

ANSI X3H2-96-503

ISO
INTERNATIONAL ORGANIZATION FOR STANDARDIZATION
ORGANISATION INTERNATIONALE DE NORMALISATION

October 22, 1996

Subject: SQL/Temporal
Status: Informational
Title: Summary of Research Results On Implementing Temporal Support in Relational Databases
Source: ANSI Expert's Contribution
Authors: Richard T. Snodgrass
Abstract: This document provides a summary of some of the extant research results concerning implementing temporal support in relational databases. This snapshot of the literature was taken in Spring, 1996; additional papers have appeared in the intervening six months. These results all assume either period or temporal element (a set of periods) timestamping. As can be seen, the research community has developed many techniques for representing and querying such data in an efficient manner. Most of these approaches are applicable to the valid-time and transaction-time proposals now under consideration. In contrast, there are only a handful of papers that consider how to implement queries on tables using datetime stamping, which result from the EXPANDING clause. Efficient representation and querying of tables using datetime stamping is still an open problem.

- Ahn, I. *Towards an Implementation of Database Management Systems with Temporal Support*, in *Proceeding of the International Conference on Data Engineering*. IEEE Computer Society. Los Angeles, CA: IEEE Computer Society Press, Feb. 1986, pp. 374–381.
- Ahn, I. *Performance Modeling and Access Methods for Temporal Database Management Systems*. PhD. Diss. Computer Science Department, University of North Carolina at Chapel Hill, July 1986.
- Ahn, I. and R. Snodgrass. *Performance Evaluation of a Temporal Database Management System*, in *Proceedings of ACM SIGMOD International Conference on Management of Data*. Ed. C. Zaniolo. Association for Computing Machinery. Washington, DC: May 1986, pp. 96–107.
- Ahn, I. and R. Snodgrass. *Performance Analysis of Temporal Queries*. *Information Sciences*, 49 (1989), pp. 103–146.
- Ahn, I. *SQL+T: a Temporal Query Language*, in *Proceedings of the International Workshop on an Infrastructure for Temporal Databases*. Ed. R. T. Snodgrass. Arlington, TX: June 1993.
- Ang, C.H. and K.P. Tan. *The Interval B-Tree: a New Time Indexing Technique*, in *Proceedings of the 5th Australasian Conference*. Christchurch, New Zealand: 1994, pp. 162–178.
- Ang, C.H. and K.P. Tan. *The Interval B-Tree*. *Information Processing Letters*, 53 (1995), pp. 85–89.
- Ariav, G. and J. Clifford. *A System Architecture for Temporally Oriented Data Management*, in *Proceedings of the Fifth International Conference on Information Systems*. Tucson, Arizona: Nov. 1984, pp. 177–186.
- Barnert, R., G. F. Knolmayer and T. Myrach. *Rules for Ensuring Referential Integrity in a Time-Extended Relational Model*. Working Paper 59. Institut fur Wirtschaftsinformatik der Universitat Bern. Mar. 1995.
- Bassiouni, M. A. and M. Llewellyn. *Handling Time in Query Languages*, in *Proceedings of Statistical and Scientific Database Management Conference*. Rome: June 1988.
- Bassiouni, M.A., A. Mukherjee and M.J. Llewellyn. *Design and Implementation of Extended Boolean and Comparison Operators for Time-oriented Query Languages*. *The Computer Journal*, 37, No. 7 (1994), pp. 576–587.
- Bækgaard, L. and L. Mark. *Incremental Evaluation of Time-Varying Selections*. Technical Report UMIACS-TR-92-65/CS-TR-2913. University of Maryland. June 1992.
- Bækgaard, L. and L. Mark. *Incremental Computation of Time-Varying Query Expressions*. *IEEE Transactions on Knowledge and Data Engineering*, 7, No. 4, Aug. 1995, pp. 583–590.
- Becker, B., S. Geschwind, T. Ohler, B. Seeger and P. Widmayer. *An Asymptotically Optimal Multiversion B-Tree*. *The VLDB Journal*, (1995).
- Becker, B., S. Geschwind, T. Ohler, B. Seeger and P. Widmayer. *On Optimal Multiversion Access Structures*, in *1993 Symposium on Spatial Databases, Singaphore*. 1993.
- Ben-Zvi, J. *The Time Relational Model*. PhD. Diss. Computer Science Department, UCLA, 1982.
- Bercken, J. van de and B. Seeger. *Temporal Query Processing with Duplicate Avoidance: Efficient Approaches to Multiversion Access Methods*. Technical Report. University of Marburg, Germany. 1995.
- Blankenagel, G. and R.H. Gueting. *External Segment Trees*. *Algorithmica*, 12, No. 6 (1994), pp. 498–532.
- Böhlen, M. H. *The Temporal Deductive Database System Chronolog*. PhD. Diss. Departement Informatik, ETH Zurich, 1994.
- Böhlen, M. H. *Valid Time Integrity Constraints*. Technical Report 94-30. Computer Science Department, University of Arizona. Nov. 1994.
- Böhlen, M. H., C. S. Jensen and R. T. Snodgrass. *Evaluating the Completeness of TSQL2*, in *Recent Advances in Temporal Databases*. Ed. S. Clifford and A. Tuzhilin. Proceedings of the International Workshop on Temporal Databases. Zurich, Switzerland: Springer Verlag, Sep. 1995, pp. 153–174.
- Böhlen, Michael H., Jan Chomicki, Richard T. Snodgrass and David Toman. *Querying TSQL2 Databases with Temporal Logic*, in *Proceedings of the 5th International Conference on Extending Database Technology (EDBT)*. Avignon, France: 1996.
- Bozkaya, T. and Z.M. Ozsoyoglu. *Indexing the Temporal Data in Multimedia Databases*. Technical Report CES-95-23. Computer Engineering and Science. 1995.
- Bozkaya, T. and Z.M. Ozsoyoglu. *Indexing Transaction-Time Databases*. Technical Report CES-95-19. Computer Engineering and Science. June 1995.

- Brusoni, V., L. Console, B. Pernici and P. Terenziani. *LaTeR: a General Purpose Manager of Temporal Information*, in *Proceedings of the 8th International Symposium on Methodologies for Intelligent Systems*. Ed. Z. Ras and M. Zemankova. Lecture Notes on Computer Science, Vol.869. Charlotte, NC: Springer, Oct. 1994, pp. 255–264.
- Brusoni, V., L. Console, P. Terenziani and B. Pernici. *Extending Temporal Relational Databases to Deal with Imprecise and Qualitative Temporal Information*, in *Recent Advances in Temporal Databases*. Ed. S. Clifford and A. Tuzhilin. Proceedings of the International Workshop on Temporal Databases. Zurich, Switzerland: Springer Verlag, Sep. 1995, pp. 3–22.
- Brusoni, V., L. Console and P. Terenziani. *Efficient Query Answering in LaTeR*, in *Proceedings of Second International Workshop on Temporal Representation and Reasoning (TIME)*. FLAIRS. Melbourne Beach, Florida: 1995.
- Brusoni, V., L. Console, B. Pernici and P. Terenziani. *LaTeR: An Efficient, General Purpose Manager of Temporal Information*. IEEE Software, (1996).
- Brusoni, Vittorio, Luca Console, Paolo Terenziani and Barbara Pernici. *Extending Temporal Relational Databases to Deal with Imprecise and Qualitative Temporal Information*, in *Proceedings of the VLDB International Workshop on Temporal Databases*. Ed. J. Clifford and A. Tuzhilin. Workshops in Computing Series. Zurich, Switzerland: Springer Verlag, Sep. 1995, pp. 3-22.
- Chen, C. Y., C. C. Chang and R. C. T. Lee. *A Line Segment Intersection Based Temporal Join*, in *International Symposium on Advanced Database Technologies and Their Integration (ADTI)*. Japan: Oct. 1994.
- Dadam, P., V. Lum and H.-D. Werner. *Integration of Time Versions into a Relational Database System*, in *Proceedings of the Conference on Very Large Databases*. Ed. U. Dayal, G. Schlageter and L.H. Seng. Singapore: Aug. 1984, pp. 509–522.
- Dadam, P. and J. Teuhola. *Managing Schema Versions in a Time-Versioned Non-First-Normal-Form Relational Database*. Technical Report TR 87.01.001. Heidelberg Scientific Center. January 1987.
- DeCastro, C., F. Grandi and M. R. Scalas. *Management of Schema Versions in Multitemporal Relational Databases*, in *Proceedings of the 2th Italian Conference on Advanced Database Systems (SEBD)*. Rimini, Italy: June 1994.
- DeCastro, C. and M.R. Scalas. *Inferred Validity of Transaction-Time Data*, in *Proceedings of Second International Workshop on Temporal Representation and Reasoning (TIME)*. FLAIRS. Melbourne Beach, Florida: 1995.
- DeCastro, C., F. Grandi and M. R. Scalas. *On Schema Versioning in Temporal Databases*, in *Proceedings of the VLDB International Workshop on Temporal Databases*. Ed. J. Clifford and A. Tuzhilin. Workshops in Computing Series. Zurich, Switzerland: Springer Verlag, Sep. 1995, pp. 272-291.
- DeCastro, C., F. Grandi and M. R. Scalas. *On Schema Versioning in Temporal Databases*, in *Recent Advances in Temporal Databases*. Ed. S. Clifford and A. Tuzhilin. Proceedings of the International Workshop on Temporal Databases. Zurich, Switzerland: Springer Verlag, Sep. 1995, pp. 272–294.
- DeCastro, C., F. Grandi and M. R. Scalas. *Extensional Data Management in Multitemporal Relational Databases Supporting Schema Versioning*, in *Proceedings of the 3rd Italian Conference on Advanced Database Systems (SEBD)*. Ravello, Italy: June 1995.
- Dey, D., T. Barron and V. Storey. *A Well-Specified Temporal Relational Model*, in *Proceedings of the Thirteenth Annual International Conference on Information Systems*. Dallas, Texas: December 1992, pp. 241–253.
- Dyreson, C. E., R. T. Snodgrass and C. S. Jensen. *On the Semantics of “Now” in Temporal Databases*. TempIS Technical Report 42. Computer Science Department, University of Arizona. April 1993.
- Dyreson, C. E. and R. T. Snodgrass. *Temporal Granularity and Indeterminacy: Two Sides of the Same Coin*. Technical Report TR 94-06. Computer Science Department, University of Arizona. Feb. 1994.
- Easton, M. C. *Key-Sequence Data Sets on Indelible Storage*. Research Report RJ 4778 (50637). IBM Research Laboratory. July 1985.
- Elmasri, R. and G. Wuu. *A Temporal Model and Query Language for ER Databases*, in *Proceedings of the 6th International Conference on Data Engineering*. Feb. 1990, pp. 76–83.
- Elmasri, R., G. Wuu and Y. Kim. *The Time Index - An Access Structure for Temporal Data*, in *Proceedings of the Conference on Very Large Databases*. Brisbane, Australia: Aug. 1990.

- Elmasri, R., Y.-J. Kim and G. T. J. Wuu. *Efficient Implementation Techniques for the Time Index*, in *Proceedings of the Seventh International Conference on Data Engineering*. 1991, pp. 102–111.
- Elmasri, R., M. Jaseemuddin and V. Kouramajian. *Partitioning of Time Index for Optical Disks*, in *Proceedings of the International Conference on Data Engineering*. Ed. F. Golshani. IEEE. Phoenix, AZ: Feb. 1992, pp. 574–583.
- Elmasri, R. and V. Kouramajian. *Indexing, Searching and Archiving Issues in Temporal Databases*, in *Proceedings of the International Workshop on an Infrastructure for Temporal Databases*. Ed. R. T. Snodgrass. Arlington, TX: June 1993.
- Elmasri, R., V. Kouramajian and R. Gunter. *Access Structures and Search Methods for Temporal Databases*. Technical Report. Computer Science Engineering, University of Texas at Arlington. 1993.
- Elmasri, R., Wuu, G. and V. Kouramajian. *The Time Index and the Monotonic B+ Tree*, in *Temporal Databases: Theory, Design, and Implementation*. Benjamin/Cummings Pub. Co, 1993. Chap. 18. pp. 433–456.
- Christos Faloutsos *Indexing Multimedia Databases (Tutorial)*, in *Proceedings of the ACM SIGMOD*. San Jose, CA: 1995, pp. 467.
- Frazier, G. F. *An Incremental Algorithm for Building Temporal Quadtrees*, in *Proceedings of the 21st Annual Conference on Computer Science (CSC)*. Indianapolis, IN: ACM Press, Feb. 1993, pp. 446–452.
- Gadai, S. K. and G. Bhargava. *SQL-like Seamless Query of Temporal Data*, in *Proceedings of the International Workshop on an Infrastructure for Temporal Databases*. Ed. R. T. Snodgrass. Arlington, TX: June 1993.
- Gadia, S. *The Role of Temporal Elements in Temporal Databases*. *Data Engineering*, 11, No. 4, Dec. 1988, pp. 19–25.
- Gadia, S. *Ben-Zvi's Pioneering Work in Relational Temporal Databases*, in *Temporal Databases: Theory, Design, and Implementation*. Benjamin/Cummings, 1993. Chap. 8. pp. 202–207.
- Gadia, S. K. *Temporal Element as a Primitive for Time in Temporal Databases and its Application in Query Optimization*. 1986. (An abstract in the Proceeding of the 1986 ACM Computer Sciences Conference.)
- Gadia, S. K. *A Homogeneous Relational Model and Query Languages for Temporal Databases*. *ACM Transactions on Database Systems*, 13, No. 4, Dec. 1988, pp. 418–448.
- Gadia, S. K. and C. S. Yeung. *A Generalized Model for a Relational Temporal Database*, in *Proceedings of ACM SIGMOD International Conference on Management of Data*. Association for Computing Machinery. Chicago, IL: June 1988, pp. 251–259.
- Gadia, S. K. and C. S. Yeung. *A Tuple Calculus for Temporal Databases and Its Comparison with TQUEL*. *Information Sciences*, (1989).
- Gal, A. and O. Etzion. *A Parallel Execution Model for Updating Temporal Databases*, in *Proceedings of the 7th International Conference on Parallel and Distributed Computing Systems, (PDCS)*. Las Vegas, Nevada: Oct. 1994.
- Gal, A., O. Etzion and A. Segev. *Representation of Highly-Complex Knowledge in a Database*. *Journal of Intelligent Information Systems*, 3, No. 2, Mar. 1994, pp. 185–203.
- Gal, A., O. Etzion and A. Segev. *Extended Update Functionality in Temporal Databases (revised version)*. ISE-TR 94-1. Israel Institute of Technology. Jan. 1995.
- Gal, Avigdor and Opher Etzion. *A Multi-Agent Update Process in a Database with Temporal Dependencies and Schema Versioning*. Technical Report. Technion—Israel Institute of Technology. Sep. 1994.
- Ghallab, M. and A. Alaoui. *Managing Efficiently Temporal Relations Through Indexed Spanning Trees*, in *Proceedings of IJCAI*. 1989.
- Goralwalla, A., M. Tamer Ozsu and A. U.Tansel. *Experimenting with Temporal Relational Databases I*, in *Proceedings of the 4th International Conference on Information and Knowledge Management (CIKM)*. Baltimore, MD: Nov. 1995, pp. 296-303.
- Goralwalla, I. and A. U. Tansel. *A Temporal Relational Database Management System*, in *Proceedings of the Sixth International Symposium on Computer and Information Sciences*. Antalya, Turkey: Oct. 1991, pp. 75–83.

- Goralwalla, I. and A. U. Tansel. *Performance Evaluation of Temporal Relational Databases*. Technical Report. Bilkent University. July 1992.
- Goralwalla, I. and A. U. Tansel. *A Temporal Relational Database Management System*. Technical Report. Bilkent University. July 1992.
- Goralwalla, I.A., A. Tansel and M. T. Özsü. *An Empirical Study of the Performance of Temporal Relational Databases*. Technical Report TR 94-15. University of Alberta. Nov. 1994.
- Grandi, F. and M. Scalas. *HotQuel: A History-Oriented Temporal Query Language*, in *Proceedings of the 5th IEEE Compeuro*. Bologna, Italy: May 1991.
- Grandi, F., M. R. Scalas and P. Tiberio. *History and Tuple Variables for Temporal Query Languages*. Technical Report 93. C.I.O.C.-C.N.R. and D.E.I.S.. January 1993.
- Grandi, F., M. Scalas and P. Tiberio. *A History-oriented Data View and Operation Semantics for Temporal Relational Databases*, in *Proceedings of the International Workshop on an Infrastructure for Temporal Databases*. Ed. R. T. Snodgrass. Arlington, TX: June 1993.
- Grandi, F., M.R. Scalas and P. Tiberio. *A History-oriented Temporal SQL Extension*, in *The Second International Workshop on Next Generation Information Technologies and Systems (NGITS)*. Naharia, Israel: June 1995.
- Gunadhi, H. and A. Segev. *Query Processing Algorithms for Temporal Intersection Joins*. Technical Report LBL-28587. Lawrence Berkeley Laboratories. Feb. 1989.
- Gunadhi, H. and A. Segev. *Efficient Indexing Methods for Temporal Relations*. Technical Report LBL-28798. University of California, Lawrence Berkeley Laboratories. 1989.
- Gunadhi, H., A. Segev and G. Shantikumar. *Selectivity Estimation in Temporal Databases*. Technical Report LBL-27435. Lawrence Berkeley Laboratories. 1989.
- Gunadhi, H. and A. Segev. *A Framework for Query Optimization in Temporal Databases*, in *Fifth International Conference on Statistical and Scientific Database Management*. Charlotte, NC: Apr. 1990, pp. 131–147.
- Gunadhi, H. and A. Segev. *Query Processing Algorithms for Temporal Intersection Joins*, in *Proceedings of the 7th International Conference on Data Engineering*. Kobe, Japan: 1991.
- Gunadhi, H. and A. Segev. *Efficient Indexing Methods for Temporal Relations*. *IEEE Transactions on Knowledge and Data Engineering*, 5, No. 3, June 1993, pp. 496–509.
- Hsu, S. and R. Snodgrass. *Optimal Block Size for Set-valued Attributes*. *Information Processing Letters*, 45, No. 3, Mar. 1993, pp. 153–158.
- Hsu, S., C. S. Jensen and R. T. Snodgrass. *Valid-Time Selection and Projection*, in *The TSQL2 Temporal Query Language*. Ed. R. T. Snodgrass. Kluwer Academic Publishers, 1995. Chap. 13. pp. 251–298.
- Hsu, S. H. *Page and Tuple Level Storage Structures for Historical Databases*. TempIS Technical Report No. 34. Computer Science Department, University of Arizona. May 1992.
- Jensen, C. and L. Mark. *Differential Query Processing in Transaction-Time Databases*, in *Temporal Databases: Theory, Design, and Implementation*. Benjamin/Cummings, 1993. Chap. 19. pp. 457–491.
- Jensen, C. S. *Towards the Realization of Transaction Time Database Systems*. PhD. Diss. Aalborg University, Department of Mathematics and Computer Science, Dec. 1990.
- Jensen, C. S. and L. Mark. *A Framework for Vacuuming Temporal Databases*. Technical Report CS-TR-2516/UMIACS-TR-90-105. University of Maryland, Department of Computer Science. Aug. 1990.
- Jensen, C. S. and L. Mark. *Replication Gives High Performance Query Processing in Relational Models Extended with Transaction Time*, in *Proceedings of the IEEE Workshop on the Management of Replicated Data*. Houston, TX: Nov. 1990.
- Jensen, C. S., L. Mark and N. Roussopoulos. *Incremental Implementation Model for Relational Databases with Transaction Time*. *IEEE Transactions on Knowledge and Data Engineering*, 3, No. 4, Dec. 1991, pp. 461–473.
- Jensen, C. S. and L. Mark. *Queries on Change in an Extended Relational Model*. *IEEE Transactions on Knowledge and Data Engineering*, 4, No. 2, Apr. 1992, pp. 192–200.
- Jensen, C. S. and R. T. Snodgrass. *Temporal Specialization*, in *Proceedings of the International Conference on Data Engineering*. Ed. F. Golshani. IEEE. Tempe, AZ: Feb. 1992, pp. 594–603.

- Jensen, C. S., M. D. Soo and R. T. Snodgrass. *Unification of Temporal Relations*, in *Proceedings of the International Conference on Data Engineering*. Vienna, Austria: Apr. 1993, pp. 262–271.
- Jensen, C. S., L. Mark, N. Roussopoulos and T. Sellis. *Using Differential Techniques to Efficiently Support Transaction Time*. *The VLDB Journal*, 2, No. 1, Jan. 1993, pp. 75–111.
- Jensen, C. S. and R. Snodgrass. *Temporal Specialization and Generalization*. *IEEE Transactions on Knowledge and Data Engineering*, 6, No. 6 (1994), pp. 954–974.
- Jensen, C. S., M. D. Soo and R. T. Snodgrass. *Unifying Temporal Models via a Conceptual Model*. *Information Systems*, 19, No. 7 (1994), pp. 513–547.
- Jensen, C. S. *Vacuuming*, in *The TSQL2 Temporal Query Language*. Ed. R. T. Snodgrass. Kluwer Academic Publishers, 1995. Chap. 23. pp. 451–462.
- Jones, S., P. Mason and R. Stamper. *LEGOL 2.0: A Relational Specification Language for Complex Rules*. *Information Systems*, 4, No. 4, Nov. 1979, pp. 293–305.
- Jones, S. and P. J. Mason. *Handling the Time Dimension in a Data Base*, in *Proceedings of the International Conference on Data Bases*. Ed. S.M. Deen and P. Hammersley. British Computer Society. University of Aberdeen: Heyden, July 1980, pp. 65–83.
- Käfer, W. *Temporal Selection, Temporal Projection, and Temporal Join Revised*, in *Proceedings of the International Workshop on an Infrastructure for Temporal Databases*. Ed. R. T. Snodgrass. Arlington, TX: June 1993.
- Kalua, P.P. and E. L. Robertson. *Benchmarks for Temporal Databases*. Technical Report 379. Computer Science Department. March 1993.
- Kanellakis, P.C., S. Ramaswamy, D.E. Vengroff and J.S. Vitter. *Indexing for Data Models with Constraints and Classes*, in *Proceedings of the ACM SIGACT-SIGMOD-SIGART PODS*. Washington, D.C.: May 1993, pp. 233–243.
- Kangelaris, N. and V. Tsotras. *Access Methods for Historical Data*, in *Proceedings of the International Workshop on an Infrastructure for Temporal Databases*. Ed. R. T. Snodgrass. Arlington, TX: June 1993.
- Keretho, S. and R. Loganathanraj. *An Interval Arithmetic for Temporal Distance Constraint Satisfaction Problems*. Technical Report CACS TR-90-2-2. University of Southwestern Louisiana. Apr. 1990.
- Kline, N. *Dissertation Proposal: Efficient Evaluation of Aggregates in Temporal Databases*. TempIS Technical Report 40. Computer Science Department, University of Arizona. Sep. 1992.
- Kline, N., R. T. Snodgrass and T. Y. Cliff Leung. *Aggregates*, in *The TSQL2 Temporal Query Language*. Ed. R. T. Snodgrass. Kluwer Academic Publishers, 1995. Chap. 21. pp. 395–425.
- Kline, Nick and Richard T. Snodgrass . *Computing Temporal Aggregates* , in *Proceedings of the 11th International Conference on Data Engineering (ICDE)*. Taipei, Taiwan: 1995, pp. 222–231.
- Knight, B. and M. Jixin. *An Extended Temporal System based on Points and Intervals*. *Information Systems*, 18, No. 2, Mar. 1993, pp. 111–120.
- Kocberber, S. and A. Tansel. *An Index Structure for Historical Databases*, in *Computer and Information Sciences VI - Proceedings of the 1991 International Symposium*. Side, Turkey: Oct.-Nov. 1991, pp. 169–178.
- Kolovson, C. and M. Stonebraker. *Indexing Techniques for Historical Databases*, in *Proceedings of the Fifth International Conference on Data Engineering*. Los Angeles, CA: Feb. 1989, pp. 127–137.
- Kolovson, C. and M. Stonebraker. *Segment Indexes: Dynamic Indexing Techniques for Multi-dimensional Interval Data*, in *Proceedings of ACM SIGMOD International Conference on Management of Data*. May 1991.
- Kolovson, C. *Indexing Techniques for Historical Databases*, in *Temporal Databases: Theory, Design, and Implementation*. Benjamin/Cummings, 1993. Chap. 17. pp. 418–432.
- Kouramajian, Vram, Ramez Elmasri and Anurag Chaudhry . *Declustering Techniques for Parallelizing Temporal Access Structures*, in *Proceedings of the 10th International Conference on Data Engineering (ICDE)*. Houston, TX: 1994, pp. 232–242.
- Kouramajian, Vram and Ramez Elmasri. *Archiving Techniques for Temporal Databases*, in *Proceedings of 4th International Symposium on Database Systems for Advanced Applications (DASFAA)*. Singapore: Apr. 1995.
- Kumar, A., V. J. Tsotras and C. Faloutsos. *Designing Access Methods for Bitemporal Databases*. AT&T Bell Labs TR 112530-950926-11-TM. Bell Laboratories. 1995.

- Kumar, Anil, Vassilis J. Tsotras and Christos Faloutsos. *Access Methods for Bi-Temporal Databases*, in *Proceedings of the VLDB International Workshop on Temporal Databases*. Ed. J. Clifford and A. Tuzhilin. Workshops in Computing Series. Zurich, Switzerland: Springer Verlag, Sep. 1995, pp. 235-254.
- Landau, G. M., J. P. Schmidt and V. J. Tsotras. *On Historical Queries Along Multiple Lines of Time Evolution*. *VLDB Journal*, 4 (1995), pp. 100-123.
- Landau, Gad M., Jeanette P. Schmidt and Vassilis J. Tsotras. *On Historical Queries along Multiple Lines of Time Evolution*. *The VLDB Journal*, 5, No. 5, Oct. 1995. Landau, G. M., J. P. Schmidt and V. J. Tsotras. *Efficient Support of Historical Queries for Multiple Lines of Evolution*, in *Ninth International Conference on Data Engineering*. Association for Computing Machinery. Vienna, Austria: ACM Press, Apr. 1993, pp. 319-326.
- Lanka, S. and E. Mays. *Fully Persistent B+-Trees*, in *Proceedings of the ACM SIGMOD*. San Jose, CA: 1991, pp. 426-435.
- Kouramajian, V. and R. Elmasri. *The TI/R Tree : A Temporal-Spatial Access Structure*.
- Jensen, C. S., R. T. Snodgrass and T. Y. Cliff Leung. *Cursors*, in *The TSQL2 Temporal Query Language*. Ed. R. T. Snodgrass. Kluwer Academic Publishers, 1995. Chap. 15. pp. 305-309.
- Kouramajian, Vram, Ibrahim Kamel, Ramez Elmasri and Syed Waheed. *The Time Index+: An Incremental Access Structure for Temporal Databases*, in *Proceedings of the Conference on Information and Knowledge Management*. Gaithersburg, Maryland: Nov. 1994.
- Lee, Eun Bae and Keun Ho Ryu. *TempIS: Interfacing System for Graphical Display of Temporal Databases*, in *Proceedings of TENCON'93, IEEE Region 10 Conference on Computer, Communication, Control and Power Engineering*. Beijing, China: Oct. 1993, pp. 319-322.
- Leung, T. and R. Muntz. *Stream Processing: Temporal Query Processing and Optimization*, in *Temporal Databases: Theory, Design, and Implementation*. Benjamin/Cummings, 1993. Chap. 14. pp. 329-355.
- Leung, T. Y. C. and R. R. Muntz. *Temporal Query Processing and Optimization in Multiprocessor Database Machines*, in *Proceedings of the Conference on Very Large Databases*. Vancouver, Canada: Aug. 1992.
- Leung, T. Y. C. and H. Pirahesh. *Querying Historical Data in IBM DB2 C/S DBMS Using Recursive SQL*, in *Recent Advances in Temporal Databases*. Ed. S. Clifford and A. Tuzhilin. Proceedings of the International Workshop on Temporal Databases. Zurich, Switzerland: Springer Verlag, Sep. 1995, pp. 215-331.
- Leung, T. Y. and R. Muntz. *Query Processing for Temporal Databases*, in *Proceedings of the 6th International Conference on Data Engineering*. Los Angeles, California: Feb. 1990.
- Leung, T. Y. and R. Muntz. *Generalized Data Stream Indexing and Temporal Query Processing*, in *Second International Workshop on Research Issues in Data Engineering: Transaction and Query Processing*. Feb. 1992.
- Leung, T. Y. C. *Query Processing and Optimization in Temporal Database Systems*. PhD. Diss. Department of Computer Science, University of California, 1992.
- Ligozat, G. and H. Bestougeff. *On Relations Between Intervals*. *Information Processing Letters*, 32, No. 4, Sep. 1989, pp. 177-182.
- Little, T. D. C. and A. Ghafoor. *Interval-Based Conceptual Models for Time-Dependent Multimedia Data*. *IEEE Transactions on Knowledge and Data Engineering*, 5, No. 4, August 1993, pp. 551-563.
- Lomet, D. and B. Salzberg. *Access Methods for Multiversion Data*, in *Proceedings of ACM SIGMOD International Conference on Management of Data*. June 1989, pp. 315-324.
- Lomet, D. *Consistent Timestamping for Transactions in Distributed Systems*. Technical Report CRL 90/3. Cambridge Research Laboratory. Sep. 1990.
- Lomet, D. and B. Salzberg. *The Performance of a Multiversion Access Method*, in *Proceedings of ACM SIGMOD International Conference on Management of Data*. Atlantic City: May 1990, pp. 353-363.
- Lomet, D. and B. Salzberg. *Media Recovery with Time-Split B-trees*. Technical Report NU-CCS-91-16. College of Computer Science Northeastern University. 1991.
- Lomet, D. and B. Salzberg. *Rollback Databases*. Technical Report NU-CCS-92-3. Northeastern University. 1992.

- Lomet, D. and B. Salzberg. *Transaction-Time Databases*, in Temporal Databases: Theory, Design, and Implementation. Benjamin/Cummings, 1993. Chap. 16. pp. 388–417.
- Lu, Hongjun, Beng-Chin Ooi and Kian-Lee Tan. *On Spatially Partitioned Temporal Join*, in *Proceedings of the Conference on Very Large Databases*. Morgan Kauffman, Sep. 1994.
- Lue, J., K. Brown and W.B. Samson. *Indexing Techniques for Temporal Data*, in *Workshop of the 6th International Conference on Database and Expert Systems Applications (DEXA)*. London, U.K.: Sep. 1995.
- Lum, V., P. Dadam and H. Werner. *Integration of Time Versions into a Relational Database System*, in *Proceedings of the Conference on Very Large Databases*. Singapore: 1984.
- Lum, V., P. Dadam, R. Erbe, J. Guenauer, P. Pistor, G. Walch, H. Werner and J. Woodfill. *Designing DBMS Support for the Temporal Dimension*, in *Proceedings of ACM SIGMOD International Conference on Management of Data*. Ed. B Yormark. Association for Computing Machinery. Boston, MA: June 1984, pp. 115–130.
- Maiocchi, R. and B. Pernici. *Time Reasoning in the Office Environment*, in *Proceedings of the IFIP WG 8.4 Working Conference on Methods and Tools for Office Systems*. IFIP. Pisa, Italy: Oct. 1986.
- Maiocchi, R. and B. Pernici. *Temporal Data Management Systems: A Comparative View*. *IEEE Transactions on Knowledge and Data Engineering*, 3, No. 4, Dec. 1991, pp. 504–524.
- Maiocchi, R., B. Pernici and F. Barbic. *Automatic Deduction of Temporal Information*. *ACM Transactions on Database Systems*, 17, No. 4 (1992).
- Martin, N. G., S. B. Navathe and R. Ahmed. *Dealing with Temporal Schema Anomalies in History Databases*, in *Proceedings of the Conference on Very Large Databases*. Ed. P. Hammersley. Brighton, England: Sep. 1987, pp. 177–184.
- McKenzie, E. and R. Snodgrass. *Extending the Relational Algebra to Support Transaction Time*, in *Proceedings of ACM SIGMOD International Conference on Management of Data*. Ed. U. Dayal and I. Traiger. Association for Computing Machinery. San Francisco, CA: May 1987, pp. 467–478.
- McKenzie, E. *An Algebraic Language for Query and Update of Temporal Databases*. PhD. Diss. Computer Science Department, University of North Carolina at Chapel Hill, Sep. 1988.
- McKenzie, E. and R. Snodgrass. *Schema Evolution and the Relational Algebra*. *Information Systems*, 15, No. 2, June 1990, pp. 207–232.
- McKenzie, E. and R. Snodgrass. *An Evaluation of Relational Algebras Incorporating the Time Dimension in Databases*. *ACM Computing Surveys*, 23, No. 4, Dec. 1991, pp. 501–543.
- McKenzie, L. and R. T. Snodgrass. *Supporting Valid Time in an Historical Relational Algebra: Proofs and Extensions*. Technical Report TR-91-15. Department of Computer Science, University of Arizona. Aug. 1991.
- Montanari, A. and B. Pernici. *Towards a Temporal Logic Reconstruction of Temporal Databases*, in *Proceedings of the International Workshop on an Infrastructure for Temporal Databases*. Ed. R. T. Snodgrass. Arlington, TX: June 1993.
- Montanari, A. and B. Pernici. *Temporal Reasoning*, in Temporal Databases: Theory, Design, and Implementation. Benjamin/Cummings, 1993. Chap. 21. pp. 534–562.
- Nair, S. and S. Gadia. *Algebraic Optimization in a Relational Model for Temporal Databases*, in *Proceedings of the International Workshop on an Infrastructure for Temporal Databases*. Ed. R. T. Snodgrass. Arlington, TX: June 1993.
- Nascimento, M., R. Elmasri and M. Dunham. *Using Incremental Trees For Space Efficient Indexing of Bitemporal Databases*, in *Proceedings of the Second International Conference on Applications of Databases (ADB'95)*. San Jose, CA: Dec. 1995.
- Navathe, S. and R. Ahmed. *Temporal Extensions to the Relational Model and SQL*, in Temporal Databases: Theory, Design, and Implementation. Benjamin/Cummings, 1993. Chap. 4. pp. 92–109.
- Navathe, S. B. and R. Ahmed. *TSQL-A Language Interface for History Databases*, in *Proceedings of the Conference on Temporal Aspects in Information Systems*. AFCET. France: May 1987, pp. 113–128.
- Navathe, S. B. and R. Ahmed. *A Temporal Relational Model and a Query Language*. *Information Sciences*, 49 (1989), pp. 147–175.
- Nebel, B. and H.J. Burckert. *Reasoning about Temporal Relations: A Maximal Tractable Subclass of Allen's Interval Algebra*. *Journal of the ACM*, 42, No. 1, Jan. 1995, pp. 43–66.

- Roddick, J. *Dynamically Changing Schemas Within Database Models*. *Australian Computer Journal*, 23, No. 3 (1991), pp. 105–109.
- Roddick, J. F. *SQL/SE - A Query Language Extension for Databases Supporting Schema Evolution*. *ACM SIGMOD Record*, 21, No. 3, Sep. 1992, pp. 10–16.
- Roddick, J. F. and J. D. Patrick. *Temporal Semantics in Information Systems – A Survey*. *Information Systems*, 17, No. 3, Oct. 1992, pp. 249–267.
- Roddick, J. F. *Implementing Schema Evolution in Relational Database Systems: An Approach Based on Historical Schemata*. 10/93. Dept. of Computer Science and Computer Engineering, La Trobe University. October 1993.
- Roddick, J. F. and R. T. Snodgrass. *Schema Versioning*, in *The TSQL2 Temporal Query Language*. Ed. R. T. Snodgrass. Kluwer Academic Publishers, 1995. Chap. 22. pp. 427–449.
- Roddick, J. F. and R. T. Snodgrass. *Transaction Time Support*, in *The TSQL2 Temporal Query Language*. Ed. R. T. Snodgrass. Kluwer Academic Publishers, 1995. Chap. 17. pp. 319–325.
- Ryu, K. H. *A Temporal Database Management Main Memory Prototype*. TempIS Technical Report 26. University of Arizona. July 1991.
- Ryu, K. H. *Users Manual and Tutorial for TempIS User Interface*. TempIS Technical Report 27. University of Arizona. July 1991.
- Betty Salzberg *On Indexing Spatial and Temporal Data*. *Information Systems*, 19, No. 6 (1994), pp. 447–465.
- Salzberg, B. and V. J. Tsotras. *A Comparison of Access Methods for Time Evolving Data*. NU-CCS 94-21. Northeastern University, Boston, MA. Aug. 1995.
- Sarda, N. *Design of a Historical Database Management System*, in *Proceedings of the CSI Indore Chapter Conference (invited paper)*. Aug. 1990.
- Sarda, N. *Extensions to SQL for Historical Databases*. *IEEE Transactions on Knowledge and Data Engineering*, 2, No. 2, June 1990, pp. 220–230.
- Sarda, N. *Algebra and Query Language for a Historical Data Model*. *The Computer Journal*, 33, No. 1, Feb. 1990, pp. 11–18.
- Sarda, N. *HSQL: A Historical Query Language*, in *Temporal Databases: Theory, Design, and Implementation*. Benjamin/Cummings, 1993. Chap. 5. pp. 110–140.
- Sarda, N. L. *Design of an Information System using a Historical Database Management System*, in *Proceedings of International Conference on Information Systems*. CIPS. Dec. 1987, pp. 86–96.
- Sarda, N. L. *Modelling of Time and History Data in Database Systems*, in *Proceedings CIPS Congress 87 Winnipeg*. CIPS. May 1987, pp. 15–20.
- Sarda, N. L. *An Algorithm for Time-rollback on Historical Relations*. Technical Report. Department of Computer Science and Engineering. May 1988.
- Sarda, N. L. *Design of a Historical Database Management System*. Technical Report. Division of Math, Engr, and Computer Science, University of New Brunswick, Saint John, N. B. Canada. 1988.
- Sarda, N. L. *Time Grid: A File Structure for Historical Databases*. Technical Report. Department of Computer Science & Engineering, I.I.T.. Apr. 1992.
- Sarda, N. L. *Recent Trends in Historical Databases*, in *International Conference on Information Systems and Management of Data (CISMOD'92)*. Bangalore, India: July 1992, pp. 205–226.
- Sarda, N. L. *Time-rollback Using Logs in Historical Databases*. *Information and Software Technology*, 35, No. 3 (1993), pp. 171–180.
- Scalas, M. R., A. Cappelli and C. De Castro. *A Model for Schema Evolution in Temporal Relational Databases*, in *7th IEEE COMPEURO Annual European Computer Conference*. Paris-Evry, France: May 1993, pp. 223–231.
- Segev, A. and A. Shoshani. *The Representation of a Temporal Data Model in the Relational Environment*, in *Proceeding of the 4th International Conference on Statistical and Scientific Database Management*. 1988.
- Segev, A. and H. Gunadhi. *Event-Join Optimization in Temporal Relational Databases*, in *Proceedings of the Conference on Very Large Databases*. Aug. 1989, pp. 205–215.
- Segev, A. and H. Gunadhi. *Query Processing in Temporal Databases*, in *Proceedings of the Workshop on Query Optimization*. Portland, Oregon: May 1989, pp. 159–164.

- Segev, A. and H. Gunadhi. *Temporal Query Optimization in Scientific Databases*. IEEE Data Engineering, 13, No. 3, Sep. 1990.
- Segev, A. *Database Support for Temporal Queries*, in International Workshop on Nonstandard Queries and Answers Approach. Tolouse, France: 1991, pp. 157–176.
- Segev, A. and H. Gunadhi. *Processing Event-joins in Temporal Databases*. Technical Report. Lawrence Berkeley Laboratory, University of California. 1992.
- Segev, A. *Join Processing and Optimization in Temporal Relational Databases*, in Temporal Databases: Theory, Design, and Implementation. Benjamin/Cummings, 1993. Chap. 15. pp. 356–387.
- Segev, A., G. Himawan, R. Chandra and J. Shanthikumar. *Selectivity Estimation of Temporal Data Manipulations*. Information Sciences, 74, No. 1-2, Oct. 1993.
- Shen, H., B. C. Ooi and H. Lu. *The TP-Index: A Dynamic and Efficient Indexing Mechanism for Temporal Databases*, in Proceedings of the 10th International Conference on Data Engineering (ICDE). Houston, TX: 1994, pp. 274–281.
- Snodgrass, R. *The Temporal Query Language TQuel*, in Proceedings of the ACM Symposium on Principles of Database Systems. Waterloo, Ontario, Canada: Apr. 1984, pp. 204–212.
- Snodgrass, R., S. Gomez and E. McKenzie. *Aggregates in the Temporal Query Language TQuel*. IEEE Transactions on Knowledge and Data Engineering, 5, Oct. 1993, pp. 826–842.
- Snodgrass, R. T. and I. Ahn. *Temporal Databases*. IEEE Computer, 19, No. 9, Sep. 1986, pp. 35–42.
- Snodgrass, R. T. *The Temporal Query Language TQuel*. ACM Transactions on Database Systems, 12, No. 2, June 1987, pp. 247–298.
- Snodgrass, R. T. *An Overview of TQuel*, in Temporal Databases: Theory, Design, and Implementation. Benjamin/Cummings, 1993. Chap. 6. pp. 141–182.
- Snodgrass, R. T., I. Ahn, G. Ariav, P. Bayer, J. Clifford, C. E. Dyreson, F. Grandi, L. Hermosilla, C. S. Jensen, W. Kafer, N. Kline, K. Kulkarni, T. Y. C. Leung, N. Lorentzos, Y. Mitsopoulos, J. F. Roddick, M. D. Soo and S. M. Sripada. *An Evaluation of TSQL2*. Commentary. University of Arizona, Department of Computer Science. Sep. 1994.
- Soo, M. D., C. S. Jensen and R. T. Snodgrass. *An Architectural Framework*, in *The TSQL2 Temporal Query Language*. Ed. R. T. Snodgrass. Kluwer Academic Publishers, 1995. Chap. 24. pp. 465–473.
- Soo, M. D., C. S. Jensen and R. T. Snodgrass. *An Algebra for TSQL2*, in *The TSQL2 Temporal Query Language*. Kluwer Academic Press, 1995. Chap. 27. pp. 505–546.
- Soo, Michael D., Richard T. Snodgrass and Christian S. Jensen. *Efficient Evaluation of the Valid-Time Natural Join*, in Proceedings of the 10th International Conference on Data Engineering (ICDE). 1994, pp. 282–292.
- Stamper, R. *The LEGOL 1 Prototype System and Language*. The Computer Journal, 20, No. 2, May 1977, pp. 102–108.
- Stonebraker, M. and L. A. Rowe. *The Design of POSTGRES*, in Proceedings of ACM SIGMOD International Conference on Management of Data. Ed. C. Zaniolo. Association for Computing Machinery. Washington, DC: May 1986, pp. 340–355.
- Tansel, A. and L. Garnett. *Nested Historical Relations*, in Proceedings of ACM SIGMOD International Conference on Management of Data. May 1989, pp. 284–293.
- Tansel, A. *A Historical Query Language*. Information Sciences, No. 53 (1991), pp. 101–133.
- Tansel, A. *SQL-T: A Temporal Extension to SQL*, in Proceedings of the International Workshop on an Infrastructure for Temporal Databases. Ed. R. T. Snodgrass. Arlington, TX: June 1993.
- Tansel, A. *A Generalized Relational Framework for Modeling Temporal Data*, in Temporal Databases: Theory, Design, and Implementation. Benjamin/Cummings, 1993. Chap. 7. pp. 183–201.
- Tansel, A., J. Clifford, S. Gadia, S. Jajodia, A. Segev and R. Snodgrass (eds.). *Temporal Databases: Theory, Design, and Implementation*. Database Systems and Applications Series. Redwood City, CA: Benjamin/Cummings, 1993.
- Tansel, A. U. *Handling Time in Relational Databases*, in Proceedings of 4th Hungarian Computer Sciences Conference. Gyor, Hungary: July 1985.
- Tansel, A. U. *Adding Time Dimension to Relational Model and Extending Relational Algebra*. Information Systems, 11, No. 4 (1986), pp. 343–355.
- Tansel, A. U. and M. E. Arkun. *Aggregation Operations in Historical Relational Databases*, in Proceedings of the Third International Workshop on Statistical and Scientific Databases. July 1986.

- Tansel, A. U. and M. E. Arkun. *HQUEL, A Query Language for Historical Relational Databases*, in *Proceedings of the Third International Workshop on Statistical and Scientific Databases*. July 1986.
- Tansel, A. U. *A Statistical Interface for Historical Relational Databases*, in *Proceedings of the International Conference on Data Engineering*. IEEE Computer Society. Los Angeles, CA: IEEE Computer Society Press, Feb. 1987, pp. 538–546.
- Tansel, A. U., M.E. Arkun and G. Ozsoyoglu. *Time-By-Example Query Language for Historical Databases*. *IEEE Transactions on Software Engineering*, 15, No. 4, Apr. 1989, pp. 464–478.
- Thompson, P. M. *A Temporal Data Model Based on Accounting Principles*. PhD. Diss. Department of Computer Science, University of Calgary, Mar. 1991.
- Torp, K., L. Mark and C. S. Jensen. *Efficient Differential Timeslice Computation*. Technical Report R-94-2055. Aalborg University, Department of Mathematics and Computer Science. Dec. 1994.
- Tsotras, J., B. Gopinath and G. Hart. *Efficient Management of Time-Evolving Databases*. *IEEE Transactions on Knowledge and Data Engineering*, (to appear) (1993).
- Tsotras, V. J. and B. Gopinath. *Efficient Algorithms Managing the History of Evolving Databases*, in *Proceedings of the International Conference on Database Theory*. 1990.
- Tsotras, V. J. and N. Kangelaris. *The Snapshot Index: An I/O-Optimal Access Method for Timeslice Queries*. *Information Systems*, 20, No. 3 (1995), pp. 237–260.
- Tsotras, V. J., B. Gopinath and G. W. Hart. *Efficient Management of Time-Evolving Databases*. *IEEE Transactions on Knowledge and Data Engineering*, 7, No. 4, Aug. 1995, pp. 591–608.
- Tuma, P. A. *Implementing Historical Aggregates in TempIS*. Master's Thesis, Wayne State University, Nov. 1992.
- Vaishnav, J. H. *A Homogeneous Temporal Extension of QUEL*. Master's Thesis, EE/CS Department, Texas Tech University, 1984.
- Varman, P.J. and R.M. Verma. *An Efficient Multiversion Access Structure*. Technical Report TR-9518. Department of Electrical and Computer Engineering, Rice University. 1995.
- Verma, R.M. and P.J. Varman. *Efficient Archivable Time Index: A Dynamic Indexing Scheme for Temporal Data*, in *Proceedings of the International Conference on Computer Systems and Education (ICCSE)*. Ed. N. Balakrishnan and others. Computer Systems and Education. Bangalore, India: Tata McGraw-Hill, June 1994, pp. 59-72.
- Verma, V. and H. Lu. *A New Approach to Version Management for Databases*, in *Proceedings of the AFIPS National Computer Conference*. Chicago, IL: AFIPS Press, June 1987, pp. 645–651.