The Time Flow Manifesto

Chapter 1.
The Logical Concept of Time Directionality.

DRAFT

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Chapter 1. Concepts of Time Directionality.

Here we introduce the basic concepts of time directions, symmetry, reversal, independently of any specific physical theories.

Defining Time Symmetry

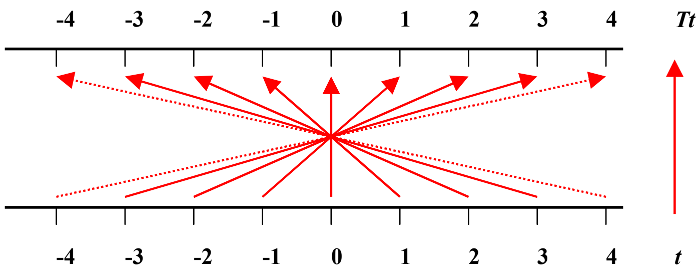
To begin with we consider what *time symmetry* means. An abstract 'mathematical' answer is:

- *Time symmetry* means *invariance under the time reversal transformation,* a symmetry transformation based on the mapping: ***T**: t* → *-t.*
- A *symmetry transformation* is based on a 1-1 mapping of a fundamental variable (like time, space, charge, etc) back onto itself. This must logically induce transformations on all other complex constructions involving this quantity. E.g. the mapping *t* → *-t determines that dr/dt* → *dr/d(-t) (velocity* reversal follows from time reversal).
- Any kind of well-defined object or logical construction (e.g. variables, states, processes, laws, worlds) for which *the time reversal transformation* is defined may have the property of *time symmetry,* meaning that the object or construction is identical to its time-reversed image.
- The laws of physics are *time symmetric (reversible) just in case they are identical to their image under the time reversal transformation.*

This assumes that we have a theory defined as a *mathematical construction*, in which all references to *time* are fully interpreted.

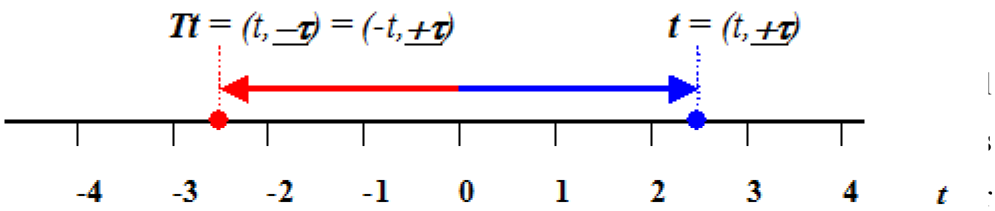
Time Reversal and Directional Properties of Time.

The *time reversal mapping* is a reflection, which reverses the *order* of moments.



Point-to-point reflection mapping of moments. $T: t \to -t$.

The *moments of time* is a linear continuum of points. But we can think of the time line as a *vector space,* with points indicated by vectors from a conventional origin. Then we have 1-dimensional *time-like vectors* defined by: $\boldsymbol{t} = (t, \underline{+\tau})$, where: $\underline{+\tau}$ is the *basis vector* (or unit vector) for time, and *t* is the magnitude.



Vector reflection mapping. $T: (t, \underline{+\tau}) \rightarrow (t, \underline{-\tau})$

Definition of the negative time direction.

- $(t, \underline{+\tau}) = (-t, \underline{-\tau})$

I.e. if we exchange the *coordinate t for the negative coordinate, -t, and the direction* $\underline{+\tau}$ *for the negative direction,* $\underline{-\tau}$, the vector is left unchanged. In other words, there is only one *independently definable direction,* and a second inter-definable direction.

To see this clearly, note that directions are properties of *pairs of temporal points,* say *(t,t')*. The proposition that: *the direction from t to t' is future,* can be written as: $\underline{+\tau}(t,t')$. It is true just in case, in vector form: $t \equiv (t, \underline{+\tau})$, $t' \equiv (t', \underline{+\tau})$, and: $t < t'$. Then by the definition: $\underline{+\tau}(t,t') \Leftrightarrow \underline{-\tau}(t',t)$. I.e the *direction from t to t' is future* <u>just in case</u> the *direction from t' to t is past.* So there not two independent facts about the temporal direction between two moments, just one relation.

The vector representation lets us identify the *directions of time* explicitly in the formal construction. The philosophical or metaphysical questions are whether or what sort of *directional properties* time has. This means: *does the* $\underline{+\tau}$ *direction have different properties to the* $\underline{-\tau}$ *direction?* The directional properties of interest are conferred by some *object of interest,* which may be processes, laws, theories, states, or anything that has an *explicit time construction* specified in the theory. For instance, if we define a velocity as usual: $\boldsymbol{v} = d\boldsymbol{r}/dt$, in time-vector form it looks like: $\boldsymbol{v} = d\boldsymbol{r}(\mathbf{t})/d(t, \underline{+\tau})$, and *the direction of time is transparent in the construction.* We can define the *time reversal of the velocity,* written: $T\boldsymbol{v}$, by substituting the negative time direction:

$T\boldsymbol{v} = d\boldsymbol{r}(\mathbf{t})/d(t, \underline{-\tau})$	[Exchange: $\underline{+\tau} \rightarrow \underline{-\tau}$ in the definition of $\boldsymbol{v}$]
$= d\boldsymbol{r}(\mathbf{t})/d(-t, \underline{+\tau})$	[Substitute definition of $\underline{-\tau}$]
$= -d\boldsymbol{r}(\mathbf{t})/d(t, \underline{+\tau})$	[Move negative sign to the front]
$= -\boldsymbol{v}$	[Substitute definition of $\boldsymbol{v}$]

As we know, the time reversal of a *velocity* is the negative velocity.

If the object of interest is a *proposition,* e.g. a *law of physics,* call it *L,* then it is a more complex construction, but as long as we can identify the term: $\underline{+\tau}$ in it, we can write is as: $\boldsymbol{L(\underline{+\tau})}$, i.e. first make the term $\underline{+\tau}$ in *L* into a *variable*, abstracting $\underline{+\tau}$ so that *L* becomes a function: ***L(.)***. This is applied to $\underline{+\tau}$, generating the original: $\boldsymbol{L(\underline{+\tau})} = L$. The function: ***L(.)*** explicitly casts the proposition in terms of what it says *<u>about</u>* the *property of the time direction* $\underline{+\tau}$.

We can then ask whether this is also a property of the *negative time direction,* i.e. $\boldsymbol{L(\underline{+\tau})}$ is true, but is: $\boldsymbol{L(\underline{-\tau})}$ true? If this is also true, then $\boldsymbol{L(\underline{.})}$ is a common property of the two directions of time: $\boldsymbol{L(\underline{+\tau})}$ & $\boldsymbol{L(\underline{-\tau})}$.

We now define the *time reversal, TZ,* of any entity, *Z,* as:

Definition of time reversal transformation.

- $TZ(\underline{-\tau}) = Z(\underline{+\tau})$
- I.e. whatever *Z* says about $\underline{+\tau}$, the time-reversal: *TZ* says about $\underline{-\tau}$.

The concept of *invariance (i.e. symmetry) under time reversal* means simply that the time reversal image of an object is identical to the original:

Definition of invariance under time reversal.

- *Z is invariant under time reversal* ⇔ $TZ(\underline{+\tau}) = Z(\underline{+\tau})$ *[Definition]*
- *Z is invariant under time reversal* ⇔ $Z(\underline{-\tau}) = Z(\underline{+\tau})$ *[Equivalent]*
- I.e. *time reversal invariance of* Z means that *Z says exactly the same things about both directions of time.*

This is a general interpretation of *time reversal* that shows how the *mathematical symmetry transformation, T,* relates precisely to *the properties conferred on the directions of time,* when we apply it to processes, propositions, laws, etc.

Contingent Process Reversal.

- If the entity is a *process, P,* then *TP* is the time-reversed process (which is like the 'movie running backwards…' almost).
- It is unusual that: $P = TP$ for actual processes, i.e. they are usually directed in time, so that: $P \neq TP$.
- This means that for most actual processes: $P(\underline{+\tau})$, *but not-*$P(\underline{-\tau})$.
- Hence almost any specific process confers a *contingent* directionality on time.
- Some common *types of processes* are called *irreversible processes,* or *physical arrows of time,* e.g. thermodynamic processes are structurally time-directed.
- The conventional paradigm is that these are still only *contingently irreversible process types,* even though they appear to be governed by strictly irreversible laws of applied physics.

While the laws of applied sciences treat irreversible processes, universal laws of fundamental physics exhibit powerful symmetries, and *time reversal symmetry* is key.

- The 'laws of physics' here means laws or theories physics has actually found.
- The 'Laws of Nature', below, refers to idealised 'real laws', that physics is ostensibly trying to discover by proposing 'laws of physics'.

Reversibility of Laws of Physics.

- The law is represented by a *proposition, L,* and *TL* is the time-reversed law.
- We are normally interested in *universal laws of physics*, or *theories of physics.*
- We primarily want to know if: $L = TL$, i.e. if the law if identical to its time reversed image. In this case it is *reversible.*
- (Note that this is an *analytic exercise:* it follows from the definition of the law, not from experimental tests.)
- If $L = TL$, *then:* $L(\underline{+\tau}) = L(\underline{-\tau})$, i.e. the law *L* confers exactly the same property, *L(.),* on both directions of time.

- A general theory (or law) that entails many laws is reversible just in case *if it entails a law, L, it also entails TL.*
- Note all theories and laws logically entail 'irreversible propositions', *L,* where: $L \neq TL$. All you have to do is restrict the time quantification of a universal law, and it is still true, but it becomes asymmetric w.r.t. time reversal.

We do not think of universal laws of physics as simply universally true *contingent* propositions however, but rather as identifying '*natural* (or *nomic*) *necessity'*.

Reversibility of Laws of Nature.

- Discovered laws of physics, *L,* are variously interpreted (in different ages, by different scientists) as *laws of nature.*
- This means that the properties of time directions that the laws *L* confer are taken as having a special significance, being 'nomically necessary' properties, or 'intrinsic properties', not merely reflecting contingent happenings *in time*.
- The interpretation of this is about the *significance* of reversibility or otherwise of *specific laws of physics proposed as laws of nature.* It is separate to the question of the time reversal of *L,* or whether $L = TL$, i.e. *L* is reversible. It is dependant on the 'metaphysical' or 'modal' status that laws and theories are interpreted to have.
- If a *modal statement* like: *L* <u>*is a law of nature*</u> is true, and it is also analytically true that: $L \neq TL$, then we expect the modal statement: *A* <u>*law of nature*</u> *is irreversible,* and subsequently: *the time directions are distinguished by at least one* <u>*law of nature*</u>. I.e. modal claims about *L* are reflected in modal claims about its implications.

Conclusion to Chapter 1.

The conclusion to emphasise is that:

- *Time reversal invariance or symmetry is the only relevant property of laws of physics with respect to identifying directional properties of time.*

A lot of debate has revolved around identifying different '*kinds of time asymmetry',* different kind of 'irreversibility', classifying them into types, e.g. 'intrinsic directionality' versus 'contingent directionality'. However, there is really just one concept of time asymmetry (*asymmetry w.r.t. the time directions*), with many different types of modal claims that can be made about any particular example of a time asymmetry. Similarly, there is a common concept of time asymmetry across the different theories of physics – we do not have a *special concept of time symmetry for quantum mechanics*, and another concept for classical physics, and so on, as some writers suggest. And time directionality properties are uniquely related to the time reversal transformation.

- *If $L = TL$ then L can confer no directional properties on time*
- *If $L \neq TL$ then L must confer directional properties on time*

Time flow requires an asymmetry between the two *directions* – since the past has been and gone and the future has yet to come – and we conventionally define the *future* as being in the *later-then direction of time.* This indicates how the physics of reversibility relates to time flow. If there is no physical directional properties of time, then what is there physical to relate to metaphysical time flow? Alternatively, if there is a physical property or process of directionality, then how does that relate to time flow?

References and Footnotes for Chapter 1.

(1) Spivak 1979 [17] is a classical modern treatment of the construction of differentiable manifolds, using tangent vector spaces. This is a very approachable text on advanced geometry, focussed on detailed application to GTR. It precisely defines the semantic interpretation of coordinate systems, tensor calculus, etc, giving a more complete interpretation than the usual introductions to STR or GTR, which present it as an applied tensor calculus, interpreted intuitively.

(ii) Some researchers try to ‘redefine the concept of reversibility’, or discover some new concept of ‘time reversal in QM’ that will let them render problematic laws ‘reversible’, and support their metaphysical preference for ‘the intrinsic symmetry of physical time’. This reflects a fundamental misunderstanding.