability amplitudes have to be added (i.e., are in superposition) unless, through a type of "*measurement-like interaction*", it is possible to determine whether a particular path is taken." This phrasing still requires that the term "measurement-like interaction" be defined more precisely. However, determining when a situation may be considered to exactly represent a measurement-like interaction is one of the open issues of the unresolved measurement problem (see Section 3.1). If the "interference destruction rule" is defined with reference to the occurrence of an event, namely, the occurrence of a measurement-like interaction, this would clearly represent a functional specification of the rule. The author claims that the subject requests a functional description.

3.3 Quantum Field Theory – Treatment of Interactions

R. Feynman made his remark on physicists inability to explain how things function (see Section 2.3 and Feynman (1985)) in the context of explaining quantum electrodynamics, the first theory which dealt with interactions (of QT). However, there are reasons to believe that he saw the strangeness of nature with QT in general. Nevertheless, theories on interaction processes are the major candidates in need of functional descriptions.

Considering quantum field theory (QFT), particularly quantum electrodynamics, there are two points that seem to contradict the doubts expressed above:

1. The declarative formulation of quantum electrodynamics and of QFT is very successful in predicting the outcome of many types of interactions (e.g., scatterings) among particles. However, the doubtless success of quantum field theory shields the fact that this applies only to cases with simple or simplified temporal conditions. With simple interactions, an idealized time span ($-\infty$ to $+\infty$) has to be assumed. For more complex interactions, for example, interactions with bound systems, where timing

relationships are more complicated and more relevant, computations can only be handled for special cases.

2. At first glance, it appears as though QFT is dealing with (true) processes: (1) Feynman uses the word "process" extensively when describing his theory (Note 1). (2) Feynman diagrams give the impression of showing a temporal structure, i.e., a process. Upon further inspection, this impression turns out to be wrong. The term "process" may be applicable when viewing the subject as a whole, but it does not provide any temporal substructures or details. Additionally, Feynman diagrams must not be viewed as showing a temporal structure (Note 2).

Possible improvements of QFT which provide a better treatment of interactions with bound systems and probably a better theory for interactions causing measurements can only be achieved with an appropriate assessment of process aspects in form of functional descriptions.

3.4 Causality, Direction of Time and the Overall Process of World Evolution

Much has been written (for example, Horwich (1987); Maudlin (2012); Price (1996); Zeh (2012)) in regard to causality and the (possible) identification of a direction of time. Often the discussion is based on considerations of the laws of physics and their general properties such as symmetries. Here again, the author claims that, in discussions on causality and the direction of time, looking at the (declarative) properties of the laws of physics is not sufficient. The laws of physics have to be regarded in the context of their primary goal and application, namely to explain the overall *process* of world evolution. The collection of functions, equations, and axioms that make up the theories of physics do not automatically imply a complete description/understanding of the overall process of the world's dynamical evolution. There are many open questions with respect to the overall process of world evolution. The questions can be grouped according to the level of detail or abstraction:

1. At the broadest level, theories about the formation of stars, planets, and galaxies are studied. At this level, the value of functional descriptions that describe the complicated temporal relationships seems to be generally agreed upon. The numerous computer models on the subjects simulate processes rather than declarative axioms or equations.
2. At the next level, there is a search for a consistent set of theories and laws of physics, or for a common "theory of everything" (TOE), which allows the derivation of the overall process of world evolution. In line with the general skepticism of the author on declarative description methods, the author doubts that it will be possible to find such a TOE based on purely declarative descriptions. The increased generality of a (to be invented) unifying declarative specification (such as for example a "TOE-Schrödinger equation") may have to be balanced with a loss of significance (Note 3).
3. When more fundamental questions on space-time structure, causality, the direction of time, or the (theoretical) possibility of time travel are discussed, it turns out that there is a further level of questioning with respect to the overall process of world evolution. One might suspect that, at least at this level, declarative descriptions, as for example, provided with general relativity theory, should be appropriate and sufficient to answer all such questions. However, it appears that upon further inspection, the existing declarative descriptions allow for more freedom than nature uses. The commonalities and interdependencies between the space dimensions and the time dimension, as

established by general relativity theory, possibly hinder the view on the special role of time within the evolution of the world.

The present paper is not the place to describe a model of the overall process of world evolution, even if the author were able to provide such a model. Nevertheless, some very general considerations may be possible and appropriate.

Let us view the laws for the evolution of the state of the world (i.e., the laws of physics) as represented by a "physics-interpreter". The physics-interpreter acts upon the state of the world.

To show the dynamical evolution, the model described here assumes the continuous repeated invocation of the physics-interpreter to realize the progression of the state of the world. The physics-interpreter continuously determines new states. The physics-interpreter acts upon an in-world to generate an out-world.

```
worldEvolution( world W ) := {
    W.t = 0; W.x1 = 0; W.x2 = 0; W.x3 = 0;
    W.ψ = initialState;
    Δt = timestep;    \\ must be positive \\
    DO UNTIL ( nonContinueState( W ) ) {
        physicsInterpreter( W, Δt );
    }
}
physicsInterpreter( W, Δt ) := {
    tdt = W.t + Δt;
    W = applyLawsOfPhysics( W, Δt );
    discardAllSpacetimePointsWithTimeCoordinate( W.t < tdt );
}
with state parameters
world := { spacetimepoint ... }
spacetimepoint := { t, x1, x2, x3, ψ }
ψ := { stateParameter1, ... , stateParametern }
```

Without knowing what exactly the complete set of laws of physics (represented by applyLawsOfPhysics()) is, the above described model implies two features which are worth mentioning:

1. Causality is implied by the fact that the states are developed in sequence, with state S_i being an input parameter for the computation of state S_{i+1}.
2. A direction of (the global) time coordinate is implied by the fact that the time coordinate W.t always increases by a uniform *positive* amount (see tdt = W.t + Δt).

These two points and the whole model may still be controversial. However, the point being pursued by the author is, that any discussion on subjects such as causality and the direction of time requires some model similar to the one described above. It is not sufficient to look only at the (declarative) properties of the laws of physics. More concretely, it does not seem possible to derive the principle of causality and the direction of time from purely declarative laws of physics such as differential equations.

3.5 Relativity Theory – Temporal Singularities

It is one of the merits of differential equations that they tell us when singularities will occur. (Almost) by definition, the differential equation cannot tell us what happens with the components of a physical system at the singularity. Consequently, theories of physics about singularities such as black holes or The Big Bang are highly speculative. This does not mean to say that you simply have to develop a functional interpretation for the singularities of general relativity theory to obtain a better understanding of black holes and The Big Bang. The author questions, however, whether the invention of new differential equations for the overall evolution of physical systems (such as, for example, the Wheeler-DeWitt equation (Hartle and Hawking 1983)) will result in significant improvements. It may only widen the basis for speculation.

4. Conclusions

The use of general purpose declarative description methods for the description of both temporal relationships and non-temporal relationships has a long tradition in the development of physics theories. The methods have resulted in powerful and beautiful theories. Nevertheless, in areas of physics involving complex temporal relationships, i.e., those associated with processes, the persistence of declarative descriptions limits the scope of possible solutions for unsolved problems.

In Section 3, prime examples of areas of physic requiring special attention to and a special treatment of temporal aspects are described. The development of functional descriptions for such "problem areas", of course, does not automatically generate solutions to existing problems. However, it may significantly enlarge the basis for possible solutions.

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Notes

Note 1. R.Feynman also wrote a book entitled "The Theory of Fundamental Processes", see (Feynman 1998)

Note 2. The fact that multiple diagrams may have to be applied for a (single) scattering process disturbs any temporal interpretation. Additionally, possible loops in Feynman diagrams do not mean temporal loops.

Note 3. For example, it is not yet clear whether the elimination of the time parameter in the Wheeler-DeWitt equation (see Hartle and Hawking (1983)) is, in fact, an improvement.