



# On what we may infer from artistic and scientific representations of time

## Document Version

Final published version

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## Citation for published version (APA):

Caddick Bourne, E. (2012). On what we may infer from artistic and scientific representations of time. *Writing Visual Culture*, 5, 43-57. <https://www.herts.ac.uk/research/groups-and-units/tvad-theorising-visual-art-and-design/writing-visual-culture>

## Published in:

Writing Visual Culture

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## Writing Visual Culture

ISSN: 2049-7180

### On what we may infer from scientific and artistic representations of time

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#### Abstract

We consider the extent to which artistic and scientific representations can give us knowledge of how things are or could be. Focusing on representations of *time*, we take two case studies: simultaneity and temporal order; time-travel to the past. We analyse relevant scientific representations – from Special Theory of Relativity and General Theory of Relativity – alongside relevant artistic representations – fictions which are non-committal about temporal order, and time-travel stories. In all the cases, we argue, drawing reliable conclusions from the representations requires an understanding of the metaphysics of their subject matter and of the nature of representation itself. If we attempt to work out *what* is represented from the representation *alone*, then, far from acquiring knowledge, we risk obscuring the representation's subject matter.

During the conference at which papers in this volume were given, there was much discussion over how, if at all, scientists and artists could collaborate to provide new knowledge of how the world is. We propose that scientists and artists should work not just alone or with each other, but also with (informed) philosophers. Scientific and artistic representations can be ways of knowing about the world only when supplemented by a philosophical framework in which to interpret them.



Both science and art use a variety of forms of representation. In this paper we focus on scientific and artistic representations of time. Both art and science use *pictorial* representations. Artistic pictorial representation of time might take the form of a photograph or a painting, whereas in the scientific case it can take the form of a diagram, such as a Minkowski space-time diagram used in the special theory of relativity (and explained in more detail below). Both art and science also use *linguistic* representations to represent time. Artistic linguistic representations of time might take the form of sentences of a natural language, such as those found in novels, typically using tensed verbs to express claims about the temporal order of events, for instance. Scientific linguistic representations of time might be expressed in a formal language, such as in the form of mathematical equations. Whilst these are familiar ways of representing time, the moral of this paper will be that drawing valid conclusions about the nature of time from either artistic or scientific representations such as these requires an understanding of the *metaphysics* of time, which cannot be gained from these representations alone, and an understanding of the nature of *representation* itself.

### **How representations can help and hinder our understanding of time**

Representations of time need careful handling. Inferences drawn about time solely on the basis of the representation are liable to lead to false conclusions concerning the nature of time. To illustrate this, we shall consider two major scientific theories of the twentieth century: (1) Special Theory of Relativity (STR) and (2) General Theory of Relativity (GTR). We shall discuss each together with closely analogous artistic representations. We shall use these cases to illustrate philosophically interesting issues surrounding: (1) the representation of temporal order and simultaneity and (2) the representation of possibilities (using time travel as an example).

### **Case-study 1: Simultaneity and Temporal Order**

#### **a) Special Theory of Relativity**

What can we learn about temporal order and simultaneity from considering time's representation in the Special Theory of Relativity (STR)? First, consider the two principles which characterise STR:

- (1) **The Law of the Propagation of Light:** it is a law of nature that light (in a vacuum) is propagated in straight lines with a constant speed  $c$  (approx  $300,000,000\text{ms}^{-1}$ )
- (2) **The Principle of Relativity:** all inertial (i.e. non-accelerating) frames of reference (i.e. co-ordinate systems) are equivalent for the description of all physical



phenomena: the same laws hold in all inertial frames. More crisply: whatever is a law of nature for one person is a law of nature for another.

So, light always travels at  $c$  within each inertial frame of reference, no matter what is the speed of that inertial frame of reference relative to any other inertial frame. In other words, principles (1) and (2) above entail:

- (3) **The Limit Principle:** regardless of the speed of an observer, they can never overtake a ray of light: however near their speed approaches that of light (as judged from another inertial frame of reference), light still travels within their frame at  $c$ .

To see the implications this has for simultaneity and temporal order, we can represent (1), (2) and (3) in a Minkowski Space-Time Diagram (Figure 1).

Since STR says that light travels at a constant speed in all directions, we can represent the path of a light-ray from the origin as a straight line (indicating constant speed) along both the positive and negative  $x$ -axis (which is the only spatial dimension represented).

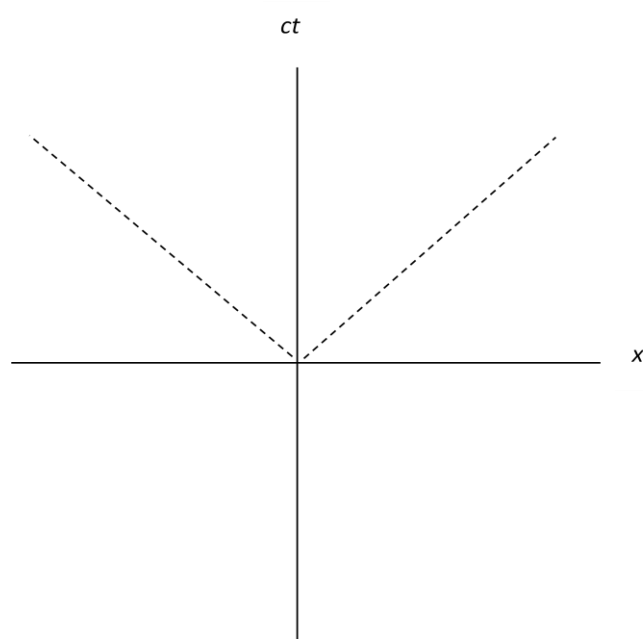


Fig. 1: Light travels at a constant speed in all directions

When we include a second spatial dimension, we can see that light travelling from the origin generates a so-called 'light cone', as in Figure 2.

As noted in the Limit Principle above, no massive object can travel faster than the speed of light. So the possible paths of massive objects (such as  $a$  and  $b$ ) through space-



time must fall within the light cone. So we can view the light cone associated with each space-time point as a theoretical boundary that marks out where objects are able to travel [Fig. 2].

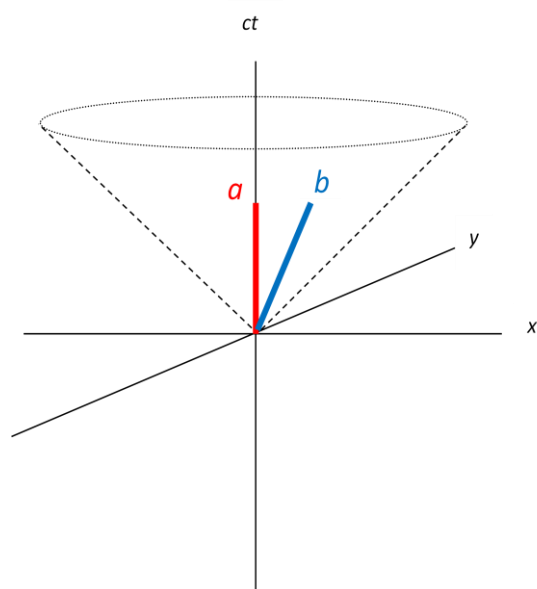


Fig. 2: *a* is taken to be at rest with *b* moving with respect to *a*; all possible trajectories of objects from the origin fall within the light cone.

But for ease, let's focus on two dimensions of the upper right-hand quadrant of this diagram. The horizontal axis represents the plane of simultaneity for *a*, who is at rest. But what about *b*? The interesting thing about STR is that light travels at a constant speed for *both a* and *b*. But how can light travel at the same speed for *a* and *b*, when *b* is *moving* with respect to *a*? It must be that *b*'s measurement of time and space is *different* from *a*'s. We can represent *b*'s coordinate system with respect to *a*'s in [Fig.3].

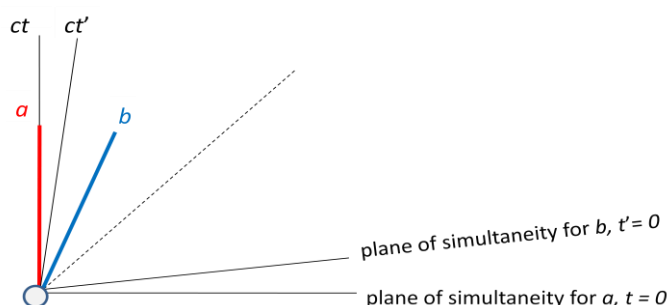




Fig.3: Representation of *b*'s coordinate system with respect to *a*'s

We can see clearly here what it means for simultaneity to be relative to a frame of reference. Consider Figure 4. Events *F* and *G* are some spatial distance from event *E* (at the origin). Now, although our observers *a* and *b* must agree that event *G* follows event *F*, they disagree over which event is simultaneous with *E*. (For *a*, the ambulance arrives *after* the start of the talk. For *b*, the ambulance arrives as the talk *begins*.)

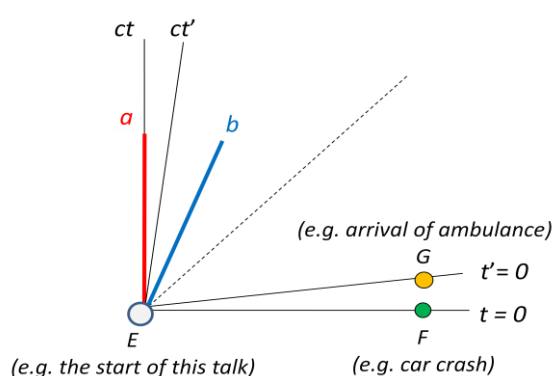


Fig. 4: Relativity of simultaneity

Those are all the facts about simultaneity which STR is prepared to allow. Or so says the orthodox interpretation of STR. But our question is: can we read off from these representational devices *all* there is to know about temporal relations between the events involved? In specifying the temporal relations between spatially separated events, can we say no more than '*E* and *F* are simultaneous in *a*'s frame of reference; *E* and *G* are simultaneous in *b*'s frame of reference, and that's that'? Is there any space for asking whether there is a further fact of the matter that could make *a* absolutely right or *b* absolutely right, or both *a* and *b* absolutely wrong concerning their judgements of simultaneity? Not if we should believe in all and only those things which are required to do the physics of special relativity. For an absolute plane of simultaneity is not required for that. But not all reasons for believing in things have to come from physics. Even physicists must agree to that. Despite the importance that time in particular plays in physics, and the important results that physicists have established about time, time is hardly exclusively in the domain of the physicist. Further, the reason that Einstein gives for thinking that there is no further question to ask about absolute simultaneity is that: 'The definition [of simultaneity] should supply us



with a method by which we can decide by experiment whether given events occurred simultaneously' (Einstein 1920, §VIII)

Clearly, if we are overly concerned with believing in the existence only of those things we can verify to exist, then since no experiment would ever show any physical difference between *a* and *b* (and any other inertial frame we include in Figure 4 – that's what the Principle of Relativity tells us), we would be disinclined to believe that there is any unverifiable further fact about the absolute simultaneity of the events. So our initial question about whether there is scope for believing in further facts about simultaneity not represented in STR depends on whether we think we may believe in facts which go beyond our ability to verify them. But of course we may! It is safe to say that the verificationist methodology is untenable. If we went along with it, we would have difficulty believing that anything *was* the case, *will be* the case, *would be* the case and *could be* the case. How could we believe universal general laws? Or believe that our favourite mug is fragile without smashing it on the floor?

This is not to give us license to believe anything we like. It just frees us from unnecessary and unjustifiable constraints when constructing our theories of how the world works. It certainly leaves open whether those who believe in the objective process of temporal becoming – such as presentists, who think that time passes as certain facts about the world come into existence and others drop out of existence – can use this metaphysical feature of the world to define an absolute plane of simultaneity. This may not be required in order to do physics, but, first, it is not as if it is *incompatible* with the physics. That STR *does not represent* the world as having this extra feature should not be confused with its representing the world as *not having* that feature. And if presentism is a good theory on other grounds, then that is reason enough to postulate facts about simultaneity which go beyond those recognised in STR. (For more detailed discussion, see Bourne 2006.)

### **b) Artistic Representations of Temporal Order**

Compare STR with temporal order in fiction. Suppose we tell a (very short!) story:

'There was a sneeze and a car crash.'

This fiction lacks the resources to tell us anything about whether these events are simultaneous. In this sense, this fiction and STR are analogous: each representation *lacks* content regarding the absolute simultaneity of events.

However, there is a difference between the two which illustrates our point that what inferences can be drawn about time from these representations is intimately bound up with a metaphysical view concerning their subject matter. The difference is this: STR leaves open



whether there is a fact about the absolute simultaneity of spatially separated events even though STR has no means of detecting it; whereas in fiction, there certainly is no space for facts outstripping what has been represented.

What is true in a fiction differs in an important way from what we take to be true in a world like ours. Fictions always leave some things indefinite. This happens when the audience cannot glean information about a certain matter from the telling of the story. Suppose a fiction about a man called Bob never tells us whether Bob is married or not. Then it is not true in the fiction that Bob is married, but nor is it true in the fiction that Bob is not married. We do not conclude, on the basis of this, that Bob is in some odd state in-between being married and not being married. We take it to be true in the fiction that Bob is either married or he is not – the point is just that the fiction does not commit to *which*. Likewise, the story 'There was a sneeze and a car crash' is naturally taken to be about a fictional world in which there is *some* temporal relation between the sneeze and the car crash. Either they are simultaneous, or one is earlier than the other. But there is no fact, it seems, about *which* of these things is the case.

This claim might be disputed by appealing to the order of words in the sentence. To write 'There was a sneeze and a car crash' suggests that the sneeze came first; to write 'There was a car crash and a sneeze' would suggest that the car crash came first. Here it is useful to distinguish between what a sentence *means* (or *says*) and what it *implicates* (Grice 1975). 'There was a sneeze and a car crash' has the same *meaning* as 'There was a car crash and a sneeze'. Both sentences say just that the two events happened, and nothing more. Nevertheless, the two sentences have different *implicatures*. 'There was a sneeze and a car crash' would still be *true* if the car crash came first, but we might accuse the speaker of talking in a misleading way. Because we expect the order in which somebody reports events to reflect the order in which the events happened, we assume that the sneeze came first.

'There was a sneeze and a car crash' may have another implicature: namely, that the sneeze caused the car crash. The meaning of the sentence is just that both the events happened, so it would not be *false* if the car crash were caused in some other way. But we assume that the speaker is mentioning them both together because the sneeze is relevant to the car crash, and an obvious way for it to be relevant is if it caused the crash.

It is not entirely obvious that the sentence does have these implicatures. It depends on whether the fact that the sneeze came first and caused the car crash would be a competitive explanation, given the surrounding circumstances, for why the fiction-maker chose to write that sentence. But let's suppose it is. Then the short story 'There was a sneeze and a car crash' conveys considerably more than it first appears to. If we take the





implicatures, not just the meaning, to play a role in establishing what is true in the story, then the story describes a fictional world in which a sneeze happened before a car crash and was the cause of the car crash. So there is a fact about the temporal order of the events, after all.

But, even if this holds for this case, it does not hold for all cases. Often a story neither says *nor* implicates what order the fictional events happen in. We often assume that the things done by different characters in successive scenes of a film or television programme take place at *roughly* the same time, but we don't take there to be any way of establishing whether (e.g.) one character's coughing in one scene happened before, after or simultaneously with another character's putting down a mug in the next scene.

It is important to reiterate that we should not conclude that fictions are about worlds in which some events are *neither* earlier than, nor later than, nor simultaneous with some other events. For this would mean the events did not take place in the same time-series at all. What we should conclude is that the fictional events take place within the same fictional time-series, but that there are sometimes no fictional truths about their precise locations, relative to each other, within that time-series.

In the case of STR, we argued that whether there is a fact about which spatially separated events are absolutely simultaneous depends on which is the right account of the nature of time. In the case of fictional stories, whether there is a fact about which fictional events are simultaneous also depends in part on which is the right account of the nature of fiction. The way we engage with fiction does not create any pressure to think that there are fictional facts about temporal relations in cases where the representation exhibits indefiniteness. To understand that two fictional events, A and B, happen within the same time-series, we only need to understand that either they are simultaneous, or A is earlier than B, or B is earlier than A. We need not think of them as standing in a *particular* relation in order to completely understand the story; and, often, wondering about which comes first would be an unhelpful distraction.

Thus, our *engagement* with fiction does not give us a reason to believe in additional fictional facts lying behind cases of indefiniteness. In the case of STR, though, it was a philosophical account of the nature of time which would give us reason to believe in extra facts. Does a philosophical account of fiction provide a similar motivation?

We think not. Indeed, we suggest that believing in such extra facts would obscure the nature of fiction. Cases of indefiniteness are cases where what the representation tells us – what information we get from the words and images the fiction-maker has used – does not fix the details of what happens – whether event A happens before, after or simultaneously with event B, for example. And there are no further facts which fix these details.



Closer comparison with the case of STR brings out this point. The representations of relative simultaneity produced within the resources of STR are taken to be representations of *our* world, as it actually is. The judgements of simultaneity which they capture differ from one another. But this does not mean that the representation gives an incoherent or impossible picture of what the world is like. For the reason the judgements of simultaneity differ is that they adopt different perspectives, according to the different speeds of the observer. Thus, they generate different representations of the same world. Whether there is a perspective-independent fact about absolute simultaneity, over and above what can be captured by these representations – and, if so, which events are absolutely simultaneous – depends on what the facts of our world are.

Fictions are not to be taken as representations of *our* world as it actually is. So if there is an extra fact lying beyond the scope of the representation in a case of indefiniteness, this fact is not to be understood as a part of our world. Rather, it is part of a fictional world; whichever fictional world the fiction represents. But how do we establish which fictional world a particular fiction represents? The only way to do this is to look at what information the representation gives us, and take the fictional world to be the one which fits the description given by the representation. But the fiction which leaves the temporal relation between A and B indefinite does not give us any resources for choosing between a world where A is earlier than B, a world where A is later, and a world where they are simultaneous. So the assumption that a specific temporal relation is built into the content of the fiction is untrue to how the content of fictions is determined.

The limitations of the representation in STR and in cases of indefiniteness in fiction looked similar, at least on the surface. We have shown that the conclusions which should be drawn concerning *what* is represented require quite different considerations in the two cases.

In short:

Fiction case: *indefinite* over simultaneity question – no further facts

STR case: *inconclusive* over simultaneity question – may well be further facts.

The point: consideration of artistic or scientific representations *alone* cannot tell us everything about the nature of reality – the inferences we can draw from a representation are bound up with a proper understanding of the metaphysics of its subject matter.

## **Case-study 2: Time Travel to the Past: Science Fiction and Science Fact as Explorations of What is Possible**



### a) General Theory of Relativity

The equations which form the basis of the general theory of relativity (GTR) have solutions which generate a representation of a world in which time-travel to the past is possible. How?

The significance of GTR is that the path that anything takes through space-time is influenced by how the space-time is shaped. Gravitational effects are explained by a distortion of the geometry of space-time; and a distorted space-time will in turn affect the paths of light-rays. The light-cones themselves could tip over in its presence. Because of the relationship between rotation and gravitation, this is what happens in one (in)famous model of GTR discovered by Kurt Gödel (Gödel 1949). According to Gödel's model, light-cones tip in the direction of rotation, as in Figure 5.

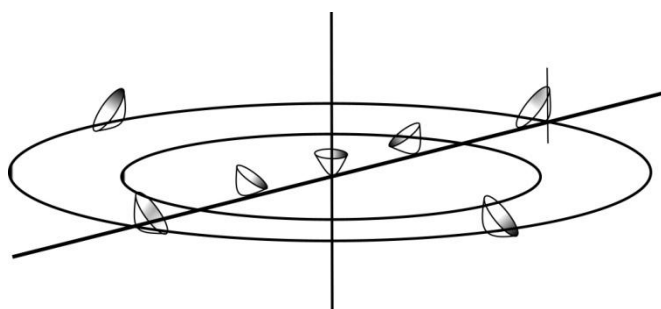


Fig. 5: Gödel's rotating universe

This figure is drawn such that we only see the future light-cones of various arbitrary points in the horizontal plane. Matter in this universe is rotating anticlockwise about the vertical axis; so as we move radially outwards, the future light-cones gradually start to tip in the direction of rotation. Note that the cones also get wider; so the vertical axis and trajectories remain time-like, as can be seen by the vertical world-line in the light-cone in the top right hand corner.

There comes a point on this journey outwards at which the cones open up such that *locally* an observer can travel into his future (i.e., along a path *within* the future light-cone, i.e., *without travelling faster than the speed of light*) but *globally* be travelling into his past. *Every* point can be reached from *any* point in this model. To see this, take the point at the origin of the axes. We can spiral upwards and outwards until we reach the critical point where the cones tip. We may then make our descent around this critical radius, such that we end up below the horizontal plane from where we began, gradually spiralling inwards and upwards to our starting point at the origin.



Thus, certain models of GTR seem to represent the possibility of time travel. But establishing its genuine physical possibility requires more than it being a feature of a solution to the equations of GTR. The logical and metaphysical possibility of time travel is what needs to be established first. But this is not peculiar to scientific representations; the very same considerations apply to artistic representations.

### **b) Artistic Representations of Time Travel**

Many stories appear to represent time-travel. Some of them seem perfectly coherent. Others seem to involve an impossibility, such as *Back to the Future* (1985, dir. R.Zemeckis), in which the hero appears to change the past. This raises two interesting questions about fictional representations which purport to represent time-travel.

- (1) Do the apparently coherent representations show that time-travel is possible?
- (2) Do the stories which seem to involve an impossibility represent something impossible?

The questions are related. Some take artistic (and scientific) representations to be explorations of what is possible, which suggests a positive answer to the first question. But if even impossibilities can be represented, then we cannot reliably draw conclusions about what is possible from the contents of representations.

Let's address the first question. Some time-travel stories seem to involve a contradiction (something of the form 'P and not P') – *Back to the Future*, for example, appears to suggest that certain things both do and do not happen at the same time in a single past. Not all time-travel stories are like this. A time-travel story which does not purport to involve changing the past need generate no contradiction. Nevertheless, we should not take the mere *logical* coherence of such stories as proof that time-travel is possible. There may well be *metaphysical* reasons to rule out the possibility of time-travel. And this goes for scientific models too. For example, time-travel to the past involves backwards causation. Earlier events (such as somebody's getting out of a time-machine in 1900) are caused by later events (such as somebody's getting into a time-machine in 2000). A metaphysical theory of time may give us reasons to deny that the past can be causally dependent on the future. (See for example, Mellor 1998, 132-5)

The point we wish to make is that whether or not we agree with the metaphysical theories in question, consideration of them goes beyond mere consideration of apparent *representations* of time-travel, such as the stories in question. We must take such representations in conjunction with an understanding of the nature of time in order to work out whether something possible is being represented. Thus, we clearly cannot draw conclusions about what is possible from the representation alone.



Let's move on to the second question. Do those time-travel stories which apparently involve contradictions represent something impossible? We propose that stories which seem to involve impossibility are best interpreted not as representations of impossible things, but as representations of perfectly *possible* things structured in a way which creates the *illusion* that an *impossible* world is being represented.

To introduce this account, consider a case of seeming impossibility which is not to do with time: M.C. Escher's *Waterfall* (1961, lithograph). Various parts of this picture, taken on their own, represent perfectly possible things: instances of water flowing downhill. Taken as a whole, however, the picture does not add up: the cases of water flowing downhill are made to look as if they combine into a closed loop. If we 'follow' each piece of the waterfall we arrive back at the start, with yet another representation of water going downhill.

This makes it *look* as if we have a representation of a loop in which water is constantly travelling downhill but ends up meeting its source. But this, we claim, is a false impression created by our ability to engage with the individual parts of the representation. To understand the nature of the picture is not, we propose, to recognise that an *impossible* waterfall *has* been represented. Once we grasp that no *possible* waterfall could be represented by the picture, we have already grasped what is significant about it.

The parts of *Waterfall* each represent something possible. But, we propose, the representation in its entirety does not represent a single, impossible waterfall. Rather, the way the representational parts are placed creates the *illusion* that an impossible whole is being represented. We shall apply this strategy to those representations which seem to be impossible time-travel stories involving changing the past.

Such stories represent distinct events which, despite apparently being supposed to happen at the same time, could not happen at the same time. Two series of past events, incompatible with each other, are represented. The question is: do those two incompatible series of events take place in the very *same* past? If so, then the fiction represents something impossible.

We propose that a better interpretation is to treat the two different sequences of events as taking place in two different fictional worlds. A story like *Back to the Future* involves *two* representations of two distinct worlds, each with a perfectly possible history. At some points in the film we are given a representation of one world, and at other points we are given a representation of the other world. When the film shifts from representing one to representing the other, there is a change on the level of the *representation* – a change from representing one world to representing a different world. But this change in the representation is disguised as a *representation of change within the world represented*. We



are given the (false) impression that what changes is the past of a single world, whereas really what changes is *which* world is being represented.

This illusion is created by certain similarities between what happens in the two worlds. The people in one world are similar to the people in the other. Many of the events which take place in each world are of the same kind as some of the events which take place in the other world. In addition, by representing the two worlds alongside each other, the story allows us to draw conclusions about one world based on the other. We are invited to think that there is some relation between the worlds – for example, that events in the second world are the ones which *would* have happened in the first world had somebody acted differently in a certain way.

The illusion that a single past is changed is reinforced because the similarities between people in the two worlds make them look as if they are stages of the *same* person in the *same* world. *Back to the Future*, on our account, represents two worlds. Thus its hero, Marty, is really not one person but two: Marty<sub>1</sub>, who is located in one of the worlds, and Marty<sub>2</sub>, who is located in the other. Marty<sub>1</sub> and Marty<sub>2</sub> are similar in their physical appearance and their personalities, just as a single person is often physically and psychologically similar at different stages of their life.

There is something which it is natural to think that our view overlooks. Marty appears to have memories from the 'old' version of events after he has 'changed' his world into one containing a 'new' series of events. For example, he is surprised to find that his 'new' family are considerably wealthier and happier than the 'old' version, thanks to the positive differences he has made to their pasts. On our account, this does not make sense. Marty<sub>2</sub> cannot have memories of something that happens to Marty<sub>1</sub>, a different person in another world!

But note that even on the rival interpretation, in which the past of a single world is changed, it makes no sense for Marty to remember how things were in the 'original' version. If the past has been changed, then it was never the case that Marty's family ended up poor, so he couldn't have memories of it. So our account is at no disadvantage, since the rival is no help in understanding Marty's mental states.

Furthermore, we propose that a clear account of the situation can be given in our terms. We say that Marty<sub>2</sub> has *quasi-memories* which match Marty<sub>1</sub>'s experiences. These quasi-memories are like the memories Marty<sub>2</sub> would have were he genuinely continuous with Marty<sub>1</sub>, but they're not causally connected with Marty<sub>1</sub>'s experiences in the way genuine memories would need to be. (They can't be, since Marty<sub>1</sub> and Marty<sub>2</sub> don't live in the same world.) Because the lack of causal connection is the only thing which distinguishes Marty<sub>2</sub>'s



quasi-memories from genuine memories, it is easy to think that Marty<sub>2</sub> really is the same person as Marty<sub>1</sub>, and the illusion that a *single* world has been represented is further strengthened.

We do not deny that when watching this film it *seems* as if impossible things happen in the story. Rather, our claim has been that we can explain how the impression of impossibility arises by saying that more than one possible world is represented. The way the film moves from the representation of one world to the representation of another creates the (false) impression that we're dealing with something which is familiar from standard narratives, and which we are practised in understanding – the unfolding of a single series of events within a single fictional world with single continuous characters. But there are certain elements of the film which it is impossible to reconcile with this assumption. Whilst the structure of the film creates the impression of a single world, the events it represents are ones which we recognise *cannot* be happening within a single world. That is what makes films like *Back to the Future* intriguing. The way the various representations of different worlds are put together makes us engage with the fictional events *as if* they form a coherent series, while at the same time we realise that this impression must be wrong.

We have suggested that fictional stories which appear to represent impossibilities are better understood as representing possibilities. An alternative account would be that *Back to the Future* really does represent a world where certain contradictions are true, because Marty changes the past. We think there are good reasons for believing that what can be represented by fiction is limited to what is possible. One is the neat analyses which this approach allows us to give. It enables us to make good sense of the representations in question while also providing an explanation of how they create the impression of impossibility. But there are some additional reasons. If fictions cannot represent the impossible, we have a good explanation of exactly what is striking about those stories which create the (false) impression of doing just that. If, on the other hand, we maintained that fictions *can* represent the impossible, it is unclear why confronting an apparent impossibility in fiction would be any more striking than confronting a possibility in fact.

Taking *Back to the Future* to represent a world where certain contradictions are true raises another question, too: what *else* would be true in this impossible fictional world? According to classical logic, anything follows from a contradiction. So it would be true in *Back to the Future* not only that Marty is human, but also that Marty is a pig, for example.

We do not claim that this is a conclusive argument for rejecting the view that fictions can represent impossibilities. The point is just that such a view should not be taken for



granted. For example, it may require the development of an alternative, non-classical logic (e.g. Priest 1997; 2005).

Our view has the nice feature of bypassing any motivation for thinking an impossibility has been represented. The fundamental point we wish to make, however, is that the appearance of impossibility generated by the representation is not sufficient to establish whether or not something impossible has been represented. Detailed technical discussion, requiring expertise in logic and metaphysics, is required in order to come anywhere close to resolving this issue.

### **The Moral**

The moral to draw here is that interpreting stories which appear to represent time-travel requires a fairly complex philosophical framework. As in the case of GTR, the representations themselves do not settle questions about time-travel and the nature of time, but rather need to be supplemented by careful philosophical analysis.

We have shown that what conclusions we should draw from representations depends, in part, on a philosophical understanding of their subject matter and of the nature of representation itself. Our argument has focused on a particular case: the representation of *time* by art and science. But it illustrates a more general conclusion.

During the conference at which the papers in this volume were given, there was much discussion over how, if at all, scientists and artists could collaborate to provide new knowledge about how the world is. Some claimed, for example, that only scientific representations deliver genuine knowledge; others that there are some truths about the world which can be identified using artistic media, so must be known through artistic rather than scientific representations.

At the level of the representations themselves, an artist may well learn a lot from a scientist, or vice versa. The structure of a scientific representation might inspire or be inspired by the structure of an artistic representation. Further, identifying what is it that an artist *aims* to represent may influence what a scientist *aims* to represent, or vice versa. A scientific representation which is *supposed* to represent that simultaneity is not absolute may influence an artist to *attempt* to represent the same thing. The question is whether the representations succeed in representing what they attempt, or are supposed, to represent; in other words, how we are to establish *what* is represented by a scientific or artistic representation.





If our argument is correct, then neither artistic representations, nor scientific representations, nor collaborations involving both types of representation, are the end of the story. We should hesitate before claiming to know something (for example, that relations of simultaneity are not absolute, or that time-travel is possible) on the basis of a representation alone, be it scientific or artistic. For these representations require a philosophical framework in order to be interpreted. If we take them at face value, and attempt to read off *what* is represented from the representation alone, then, far from acquiring knowledge, we may end up obscuring our subject matter. In order to have a full understanding of what their representations are *of*, scientists and artists should work not just alone or with each other, but also with (informed) philosophers.

### **Acknowledgements**

Emily Caddick gratefully acknowledges the support of the Arts and Humanities Research Council.

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