Bibliography on Spatiotemporal Databases

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Spatial and temporal databases are important and well-established sub-disciplines of database research. Some 350 papers in temporal databases have appeared, authored by almost 300 researchers. The literature on spatial databases is also substantial; the bibliography of Samet's landmark book on spatial data structures lists 823 references.

Only recently have issues concerning the simultaneous support of both space and time in databases been considered. While this new area of research was presaged by Thrift's observation in 1977 that time could be considered to be an additional dimension in a two or three dimensional space [Thrift 1977], little was done until Nikos Lorentzos' and Gail Langran's doctoral dissertations [Langran 1989A, Lorentzos 1988]. Several more dissertations have followed [Al-Taha 1992, Hazelton 1991A, Kelmelis 1991, Kolovson 1990, Li 1992, Miller 1991A, Sandhu 1990], and in September, 1992 the first conference was devoted to the topic [Frank et al. 1992]. (This conference was preceded by a small workshop [Barrera et al. 1991].) The first book devoted to the topic also appeared recently [Langran 1992D]. The NSF-funded National Center for Geographic Information and Analysis (NCGIA) has assigned one of its dozen-odd initiatives to spatiotemporal reasoning. With the rise in interest in scientific databases, such as those supporting satellite sensing, the area of spatiotemporal databases is certain to receive more emphasis in the next few years.

This bibliography lists papers that consider the interaction of spatial *and* temporal database management system support. For information on the literature of temporal databases, see the most recent bibliography (of four) in the March, 1991 issue of *SIGMOD Record*. For discussions of the separate research issues of temporal and of spatial databases, see the two articles in the December, 1990 issue of *SIGMOD Record*. We have attempted to collect here references to all existing literature that simultaneously consider space and time.

The bibliographic entries for these references (most including abstracts) in LaTeX bibtex format may be acquired via anonymous FTP from `cs.arizona.edu` in the `bib` directory in the file `spacetime.bib`. Corrections and additions would be greatly appreciated, and may be sent to Richard Snodgrass at the above address.

[Al-Taha & Barrera 1990] Al-Taha, K. K. and R. Barrera. "Temporal Data and GIS: An Overview," in *Proceedings of GIS/LIS '90*. Nov. 1990.

[Al-Taha & Frank 1991] Al-Taha, K. K. and A. Frank. "Temporal GIS Keeps Data Current," in *1991–1992 International GIS Sourcebook*. GIS-World, 1991. pp. 382–388.

[Al-Taha 1992] Al-Taha, K. K. "Temporal Reasoning in Cadastral Systems." PhD. Dissertation. University of Maine, Dec. 1992.

[Allen et al. 1990] Allen, K. M. S., S. W. Green and E. B. W. Zubrow (eds.). "Interpreting Space: GIS and Archaeology." London: Taylor and Francis, 1990.

[Armenakis 1992] Armenakis, C. "Estimation and Organization of Spatio-Temporal Data," in *Proceedings of the Canadian Conference on GIS '92*. Mar. 1992.

[Armstrong 1988] Armstrong, M. "Temporality in Spatial Databases," in *Proceedings of GIS/LIS '88*. 1988, pp. 880–889.

[Barrera & Al-Taha 1990] Barrera, R. and K. K. Al-Taha. "Models in Temporal Knowledge Representation and Temporal DBMS." NGCIA Technical Report 90-8. University of Maine. 1990.

[Barrera et al. 1991] Barrera, R., A. Frank and K. K. Al-Taha. "Temporal Relations in Geographic Information Systems: A Workshop at the University of Maine." *ACM SIGMOD Record*, 20, No. 3, Sep. 1991, pp. 85–91.

[Basoglu et al. 1978] Basoglu, U. and J. Morrison. "The Efficient Hierarchical Data Structure for the U.S. Historical Boundary File," in G. Dutton (ed.), Harvard Papers on GIS. Reading, MA: Addison-Wesley, 1978. Vol. 4.

[Bell et al. 1990] Bell, S. B. M., R. A. Chadwick, A. P. R. Coopert, D. C. Mason, M. O'Connell and P. A. V. Young. "Handling Four Dimensional Geo-Coded Data," in *Proceedings of the 4th International Symposium on Spatial Data Handling*. 1990, pp. 918–927.

[Beller 1991] Beller, A. "Spatial/Temporal Events in a GIS," in *Proceedings of GIS/LIS '91*. 1991, pp. 766–775.

[Beller et al. 1991] Beller, A., T. Giblin, L. K. Litz and D. Schimel. "A Temporal GIS Prototype for Global Change Research," in *Proceedings of GIS/LIS '91*. 1991, pp. 752–765.

[Berry 1964] Berry, B. J. L. "Approaches to Regional Analysis: A Synthesis." *Annals of the Association of American Geographers*, 54, No. 1 (1964), pp. 2–11.

[Burrough et al. 1988] Burrough, B. J. L., W. Van Deursen and G. Heuvelink. "Linking Spatial Process Models and GIS: A Marriage of Convenience or a Blossoming Partnership," in *Proceedings of GIS/LIS '88*. Dec. 1988, pp. 598–607.

[Charlton et al. 1990] Charlton, M. E., S. Openshaw and C. Wymer. "Some Experiments with an Adaptive Data Structure in the Analysis of Space-Time Data," in *Proceedings of the 4th International Symposium on Spatial Data Handling*. 1990, pp. 1030–1039.

[Cheng & Gadia 1992] Cheng, T. S. and S. K. Gadia. "A Seamless Object-Oriented Model for Spatio-Temporal Databases." Technical Report TR-92-41. Computer Science Department, Iowa State University. 1992.

[Cheng et al. 1992] Cheng, T. S., S. K. Gadia and S. Nair. "Relational and Object-Oriented Parametric Databases." Technical Report TR-92-42. Computer Science Department, Iowa State University. 1992.

[Chrisman 1983] Chrisman, N. "The Role of Quality Information in the Long-Term Functioning of a Geographic Information System," in *Proceedings of Auto-Carto 6*. 1983, pp. 303–321.

[Chrisman 1984] Chrisman, N. "The Role of Quality Information in the Long-Term Functioning of a Geographic Information System." *Cartographica*, 21, No. 2 (1984), pp. 79–87.

[Davis & Williams 1989] Davis, B. and R. Williams. "The Five Dimensions of GIS," in *ACSM/ASPRS*. Oct. 1989, pp. 382–388.

[Dutta 1991] Dutta, S. "Topological Constraints: A Representational Framework for Approximate Spatial and Temporal Reasoning," in Advances in Spatial Databases—Second Symposium SSD '91. Vol. 525 of Lecture Notes in Computer Science. New York: Springer-Verlag, 1991. pp. 161–180.

[Easterfield et al. 1991] Easterfield, M., R. G. Newell and D. Theriault. "Modelling Spatial and Temporal Information," in *Proceedings of EGIS '91*. Apr. 1991, pp. 294–304.

[Egenhofer & Al-Taha 1992] Egenhofer, M. and K. Al-Taha. "Reasoning about Gradual Changes of Topological Relationships," in A. U. Frank, I. Campari, and U. Formentini (eds.), Theories and Methods of Spatio-Temporal Reasoning in Geographic Space. Vol. 639 of Lecture Notes in Computer Science. Springer-Verlag, 1992. pp. 169–219.

[Flewelling et al. 1992] Flewelling, D., A. Frank and M. Egenhofer. "Constructing Geological Cross Sections with a Chronology of Geological Events," in *Proceedings of the 5th International Symposium on Spatial Data Handling*. 1992.

[Frank et al. 1992] Frank, A. U., I. Campari and U. Formentini (eds.). "Theories and Methods of Spatio-Temporal Reasoning in Geographic Space." Vol. 639 of Lecture Notes in Computer Science. Springer-Verlag, 1992.

[Gabbay & McBrien 1991] Gabbay, D. and P. McBrien. "Temporal Logic and Historical Databases," in *Proceedings of the Conference on Very Large Databases*. Sep. 1991, pp. 423–430.

[Gadia & Chopra 1992] Gadia, S. K. and V. Chopra. "A Relational Model and SQL-Like Language For Seamless Query of Temporal Data." Technical Report TR-92-05. Computer Science Department, Iowa State University. 1992.

[Gadia et al. 1992B] Gadia, S. K., V. Chopra and U. S. Tim. "Seamless SQL-Like Query of Spatiotemporal Data and a Case Study in Agricultural Environment Management." Technical Report TR-92-21. Computer Science Department, Iowa State University. 1992.

[Gadia et al. 1992A] Gadia, S. K., V. Chopra, S. Nair and U. S. Tim. "An SQL-Like Seamless Query Language and Optimization of Spatio-Temporal Data." Technical Report TR-92-40. Computer Science Department, Iowa State University. 1992.

[Gadia & Chopra 1993] Gadia, S. K. and V. Chopra. "A Relational Model and SQL-Like Query Language for Seamless Query of Temporal Data," in Advanced Database Concepts and Research Issues (to appear).Lecture Notes in Computer Science. Springer-Verlag, 1993.

[Gadia & Nair 1993] Gadia, S. K. and S. Nair. "Temporal Databases: A Prelude to Parametric Data," in A. Tansel, J. Clifford, S. K. Gadia, S. Jajodia, A. Segev, and R. Snodgrass (eds.), Temporal Databases: Theory, Design, and Implementation. Benjamin/Cummings, 1993.

[Gillespie & Davis 1981] Gillespie, R. and W. A. Davis. "Tree Data Structures for Graphics and Image Processing," in *Proceedings of the 7th Conference of the Canadian Man-Computer Communications Society (CM-CCS '81 / ACCHO '81)*. June 1981, pp. 155–162.

[Grossman & Eberhardt 1992] Grossman, W. D. and S. Eberhardt. "Geographical Information Systems and Dynamic Modeling: Potentials of a New Approach." *Annals of Regional Science*, 26, No. 1 (1992), pp. 53–66.

[Guesgen 1989] Guesgen, H. W. "Spatial Reasoning Based on Allen's Temporal Logic." Technical Report 89-049. International Computer Science Institute, Berkeley, CA. Aug. 1989.

[Guptill 1992] Guptill, S. C. "Multiple Representations of Geographic Entities through Space and Time," in *Proceedings of the 4th International Symposium on Spatial Data Handling*. 1992, pp. 859–868.

[Hasting et al. 1982] Hasting, H., R. Pekelney, R. Monticciolo, D. Vun-Kannon and D. DelMonte. "Time Scales, Persistence and Patchiness." *BioSystems*, 15 (1982), pp. 281–289.

[Hazelton et al. 1990A] Hazelton, N. W. J., F. J. Leahy and I. P. Williamson. "Incorporating Dynamic Modelling into GIS," in *Proceedings of the AURISA '90 / URPIS 18 Conference.* Nov. 1990, pp. 77–84.

[Hazelton et al. 1990B] Hazelton, N. W. J., F. J. Leahy and I. P. Williamson. "On the Design of Temporally Referenced 3-D Geographical Information Systems: Development of Four-Dimensional GIS," in *Proceedings of GIS/LIS '90.* 1990, pp. 357–372.

[Hazelton 1991A] Hazelton, N. W. J. "Integrating Time, Dynamic Modeling and Geographical Information Systems: Development of Four-Dimensional GIS." PhD. Dissertation. The University of Melbourne, 1991.

[Hazelton 1991C] Hazelton, N. W. J. "Extending GIS to Include Dynamic Modelling," in *Proceedings of the Third Colloquium of the Spatial Information Research Centre, University of Otago, Dunedin, New Zealand.* May 1991, pp. 73–82.

[Hazelton 1991B] Hazelton, N. W. J. "Using GIS with Non-Point-Source and Distributed Models: The 'How' and 'Why' of an Information Opportunity," in *Proceedings of the AURISA '91 Conference.* Nov. 1991, pp. 298–314.

[Hazelton 1992C] Hazelton, N. W. J. "Developments in Spatio-Temporal GIS," in *Geographical Information Sciences Research in Victoria and Tasmania Conference.* Sep. 1992.

[Hazelton 1992B] Hazelton, N. W. J. "Time in GIS," in *The Monash University GIS Seminar Series.* Oct. 1992.

[Hazelton 1992A] Hazelton, N. W. J. and S. Pigot. "Basic Concepts in 3-D and 4-D Geographic Information Systems and Their Application in the Earth Sciences," in *Proceedings of the Conference on the Geological Applications of Geographic Information Systems.* July 1992, pp. 9–19.

[Hazelton 1992D] Hazelton, N. W. J. "Beyond the 2-D Map: A New Metaphor for Multi-Temporal 4-D GIS," in *Proceedings of GIS/LIS '92.* 1992, pp. 303–313.

[Hazelton & Bennett 1992] Hazelton, N. W. J. and L. M. Bennett. "Topological Relationships in Four-Dimensional Geographical Information Systems." Technical Report. Department of Surveying and Land Information, The University of Melbourne. 1992.

[Hazelton et al. 1992] Hazelton, N. W. J., L. Bennett and J. Masel. "Topological Structures for 4-Dimensional Geographic Information Systems." *Computers, Environment, and Urban Systems,* 16, No. 3 (1992), pp. 227–237.

[Herring 1991] Herring, J. R. "Using Spline Functions to Represent Distributed Attributes," in *Proceedings of Auto-Carto 10.* Mar. 1991, pp. 46–58.

[Hintz & Onsrud 1990] Hintz, R. and H. Onsrud. "A Methodology for Upgrading Real Property Boundary Information in a GIS Using a Temporally Efficient Automated Survey Measurement Management System." Technical Report. Department of Surveying Engineering, University of Maine. 1990.

[Hunter 1988] Hunter, G. "Non-Current Data and Geographical Information Systems. A Case for Data Retention." *International Journal of Geographical Information Systems,* 2, No. 3 (1988), pp. 281–286.

[Hunter & Williamson 1990] Hunter, G. and I. Williamson. "The Development of a Historical Digital Cadastral Database." *International Journal of Geographical Information Systems,* 4, No. 2 (1990), pp. 169–179.

[Hunter 1986] Hunter, G. J. "Non-Current Data and Land Information Systems." Master's Thesis, Department of Surveying and Land Information, The University of Melbourne, 1986.

[Hunter 1992] Hunter, G. J. "Selection Criteria for Archiving Non-Current Data in Land Information Systems." *CISM Journal ACSGC,* 46, No. 3, Autumn 1992, pp. 255–264.

[Jensen et al. 1992] Jensen, C. S., R. T. Snodgrass and M. D. Soo. "Extending Normal Forms to Temporal Relations." TR 92-17. Computer Science Department, University of Arizona. July 1992.

[Kelmelis 1991] Kelmelis, J. A. "Time and Space in Geographic Information: Toward a Four-Dimensional Spatio-Temporal Data Model." PhD. Dissertation. Department of Geography, Pennsylvania State University, 1991.

[Kolovson 1990] Kolovson, C. "Indexing Techniques for Multi-Dimensional Spatial Data and Historical Data in Database Management Systems." PhD. Dissertation. University of California, Berkeley, Nov. 1990.

[Kolovson & Stonebraker 1991] Kolovson, C. and M. Stonebraker. "Segment Indexes: Dynamic Indexing Techniques for Multi-Dimensional Interval Data," in *Proceedings of ACM SIG-MOD 1991.* Ed. J. Clifford and R. King. June 1991, pp. 138–147.

[Kolovson 1993] Kolovson, C. "Indexing for Historical Databases," in A. Tansel, J. Clifford, S. K. Gadia, S. Jajodia, A. Segev, and R. Snodgrass (eds.), Temporal Databases: Theory, Design, and Implementation. Benjamin/Cummings, 1993.

[Langran 1988] Langran, G. "Temporal GIS Design Tradeoffs," in *Proceedings of GIS/LIS '88.* 1988, pp. 890–899.

[Langran & Chrisman 1988] Langran, G. and N. Chrisman. "A Framework for Temporal Geographic Information." *Cartographica,* 25, No. 3 (1988), pp. 1–14.

[Langran 1989A] Langran, G. "Time in Geographic Information Systems." PhD. Dissertation. University of Washington, 1989.

[Langran 1989C] Langran, G. "A Review of Temporal Database Research and Its Use in GIS Applications." *International Journal of Geographical Information Systems.,* 3, No. 3 (1989), pp. 215–232.

[Langran 1989B] Langran, G. "Accessing Spatiotemporal Data in a Temporal GIS," in *Proceedings of Auto-Carto 9.* 1989, pp. 191–198.

[Langran 1990B] Langran, G. "Temporal GIS Design Tradeoffs." *Journal of the Urban and Regional Information Systems,* 2, No. 2 (1990), pp. 16–25.

[Langran 1990A] Langran, G. "Tracing Temporal Information in an Automated Nautical Charting System." *Cartography and Geographic Information Systems,* 17, No. 4 (1990), pp. 291–299.

[Langran 1991] Langran, G. "Issues in Implementing a Spatiotemporal System," in *Proceedings of the International Cartographic Conference.* Bournemouth: Sep. 1991.

[Langran 1992B] Langran, G. "States, Events, and Evidence: The Principal Entities of A Temporal GIS," in *Proceedings of GIS/LIS '92.* 1992, pp. 417–425.

[Langran 1992C] Langran, G. "Preparing for a Temporal Forest GIS." *COMPILER,* 10, No. 3 (1992), pp. 18–26.

[Langran 1992D] Langran, G. "Time in Geographic Information Systems." Technical Issues in Geographic Information Systems Series. London: Taylor and Francis, 1992.

[Langran 1992A] Langran, G. "Forest Monitoring Using Temporal GIS Techniques," in *Proceedings of GIS/LIS '92.* 1992.

[Langran 1993] Langran, G. "Manipulation and Analysis of Temporal Geographic Information," in *Proceedings of the Canadian Conference on GIS '93.* Mar. 1993.

[Lawrence 1975] Lawrence, N. "Temporal Passage and Spatial Metaphor." The Study of Time II. Springer-Verlag, 1975.

[Lester 1990] Lester, M. "Tracking the Temporal Polygon: A Conceptual Model of Multidimensional Time of Geographic Information Systems," in *Proceedings of the Temporal GIS Workshop*. University of Maine. Oct. 1990.

[Li 1992] Li, K.-J. "Contributions on Hypermedia Systems: Modeling and Indexing Spatiotemporal Objects (in French)." PhD. Dissertation. National Institute of Applied Science, 1992.

[Li et al. 1992A] Li, K.-J., N. Badji and R. Laurini. "Modeling Moving Objects in Spatiotemporal Databases." Technical Report. Department of Information and Communication Engineering, KAIST. 1992.

[Li et al. 1992B] Li, K.-J., N. Badji and R. Laurini. "Toward Spatiotemporal Databases: Modeling Moving Objects (in French)," in *Proceedings of the Eighth Conference on BDA*. Tregastel, France: Sep. 1992.

[Lin & Calkins 1991] Lin, H. and H. W. Calkins. "A Rationale for Spatiotemporal Intersection," in *Proceedings of the ACSM-ASPRS Annual Convention*. 1991, pp. 204–213.

[Lorentzos & Johnson 1988B] Lorentzos, N. and R. Johnson. "Requirements Specification for a Temporal Extension to the Relational Model." *Database Engineering*, 11, No. 4 (1988), pp. 204–211.

[Lorentzos 1988] Lorentzos, N. A. "A Formal Extension of the Relational Model for the Representation and Manipulation of Generic Intervals." PhD. Dissertation. Birkbeck College, University of London, 1988.

[Lorentzos & Johnson 1988C] Lorentzos, N. A. and R. G. Johnson. "An Extension of the Relational Model to Support Generic Intervals," in J. W. Schmidt, S. Ceri, and M. Missikoff (eds.), Advances of Database Technology— EDBT '88. Springer-Verlag, 1988. pp. 528–542.

[Lorentzos & Johnson 1988A] Lorentzos, N. A. and R. G. Johnson. "Extending Relational Algebra to Manipulate Temporal Data." *Information Systems*, 13, No. 3 (1988), pp. 289–296.

[Lorentzos & Kollias 1989] Lorentzos, N. A. and V. Kollias. "The Handling of Depth and Time Intervals in Soil-Information Systems." *Computers and Geosciences*, 15, No. 3 (1989), pp. 395–401.

[Lorentzos 1993B] Lorentzos, N. A. "Axiomatic Generalization of the Relational Model to Support Valid Time Data." Internal Report. Informatics Laboratory, Agricultural University of Athens. 1993.

[Lorentzos 1993C] Lorentzos, N. A. "The Interval Extended Relational Model and Its Application to Valid Time Databases," in Tansel, A., J. Clifford, S. Gadia, S. Jajodia, A. Segev, and R. Snodgrass (eds.), Temporal Databases: Theory, Design, and Implementation. Benjamin/Cummings, 1993.

[Lorentzos 1993A] Lorentzos, N. A. "DBMS Support for Time and Totally Ordered Compound Data Types." *Information Systems*, to appear (1993).

[Lorentzos 1994] Lorentzos, N. A. "DBMS Support for Non-Metric Measurement Systems." *IEEE Transactions on Knowledge and Data Engineering*, to appear, May 1994.

[MacDougall 1991] MacDougall, E. B. "Dynamic Statistical Visualization of Geographic Information Systems," in *Proceedings of GIS/LIS '91*. Oct. 1991, pp. 158–65.

[MacEachren 1993] MacEachren, A. "Time as a Cartographic Variable," in D. Unwin and H. Hearnshaw (eds.), Visualization in Geographic Information Systems. London: Belhaven Press, 1993.

[Mackaness & Buttenfield 1991] Mackaness, W. and B. Buttenfield. "Incorporating Time into Geographic Process: A Framework for Analyzing Process in GIS," in *15th Conference and 9th General Assembly of the International Cartographic Association.* 1991, pp. 565–574.

[Maddux 1990] Maddux, R. "Some Algebras and Algorithms for Reasoning about Time and Space." 1990. (Unpublished paper.)

[Mark 1992] Mark, D. "Spatiotemporal Relations and GIS: A Geographer's View," in *GIS From Space to Territory: Theories and Methods of Spatiotemporal Reasoning.* Sep. 1992.

[McDonald & Pullan-Cuthbertson 1989] McDonald, J. R. and T. M. Pullan-Cuthbertson. "Time and Spatial Information Systems," in *Proceedings of the Inaugural Colloquium of the Spatial Information Research Centre.* University of Otago. Nov. 1989, pp. 79–89.

[Miller 1991A] Miller, H. "Modeling Accessibility Using Space-Time Prism Concepts Within GIS." PhD. Dissertation. Department of Geography, Ohio State University, 1991.

[Miller 1991B] Miller, H. "Modelling Accessibility Using Space-Time Prism Concepts within Geographical Information Systems." *International Journal of Geographical Information Systems*, 5, No. 3 (1991), pp. 287–301.

[Monmonier 1990] Monmonier, M. "Strategies for the Visualization of Geographic Time-Series Data." *Cartographica*, 27, No. 1 (1990), pp. 30–45.

[Needham & Vieux 1989] Needham, S. and B. E. Vieux. "A GIS for AgNPS Parameter Input and Mapping Output," in *ASAE Winter Meeting Paper Number 89-2673.* Dec. 1989.

[Newell & Easterfield 1990] Newell, R. G. and M. Easterfield. "Version Management—The Problem of the Long Transaction." *Mapping Awareness*, 4, No. 2 (1990).

[Newell et al. 1990] Newell, R. G., D. Theriault and M. Easterfield. "Temporal GIS—Modelling the Evolution of Spatial Data in Time," in *Functionality Conference.* University of Leicester. U.K.: Mar. 1990.

[Newell et al. 1992] Newell, R. G.,, D. Theriault and M. Easterfield. "Temporal GIS—Modeling the Evolution of Spatial Data in Time." *Computers and Geosciences*, 18, No. 4 (1992), pp. 427–433.

[Onsrud & Hintz 1989] Onsrud, H. J. and R. J. Hintz. "Upgrading Boundary Information in a GIS Using an Automated Survey Measurement Management System," in *Technical Papers, ACSM Annual Convention.* Apr. 1989, pp. 275–384.

[Osborne & Stoogenke 1989] Osborne, S. and M. Stoogenke. "Integration of a Temporal Element into a Natural Resource Decision Support System," in *Proceedings of GIS/LIS '89.* Dec. 1989, pp. 221–227.

[Papagno 1992] Papagno, G. "Seeing Time Contribution to the Discussion on Space-Time Dynamic," in *Four Contributions to GIS Theory and Application.* Ed. A. U. Frank, I. Campari and U. Formentini. Sep. 1992, pp. 29–46.

[Parks & Thrift 1980] Parks, D. and N. Thrift. "Times, Spaces, and Places." New York: John Wiley and Sons, 1980.

[Peuquet 1992] Peuquet, D. J. "Toward the Representation and Analysis of Spatiotemporal Processes in Geographic Information Systems." Technical Report. The Pennsylvania State University. 1992.

[Pigot & Hazelton 1992] Pigot, S. and B. Hazelton. "The Fundamentals of a Topological Model for a Four-Dimensional GIS," in *Proceedings of the Fifth International Symposium on Spatial Data Handling.* IGU Commission on GIS. Aug. 1992, pp. 580-591.

[Price 1989] Price, S. "Modelling the Temporal Element in Land Information Systems." *International Journal of Geographical Information Systems*, 3, No. 3 (1989), pp. 233–243.

[Radic et al. 1987] Radic, U., D. Jenssen and B. McInnes. "On the Surging Potential of Polar Ice Streams. Antarctic Surges—A Clear and Present Danger?." Report DOE/ER/60197-H1. US Department of Energy. July 1987.

[Ridd 1991] Ridd, M. R. "Spatial and Temporal Scale Issues Related to the Integration of GIS and Remote Sensing," in *Proceedings: Remote Sensing and Geographic Information Systems, ACSM-ASPRS*. 1991.

[Ris 1991] Ris, F. "Toward a 'Scientific GIS'," in *Proceedings of GIS/LIS '91*. 1991, pp. 740-751.

[Robertson et al. 1991] Robertson, G. G., J. D. MacKinlay and S. K. Card. "Cone Trees: Animated 3D Visualizations of Hierarchical Information," in *Proceedings of the CHI '91 Conference*. Ed. Robertson et al.. 1991, pp. 189–194.

[Sandhu 1990] Sandhu, J. "Combining Exploratory Data Analysis and Scientific Visualization in the Study of Very Large Space-Time Data Sets." PhD. Dissertation. Department of Geography, Ohio State University, 1990.

[Schneider & Kriegel 1992] Schneider, R. and H.-P. Kriegel. "Indexing the Spatiotemporal Monitoring of a Polygonal Object," in *Proceedings of the 5th International Symposium on Spatial Data Handling*. Charleston, SC: 1992, pp. 200–209.

[Schumm & Lichty 1965] Schumm, S. and R. Lichty. "Time, Space, and Causality in Geomorphology." *American Journal of Science*, 263, No. 2 (1965), pp. 110–119.

[Sharpley & Williams 1990] Sharpley, A. N. and J. R. Williams (eds.) . "EPIC - Erosion / Productivity Impact Calculator. Vol. 1 (Model Documentation) and Vol. 2 (User Manual)." Technical Bulletin No. 1768. Agricultural Research Service, United States Department of Agriculture. 1990.

[Smith 1992] Smith, T. "Towards a Logic-Based Language for Modeling and Database Support for Spatio-Temporal Domains," in *Proceedings of the 5th International Conference on Spatial Data Handling*. 1992, pp. 592–601.

[Smyth 1992] Smyth, S. "A Representational Framework for Route Planning in Space and Time," in *Proceedings of the 5th International Symposium on Spatial Data Handling*. 1992, pp. 692–701.

[Snodgrass 1992] Snodgrass, R. T. "Temporal Databases," in A. U. Frank, I. Campari, and U. Formentini (eds.), Theories and Methods of Spatio-Temporal Reasoning in Geographic Space. Vol. 639 of Lecture Notes in Computer Science. Springer-Verlag, 1992. pp. 22–64.

[Thrift 1977] Thrift, N. "An Introduction to Time Geography," in Concepts in Modern Geography. London: Geo-Abstracts, Ltd., 1977. Vol. 13.

[Varma et al. 1990] Varma, H., H. Boudreau and W. Prime. "A Data Structure for Spatio-Temporal Databases." *International Hydrographic Review*, 67, No. 1, Jan. 1990, pp. 71–92.

[Vasiliev 1990] Vasiliev, I. "Examples of the Treatment of Times as a Variable on Maps," in *Temporal GIS Workshop*. University of Maine. Oct. 1990.

[Vieux 1991] Vieux, B. E. "Geographic Information Systems and Non-Point Source Water Quality and Quantity Modelling." *Hydrological Processes*, 5, No. 7 (1991), pp. 101–113.

[Vrana 1989] Vrana, R. "Historical Data as an Explicit Component of Land Information Systems." *International Journal of Geographical Information Systems*, 3, No. 1 (1989), pp. 33–49.

[Weismiller et al. 1977] Weismiller, R. A., S. J. Kristof, D. K. Scholz, P. F. Anuta and S. A. Momin. "Change Detection in Coastal Zone Environments." *Photogrametric Engineering and Remote Sensing*, 43, No. 12 (1977), pp. 1533–1539.

[Worboys 1990A] Worboys, M. F. "Reasoning About GIS Using Temporal and Dynamic Logics," in *Temporal GIS Workshop*. University of Maine. Oct. 1990.

[Worboys 1990B] Worboys, M. F. "The Role of Modal Logics in the Description of Knowledge in a Geographical Information System," in *Cognitive and Linguistic Aspects of Geographic Space*. NATO ASI. 1990.

[Worboys 1992A] Worboys, M. F. "A Model for Spatio-Temporal Information," in *Proceedings of the 5th International Symposium on Spatial Data Handling*. IGU Commission on GIS, Aug. 1992, pp. 602–611.

[Worboys 1992B] Worboys, M. F. "Object-Oriented Models of Spatiotemporal Information," in *Proceedings of GIS/LIS '92*. 1992, pp. 825–834.

[Xiao et al. 1989] Xiao, Q., H. Raafat and D. Gauthier. "A Temporal/Spatial Database Structure for Remotely Sensed Image Data Management Within GIS," in *Proceedings of GIS/LIS '89*. 1989, pp. 116–122.

[Xu et al. 1990] Xu, X., J. Han and W. Lu. "RT-Tree: An Improved R-Tree Index Structure for Spatiotemporal Databases," in *Proceedings of the 4th International Symposium on Spatial Data Handling*. 1990.

[Yau & Srihari 1983] Yau, M.-M. and S. N. Srihari. "A Hierarchical Data Structure for Multidimensional Digital Images." *Communications of the Association of Computing Machinery*, 26, No. 7 (1983), pp. 504–515.

[Yeh, T. 1992] Yeh, T. "Temporal Aspects of Geographical Databases," in *Proceedings of EGIS '92*. Mar. 1992, pp. 320–328.