[FC-04-009] Relationships Between Space and Time

Abstract

Relationships between space and time evoke fundamental questions in the sciences and humanities. Many disciplines, including GIScience, consider that space and time extend in separate dimensions, are interchangeable, and form co-equal parts of a larger thing called space-time. Our perception of how time operates in relation to space or vice verso influences how we represent space, time, and their relationships in GIS. The chosen representation, furthermore, predisposes what questions we can ask and what approaches we can take for analysis and modeling. There are many ways to think about space, time, and their relationships in GIScience. This article synthesizes five broad categories: (1) Time is independent of space but relates to space by movement and change; (2) Time collaborates with space to probe relationships, explanations, and predictions; (3) Time is spatially constructed and constrained; (4) Time and space are mutually inferable; and (5) Time and space are integrated and co-equal in the formation of flows, events, and processes. Concepts, constructs, or law-like statements arise in each of the categories as examples of how space, time, and their relationships help frame scientific inquiries in GIScience and beyond.

Keywords: Domains of geographic information, space, space-time, temporal, time

Author & citation

Yuan, M. (2020). Relationships between Space and Time. The Geographic Information Science & Technology Body of Knowledge (3rd Quarter 2020 Edition), John P. Wilson (ed.). DOI: 10.22224/gistbok/2020.3.7.

Explanation

1. Introduction

To Albert Einstein, “time and space are modes by which we think and not conditions in which we live” (Marianoff and Wayne 1944, p. 62). Geographic Information Science (GIScience) has long adopted the perspective of space and time as reasoning frameworks to conceptualize and represent geographic worlds digitally for comprehension and prediction. Besides the absolute and relative conceptualizations of space and time, GIScience research delves into the relationships between space and time in cognition, representation, computation, and visualization of geographic information.

Space and time are subject to several conceptual dichotomies. Are they continuous (i.e., with infinite details) or discrete (i.e., with minimum units)? Are they absolute (i.e., existing on their own) or relative (i.e., determined by others)? Are they orthogonal (i.e., independent) or relational (i.e., related, connected, or dependent)? Are they separate (i.e., space and time) or integrated (i.e., space-time)? In GIScience, these conceptual dichotomies of space and time influence what we can represent, reason, analyze, and model, and consequently, how we may understand the world. Below is an unexhaustive list of the relationships between space and time. Central to the five items is the emphasis on the modes by which we think in GIScience.

2. Time is Independent of Space but Relates to Space by Movement and Change

The most common function of space and time in GIScience is to serve as referents for organizing geographic things, either abstract or concrete constructs. To this end, Geographic Information Systems (GIS) adopt continuous, absolute, orthogonal, separate space and time to build spatial and temporal coordinate systems that anchor geographic things and compute their relationships in space (e.g., distance), time (e.g., periodicity), and space-time (e.g., trajectories).

A popular absolute conceptualization is a 3D container with a 1-D time orthogonal to a 2-D Euclidean space. Hägerstrand’s (Hägerstrand 1970) Time Geography follows the absolute view of space independent of time and conceptualizes a space-time aquarium in which humans project space-time paths and space-time prisms individually and stations and bundles collectively through activities in space and over time. GIScience researchers operationalize Time Geography to calculate and visualize accessibility, activity patterns, visit probability, mobility, and life course analysis of exposure (Miller 1991, Kwan 2004, Kwan et al. 2014, Song and Miller 2014, Wang et al. 2018). In Time Geography, the concept of movement (or stay – no movement) serves the function to relate space and time. Otherwise, space and time remain independent.

While GIScience researchers conventionally use the terms “space-time aquarium” and “space-time cube” interchangeably (Gatalsky et al. 2004, Nakaya 2013, Travis 2014, Kveladze et al. 2015), the convenience of Space-Time Pattern Mining toolbox readily available in the ArcGIS package released in December 2014 quickly popularizes a raster view towards the space-time cube model. After that, the term “space-time cube” refers to a cube of regular, discrete, predefined spatial and temporal units exhaustive of the entire cube, especially in GIS applications. Because of the predefined space-time bins, the concept of change explicitly connects space and time in the raster space-time cube. For example, a raster space-time cube collects events or occurrences based on spatial locations and time stamps to determine the attribute values (e.g., density) of individual bins. Examining bin values over space and time can elicit change patterns at locations, such as persistent hotspots, emergent hotspots, diminishing hotspots, oscillating hotspots, and sporadic hotspots.

3. Time Collaborates with Space to Probe Relationships, Explanations, and Predictions

Modern physics deconstructs our common sense of time to an illusion of the mind (Barbour 1999, Rovelli 2018). More generally, the absolute mode of space-time thinking is an arbitrary invention for the convenience of humans to create coordinate systems so to subserve the purpose of using space and time as principles to (1) organize things to give rise to a meaningful geographic context and (2) search and deliver information within the context. Google effectively applies “genus loci – the sense of place – to advance Google’s mission to organize the world’s information and make it universally accessible and useful” (Jones 2007, p. 8).

The coordinates of space and time position things and simultaneously provide measures for their relationships, such as distance, proximity, orientation, density (or frequency), ordering, association (i.e., agglomeration or assembly in coincidence or proximity), and many other spatial patterns (e.g., clustering, dispersed, or random) or structures (e.g., connectivity, alignment, or partitions). Understanding how things relate to each other in, albeit illusionary, space and time helps unfold sites, situations, and histories for meaningful explanations. Subsequent space-time relationships help develop models to make predictions with empirical regressions, computational simulations, or machine learning algorithms. Geography matters, not for the simplistic and overly used reason that everything happens in space and time, but because where and when things happen is critical to knowing how and why they happen (Added “and time” and “and when” in a statement by Warf and Arias 2009, p. 1).

Space-time proximity commonly implies the strength of some relationships among things. Tober’s first law centers on the role of space in relating things: near things are more related than distant things (Tobler 1970). Strong spatial relation indicates a high correlation or association but not causation. Hume’s temporal priority principle states that all causes must precede their effects (Hume 1740). Temporal relation is a precondition for causality (Chambliss and Schutt 2018). Space-time clustering and ordering separate things that are worth noting from randomness and expose opportunities for scientific inquiries. One interesting relationship between space and time, but understudied in GIS, is teleconnection: when two things happen close in time but distant in space. Teleconnections are common in climate phenomena (e.g., El Nino and Southern Oscillations) that reflect large-scale changes in atmospheric dynamics. Identification of teleconnections helps uncover previously unknown geographic processes that drive happenings around the same time over a vast spatial extent.

4. Time is Spatially Constructed and Constrained

Cognitively and linguistically, many temporal expressions adopt spatial terms. Examples include “the end is near” and “The difficult time is behind us.” Although temporal analysis prevails in a much wider range of disciplines than spatial analysis, perception of time is more abstract than space. However, time and space share relational similarities, which allow us to comprehend the abstract concepts of time through spatial metaphors that reflect the relational structure in the more concrete domain of space (Boroditsky 2000). The common relational similarities between space and time afford languages to express and reason temporal relations in spatial metaphors. The overlapping relational structure between space and time empowers the use of spatial metaphors of time.

We adopt a metaphorical mapping to talk about time with spatial terms that appear to follow a sagittal mental timeline. English, Arabic, and Spanish follow future-front/past-back mapping, Aymara in the Andes assumes the future-back mapping (Núñez and Sweetser 2006), and Chinese language consists of both future-front and future-back mapping (Gu et al. 2019). Furthermore, the spatial mapping may follow either the ego-moving or time-moving metaphor of time, such as “we are coming up on the New Year” or “the New Year is coming.” A comparison of sighted and early blind participants shows that the ego-moving metaphor relies on visuo-locomotor coupling, and the blind participants have no mental representation of time along the sagittal plane (Rinaldi et al. 2017).

Galton (2011) delimits spatial metaphors of time as “no purely spatial metaphor can capture the transience of time” (p. 695), and as “we only experience time at the time we are experiencing it” (p. 698). Expanding the ego-moving and time-moving metaphors, Moore (2017) overcomes the limitation by proposing space-motion metaphors with (1) imagination-oriented deixis (i.e., the meaning of a word depends on its situation of utterance and reference. For example, the word “now” is “understood relative to an imaginary ‘here and now’,” p. 197); (2) ego- or field-perspective frames of reference for mapping locations; and (3) path configured between a mover (i.e., figure) and a location (i.e., ground) in which “sequence is position” (p. 200). Moore’s space-motion metaphor of time is mapping from frames that involve space and time to other frames that involve time only. The space-motion metaphor brings spatial and temporal concepts together to organize temporal concepts effectively.

5. Time and Space are Mutually Inferable

Charles Lyell extended William Hutton’s ideas of uniformity in his three-volume book entitled Principles of Geology (1830-1833) to the theory of uniformitarianism, as an alternative to catastrophism (Cannon 1960). Uniformitarianism considers the invariance of natural laws and processes in space and time. The agents at work, their quantity, and intensity remain constant, and therefore, the geological forces and landform processes observable today are the same ones that have shaped the earth’s landscape throughout the natural history. Uniformitarianism legitimizes two ideas: (1) the present is the key to the past, and (2) the reservation of time in space. Geologists, hence, can infer temporal transitions of earth processes from spatial arrangements of geological structures and can deduce environmental changes from fossils, sedimentary particles, and rock formations. Ecologists can hypothesize the spatial disposition of paleo-ecosystems, such as Darwin’s famous coral island hypothesis (Stoddart 1976). Linguists apply uniformitarianism to linguistic evolution in search of the underlying psychological processes at work now as in the past (Christy 1983).

The over simplicity of uniformitarianism inevitably invites criticisms. Romano (2015) extends Gould’s (Gould 1965) claim that empirical evidence has falsified the uniformity of rate (i.e., gradualism), which is the foundation of uniformitarianism, such that recent cataclysmic mega-flooding has reshaped the landscape. Moreover, the rising force of human activities disrupts natural processes and challenges the principle of uniformity in the Anthropocene era (Knight and Harrison 2014). Nevertheless, uniformitarianism serves a vital role in scientific research as a necessary assumption for scientific inquiry, as a null hypothesis, to cogitate the spatial structure and organization under the invariance of processes in space and time. The null hypothesis can compare empirical observations to elicit potential factors responsible for any discrepancies. Space-for-time substitution infers past or future trajectories of ecological systems from contemporary spatial patterns based on the assumption that relationships between climate and biodiversity identified in the current spatial patterns serve the foundation to project temporal trajectories of biodiversity under changing climates (Blois et al. 2013). The existing knowledge of spatial organization guides us to project temporality.

Comparing spatial structure and organization also serves the basis for the analysis of temporal or spatial patterns. Human dynamics is also manifest with the mutual control of space and time through spacing time and timing space (Yuan 2018). What activities people do and where, how long, and in what schedule they take on the activities are subject to spatial and temporal constraints. Queuing theories of doing tasks explain our spacing time as bursts and heavy tails in human activities (Barabasi 2005, Gonzalez et al. 2008). Alternatively, accessibility and travel behaviors produce patterns of timing space as to how far we can reach, where we can meet, and how to plan tour options. Nystuen (1963, p. 40) explains traffic congestion during peak hours as “When time is short, space is conserved.” Temporal constraints can drive spatial clustering. Likewise, we can expect when space is confined, time is reserved (i.e., the reservation of time in space), which explicates how a geological profile can tell the story of what has happened at the location. According to the principle of superposition, the position of a geological or archaeological stratum in an undeformed stratigraphic sequence reflects its chronological order in the deposition process: the deeper, the older (Harris 2014). Similarly, historians manipulate space and time through selectivity, simultaneity, and shifting to construct narratives that interpret the past (Gaddis 2002). Cultural geographers interpret a landscape as a historical manifestation of human’s records upon the landscape (Denevan and Mathewson 2009). Such a relational view of space and time gains much attention in human geography with the emphasis that the operation of social relations constitutes space and time as well as entities (Massey 1999). Beyond social relations, relatedness provisions entities of flows, events, and processes that create local time-spaces.

6. Time and Space are Integrated and Co-Equal in the Formation of Flows, Events, and Processes

Instead of being dimensional, time and space are intrinsic properties of flows, events, and processes. Flows are interactions of substances (e.g., air, water, goods, or people) or intangibles (e.g., services, messages, news, or ideas) between locations of origins and destinations. A flow takes time to travel from one location to another, and the time and locations are intrinsic to the existence of the flow. Likewise, events and processes inherit space and time as they initiate. GIS research commonly considers flows as spatial interactions. However, flows may be considered as special cases of events or processes. A mudflow can be a hazardous event. Flows of goods and services substrate urbanization processes.

There is a rich GIS literature on events and processes, but universally accepted definitions of events and processes are lacking. In general, events stress happenings, but processes highlight a series of steps in development. However, an event (e.g., a conference) may become a process (e.g., siting, paper selection, room assignment, and program scheduling prior to the conference as well as steps to carry out the program during the conference) when detailing how the event takes place. Yuan (2001) encapsulates the scale dependence of events and processes in a hierarchy to represent components, phases, and life-courses in the development of individual complex geographic phenomena. With their intrinsic properties of space and time, the life-course of a phenomenon can experience contraction, expansion, bifurcation, merger, and dissipation. The hierarchical structure becomes the organization, contextualization, and delivery of geographic information about the evolutions and interactions that phenomena have encountered. Worboys (2005) catalyzes event-oriented approaches to support reasoning with temporal logics, situation calculus, event calculus, temporal interval calculus, and process calculi (i.e., formal models of concurrent occurrents).

Inheriting time and space also allows flows, events, and processes to define spatial and temporal extents and relations. Hierarchy Theory organizes processes into levels of scale: the higher level consists of large-scale processes that are operating at a lower frequency over a greater spatial extent (Ahl and Allen 1996). Identification of the levels is subject to (1) the scale of observations, (2) the criteria for taking an observation, and (3) the space-time relationships embedded in the hierarchy of processes. Upper-level processes set the boundary conditions for component processes at lower levels; lower-level processes, in turn, sustain operations at the upper-level composing processes. Hence, time and space are interrelated and mutually constrained through processes across levels in the hierarchy. With a bottom-up approach, the hierarchy helps illustrate how lower-level processes can influence the working and nature of higher-level processes. Conversely, a top-down approach helps answer the so-what question to address various local and momentary impacts of seemly remote higher-level processes (e.g., climate change) on lower-level processes (e.g., heat waves, crop production). Moreover, levels of processes generate complex patterns of spatial distributions consisting of first-order patterns from higher-level processes (such as climate influences on species distributions) and second-order patterns from lower-level processes (such as competition effects on species distribution).

References

Ahl, V. and Allen, T.F.H. (1996). Hierarchy Theory: A Vision, Vocabulary, and Epistemology. New York, NY: Columbia University Press.

Barabasi, A.-L. (2005). The origin of bursts and heavy tails in human dynamics. Nature, 435 (7039), 207–211.

Barbour, J. (1999). The end of time: The next revolution in physics. Oxford, UK: Oxford University Press.

Boroditsky, L. (2000). Metaphoric structuring: Understanding time through spatial metaphors. Cognition, 75 (1), 1–28.

Cannon, W.F. (1960). The Uniformitarian-Catastrophist Debate. Isis, 51 (1), 38–55.

Chambliss, D.F. and Schutt, R.K. (2018). Making sense of the social world: Methods of investigation. 6th Edition. Los Angeles: SAGE Publications, Inc.

Christy, T.C., 1983. Uniformitarianism in Linguistics. Amsterdam/Philadelphia: John Benjamins Publishing.

Denevan, W.M. and Mathewson, K. (2009). Carl Sauer on culture and landscape: readings and commentaries. Baton Rouge: Louisiana State University.

Gaddis, J. L. (2002). The landscape of history: how historians map the past. New York: Oxford University Press.

Galton, A. (2011). Time flies but space does not: Limits to the spatialisation of time. Journal of Pragmatics, 43 (3), 695–703.

Gatalsky, P., Andrienko, N., and Andrienko, G. (2004). Interactive analysis of event data using space-time cube. Proceedings of the International Conference on Information Visualization, 8, 145–152.

Gonzalez, M.C., Hidalgo, C.A., and Barabasi, A.-L., 2008. Understanding individual human mobility patterns. Nature, 453 (7196), 779–782.

Gould, S. J. (1965). Is uniformitarianism necessary? American Journal of Science 263(3): 223-228.

Gu, Y., Zheng, Y., and Swerts, M. (2019). Which Is in Front of Chinese People, Past or Future? The Effect of Language and Culture on Temporal Gestures and Spatial Conceptions of Time. Cognitive Science, 43 (12), 1–32.

Hägerstrand, T. (1970). What About People in Regional Science? Papers of the Regional Science Association 24(1): 7–21.

Harris, E. C. (2014). Principles of Archaeological Stratigraphy. London: Academic Press.

Hume, D. (1740). A treatise of human nature: being an attempt to introduce the experimental method of reasoning into moral subjects. London.

Jones, M. T. (2007). Google's Geospatial Organizing Principle. IEEE Computer Graphics and Applications, 27 (4), 8–13.

Knight, J. and Harrison, S. (2014). Limitations of uniformitarianism in the Anthropocene. Anthropocene, 5, 71–75.

Kveladze, I., Kraak, M.J., and van Elzakker, C.P.J.M. (2015). The space-time cube as part of a GeoVisual analytics environment to support the understanding of movement data. International Journal of Geographical Information Science, 29 (11), 2001–2016.

Kwan, M-P. (2004). GIS methods in time-geographic research: Geocomputation and geovisualization of human activity patterns. Geografiska Annaler, Series B: Human Geography, 86 (4), 267–280.

Kwan, M-P., Xiao, N., and Ding, G. (2014). Assessing Activity Pattern Similarity with Multidimensional Sequence Alignment Based on a Multiobjective Optimization Evolutionary Algorithm. Geographical Analysis, 46 (3), 297–320.

Marianoff, D. and Wayne, P. (1944, republished 2019). Einstein: An Intimate Study of a Great Man. Garden City, New York: Doubleday, Doran and Co., Inc.

Massey, D. (1999). Space-Time, 'Science' and the Relationship between Physical Geography and Human Geography. Transactions of the Institute of British Geographers, 24 (3), 261–276.

Miller, H. J. (1991). Modelling accessibility using space-time prism concepts within geographical information systems. International Journal of Geographical Information Systems, 5(3), 287-301.

Moore, K. E. (2017). Elaborating time in space: The structure and function of space-motion metaphors of time. Language and Cognition, 9 (2), 191–253.

Nakaya, T. (2013). Analytical Data Transformations in Space–Time Region: Three Stories of Space–Time Cube. Annals of the Association of American Geographers, 103 (5), 1100–1106.

Núñez, R.E. and Sweetser, E. (2006). With the Future Behind Them: Convergent Evidence From Aymara Language and Gesture in the Crosslinguistic Comparison of Spatial Construals of Time. Cognitive Science, 30 (3), 401–450.

Nystuen, J. D. (1963). Identification of some fundamental spatial concepts. Papers of the Michigan Academy of Science, Arts, and Letters, 48, 373–384.

Rinaldi, L., Fantino, M., Vecchi, T., Merabet, L.B., and Cattaneo, Z. (2017). The ego-moving metaphor of time relies on visual experience: No representation of time along the sagittal space in the blind. Journal of Experimental Psychology: General, 147 (3), 444–450.

Romano, M. (2015). Reviewing the term uniformitarianism in modern Earth sciences. Earth-Science Reviews, 148, 65–76.

Rovelli, C. (2018). The Order of Time. New York, NY: Riverhead books.

Song, Y. and Miller, H.J., (2014). Simulating visit probability distributions within planar space-time prisms. International Journal of Geographical Information Science, 28 (1), 104–125.

Stoddart, D.R. (1976). Darwin, Lyell, and the Geological Significance of Coral Reefs. The British Society for the History of Science, 9 (2), 199–218.

Tobler, W. R. (1970). A Computer Movie Simulating Urban Growth in the Detroit Region. Economic Geography 46: 234–240.

Travis, C. (2014). Transcending the cube: Translating GIScience time and space perspectives in a humanities GIS. International Journal of Geographical Information Science, 28 (5), 1149–1164.

Wang, J., Kwan, M.-P., and Chai, Y. (2018). An Innovative Context-Based Crystal-Growth Activity Space Method for Environmental Exposure Assessment: A Study Using GIS and GPS Trajectory Data Collected in Chicago. International Journal of Environmental Research and Public Health, 15 (4), 703.

Warf, B. and Arias, S., (2009). Introduction: the reinsertion of space in the humanities and social sciences. In: The Spatial Turn: Interdisciplinary Perspectives. London and New York.: Routledge, 1–11.

Worboys, M. F. (2005). Event-oriented approaches to geographic phenomena. International Journal of Geographical Information Science, 19 (1), 1–28.

Yuan, M. (2001). Representing Complex Geographic Phenomena in GIS. Cartography and Geographic Information Science 28(2): 83-96.

Yuan, M. (2018). Human Dynamics in Space and Time: a brief history and a view forward. Transactions in GIS, 22 (4), 900–912.