An Annotated Bibliography on Temporal and Evolution Aspects in the World Wide Web

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    The two Rune arrows in the icon denote "T" and "C," respectively.

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1   Introduction

Time is a pervasive dimension of reality as everything evolves as time elapses. Information systems and applications at least mirror, and often have to capture, the time-varying and evolutionary nature of the phenomena they model and the activities they support. This aspect has been acknowledged and long studied in the field of temporal databases but it truly applies also to the World Wide Web, although it has not seemingly considered as a primary issue yet. However, several papers addressing, in an explicit or implicit way, the representation and management of time and change in the World Wide Web appeared recently and, on some aspects, showed a clear upward trend in last months, witnessing a sustained and/or growing interest.

The present bibliography reflects such interest by collecting the references concerning the handling of time and evolution issues in World Wide Web research. This follows several fortunate bibliographies on time-varying information, including seven ones on temporal databases (Bolour, Anderson, Dekeyser & Wong, *ACM SIGMOD Record* **12**:3, 1983; McKenzie, *ACM SIGMOD Record* **15**:4, 1986; Stam & Snodgrass, *IEEE Database Engineering* **17**:4, 1988; Soo, *ACM SIGMOD Record* **20**:1, 1991; Kline, *ACM SIGMOD Record* **22**:4, 1993; Tsotras & Kumar, *ACM SIGMOD Record* **25**:1, 1996; Wu, Jajodia & Sean Wang, in *Temporal Databases: Research and Practice*, Springer LNCS 1399, 1998), two ones on spatio-temporal databases (Al-Taha, Snodgrass & Soo, *ACM SIGMOD Record* **22**:1, 1993; Al-Taha, Snodgrass & Soo, *Intl' Journal of Geographical Inf. Sys.* **8**:1, 1994), two ones on spatio-temporal data mining (Roddick & Spiliopoulou, *ACM SIGKDD Explorations* **1**:1, 1999; Roddick, Hornsby & Spiliopoulou, *Proc. TSDM 2000 Intl' Workshop*, Springer LNCS 2007, 2000), one on schema evolution (Roddick, *ACM SIGMOD Record* **21**:4, 1992), and one on (temporal) indeterminacy (Dyreson, in *Uncertainty Management in Information Systems*, Kluwer, 1996).

We apologize in advance (with the readers and especially with the authors) for any **errors**, **misclassifications** and **omissions** may result from the collected entries. Additions, corrections and comments are welcome.

2 PAPERS

The references are organized into ten main sections, where they are further grouped by some similarity criterion introduced by brief notes. Entries are listed in ascending chronological order within (sub)groups.

2.1 Transaction Time

Transaction time is the time some fact is current in a database, from when it is stored in the system to when it is deleted. With respect to the Web, it represents the on-line availability and versioning of resources in a Web site, even if they are not created by "transactions" in a strict sense. Although in several cited papers it was called "valid time", if it concerns the time Web documents are modified it is properly transaction time.

The first group of papers explicitly deals with transaction-time versioning of Web resources, which can be selectively accessed, on user's request, through a transaction-time aware temporal Web server.

[1] Tom Dalling, "Versioning of Web Resources", Honour's Thesis, James Cook University, Australia, 1998.

[2] Claudio Cristofori, Fabio Grandi, Federica Mandreoli, Maria Rita Scalas, "Management of Temporal Versions of World Wide Web Resources along Transaction Time", Technical Report, T6-R03, INTER-DATA Project, 1998, *(in Italian)*, `http://www.difa.unibas.it/users/gmecca/interdata/`.

[3] Claudio Cristofori, "Temporal Extensions of the World Wide Web Technology" *(in Italian)*, Master Thesis, Faculty of Engineering, University of Bologna, Italy, 1999.

[4] Tony Allan, Gayle Allan, "Temporal and Version Extensions to XML and the W3C Document Object Model" (Poster), *Proc. of 8th Intl' WWW Conf. (WWW8) – Posters*, Toronto (May 1999), Ontario, 1999, `http://www8.org/`.

[5] Curtis E. Dyreson, "Transaction-Time World-Wide Web (WWW) Server", in The Dagstuhl Seminar Researchers, "Summary of Current Work", in *Temporal Databases: Research and Practice*, LNCS Vol. 1399, Springer-Verlag, Heidelberg, p. 416, 1999.

[6] Stefan Zapf, Thomas Myrach, "A Prototype for the Support of Temporal Aspects of Web Administration on the Basis of a Repository" *(in German)*, *Proc. of Workshop on Application of Concepts of Temporal Data Management in Database Systems and World Wide Web (ZobIS)* (in conj. with MobIS-Fachtagung 2000), Siegen (October 2000), Germany, Gesellschaft für Informatik, Bonn, pp. 291–297, 2000.

[7] Curtis E. Dyreson, "Towards a Temporal World-Wide Web: A Transaction Time Web Server", *Proc. of 12th Australasian Database Conf. (ADC '01)*, Gold Coast (January 2001), Australia, IEEE Computer Society Press, Los Alamitos, pp. 169–175, 2001.

[8] Curtis E. Dyreson, "Observing Transaction-time Semantics with TTXPath", *Proc. of 2nd Intl' Conf. on Web Information Systems Engineering (WISE '01) – Vol. 1, Main Program*, Kyoto (December 2001), Japan, IEEE Computer Society Press, Los Alamitos, pp. 193–202, 2001.

[9] Kjetil Nørvåg, "Temporal Query Operators in XML Databases", *Proc. of 17th ACM Symposium on Applied Computing (SAC '02)*, Madrid (March 2002), Spain, ACM Press, New York, pp. 402–406, 2002.

[10] Kjetil Nørvåg, "Algorithms for Temporal Query Operators in XML Databases", *Proc. of Workshop on XML-Based Data Management (XMLDM'02)* (in conj. with EDBT'2002), Prague (March 2002), Czech Republic, LNCS Vol. 2490, Springer-Verlag, Heidelberg, pp. 169–183, 2002.

[11] Lene Myklebust, Marit Limstrand, "Temporal XML Database" *(in Norwegian)*, Master Thesis, Norwegian University of Science and Technology, Trondheim, Norway, June 2002.

[12] Peter Buneman, Sanjeev Khanna, Keishi Tajima, Wang-Chiew Tan, "Archiving Scientific Data", *Proc. of ACM Intl' Conf. on Management of Data (SIGMOD 2002)*, Madison (June 2002), WI, ACM Press, New York, pp. 1–12, 2002.

[13] Kjetil Nørvåg, "Design, Implementation, and Performance of the V2 Temporal Document Database System", Technical Report, IDI-TR-10/2002, Dept. of Computer and Information Science, Norwegian University of Science and Technology, Trondheim, Norway, 2002.

[14] Kjetil Nørvåg, "The V2 Temporal Document Database System" (Poster), *Proc. of 12th Intl' World Wide Web Conf. – Posters (WWW 2003)*, Budapest (May 2003), Hungary, ACM Press, New York, 2003.

[15] Kjetil Nørvåg, "V2: A Database Approach to Temporal Document Management", *Proc. of 7th Intl' Database Engineering and Applications Symposium (IDEAS'2003)*, Hong Kong (July 2003), China, IEEE Computer Society Press, Los Alamitos, pp. 212–223, 2003.

[16] Kjetil Nørvåg, "Space-Efficient Support for Temporal Text Indexing in a Document Archive Context" *Proc. of 7th European Conf. on Research and Advanced Technology for Digital Libraries (ECDL 2003)*, Trondheim (*to be held* August 2003), Norway.

[17] Kjetil Nørvåg, "Supporting Temporal Text-Containment Queries", Technical Report, IDI-TR-11/2002, Dept. of Computer and Information Science, Norwegian University of Science and Technology, Trondheim, Norway, 2002.

The second group of papers deals with temporal extensions of data models (e.g. OEM and XML) and query languages for semistructured data. Since data versions are generated by updates (and without an explicit management of time), the involved temporal dimension is obviously transaction time.

[18] Sudarshan S. Chawathe, Serge Abiteboul, Jennifer Widom, "Representing and Querying Changes in Semistructured Data", *Proc. of Intl' Conf. on Data Engineering (ICDE '98)*, Orlando (February 1998), FL, IEEE Computer Society Press, Los Alamitos, pp. 4–13, 1998.

[19] Sudarshan S. Chawathe, Serge Abiteboul, Jennifer Widom, "Managing Historical Semistructured Data", *Theory and Practice of Object Systems*, Vol. 5, No. 3, pp. 143–162, 1999.

[20] Toshiyuki Amagasa, Masatoshi Yoshikawa, Shunsuke Uemura, "A Data Model for Temporal XML Documents", *Proc. of 11th Intl' Conf. on Database and Expert Systems Applications (DEXA 2000)*, London (September 2000), England, LNCS Vol. 1873, Springer-Verlag, Heidelberg, pp. 334–344, 2000.

[21] Toshiyuki Amagasa, Masatoshi Yoshikawa and Shunsuke Uemura, "Realizing Temporal XML Repositories using Temporal Relational Databases" (Poster), *Proc. of Intl' Symposium on Cooperative Database Systems for Advanced Applications (CODAS '01)*, Beijing (April 2001), China, pp. 63–67, 2001.

[22] Barbara Oliboni, Elisa Quintarelli, Letizia Tanca, "Temporal Aspects of Semistructured Data", *Proc. of 8th Intl' Symposium on Temporal Representation and Reasoning (TIME-01)*, Cividale del Friuli (June 2001), Italy, IEEE Computer Society Press, Los Alamitos, pp. 119–127, 2001.

[23] Ernesto Damiani, Barbara Oliboni, Elisa Quintarelli, Letizia Tanca, "Temporal Aspects of Semistructured Data (Extended Abstract)" *Proc. of Natl' Conf. on Advanced Database Systems (SEBD '01)*, Venezia (June 2001), Italy, LCM Selecta, Milan, pp. 215–222, 2001.

[24] Elisa Quintarelli, "Model-Checking Based Data Retrieval: An Application to Semistructured and Temporal Data" Ph.D. Thesis, Politecnico di Milano, Italy, 2002.

[25] Barbara Oliboni, Elisa Quintarelli, Letizia Tanca, "Model-Checking Techniques for Efficiently Querying Semistructured Temporal Data" *Proc. of Natl' Conf. on Advanced Database Systems (SEBD '02)*, Portoferraio – Isola d'Elba (June 2002), Italy, Centro Stampa 2P, Florence, pp. 376–389, 2002.

[26] Yannis Stavrakas, Manolis Gergatsoulis, Christos Doulkeridis, Vassilis Zafeiris, "Accomodating Changes in Semistructured Databases Using Multidimensional OEM", *Proc. of 6th East-European Conference on Advances in Databases and Information Systems (ADBIS'2002)*, Bratislava (September 2002), Slovakia. LNCS Vol. 2435, Springer-Verlag, Heidelberg, pp. 360–373, 2002.

[27] Kjetil Nørvåg, Marit Limstrand, Lene Myklebust, "TeXOR: Temporal XML Database on an Object-Relational Database System", *Proc. of Perspectives of System Informatics (PSI'03)*, Novosibirsk (July 2003), Russia, 2003.

[28] Manolis Gergatsoulis, Yannis Stavrakas, "Representing Changes in XML Documents using Dimensions", *Proc. of XML Database Symposium (XSym 2003)* (in conj. with VLDB 2003), Berlin (*to be held* September 2003), Germany.

[29] Manolis Gergatsoulis, Yannis Stavrakas, Christos Doulkeridis, Vassilis Zafeiris, "Representing and Querying Histories of Semistructured Databases Using Multidimensional OEM", *Information Systems*, 2003 *(in press)*.

2.2   Valid Time

Valid time is the time some fact is true in the real world. In the Web, it concerns the temporal validity of the information carried by the contents of a Web resource. In the following group of papers, modeling and management of historical Web documents is properly concerned.

[1] Fabio Grandi, Federica Mandreoli, Maria Rita Scalas, "Management of Temporal Versions of World Wide Web Resources along Valid Time", Technical Report, T6-R13, INTERDATA Project, 1999, *(in Italian)*, http://www.difa.unibas.it/users/gmecca/interdata/.

[2] Fabio Grandi, Federica Mandreoli, "The Valid Web: it's Time to Go...", Technical Report, TIMECENTER TR-46, 1999, http://www.cs.auc.dk/research/DP/tdb/TimeCenter/.

[3] Fabio Grandi, Federica Mandreoli, "The Valid Web [©]", *Proc. of Software Demonstrations Track at the EDBT'2000 Intl' Conf.*, Konstanz (March 2000), Germany, pp. 31–32, 2000.

[4] Fabio Grandi, Federica Mandreoli, "An XML/XSL Infrastructure for Temporal Management of Documents and Data on the Web" *(in Italian)*, Proc. of *8th Natl' Conf. on Advanced Database Systems (SEBD 2000)*, L'Aquila (June 2000), Italy, University of L'Aquila, L'Aquila, pp. 227–240, 2000.

[5] Fabio Grandi, Federica Mandreoli, "The Valid Web: an XML/XSL Infrastructure for Temporal Management of Web Documents", Proc. of *1st Intl' Conf. on Advances in Information Systems (ADVIS 2000)*, Izmir (September 2000), Turkey, LNCS Vol. 1909, Springer-Verlag, Heidelberg, pp. 294–303, 2000.

[6] Fabio Grandi, Franco Niccolucci, "XML Technologies for the Representation and Management of Spatiotemporal Information in Archaeology" (abstract), *Proc. of 17th Intl' CODATA Conf.*, Baveno (October 2000), Italy, CODATA, Paris, pp. 39–41, 2000.

[7] Raymond K. Wong, Franky Lam, Mehmet A. Orgun, "Modelling and Manipulating Multidimensional Data in Semistructured Databases", *World Wide Web*, Vol. 4, No. 1–2, pp. 79–99, 2001.

[8] Theodoros Mitakos, Manolis Gergatsoulis, Yannis Stavrakas, Efstathios V. Ioannidis, "Representing Time-Dependent Information in Multidimensional XML", *Journal of Computing and Information Technology*, Vol. 9, No. 3, pp. 233–238, 2001.

[9] Franky Lam, Raymond K. Wong, Mehmet A. Orgun, "Modelling and Manipulating Multidimensional Data in Semistructured Databases", *Proc. of 7th Intl' Conf. on Database Systems for Advanced Applications (DASFAA 2001)*, Hong Kong (April 2001), China, IEEE Computer Society Press, Los Alamitos, pp. 14–21, 2001.

[10] Fabio Grandi, Federica Mandreoli, "Effective Representation and Efficient Encoding of Indeterminate Dates", *Proc. of 8th Intl' Symposium on Temporal Representation and Reasoning (TIME-01)*, Cividale del Friuli (June 2001), Italy, IEEE Computer Society Press, Los Alamitos, pp. 164–169, 2001.

[11] Theodoros Mitakos, Manolis Gergatsoulis, Yannis Stavrakas, Efstathios V. Ioannidis, "Representing Time-Dependent Information in Multidimensional XML", *Proc. of the 23rd Intl' Conf. on Information Technology Interfaces (ITI 2001)*, Pula (June 2001), Croatia, IEEE Computer Society Press, Los Alamitos, pp. 111–116, 2001.

[12] Fabio Grandi, Maria Rita Scalas, "XML Representation and Management of Temporal Information on the Web for Cultural Heritage Applications", *Proc. of Intl' Conf. on Advances in Infrastructure for Electronic Business, Education and Science on the Internet (SSGRR '01)*, L'Aquila (August 2001), Italy, SSGRR, ISBN:88-85280-61-7 (cd-rom), 2001.

[13] Fabio Grandi, Federica Mandreoli, "The "XML/Repett" Project: XML Encoding and Manipulation of Temporal Information in Historical Text Sources", *Proc. of Intl' Cultural Heritage Informatics Meeting (ICHIM'01) – Volume 2, Short Papers / Posters and Demo*, Milan (September 2001), Italy, Archives & Museum Informatics, Pittsburgh, PA, pp. 243–252, 2001.

[14] Fabio Grandi, Federica Mandreoli, "XML Encoding and Management of Temporal Information in Large Digitized Historical Sources" *(in Italian)*, *Proc. of 39th Annual Conf. of the Italian Society for Informatics and Computing (AICA '01)*, Cernobbio (September 2001), Italy, AICA, Milan, pp. 89–100, 2001.

[15] Rosalba Rossato, "MTGM: A Semistructured Data Model for Management of Multimedia and Temporal Information" (*in Italian*), Master Thesis, Faculty of Sciences, University of Verona, Verona, Italy, 2002.

[16] Fabio Grandi, "XML Representation and Management of Temporal Information for Web-based Cultural Heritage Applications", *Data Science Journal*, Vol. 1, No. 1, pp. 68–83, April 2002.

[17] Fusheng Wang, Carlo Zaniolo, "Preserving and Querying Histories of XML-Published Relational Databases" *Proc. of 2nd Intl' Workshop on Evolution and Change in Data Management (ECDM 2002)* (in conj. with ER 2002), Tampere (October 2002), Finland, 2002, pp. 26–38.

[18] Shuohao Zhang and Curtis E. Dyreson, "Adding Valid Time to XPath", *Proc. of 2nd Intl' Workshop on Databases in Networked Information Systems (DNIS 2002)*, Aizu (December 2002), Japan, LNCS Vol. 2544, Springer-Verlag, Heidelberg, pp. 29–42, 2002.

[19] Dengfeng Gao, Richard T. Snodgrass, "Syntax, Semantics, and Query Evaluation of the τXQuery Temporal XML Query Language", Technical Report, TIMECENTER TR-72, 2003, `http://www.cs.auc.dk/research/DP/tdb/TimeCenter/`.

[20] Carlo Combi, Barbara Oliboni, Elisa Quintarelli, "A Unified Model for Semistructured Temporal Data (Extended Abstract)", *Proc. of Natl' Conf. on Advanced Database Systems (SEBD 2003)*, Cetraro (June 2003), Italy, Rubbettino, Soveria Mannelli, pp. 161–168, 2003.

[21] Fusheng Wang, Carlo Zaniolo, "Temporal Queries in XML Document Archives and Web Warehouses" *Proc. of 10th Intl' Symposium on Temporal Representation and Reasoning (TIME-03)*, Cairns (July 2003), Queensland. IEEE Computer Society Press, Los Alamitos, pp. 47–55, 2003.

[22] Fusheng Wang, Carlo Zaniolo, "Representing and Querying the Evolution of Databases and their Schemas in XML" *Proc. of 15th Intl' Conf. on Software Engineering and Knowledge Engineering (SEKE2003)*, San Francisco (July 2003), CA, Knowledge Systems Institute, Skokie, IL, 2003.

[23] Dengfeng Gao, Richard T. Snodgrass, "Temporal Slicing in the Evaluation of XML Queries", *Proc. of 29th Intl' Conf. on Very Large Data Bases (VLDB'03)*, Berlin (September 2003), Germany, Morgan Kaufmann, San Francisco, pp. 632–643, 2003.

[24] Carlo Combi, Barbara Oliboni, Rosalba Rossato, "Modeling Multimedia and Temporal Aspects of Semistructured Clinical Data", *Proc. of 9th Conf. on Artificial Intelligence in Medicine Europe (AIME 2003)*, Cyprus (*to be held* October 2003), Greece.

[25] Fusheng Wang, Carlo Zaniolo, "Publishing and Querying the Histories of Archived Relational Databases in XML" *Proc. of 4th Intl' Conf. on Web Information Systems Engineering (WISE '03)*, Rome (*to be held* December 2003), Italy.

[26] The TAU Project Homepage, `http://www.cs.arizona.edu/tau/`.

Several papers (e.g. in the humanities field), though not dealing with temporal data modeling and querying in a strict sense, consider (valid) time as a useful annotation dimension. Some works are also mainly concerned with extraction and visualization of temporal information available on the Web.

[27] Robin L. Kullberg, "Dynamic Timelines: Visualizing Historical Information in Three Dimensions", Master Thesis, MIT, Cambridge, MA, 1995.

[28] Robert B. Allen, "Timelines as Information System Interfaces", *Proc. of Intl' Symposium on Digital Libraries (ISDL '95)*, Tsukuba (August 1995), Japan, University of Library and Information Science, Tsukuba, Japan, pp. 175–180, 1995.

[29] Catherine Plaisant, Brett Milash, Anne Rose, Seth Widoff, Ben Shneiderman, "LifeLines: Visualizing Personal Histories", *Proc. of ACM Intl' Conf. on Human Factors and Computing Systems (CHI '96)*, Vancouver (April 1996), BC, pp. 221–227, 1996.

[30] Ido Dagan, Ronen Feldman, "Keyword-based Browsing and Analysis of Large Document Sets", *Proc. of 5th Annual Symposium on Document Analysis and Information Retrieval (SDAIR'96)*, Las Vegas (April 1996), NV, 1996.

[31] Gregory Crane, "The Perseus Project and Beyond: How Building a Digital Library Challenges the Humanities and Technology", *D-Lib Magazine*, Vol. 4, No. 1, January 1998, `http://www.dlib.org/`.

[32] Vijay Kumar, Richard Furuta, Robert B. Allen, "Metadata Visualization for Digital Libraries: Interactive Timeline Editing and Review", *Proc. of 3rd ACM Intl' Conf. on Digital Libraries (ACM DL '98)*, Pittsburgh (June 1998), PA, ACM Press, New York, pp. 126–133, 1998.

[33] Franco Niccolucci, Andrea Zorzi, Marianna Baldi, Fausto Carminati, Patrizia Salvatori, Tommaso Zoppi, "Historical Text Encoding: an Experiment with XML on Repetti's Historical Dictionary", *Proc. Conf. of the Association for History and Computing - UK Branch (AHC-UK'99)*, London (September 1999), England, AHC-UK, 1999.

[34] Russell C. Swan, James Allan, "Extracting Significant Time Varying Features from Text", *Proc. of 8th ACM Intl' Conf. on Information and Knowledge Management (CIKM '99)*, Kansas City (November 1999), MO, ACM Press, New York, pp. 38–45, 1999.

[35] Robert B. Allen, John Schalow, "Metadata and Data Structures for the Historical Newspaper Digital Library", *Proc. of 8th ACM Intl' Conf. on Information and Knowledge Management (CIKM '99)*, Kansas City (November 1999), MO, ACM Press, New York, pp. 147–153, 1999.

[36] Anna Benvenuti, Franco Niccolucci, Sandra Baragli, Claudio Carpini, "Advances in XML Treatment of Historical Documents", *History in a New Frontier – Proc. 13th Intl' Conf. of the Association for History and Computing (AHC'98)*, Toledo (July 1998), Spain, Castilla-La Mancha University Press, Cuenca, 2000.

[37] Amy C. Smith, Jeffrey A. Rydberg-Cox, Gregory Crane, "The Perseus Project": A Digital Library for the Humanities", *Literary and Linguistic Computing*, Vol. 15, No. 1, pp. 15–25, 2000.

[38] Diego Calvanese, Tiziana Catarci, Giuseppe Santucci, "Building a Digital Library of Newspaper Clippings: The Laurin Project", *Proc. of IEEE Forum on Research and Technology Advances in Digital Libraries (ADL 2000)*, Washington (May 2000), DC, IEEE Computer Society Press, Los Alamitos, pp. 15–26, 2000.

[39] Sônia Fernandes Silva, Tiziana Catarci, "Visualization of Linear Time-Oriented Data: A Survey", *Proc. of 1st Intl' Conf. on Web Information Systems Engineering (WISE 2000) – Volume I, Main Program*, Hong Kong (June 2000), China, IEEE Computer Society Press, Los Alamitos, pp. 310–319, 2000.

[40] Sherman S.-M. Chan, Qing Li, "VideoMAP*: A Web-based Architecture for a Spatio-Temporal Video Database Management System", *Proc. of 1st Intl' Conf. on Web Information Systems Engineering (WISE 2000) – Volume I, Main Program*, Hong Kong (June 2000), China, IEEE Computer Society Press, Los Alamitos, pp. 393–400, 2000.

[41] Gregory Crane, "Designing Documents to Enhance the Performance of Digital Libraries: Time, Space, People and a Digital Library on London", *D-Lib Magazine*, Vol. 6, No. 7–8, 2000, `http://www.dlib.org/`.

[42] Jeffrey A. Rydberg-Cox, Robert F. Chavez, David A. Smith, Anne Mahoney, Gregory R. Crane, "Knowledge Management in the Perseus Digital Library", *Ariadne*, No. 25, September 2000, `http://www.ariadne.ac.uk/`.

[43] Gregory Crane, Brian Fuchs, Amy C. Smith, Clifford E. Wulfman, "The Symbiosis Between Content and Technology in the Perseus Digital Library", *Cultivate Interactive*, No. 2, October 2000, `http://www.cultivate-int.org/issue2/perseus/`.

[44] Diego Calvanese, Tiziana Catarci, Giuseppe Santucci, "LAURIN: A Distributed Digital Library of Newspaper Clippings", *Proc. of Kyoto International Conference on Digital Libraries: Research and Practice*, Kyoto (November 2000), Japan, pp. 187–194, 2000.

[45] Diego Calvanese, Tiziana Catarci, Giuseppe Santucci, "LAURIN: A Distributed Digital Library of Newspaper Clippings", *World Wide Web*, Vol. 4, No. 1–2, pp. 5–20, 2001.

[46] Gregory Crane, David A. Smith, Clifford E. Wulfman, "Building a Hypertextual Digital Library in the Humanities: A Case Study on London", *Proc. of ACM/IEEE Joint Conf. on Digital Libraries (JCDL 2001)*, Roanoke (June 2001), VA, ACM Press, New York, pp. 426–434, 2001.

[47] Michael G. Christel, "Accessing News Video Libraries through Dynamic Information Extraction, Summarization, and Visualization" *Proc. of 1st Intl' Workshop on Visual Interfaces to Digital Libraries* (in conj. with JCDL '01), Roanoke (June 2001), VA, `http://vw.indiana.edu/visual01/`.

[48] Dolores Llidó, Rafael Berlanga Llavori, Mara José Aramburu Cabo, "Extracting Temporal References to Assign Document Event-Time Periods", *Proc. of 12th Intl' Conf. on Database and Expert Systems Applications (DEXA 2001)*, Munich (September 2001), Germany, LNCS Vol. 2113, Springer-Verlag, Heidelberg, pp. 62–71, 2001.

[49] Giuseppe Sindoni, Leonardo Tininini, Amedea Ambrosetti, Cristina Bedeschi, Stefano De Francisci, Orietta Gargano, Rossella Molinaro, Mario Paolucci, Paola Patteri, Pina Ticca, "SIT-IN: a Real-Life Spatio-Temporal Information System", *Proc. of 27th Intl' Conf. on Very Large Data Bases (VLDB'01) – Demonstrations*, Rome (September 2001), Italy, Morgan Kaufmann, San Francisco, pp. 711–712, 2001.

[50] José Luis Ambite, Craig A. Knoblock, Mohammad R. Kolahdouzan, Maria Muslea, Cyrus Shahabi, Snehal Thakkar, "The WorldInfo Assistant: Spatio-Temporal Information Integration on the Web", *Proc. of 27th Intl' Conf. on Very Large Data Bases (VLDB'01) – Demonstrations*, Rome (September 2001), Italy, Morgan Kaufmann, San Francisco, pp. 717–718, 2001.

[51] Carlos Monroy, "Augmenting Cognition through Information Visualization Using a Timeline Viewer", Masters of Computer Science Project Report, Texas A&M Univeristy, TX, 2002.

[52] Sônia Fernandes Silva, Tiziana Catarci, "Visualization of Linear Time-Oriented Data: A Survey", *Journal of Applied System Studies* (special issue on "WEB Information Systems Applications"), Vol. 3, No. 2, 2002.

[53] Rajiv Kochumman, Carlos Monroy, Richard Furuta, Arpita Goenka, Eduardo Urbina, and Erendira Melgoza, "Towards an Electronic Variorum Edition of Cervantes' Don Quixote: Visualizations that Support Preparation", *Proc. of 2nd ACM/IEEE Joint Conf. on Digital Libraries (JCDL '02)*, Portland (July 2002), OR, ACM Press, New York, pp. 199–200, 2002.

[54] Adrian Graham, Hector Garcia-Molina, Andreas Paepcke, Terry Winograd, "Time as Essence for Photo Browsing through Personal Digital Libraries", *Proc. of 2nd ACM/IEEE Joint Conf. on Digital Libraries* (JCDL '02), Portland (July 2002), OR, ACM Press, New York, pp. 326–335, 2002.

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Consistent research efforts have been devoted to the management of (non-temporal) resource *versions* over the Web.

A first stream of research, where the main focus is on collaborative work and distributed document authoring, is concerned with maintenance of versions as produced by sequences of modifications. The implicit temporal dimension underlying the editing process (i.e. transaction time) is neglected.

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Other papers on adaptive techniques for Web personalization based on user profiling can also be found at the end of **Sec. 2.7**.

2.5 Updates on the Web

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2.6 Time in Web Warehousing

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2.7 Navigation Time

An autonomous research thread concerns time in Web usage. We can define *navigation time* the temporal dimension marking the navigation of the Web by a user. A user's navigation history also corresponds to what has been called "clickstream", and analysis of Web logs (e.g. for Web user profiling) is also known as Web usage mining.

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The "history" facility of Web browsers is based on rollback along navigation time. Several papers focused on equipping browsers with enhanced history mechanisms.

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[105] The Kulturarw[3] Project Homepage, `http://www.kb.se/kw3/ENG/Default.htm`.

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[107] The MINERVA Web Preservation Project Homepage, `http://www.loc.gov/minerva/`.

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[109] The Nordic Web Archive Homepage, `http://nwa.nb.no/`.

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Another temporal aspect in Web navigation involves the human-computer interaction (e.g. Web response time and its perception by users). A good starting point for the related bibliography is the Alan Dix's Web page about time, `http://www.comp.lancs.ac.uk/computing/users/dixa/topics/time/`. This includes, for instance, also a link to the Homepage of the Workshop on "*Time and the Web*" organized by the British HCI Group in June 1997 at Stafford, `http://www.hiraeth.com/conf/web97/` (workshop report on *ACM SIGCHI Bulletin* **30**:1, January 1998).

A strictly related issue is the "optimization" of the interaction leading, for example, to the development of caching and prefetching techniques or to site restructuring (e.g. personalization). Such issue is covered in a quite broad specific literature. We try to reference most of the papers where the proposed techniques are, in turn, based on temporal or evolutionary aspects (e.g. analysis of navigation histories).

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2.8   Time and Change in Semantic Web

Temporal and evolution aspects have also been considered in the definition of *ontologies* for the so-called *semantic Web*, and further developments are likely to appear in the next future. Good starting points for finding related resources are the "SemanticWeb.org" Portal (`http://www.semantic web.org/`) or the W3C "Semantic Web" Homepage (`http://www.w3c.org/2001/sw/`). For instance, sample DAML ontologies involving time can be found from URL `http://www.daml.org/ontologies/` (e.g. searching the repository by "time", "temporal" or "version" keywords).

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2.9 WWW Evolution

Several papers deal with the history and evolution of the Web itself. Technical issues but also "cultural" (e.g. sociological or media) aspects can be considered. This is also a broad literature, for which a separate bibliography could be compiled. For the sake of brevity, we only cite a few representatives.

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A related research field, more focused on technical aspects and aiming at a development of Web technologies, concerns the *Web dynamics*. The Web dynamics field has been initiated by the *Intl' Workshop on Web Dynamics* (London, England, January 2001, co-located with ICDT '01), `http://www.dcs.bbk.ac.uk/webDyn/`. The field has been surveyed by Mark Levene and Alexandra Poulovassilis in "Web Dynamics", *Software Focus* **2**:2, pp. 60–67, 2002. A special issue of *Computer Networks* (Vol. 39, No. 3, June 2002, edited by Levene & Poulovassilis) is also devoted to several aspects of

Web dynamics. Table of contents and abstracts are available at URL `http://www.elsevier.com/ inca/publications/store/5/0/5/6/0/6/index.htt`. A second edition of the Intl' Workshop on Web Dynamics was held in May 2002 (Honolulu, Hawaii, in conj. with WWW 2002), `http: //www.dcs.bbk.ac.uk/webDyn2/` (workshop report on *ACM SIGMOD Record* **31**:3, September 2002).

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2.10   Other Time Aspects

Several efforts involve standardization of temporal expressions to be used on the Web (e.g. as metadata). For instance, the issue has been addressed by the W3C Consortium, and is part of the XML-Schema datatype

definitions. Metadata carrying temporal information have also been considered in the TEI, Dublin Core, MUC and EAD initiatives. In the Open Archives Initiative, (transaction-time) *datestamps* are used for *selective harvesting* of metadata.

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[15] "International Date Format Campaign", `http://www.saqqara.demon.co.uk/datefmt.htm`.

Some multimedia Web resources have an intrinsic temporal dimension connected with the user's fruition of the resource itself. These include streaming video and music, animated presentations and so on. For the sake of completeness, we only give a few representative references; although dealing with time, they quite represent a world apart.

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Finally, according to some authors, the Web itself has developed its own time dimensions (e.g. "Internet time", "virtual time", etc).

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3 Acknowledgments