A spatio-temporal model of activity and state

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1 Abstract

This paper presents informally a spatio-temporal account of activities and states. The principles of the spatio-temporal paradigm are presented, together with their consequences in terms of enabling a strong foundation based on mereology and non-well-founded set theory and how change can be accounted for. Space-time maps for various sorts of individual are presented, including activity, and key concepts around activity.

2 Background

Shell[*] has had an interest in improving data management for a period of more than 15 years, with a focus on integrating data from different parts of the business as a component of increasing business integration in a company that has traditionally been highly devolved. Early investigations looked at:

- why different Group companies in the same business had developed different data models and systems in the same area,
- why attempts to share these systems failed, and
- how to improve data models so that sharing became easier.[1]

This also lead to the development of principles for developing data models, together with a Generic Entity Framework that for Shell represented an initial attempt at what might now be described as an upper ontology.[2,3,4] A key element of this work was achieving a consistent approach to activity and change.

This work lead to the development of a system called Kalido[5] which has played a major part in integrating quantitative business performance data for Shell's downstream (refining and marketing) business, and has since been established as a separate company that develops and markets the software both inside and outside Shell.

If integration is a significant issue with significant benefits within Shell, then integrating with business partners is even more challenging. One area of particular importance to Shell is the handover of the design data for major assets like offshore platforms from the engineering contractors who design and build these facilities to ourselves as operators and maintainers. To support this requirement we have become involved in industry consortia such as PISTEP[6], USPI-NL[7], and EPISTLE[8] to develop ISO standards within ISO TC184/SC4 – Industrial Data[9].

This stream of work took the Shell Generic Entity Framework as its start point, from a number of alternatives, and further developed it as the EPISTLE Core Model and ISO15926-2. The EPISTLE Core Model is now at Version 4.2, and ISO15926-2 is being prepared for its Final Draft International Standard ballot.

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[*] "Shell", or the "Group", refer to the companies that are owned jointly by the Royal Dutch Petroleum and Shell Transport and Trading Companies.

A key requirement for developing the data model has been to minimise the number of ways that the same facts could be expressed. This drives development towards a strong paradigm with minimum ambiguity of expression. The result of this has been a move from a paradigm of temporally indexed objects and relationships with a set theory that allowed membership to change over time, to a paradigm based on spatio-temporal extents, where the time element of relationships is captured by making them between the relevant temporal parts of the individuals concerned. This in turn allows a set theory of unchanging set membership to be applied, and also a classical mereology, which is both strong and simple. A possible worlds approach is preferred to modal logic.

The remainder of this paper explains how this paradigm works in more detail.

3 Individuals as spatio-temporal extents

In this paper individual means an object that exists in the space-time continuum, whilst universal will be used to apply to objects, like sets, that exist outside the space-time continuum. There are a number of ways that individuals can be defined. A spatio-temporal definition says that an individual is a chunk of the space-time continuum that may be extended in both space and time. Further, any two individuals are the same if all the parts of each are also parts of the other, i.e. the identity basis is extensional in space-time. This is a one-size-fits-all definition that covers both activities and physical objects that in some approaches have a different identity basis.

A convenient tool for representing individuals and the patterns they form in space-time, is the space-time map. For representation in two dimensions, the three spatial dimensions are collapsed into the vertical dimension, and time is represented on the horizontal dimension. An example is given below in Figure 1.

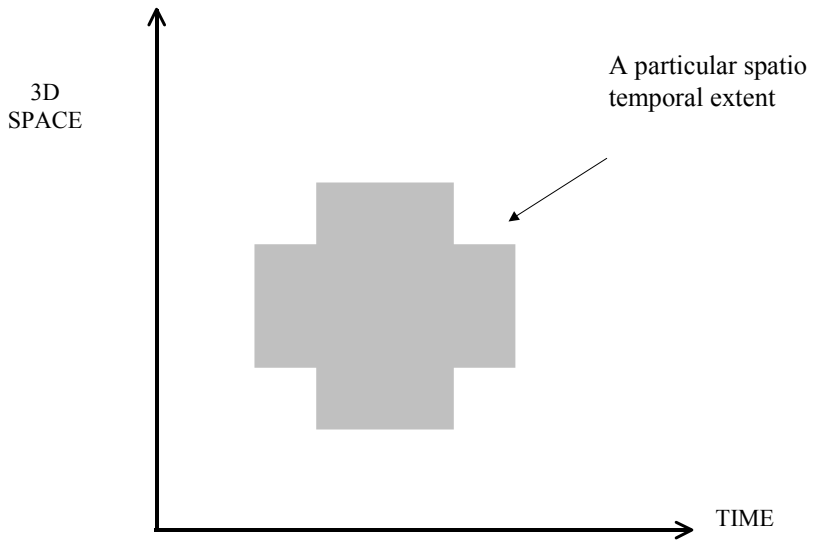

Figure 1: An example of a space-time map

Different types of individual, with different identity criteria can be illustrated and analysed using this type of diagram. For example, for "ordinary" physical objects we normally allow that the object continues its existence if some parts change, but not if all parts change.

A physical object may have temporal parts. We call these states, and are illustrated in Figure 2 below.

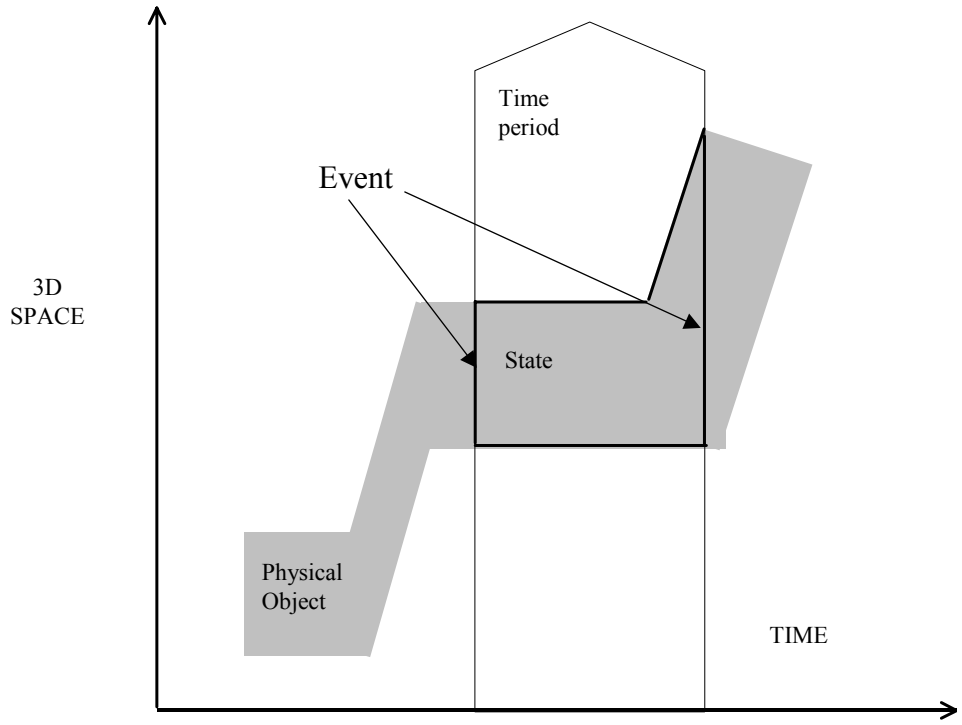

Figure 2: State

Some properties or relationships may be true for a state that are not true for the whole life of the physical object. For example, my car may originally have been red, but now it is blue. In this case there is a state of the car that is red, and a state of the car that is blue. This is illustrated in Figure 3 below.

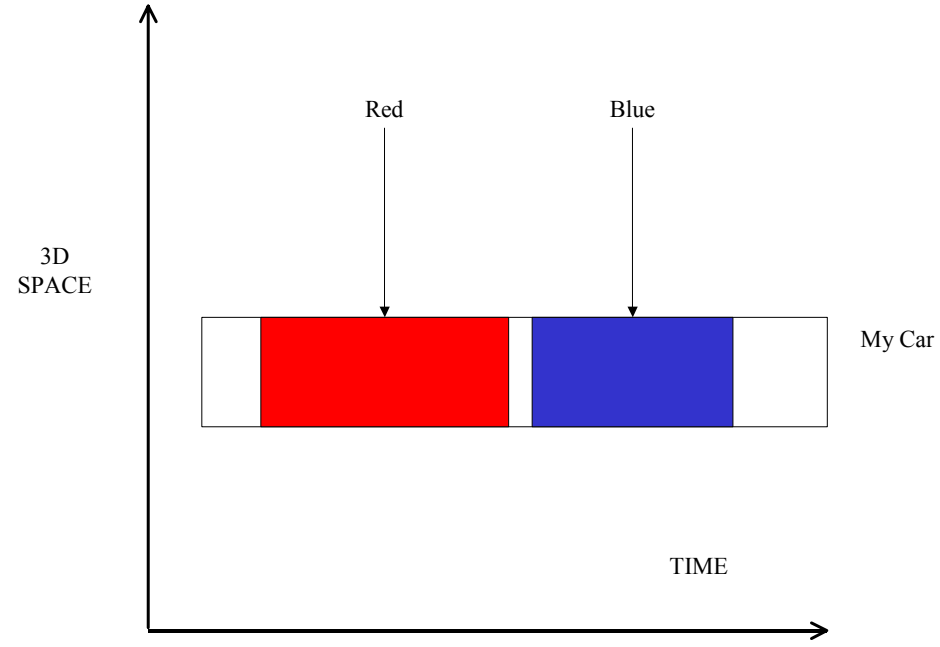

Figure 3: The colour of different states of my car

The temporal boundaries of states we call events. This is quite a restricted use of the term. It reflects a state coming into or going out of existence. It is not necessarily a transition from one state to another.

This approach supports a classical mereology extended into four dimensions, which is a considerable simplification over more traditional approaches as Simons describes[10].

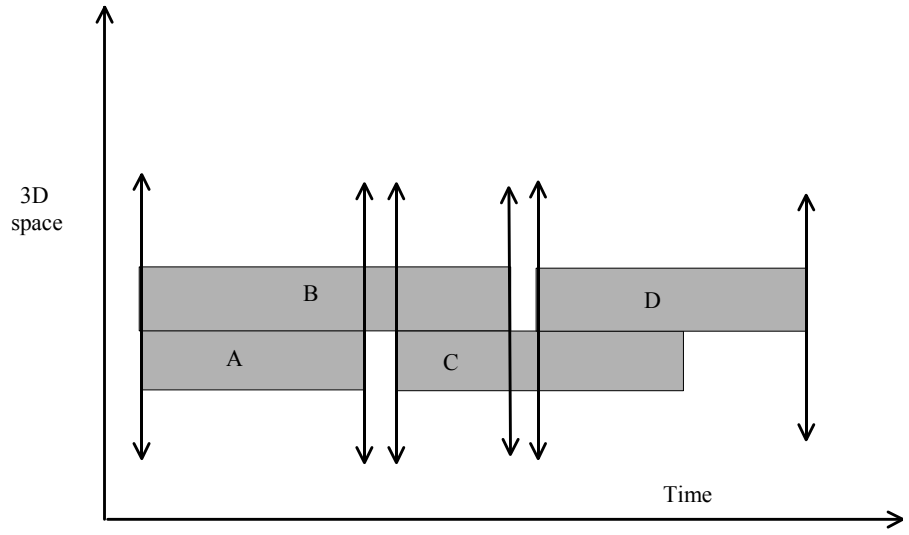

Figure 4: A space-time map for an "ordinary" physical object

Figure 4 illustrates this for a simple example like a broom that has a head and a handle. At some point in time the old head is replaced, and at another time the old handle is replaced, but the identity of the broom is allowed to persist through these changes.

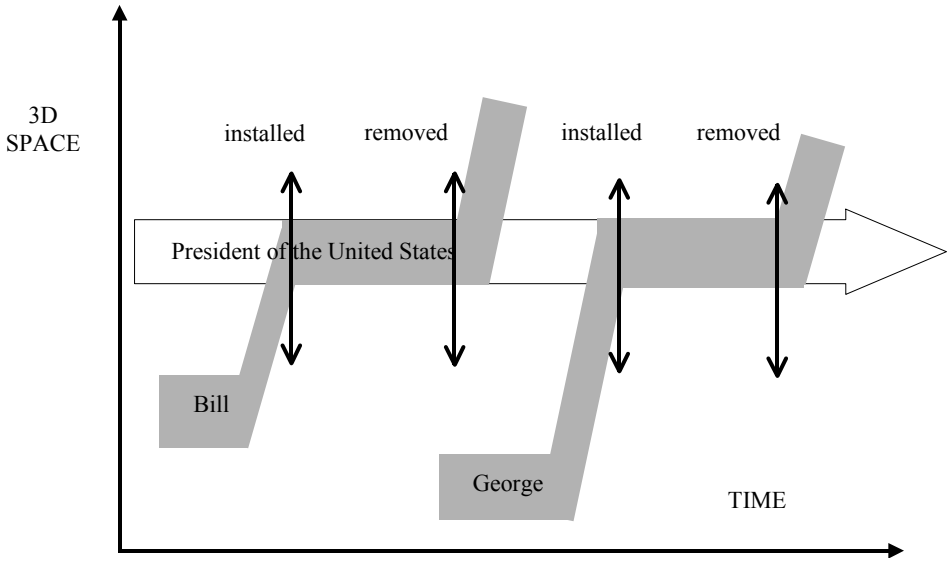

Figure 5: Space-time map for President of the United States

Not all physical objects take this form. Take for example the President of the United States. This is an object that exists in space-time, but it does not observe the identity criteria for "ordinary" physical objects, because from time to time all the parts change. This is illustrated in Figure 5 above. Because of this, some paradigms do not recognise this sort of object as a physical object at

all, but you can quite definitely talk to the President of the United States, and you can see the extent of this object in space-time. The interesting thing about this pattern is that some temporal parts of the President are also temporal parts of other objects, in this example Bill and George.

A key issue in ontology is how to deal with what could be, as well as what is. We adopt an approach based on possible worlds. This allows a number of things, including allowing worlds where the basic laws of physics might be different, and allowing alternative views of history or the future to be explored.

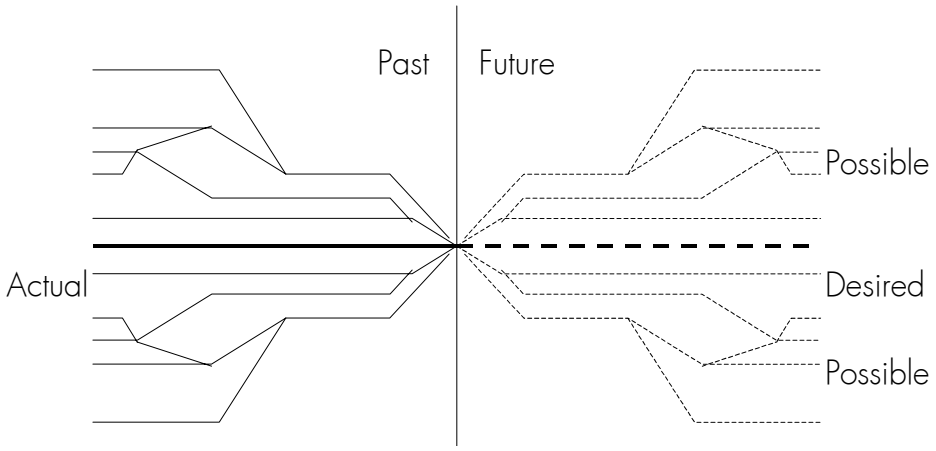

Figure 6: Possible worlds

Figure 6 illustrates how this can work. With a spatio-temporal approach to individuals, possible worlds can be allowed to intersect, with temporal parts of individuals being shared across possible worlds, since the possible world would be defined by its whole spatio-temporal extent, and only this would have to be unique.

4 Classes, physical properties, and set theory

One of the difficulties with some traditional approaches to ontology is managing change. If my car is red at one time and blue at another, not only has my car changed, but so also has the membership of the classes blue and red. This needs to be taken into account in the way that class membership works, and in particular means that classes are not sets, since the membership can change.

On the other hand, if a spatio-temporal paradigm is adopted, then we talk in terms of states. The state of my car that is red is always red, and the state of my car that is blue is always blue (even when looking into the future) and as a consequence classes become sets with unchanging membership. Similarly, physical properties, e.g. the particular degree of hotness that maps to the number 20.0 on the Celsius scale, are also sets, and some states of individuals will be unchanging members of that set.

Having concluded that sets can play a central role, the question arises as to which set theory to adopt. Classical set theories, such as Zermelo-Fraenkel set theory, allow a set to be defined by any predicate. They are also well-founded. This means that sets cannot be members of themselves, see Figure 7. This was a constraint that was introduced into set theory as a result of Russell's Paradox, which defined as a predicate the set of all sets that were not members of themselves, a set that cannot be constructed, and hence causes a contradiction. This requires some objects that are not sets to be defined, or else some severe restrictions on what can be said.

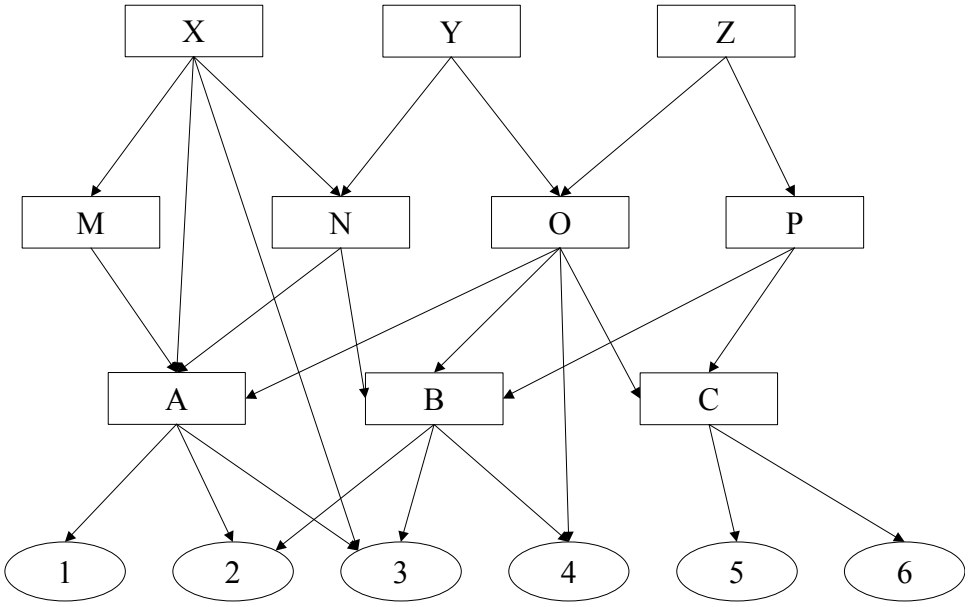

Figure 7: Well-founded sets

Another approach that can be taken, is rather not to insist that there is necessarily a set for the evaluation of every predicate, but only in requiring that sets can be constructed. These are non-well-founded sets[11]. See Figure 8.

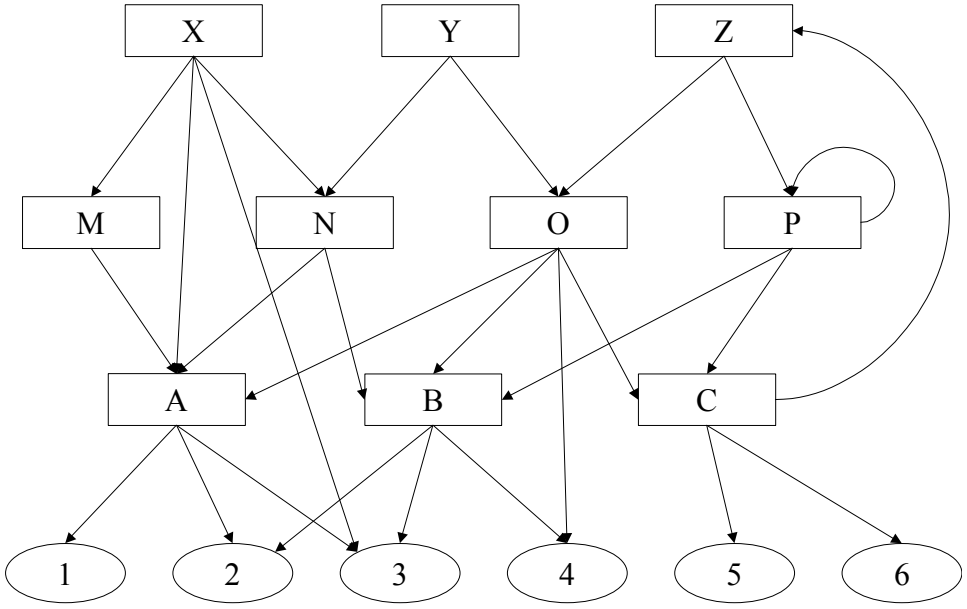

Figure 8: Non-well-founded sets

An advantage of non-well-founded sets is that other membership based universals are not required.

5 Roles

Like almost all words, role takes on several meanings. In this context I mean by role, the role indicated by the position an object occupies in a relation, or the way it participates in an activity, and not, for example, the position held in an organisation.

In the spatio-temporal paradigm roles have a significance that is sometimes lost in other approaches. So you might find a relation expressed in the following terms:

Part-of (X, Y)

This would be intended to be read as "*X is a part of Y*". The name of the relation is expressed in terms of the role that one part plays with respect to the other in the relation, and there is an implicit linguistic convention that indicates that the element in the first position is the part in the relation and the element in the second position is the whole. Some go as far as indicating the domain that X and Y must come from, but the domain is still not the role. The difference is that the domain is the set of objects that could take up the position in the relation, the role is the set of things that do take up that position in the relation.

With the spatio-temporal paradigm, the significance of roles becomes clearer. The reason for this is that relations that involve individuals will be between those temporal parts of individuals for which the relation holds. So if we look at the married relation, rather than:

Married (John, Jane)

We would have:

Married (JohnA, JaneA)

This is illustrated in Figure 9 below.

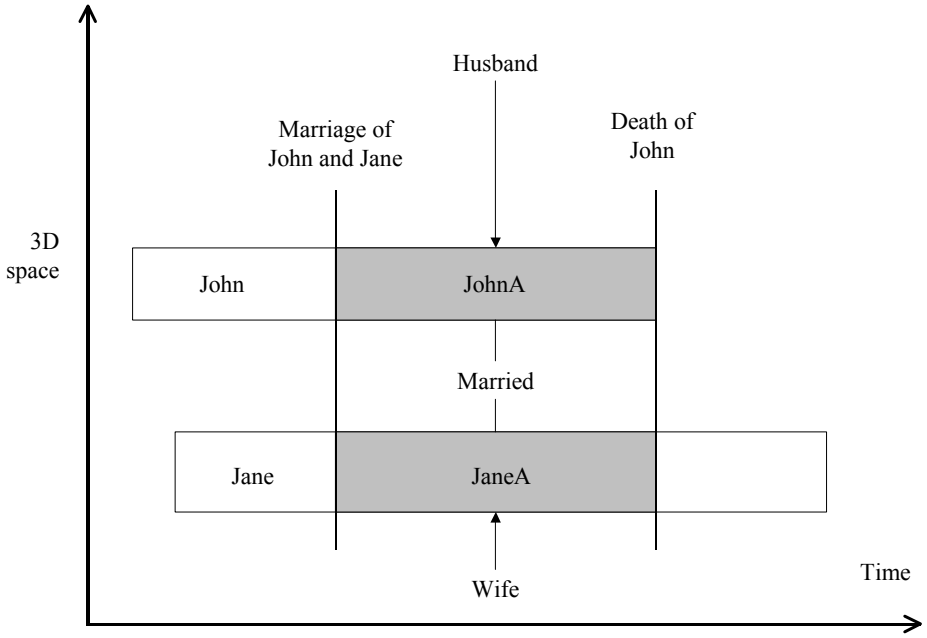

Figure 9: Spatio-temporal illustration of the married relation

6 Activity

We now have all the foundations we need to start talking about activity. The first thing is to establish what we mean by an activity. I take an activity to be something that brings about change. So in terms of the concepts we have discussed above, it causes an event that is the beginning or the end of a state, where a state is a spatio-temporal extent for which something does not change. These are not mutually exclusive. For example, a person is both a state – they are a person and alive – but they are also a living process, an activity, and changes are taking place in their body all the time. In fact this duality is quite normal, and it is mostly a matter of timescale whether change is taking place or not.

This still leaves open exactly what spatio-temporal extent an activity covers. Some options that could be considered include:

- The temporal parts of those individuals participating in the activity (i.e. present rather than referenced).
- The events caused by the activity.
- Both of the above.

Whilst all of these are valid spatio-temporal objects, we have chosen to use the first as our definition. So for example, a meeting activity consists of the temporal parts of those taking part in the meeting, whilst they are present in the meeting, and the room where the meeting is taking place, for the meeting duration (assuming it is a face-to-face meeting). This is illustrated in Figure 10 below.

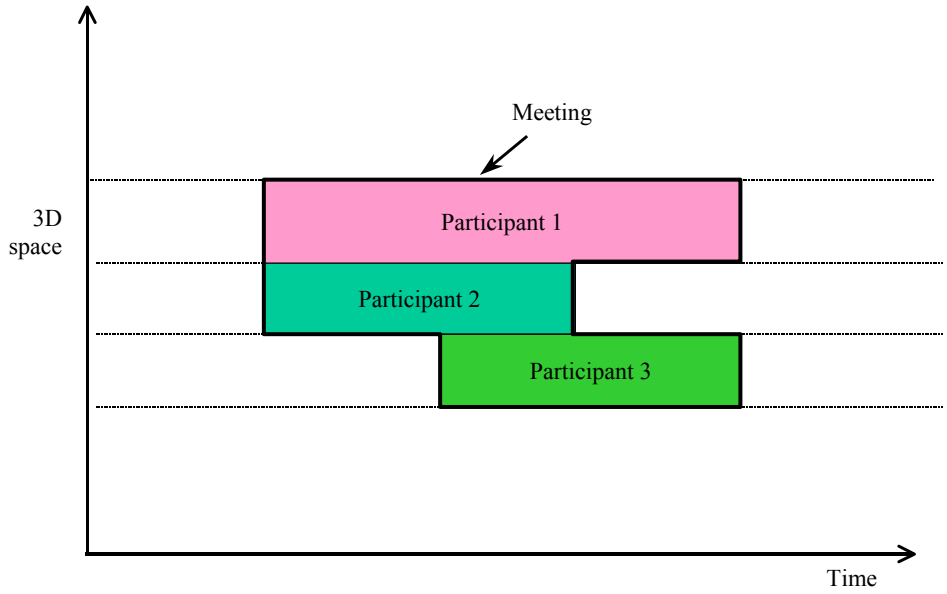

Figure 10: The spatio-temporal extent for a meeting activity

One common issue is the difference between a relation between two states, and an activity. Take the married relation illustrated in Figure 9 above. One could argue that being married is an activity, and it is true that there is an activity that might be described as operating a marriage. However, this is not the same as the married relation, which is about an unchanging property of the related states, and not what goes on within the marriage.

A fragment of data model covering activity from the EPISTLE Core Model is given below using the EXPRESS-G notation (ISO10303-11) in Figure 11 below.

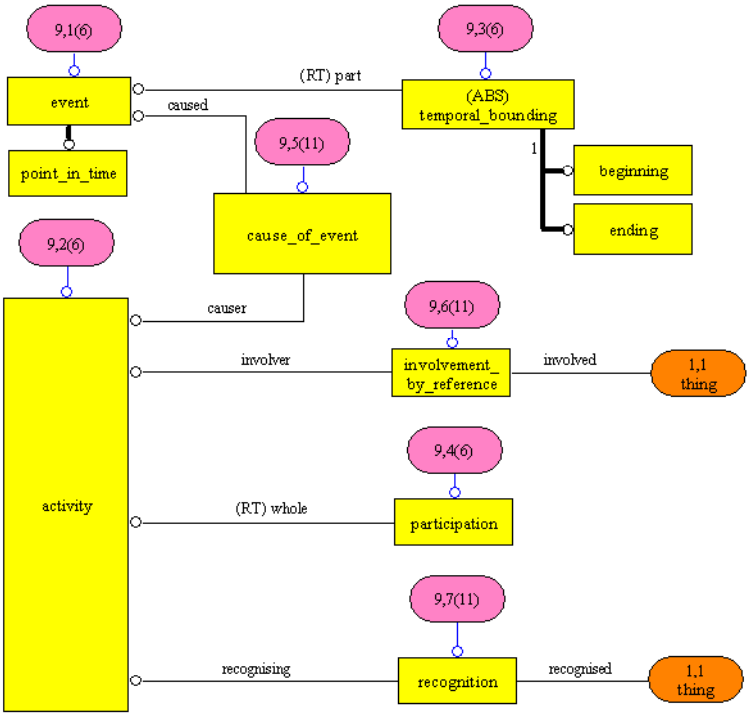

Figure 11: A fragment of the EPISTLE Core Model covering activity

Notes:

- The yellow boxes are the entity types that are the focus of this diagram.
- The brown ovals are references to entity types that are the focus of another diagram.
- The magenta ovals are references to other diagrams where these entity types occur, in all cases here identifying the supertype for the entity type.
- The thick black line shows a subtype/supertype relationship. The subtype is at the end with the lollipop. The "1" indicates that an instance of the supertype can only be a member of one of its subtypes. The "ABS" indicates that an instance must be an instance of one of its subtypes.
- The thin lines show relationship types. The instances of entity types at the sharp end of the relationship type are related to an instance of the entity type at the lollipop end of the relationship type in the role defined by the name of the relationship type.
- Participation inherits a "part" relationship type from its supertype (ultimately composition) on another diagram.
- Temporal_bounding inherits a "whole" relationship type from its supertype (ultimately composition) on another diagram.

7 Conclusions

This informal paper has shown how activity and change can be represented in a spatio-temporal paradigm. The principles of the spatio-temporal paradigm have been presented, together with their consequences in terms of enabling a strong foundation based on mereology and non-well-founded set theory and how change can be accounted for. Space-time maps for various sorts of individual have been presented, including activity, and key concepts around activity.

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[2] West, M.R. *Developing High Quality Data Models: Principles and Techniques* 1994, Shell International, IC94-033

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[6] http://www.pistep.org.uk/

[7] http://www.uspi.nl/

[8] http://www.epistle.ws/

[9] http://www.tc184-sc4.org/

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[11] Aczel, P. *Non-well-founded sets* CSLI Publications, 1988, ISBN 0-937973-22-9