managing multiple spaces

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setting the scene

This paper is about our experiences of space in the Equator project, in particular, the way in which multiple spaces, both virtual and physical, can co-exist. This is driven partly by practical experience, and partly by previous theoretical work such as the models and taxonomies of spatial context in [2], the models for mixed reality boundaries [5] and capturing human spatial understanding exposed in sources such maps, myths and mathematics [3]. We are also building on established work on informal reasoning about space from the AI and GIS communities [4, 6] similar to Allen's well known temporal relations [1].

spaces we have known

Within Equator are a number of 'experience projects'. These are sub-projects focused around the creation of a particular event or outcome, which allow the integration of practical and theoretical work of many kinds. The focus of Equator as a whole is the confluence of physical and digital life and so unsurprisingly the nature of space has been important in many of these projects. We will mention a few here.

The City project allows participants who may be present in person, through VR or through a simple web interface to all 'share' a visit to the Mackintosh Room at the Lighthouse in Glasgow. As well as the physical space of the museum there is a digital reproduction of it for the VR users and a map view used by all. The VR visitor has a very precisely known 'position' within the virtual room, whereas the web visitor only has a position determined by the current web page – corresponding to a zone and sub-set of exhibits within the physical room. The real visitors of course have a precise position known to them, but this is sensed using ultrasound, which has varying degrees of accuracy (and also coverage black spots within the physical space). So there are at least 5 spaces that impinge upon the user not to mention various coordinate spaces used internally within the software.

In the CityWide project participants play a game within an urban environment where they chase characters within a virtual city. The virtual and physical spaces are overlaid as if there were an invisible ghostly realm behind the surface of buildings and streets. Again varying degrees of accuracy of the GPS sensors used to track the physical participants mean that the measured locations available to the virtual participants may not represent truly the actual physical locations.

The Drift Table, part of the Equator work on domestic environments, is a coffee table with a small porthole in the middle through which can be viewed an aerial view of the whole UK. Weight on different sides of the table makes it drift, like a balloon, over the country. When the table was installed in a

real home, the 'owner' augmented the table with a road map and used this to help guide the table to specific locations, thus adding the road map's spatial model to the physical space in the room and the virtual space in the porthole ... which is of course itself a photograph of the real physical space of the UK.

Finally in Ambient Wood, school children wander around a wood in Sussex on a 'digitally enhanced fieldtrip' and take readings with a light and humidity sensor. The location of their readings are recorded so that they can be shown later collected together on a map of the wood. Also as they move through the wood there are wireless hot spots; when the children enter them sounds or other events are triggered.

relating the real and the virtual – 3 types of space

Although we usually think of relating physical space and virtual space in augmented reality, there are in fact three types of space to consider:

- real space – actual objects in actual physical space
- measured space – the representation of that space in the computer and the representation of locations of objects from sensor data, etc.
- virtual space – electronic spaces created to be portrayed to users, but not representing explicitly the real world

Note that virtual spaces may themselves be models of real world things (e.g. an architect's walkthrough, the virtual Mack room, aerial photographs in the Drift table), but this differs in intent from a similar representation used to track locations of real objects.
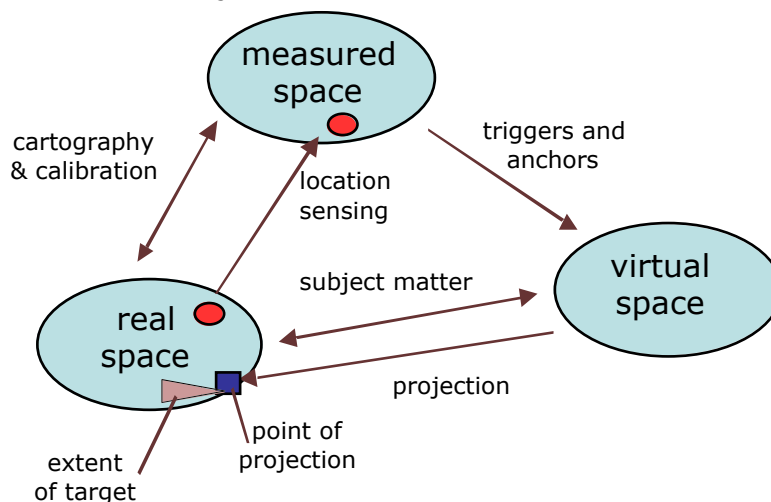
These three types of space are related in different ways.

real – measured

- mapping – the representation of the real space will involve some cartographic process of measuring points and their relations, either against a global system (e.g. GPS) or relative to one another (e.g. theodolite or simple tape measure)
- location sensing – this will involve issues of accuracy (e.g. GPS errors range from less than a metre to tens of metres), and also areas where location cannot be sensed at all (e.g. ultrasound in the Mack room was shadowed by some exhibits)

measured – virtual

- triggers – events (collisions, entering active anchor areas as in Ambient Wood, proximity) may trigger actions in the virtual world. Note that as these are triggering electronic world events they will normally (always) be triggered from representations of the objects and space in the measured spaces rather than directly by the physical space (arguably something like triggering by physical contact would be a counter-example).
- identity – the same measurements of a real space may be used to construct a virtual space (e.g. real Mack room -> VR version)

virtual – real

- subject matter – the virtual space may in some way represent or be about a particular real space. For example, a web page about London, or a virtual model of the Eiffel Tower.
- projection – the virtual world must be made manifest at some particular point in the real world. This has two aspects:
  ◇ point of projection – the device that embodies the projection is in the space (on a screen, in VR goggles, the Drift table porthole)
  ◇ extent of target – where the projection appears to be in physical space. For example, in augmented reality we may see something projected via stereo vision within the real world. Also, in a video wall, the space being projected would appear to be 'the other side' of the screen – that is occupying actual space (albeit through a wall!) Again in the Drift table it appears as though the places in the photographs are somewhere far below and the room floating above.

Note that the penultimate example would also be true if the video wall was projecting a web-cam picture – that is projection can also be a property of themeasured–real spatial relationship.

joining space

As we saw in the examples earlier, it is not that we have a single measured, real and virtual space, but typically several of each. Even physical space has different characteristics depending on perspective: "in this room", as opposed to "near Aunty Mo" or "at 37.32E, 12.56N".

Notice also how this location information is of very different kinds:

- coordinates – precise, although not necessarily accurate, Cartesian points in space
- zonal – in the range of a particular IR sensor, in a room, etc.
- relative – where location is reported relative to some other object

Furthermore, measured spaces differ in both accuracy and extent. For example, the ultrasound location in the Mack room only has meaning within the room and even then has voids in information booths that create an ultrasound shadow.

In fact, people are remarkably adept at dealing with these multiple spaces. In CityWide the participants made use of areas where the GPS coverage was poor in order to 'hide'. Also some of the physical visitors in the Mack room, when they entered one of the information booths, would hold their PDA, in which was the location sensor, at arms length outside the booth. This gave the remote participants a more accurate view of the physical participant's location (albeit being portrayed just outside the booth). As we saw the user

of the Drift Table brought maps and atlases into the experience – choosing voluntarily to add yet more spaces.

Computationally things are more difficult!

In mathematics differential geometry deals with spaces that are curved or broken in ways such that no single coordinate system can cover them. Instead a patchwork of overlapping coordinate systems are used with mappings in the areas of overlap. A similar technique is used in VR systems so that two rooms may have separate VR models which are linked at the doorway by a local mapping between the coordinate systems.

Note however that in both these case the partial spaces are Cartesian and also that the mapping is largely fixed. Unfortunately, neither are necessarily true in the digitally enhanced environments we are considering.

In order to explore these issues further we have been using rich scenarios. For example, considering a series of stories about train travel has enabled us to explore issues where a local coordinate system (the location within the train) moves relative another coordinate system (the track and stations) and is not even of constant shape (the train bends).

no more space

In brief, we have seen how experiences with digitally enhanced environments reveal multiple interacting spaces. We distinguished physical, measured and virtual spaces and saw how each can be of several kinds and differ in accuracy and extent. People deal remarkable well with complex special relationships, but it is harder for mere computers! In order to understand the mappings between these complex spaces we have been using scenarios to explore different types of space, complementing our more practical observations.

Detailed scenarios and more about space at:
http://www.hcibook.com/alan/papers/space-2003/

other places

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